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Polar Knowledge: Aqhaliat Report

Volume 4




Polar Knowledge Canada | Savoir polaire Canada

Canada

Message from the Chief Scientist, David Hik

I am excited to share this special edition of the Polar Knowledge Aqhaliat Report, featuring diverse content that highlights some of the latest scientific results and knowledge mobilization programming supported by Polar Knowledge Canada. This unique edition focuses on 5 themes, co-developed with community partners in the North. Technical papers were written by multi-author teams via a collaborative assessment process that we describe in the overview section. Authors have worked across disciplinary boundaries to summarize current research and design beautiful infographics. We have also introduced a new infosheet section that provides summaries of individual projects at-a-glance. The technical papers and infosheets are presented together in a visually appealing new format we hope sparks discussion and fuels improved understanding. We look forward to hearing your thoughts about Aqhaliat volume 4!

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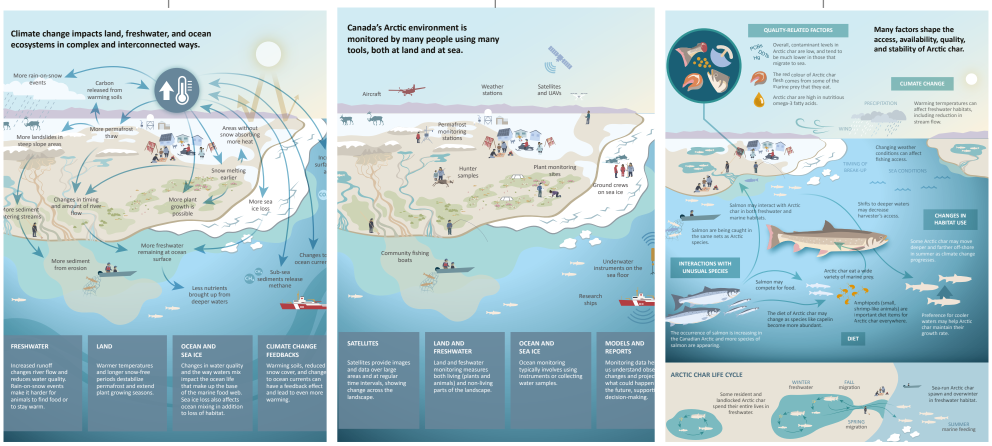
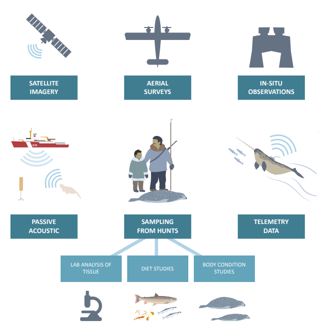
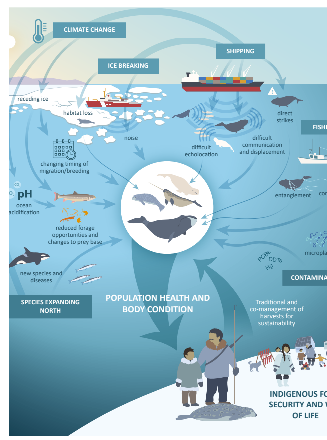
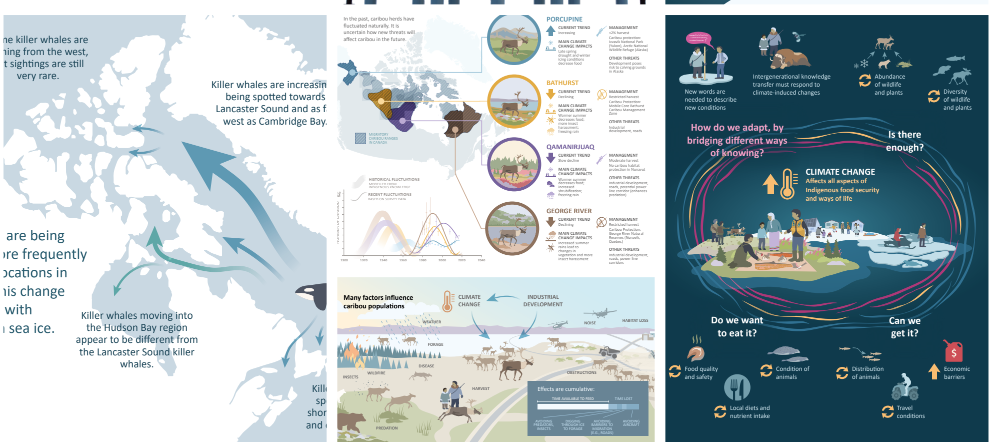




Aqhaliat Report





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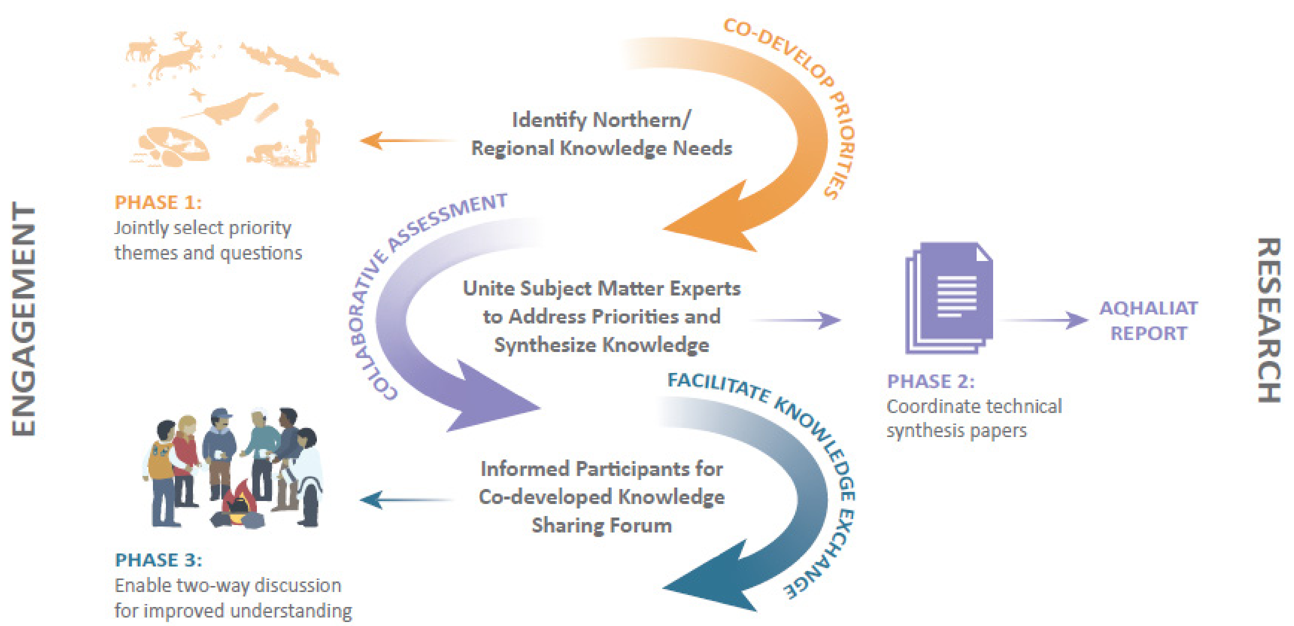
Methods of the collaborative assessment

Polar Knowledge Canada (POLAR) is mandated to strengthen Canada's leadership on Arctic issues and advance knowledge of the Canadian Arctic. Through leadership, partnerships and collaboration on polar science and technology, one of the federal agency's major functions is to create and synthesize knowledge and share information for decision making, for the benefit of northern communities and all Canadians. In March 2020, POLAR hosted a *Regional Planning and Knowledge Sharing Workshop* at the Canadian High Arctic Research Station (CHARS) campus in Cambridge Bay, Nunavut, Canada. The workshop focused on perspectives of Indigenous knowledge holders, knowledge producers and knowledge users in Nunavut and the Northwest Territories to identify key thematic sessions of relevance to communities, while establishing guidelines for communicating and sharing knowledge within a northern context.

Over its first five years of operation (2015–2019), POLAR-led and POLAR-supported research has encompassed a broad range of topics, including: climate change, ecosystems and biodiversity monitoring, physical sciences research, community-led wildlife research and monitoring, *Inuit Qaujimajatuqangit*, changing sea ice, permafrost and snow conditions monitoring as well as improving northern-built infrastructure, alternate and renewable energy and applied technologies. While many topics are important to Northerners, POLAR invited the Indigenous delegates and other partners to identify five key topics that could serve as meaningful session themes for an eventual knowledge sharing forum. After meaningful discussion, the 2020 workshop participants selected five themes of highest relevance:

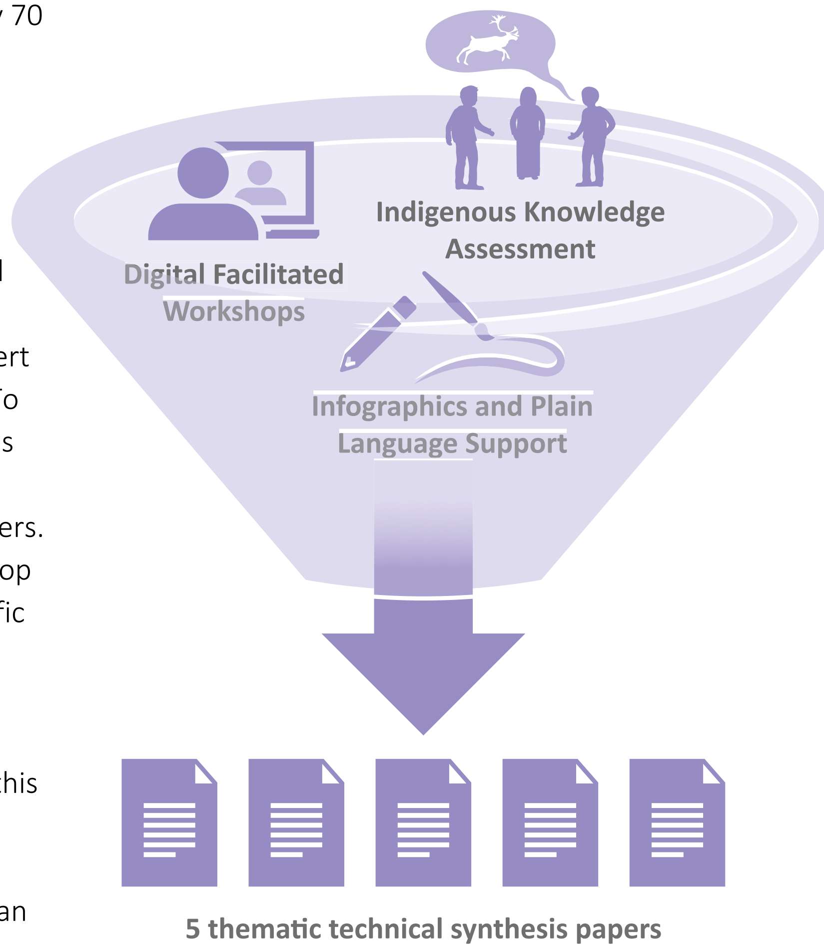
1. Caribou population abundance and migration;
2. Arctic char and other fish population dynamics;
3. Whale populations and marine ecosystem biodiversity;
4. Climate change research and monitoring;
5. Environmental change – snow, ice, precipitation.



To further refine themes, each participant was invited to write down a key question of relevance. Over 40 questions were compiled as part of the co-development and engagement process. These form the basis of POLAR's collaborative assessment project.

The Collaborative Assessment project united experts to address these questions and synthesize knowledge on these priority themes for a northern audience. This was done by coordinating diverse subject-matter experts, including Indigenous Knowledge holders, to discuss research and monitoring results, interpret trends, identify key areas for further research, and organize information to address policy relevant issues in comprehensive manner through the production of five technical synthesis reports. Co-authorship working groups were formed for each identified theme, drawing upon the expertise of approximately 70 researchers, wildlife managers and analysts from across Canada. An external digital facilitator was hired to lead workshops and help working groups cater subject content. Working groups met via a set of virtual workshops during summer of 2021, designed to enable cross-disciplinary discussion and collaboration towards the production of expert driven, northern–tailored synthesis papers. To facilitate knowledge exchange, each synthesis report was edited for plain language, augmented with infographics for visual learners. Working group were given flexibility to develop a unique path forward to address their specific theme, associated questions, and relay pertinent information critical to northern decision-making, resulting in variety in the presentation the final 5 papers published in this *Aqhaliat Report*.

The collaborative assessment ran parallel to an Indigenous Knowledge (IK) assessment. This assessment ensured that Indigenous Knowledge holders were provided the full opportunity to participate in sharing knowledge on the five themes and that IK will be represented in final technical paper submission. This was facilitated by Ajungi Arctic Consulting Group. Despite the short timeframe to recruit, a good selection from across the North, of different ages, genders and professions participated and shared their knowledge in the workshops. Two members of each working group were able to observe the workshop and given an opportunity at the end of the session to ask questions for clarification or additional information. Summary reports were developed from the workshops and sent to IK assessment participants to review for accuracy. These summaries were integrated into each thematic report into an Indigenous Knowledge section. The workshops were deemed a success by those who participated.



Environmental change in the Kitikmeot Region of western Nunavut and Ulukhaktok region of eastern Northwest Territories

Executive Summary

There are many impacts observed across the Canadian North because of changing environmental conditions. Increasing heat in the atmosphere caused by human pollution is causing the Arctic to warm up faster then anywhere else on Earth, and more frequent and intense weather has been occurring across the North. More unpredictable weather, tundra fires, forceful winds and storminess is expected to occur, with important impacts on northern communities. Air temperature controls all aspects of Arctic life, including which animals and plants can survive, when rivers and oceans freeze and break up, and the thickness of sea ice and permafrost. Canadian Arctic communities are warming the most in winter. Rainfall changes affect caribou and muskoxen, as they must break ice to get to their food. The snow season is shorter. Permafrost is warming and thawing. Arctic plants are changing in complex ways, in some areas climate change is causing them to grow more, shrubs becoming denser, and more grasses are present. Eventually, the tree line will move Northward. Ocean water is changing with increasing freshwater and sediments from melt, and this affects ocean life from microscopic species to fish and marine mammals. Global sea level rise will be less significant in the Canadian Arctic compered to low-laying islands elsewhere in the world. Arctic Sea Ice is melting, and this affects the safety of ice travel.

There still is much to learn about the effects of climate change to the environment in the Canadian Arctic. Key indicators such as rain, temperature, vegetation change and more can be observed, measured and monitored. More monitoring,both local and regional, is needed so that these indicators can tell us about the environment and how it is changing over time. Monitoring will provide information to help improve our understanding of the key indicators, so that we can give more complete answers to questions about regional concerns. Natural scientists need to work with Indigenous Knowledge holders to better understand these key indicators.

To better understand the environmental effects of climate change and to build linkages between Indigenous Knowledge and Science, the Working Group came up with the following list of six Emerging Opportunities:

1. Develop research partnerships with northern communities that focus on community-based research needs; include knowledge sharing and knowledge co-production for all aspects of environmental change research in the region.

2. Develop a new set of environmental indicators with Indigenous rights holders. These would include indicators developed by Indigenous Knowledge holders and scientists and would be included in the research design. The indicators could be adapted for regional and local needs.

3. Establish Community-Based Monitoring initiatives with long-term support that builds capacity in the community and enables the collection of consistent, continuous, and high-quality observations of key environmental indicators.

4. Create opportunities for Inuit youth to participate in monitoring programs and use research tools and educational resources to develop their own youth-led projects.

5. Develop models that predict how climate change will affect each community, to help them adapt.

6. Develop tools for two-way exchange of information that are available to the public and simple to use.

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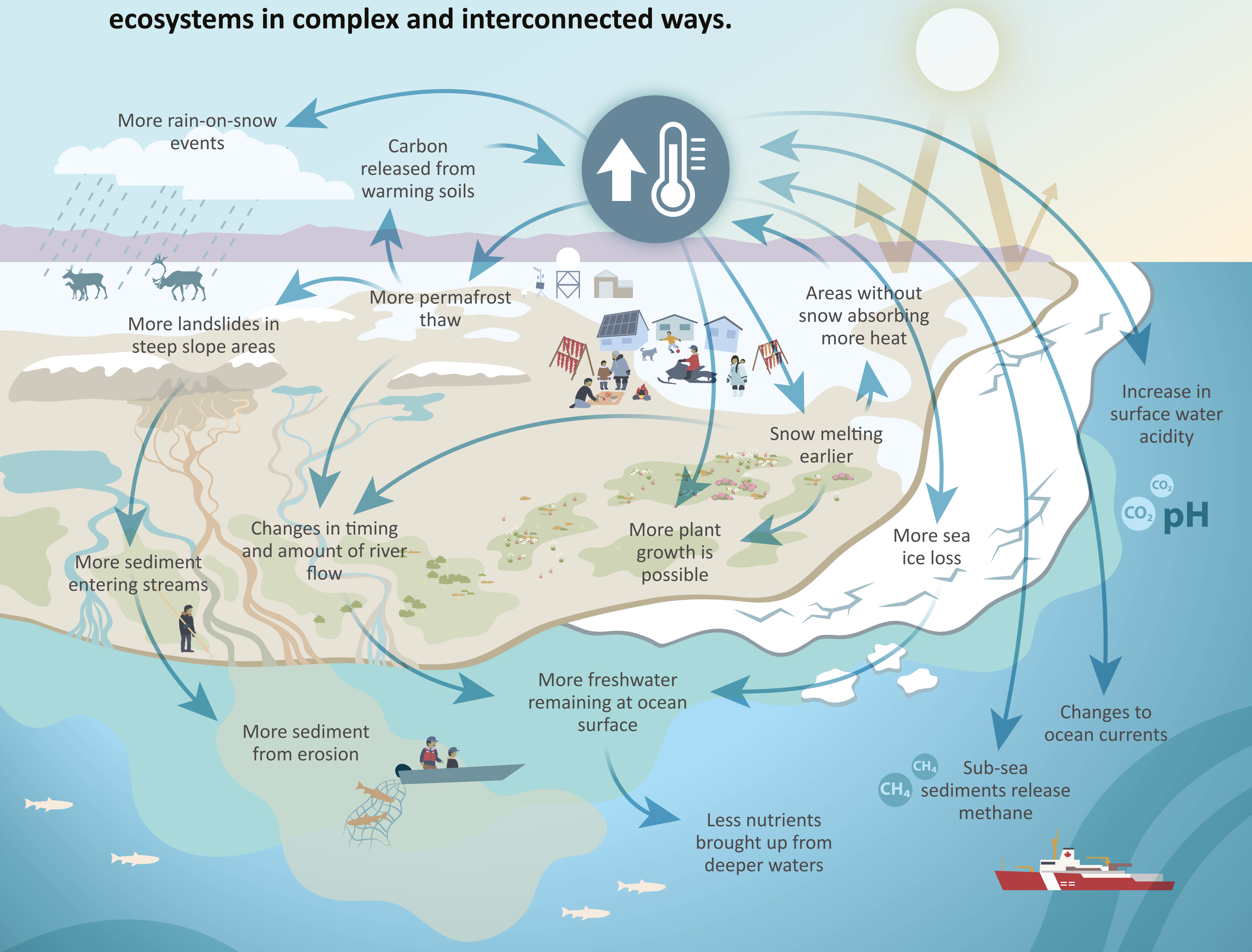
Climate change impacts land, freshwater, and ocean ecosystems in complex and interconnected ways.



FRESHWATER

Increased runoff changes river flow and reduces water quality. Rain-on-snow events make it harder for animals to find food or to stay warm.

LAND

Warmer temperatures and longer snow-free periods destabilize permafrost and extend plant growing seasons.

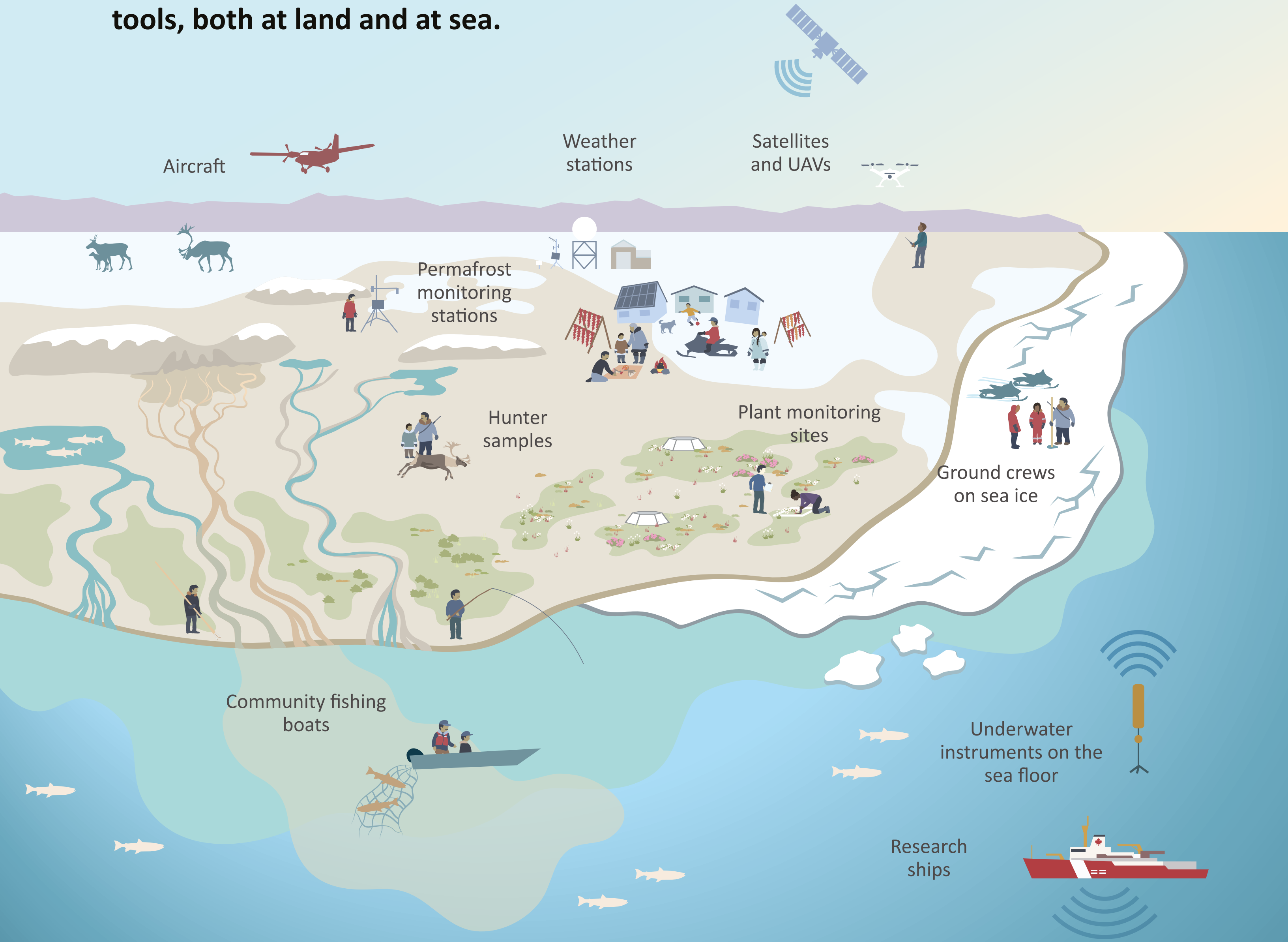
OCEAN AND SEA ICE

Changes in water quality and the way waters mix impact the ocean life that make up the base of the marine food web. Sea ice loss also affects ocean mixing in addition to loss of habitat.

CLIMATE CHANGE FEEDBACKS

Warming soils, reduced snow cover, and changes to ocean currents can have a feedback effect and lead to even more warming.

Canada's Arctic environment is monitored by many people using many tools, both at land and at sea.



SATELLITES

Satellites provide images and data over large areas and at regular time intervals, showing change across the landscape.

LAND AND FRESHWATER

Land and feshwater monitoring measures both living (plants and animals) and non-living parts of the landscape.

OCEAN AND SEA ICE

Ocean monitoring typically involves using instruments or collecting water samples.

MODELS AND REPORTS

Monitoring data helps us understand observed changes and project what could happen in the future, supporting decision-making.

Introduction

In this paper we answer three questions about climate change that people from the Kitikmeot Region (Nunavut) and from Ulukhaktok (Northwest Territories) asked at a workshop at the Canadian High Arctic Research Station in March 2020.[1]

- Why is the weather changing so quickly? It is very cold, but the ocean is warmer, and ice breaks up sooner – there is also more vegetation even though winter is colder. Why is this happening?
- What are the main impacts of climate change on sea ice, permafrost, snow, lakes, and rivers in the Kitikmeot region?
- What areas should research and monitoring focus on to prepare for changing environmental conditions?

Because Inuit depend on the land and ice for food and to maintain their culture, workshop participants want a better understanding of climate change so that communities can develop ways to adapt.

For the purposes of this document, we will be using the Government of Nunavut terms and definitions for weather, climate and climate change shown in Table 1.[2]

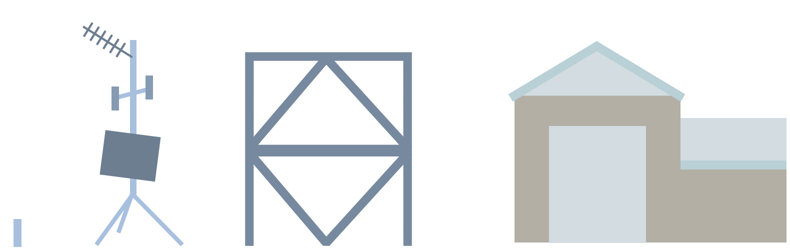


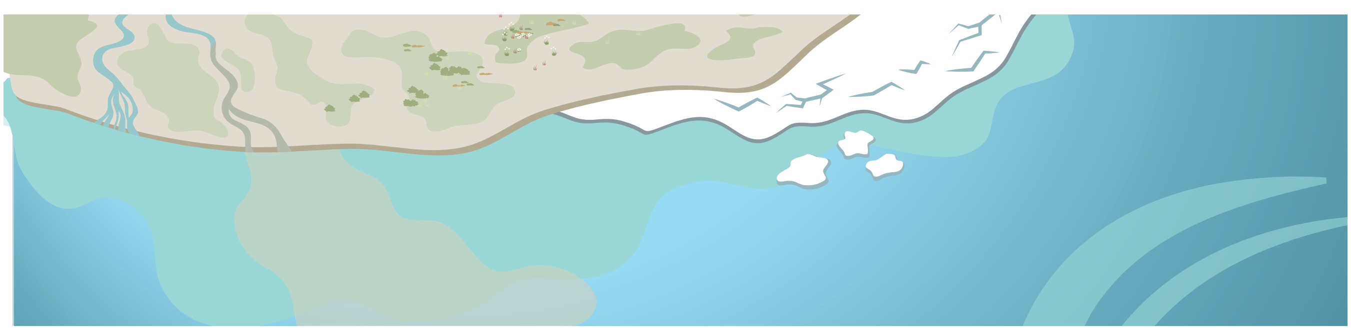
Table 1 Government of Nunavut terms and definitions for weather, climate, and climate change.

English	Inuktitut	Inuinnaqtun	Definition
weather	sila	hila	"The short-term (hours or days) conditions of the air and sky over an area. It is described by the temperature, clouds, winds and rainfall or snowfall" (GN and NTI, 2005, p. 135).
climate	silaup qanuinnirigajuktanga	hilaup ilitquhia	"[t]he usual temperature, rain or snow and wind conditions of an area over a very long number of seasons" (GN and NTI, 2005, p. 39).
climate change	silaup asijjiqpallianinga	hilaup aalannguqtirninga	"A difference in the usual and extreme global temperatures that is not just a short cycle, but lasts for decades" (GN and NTI, 2005, p. 35).

Why are the weather and the climate changing so quickly?

Climate change is caused by humans polluting the atmosphere.[3] Between 1971 and 2019 the Arctic warmed more than three times faster than the rest of the planet, Figure 1; AMAP.[4] This has disrupted normal global weather patterns. Very warm air has begun entering the Arctic and very cold air sometimes moves all the way to the southern United States.[5] Ice and snow reflect heat from the sun while open water and land absorb it. With less sea ice there is more open ocean to absorb heat. Also, a shorter snow season means that the land absorbs more heat. This feedback of heat from the earth's surface to the atmosphere accelerates warming. As a result, the Arctic is experiencing more direct effects of warming than any other place on Earth. We are just beginning to understand how this warming is impacting Arctic communities and ecosystems.

More heat in the atmosphere is causing extreme weather events around the world including unusual heat waves, droughts, hurricanes, and wildfires that are more frequent and hotter.[6] These happen less in the Arctic than in the south—but recent heat waves in Siberia, more tundra fires, and more forceful winds and storminess show that extreme weather events in the Arctic are increasing.[7] Given our slow progress in reducing atmospheric pollution, we can expect that the Arctic climate will continue to warm,[8] and extreme Arctic weather events will probably become more frequent and more intense, with important impacts on northern communities.



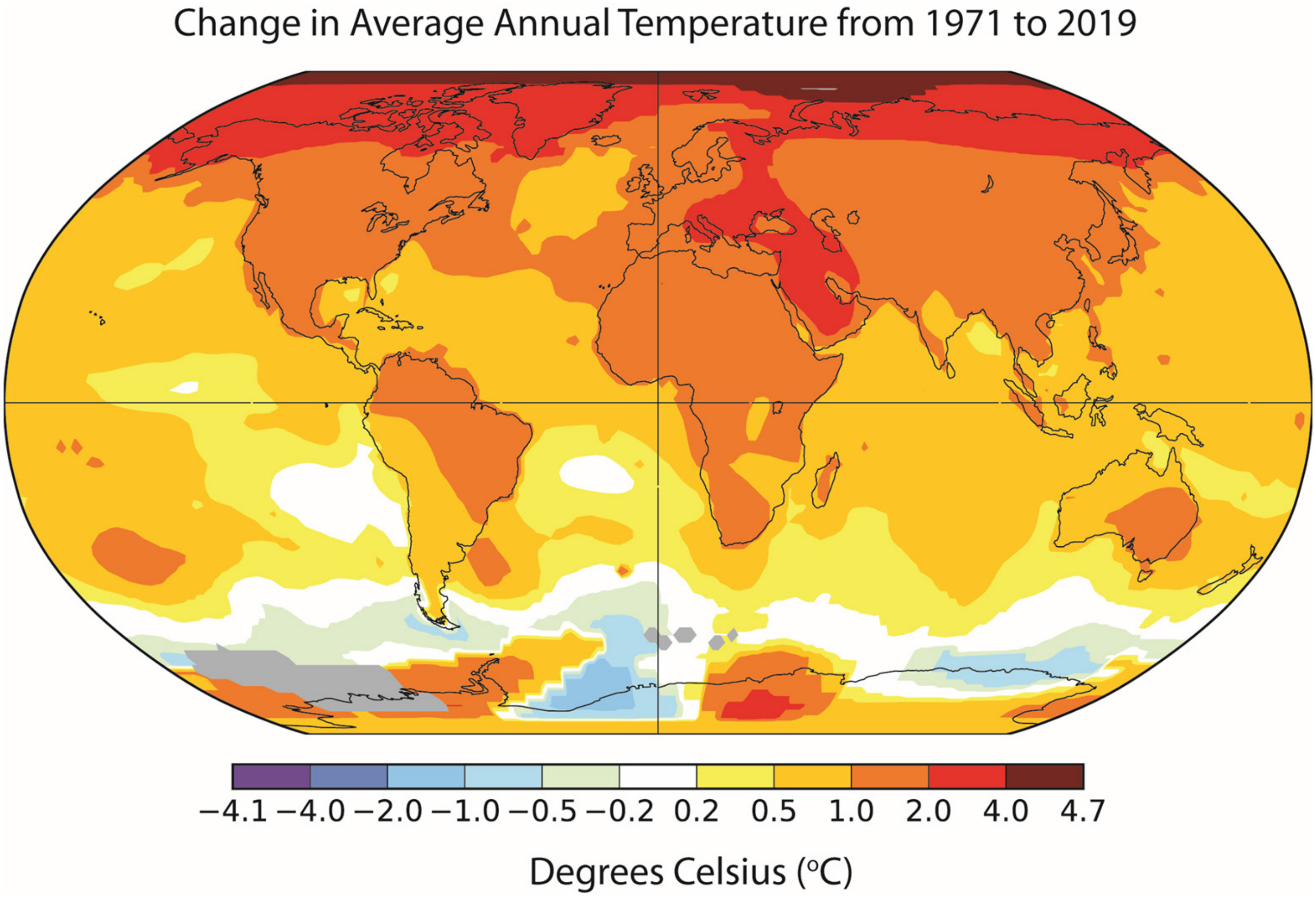


Figure 1: Changes in Average Annual Temperature from 1971 to 2019.[9] The areas of the planet that have warmed the most are shown in red.

Indigenous Knowledge Box 1: Observed Change in Weather Across Nunavut (Gjoa Haven, Inuvik, and Clyde River)

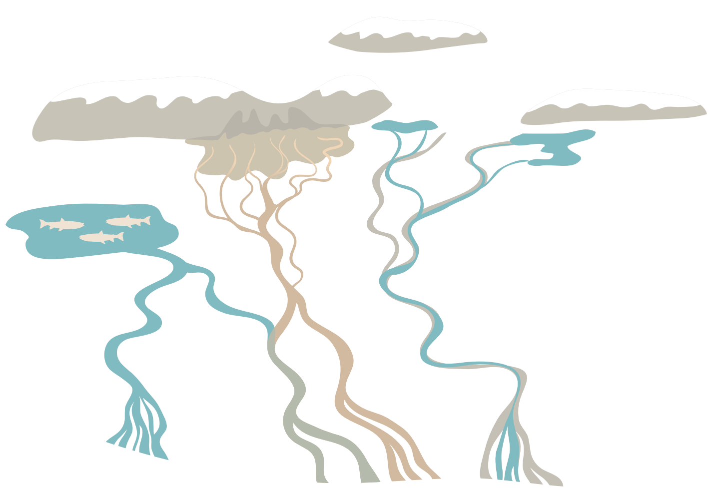
Discussions from the Indigenous Knowledge workshop, 7 July 2021

Indigenous peoples and northerners are observing that the weather is changing in the Arctic. In Inuvik there have been changes to the sea ice and the weather is less predictable. In Gjoa Haven there is an increase in the amount of cloud, changes to precipitation and differences in the length of the snowmelt. Also, there have been observable differences in sea ice thickness with the past year having exceptionally thick ice that lasted longer. In Clyde River the weather is getting warmer resulting in ice formation later than observed decades before, a longer breakup season, and an earlier snowmelt. The ice and rain have changed with less snow than two decades ago, and less blizzards, cold northern winds and cold temperatures in general. As well, Clyde River used to get blizzards that lasted one to two weeks and now blizzards are only one to two days, and the wind direction is less consistently from the North.

How does climate change affect sea ice, permafrost, snow, lakes, and rivers in the Kitikmeot region?

Temperature is the most important factor for arctic ecosystems

Air temperature controls all aspects of arctic ecosystems including the rate at which plants grow, what kinds of plants and animals can survive, when lakes, rivers and the oceans freeze and break up, the depth and season of sea ice, and the depth of the thaw in the soil. As temperatures warm, plants are growing more rapidly, shrubs are more abundant, new kinds of animals are appearing, lakes and rivers are melting earlier, sea ice is freezing, and the ground thaw is deeper (as shown in the climate change impacts infographic).



Indigenous Knowledge Box 2: Impacts of Changing Conditions Across Nunavut (Gjoa Haven, Inuvik, and Clyde River)

Discussions from the Indigenous Knowledge workshop, 7 July 2021

Over the last two years in Gjoa Haven, the vegetation is richer and lusher, than before, possibly because the ice and snow is melting so slowly. In the spring of 2021, caribou, muskox, and other wildlife are more abundant travelling by the ice near Gjoa Haven instead of the west side of King William Island. This abundance could be because ice in the area this year was thicker and lasted longer.

In the Inuvialuit region, the permafrost changes and related soil conditions create more habitable space for a more vegetation, leading to increasing spread of leafy or deciduous plants especially along the Mackenzie River. This also seems to be leading to changes in plant productivity, like berries which are variable from year to year. In the Inuvialuit region, community members are concerned about traveling to cabins because they're unsure of travel conditions, due to less predictable weather. In the past, there was a predictable time of year that people could go out, but this is now changed. Wet land conditions and melting or slumping of permafrost all impacts travel and cabins. There is also concern that the water runoff from permafrost may affect freshwater systems. Additionally, in this region, there is also rising sea levels and coastal erosion that is impacting communities.

In Clyde River, there have been similar concerns of weather impacting travel routes. For example, old travel routes used by our ancestors that were mapped out are no longer being used because of changes in conditions in a lot of areas. The hunters and campers have to be careful to figure out new travel routes as the maps of routes are no longer usable. Conditions are too slushy.

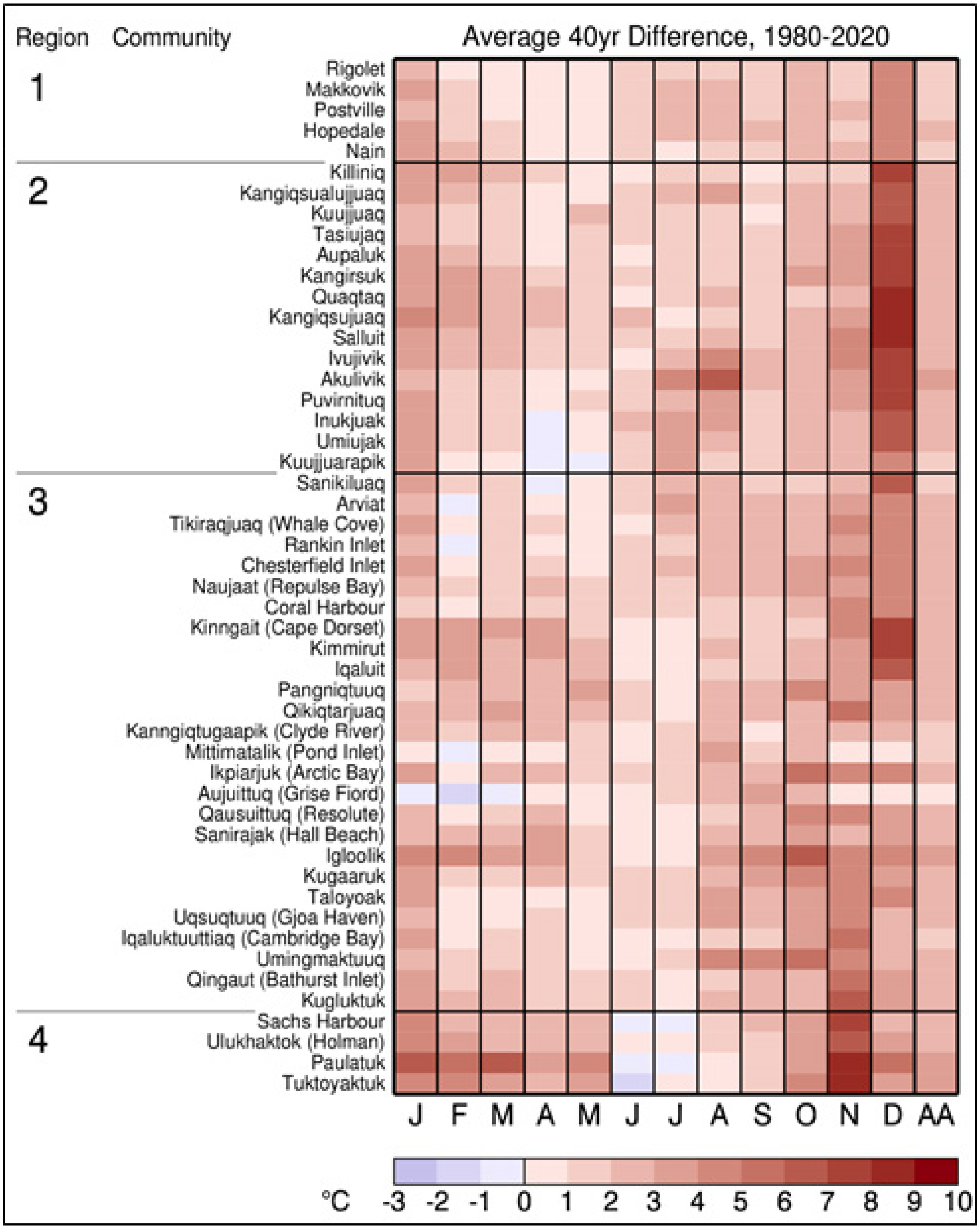


Figure 2: Northern Community Temperature Changes 1980 to 2020 for all Inuit Nunangat communities and by regions: 1 = Nunatsiavut, 2 = Nunavik, 3 = Nunavut, 4 = Inuvialuit. (Source: Lawrence Mudryk, ECCC).* Dark red indicates the most warming.

* For each community, data shown corresponds to the nearest ERA5 reanalysis grid cell. A linear trend is fit for each community-specific time series between 1980 and 2020, and the magnitude of the resulting 40-yr trend is used as the average temperature change that would have occurred locally since 1980. (Analysis and graphic by Lawrence Mudryk, ECCC).

Canadian Arctic communities are warming - mostly in winter

The Canadian Arctic is getting warmer, and some areas are warming more than others (Figure 2). Most warming is occurring in winter: December in Nunavik, and November in the Inuvialuit region. Summers are only warming slightly across Inuit Nunangat.

Rainfall changes affect caribou and muskoxen

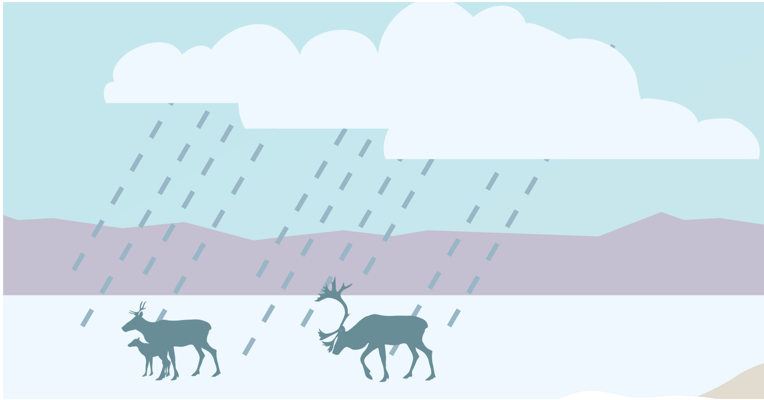
Arctic rainfall has increased slightly.[10] It rains on snow-covered land more often than before. Rain on snow causes hardship for caribou and muskoxen because they must break through ice to get at their food. Groups of these animals have been found dead as a result.[11, 12] After rain falls on snow, the snow does not insulate as well. This stresses small mammals because it gets colder underneath the snow, where they live in winter.[13]

The snow season is shorter

Snow has changed in different ways across the Arctic. Overall, the time when snow is on the ground is shorter.[14] This is because the snow is melting earlier in spring. Warmer spring temperatures make the growing season for plants longer, so they can grow more.

Permafrost is warming and thawing

Permafrost is soil and rock that stays frozen for two or more years in a row.[15] There is permafrost in most of the Arctic. It has been there for thousands of years and is hundreds of meters deep in some places. Permafrost temperatures are rising as the air warms.[16] The depth of ground that thaws each year (the active layer) is increasing,[17] and some permafrost is thawing.



On steep slopes permafrost thaw is causing landslides. These can be small or very large. They temporarily block streams and cause mud to flow into them.[18] This stops fish movements, degrades fish habitat and water quality near the slide, and affects downstream lakes and coastal areas.

Arctic plants are changing in complex ways

Research shows that climate warming is causing some Arctic plants to grow more.[19] In southern areas of the Arctic, shrubs such as willows and alders are growing more rapidly and getting more dense.[20] Sedges and grasses are also growing more across the Arctic.[21] At the moment, new plant species are not moving north except for limited movement in trees near the tree line. Eventually rising global temperatures will cause trees and other boreal forest plants to move northward into the Arctic.

Lakes and river flows are changing

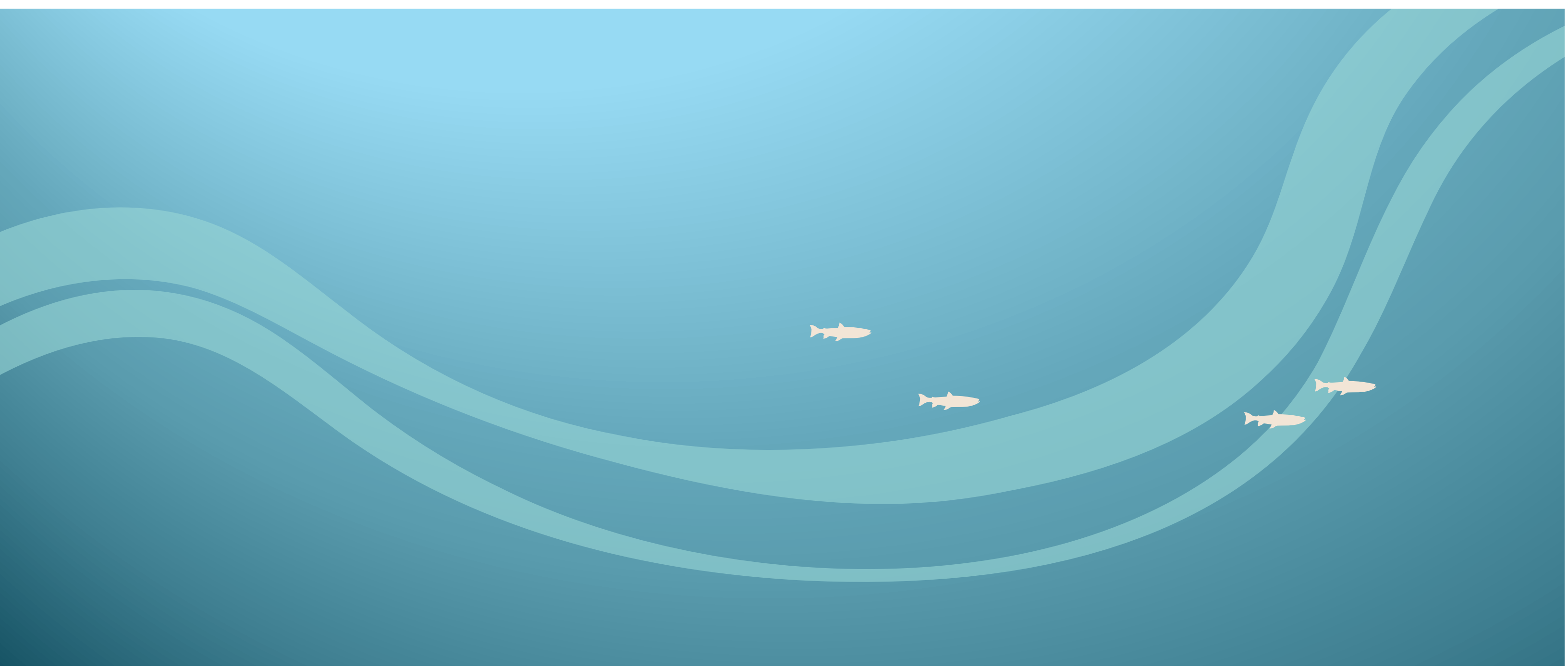
Changing precipitation and snowmelt alters lake levels, the timing of river break-up, and the amount of water rivers carry. Observers across the Arctic have noticed changes in winter ice travel conditions on rivers and lakes. Ice roads have shorter seasons, which affects communities and industry. River flow is peaking earlier in spring and flows in late summer and in winter have increased.[22] Warming and deepening of the layer of ground that thaws in spring also changes the materials rivers carry to the ocean, including carbon and nutrients. This in turn impacts river and ocean food webs. This can also affect fish habitat by raising water temperatures, lowering the amount of oxygen in the water, and changing the food supply. Rivers with long-term discharge records have shown small increases (Anderson, Burnside, and Ellice rivers), small decreases (Coppermine, Tree, and Back rivers), or no change (Freshwater Creek) in annual discharge over the past 50 years, with a general trend towards increased discharge in spring and fall, and lower discharge in summer.[23]

Ocean water is changing, and this affects ocean life

The effects of climate change on the land and in the atmosphere are affecting the ocean. In the ocean, waters from different depths mix. This mixing brings nutrients up from deep waters and increases productivity. Rivers and melting sea ice are now bringing more freshwater into the ocean, and this extra freshwater prevents ocean water from mixing. Thawing permafrost and more storm activity are adding sediment to coastal waters and reducing the amount of light. This makes life more difficult for microscopic plants at the base of the food web and impacts fish and marine mammals. Surface waters in the Arctic have become more acidic over the last decade.[24] This could have important consequences for many types of marine species, including food for small fish.[25]

Global sea level rise will be less significant in the Canadian Arctic

While rising sea levels, caused in part by melting glaciers, are threatening coastal areas and low-lying islands elsewhere in the world, this will not be a significant problem in most of the Canadian Arctic. This is because sea level doesn't rise uniformly around the world, and in the Canadian Arctic the land is still rising after being pressed down under the weight of massive glaciers during the last Ice Age.



Arctic Sea Ice is melting, and this affects the safety of ice travel

Arctic sea ice area in Canada has been declining since 1968.[14] The Northern Labrador Sea and Hudson Strait have lost the most ice. Everywhere there is less multi-year ice, which is the thick ice that has survived at least two years.[14] The shore fast first-year sea ice near most coastal Arctic communities is forming later in the fall and melting earlier in the spring.[27] Sea ice that forms later in the autumn is usually rougher and more difficult to travel on because it has been disrupted by strong winds.[28] Tides and currents also affect sea ice thickness, creating visible open water, or invisible thin ice hidden by snow.[29]

Changes in the Arctic affect the rest of the planet

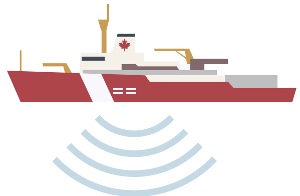
Researchers are starting to understand how changes in the Arctic are affecting the whole planet. Less sea ice and snow means that the land and the ocean absorb more heat. This not only makes the Arctic warmer in summer but also sends cold outbursts of Arctic air far to the south in the winter. Changes in Arctic soils may also play a role. Carbon normally accumulates in Arctic soils because summers are too cold for soil bacteria to break it down. As soil temperatures warm, soil bacteria are decomposing this store of soil carbon. This produces greenhouse gases that are added to the Earth's atmosphere likely causing further warming.[26, 30] However, this process is complex and may be balanced by the increased growth of plants. Researchers do not yet understand how much this increased decomposition of soil carbon will contribute to warming the atmosphere.[31] Finally, the large amounts of freshwater flowing into the Arctic's oceans could affect major ocean currents like the Gulf Stream, which warms much of northern Europe.[32] What is clear is that "what happens in the Arctic does not stay in the Arctic."

What should research and monitoring focus on?

For monitoring changes in the ocean, land, weather, and sea ice, researchers must keep repeating the same measurements and observations over time and look for changes. There are many methods and tools to record and report environmental change, including community-based observations and measurements. These can range from drilling holes to measure sea ice thickness to observing changes in sea ice from satellites (as shown in the monitoring of Canada's Arctic infographic). In this section, we review the monitoring methods used in the Canadian North. We also look at the gaps in our knowledge and suggest some ways to work together to fill them.

Monitoring the ocean

Ocean monitoring in the Canadian Arctic involves using instruments to measure and collect water samples. Researchers can do this from large ships, like the Canadian Coast Guard icebreakers; from smaller ships, like the RV Martin Bergmann in Cambridge Bay; and even from community fishing boats. Some



instruments, such as moorings, can be left in the ocean to record data over longer periods of time. Moorings are anchored to the seafloor and often left for a year or longer to measure temperature, currents, and salinity (how much salt is in the water). The largest moorings must be deployed from ships with cranes, but smaller instruments can be safely deployed from small boats, as shown in Figure 3b. Ocean Networks Canada has started to deploy instruments in the Arctic that send data directly to the internet. Their community underwater observatory in Cambridge Bay is a good example, as shown in Figure 3c (https://data.oceannetworks.ca/Dashboards/id/172).

Sea ice is also an excellent platform for measuring the ocean. Small instruments lowered through a hole in the ice measure the ocean temperature and salinity, as shown in Figure 3d. Researchers can also collect water samples through the ice. The Canadian Rangers Ocean Watch program has trained community members in the western Arctic to make such measurements. The Arctic Eider Society runs a similar program that collects winter samples in Sanikiluaq and other Hudson Bay and James Bay communities.

Figure 3: Arctic marine monitoring activities. The research icebreaker CCGS *Amundsen* (a, top left), Photo credit: B. Else; community-based research vessel *Martin Bergmann* (b, top right), Photo credit: B. Else; the Ocean Networks Canada underwater observatory (c, bottom left), Photo credit: ONC; the Canadian Rangers Ocean Watch (d, bottom right), Photo credit: D. McLennan.

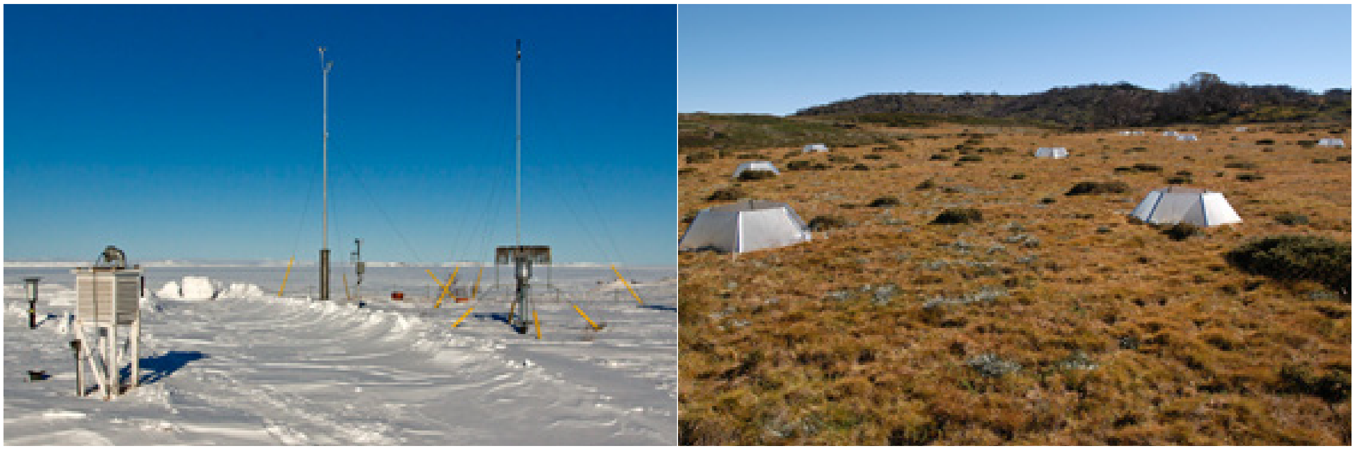
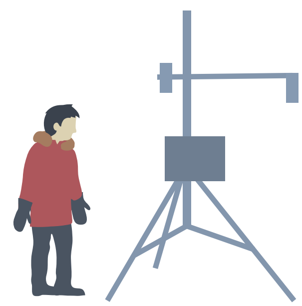


Figure 4: (a, left) Weather instruments at Ulukhaktok Airport; (b, right) ITEX mini greenhouses that track changes in tundra vegetation.

Monitoring on the land

Measuring environmental factors that directly affect plants and animals is important for observing changes on the land, and within lakes and rivers. These can include: the air temperature, wind speed and direction, and the amount of rain and snow. In Inuit Nunangat, government agencies such as Environment and Climate Change Canada (ECCC) measure these weather factors using weather instruments near local airports (shown in Figure 4a). Permafrost and the length of the growing season also need to be measured. Natural Resources Canada (NRCan) supports a network of permafrost monitoring stations across the Arctic. The International Tundra Experiment (ITEX) has monitored plants across the circumpolar North for many years, comparing plant growth in mini-greenhouses that imitate climate warming to plants outside the greenhouses (Figure 4b).

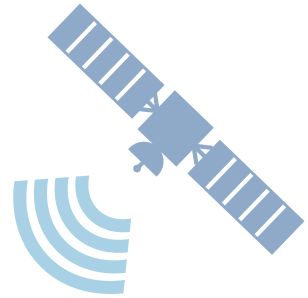
Environment and Climate Change Canada also monitors the chemistry (the substances in the water) of major Arctic rivers, and the amount of water they discharge into the ocean. Measuring the discharge helps show the impacts from changes in the timing of snowmelt, the amounts of rain and snow, soil erosion from melting permafrost, and the stream temperature. River and stream discharge and water temperatures are very important for fish species such as char that migrate to the oceans in summer.



Only a small number of Arctic lakes are being monitored. On Victoria Island, researchers from the Université du Quebec à Trois Rivières are studying lake temperature and chemistry and how they affect lake plants and animals. The researchers hope to learn whether changes in the tiny organisms (phytoplankton) in lakes affects the nutritional value of the lake char that are an important food source for Cambridge Bay.

Monitoring the land and ocean from above

Satellites play an important role in monitoring the massive area of the Canadian Arctic. Some monitor the land and sea ice. Optical satellites use the sun's light to provide colour images similar to a digital photograph. Radar satellites use radio waves to produce black and white images that show the roughness of the earth's surface. They operate well in darkness and poor weather and can be used all year in the Arctic. Usually, a satellite image covers an area several hundred kilometres wide and can show features as small as a few metres in size. Researchers use these images to make maps of land cover type (water, bare rock, vegetation), sea ice type, ocean surface temperature, and the amount of vegetation in an area (tundra greenness). Satellites can record long-term changes, such as the decrease in Arctic sea ice. Satellites do not always show the local ice conditions for sea ice travel. Local ice conditions can vary because of sheltered bays, pack ice, weather conditions (wind, snowfall), currents and tides, and location. Satellites can show sea ice roughness and open polynyas,[33, 34] but communities do not have free access to this information.



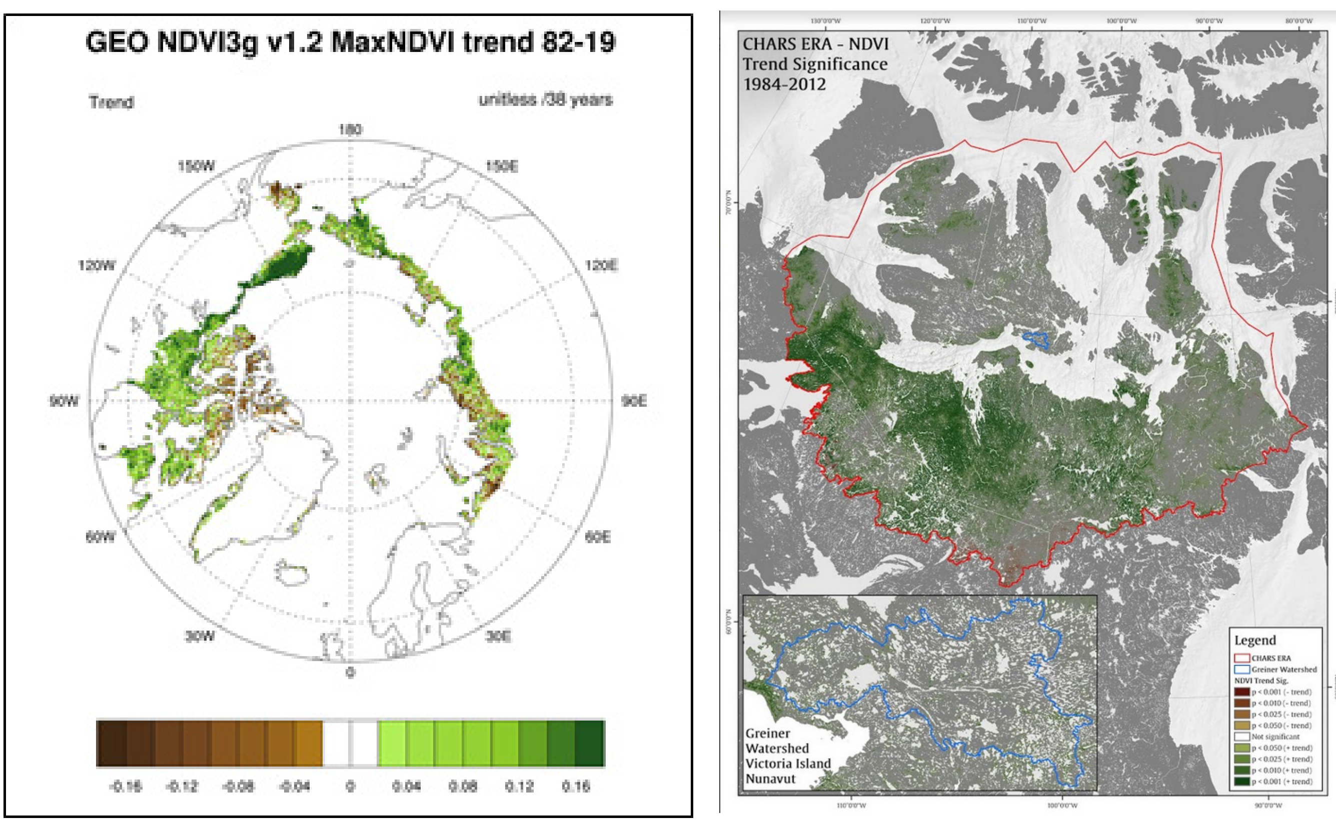


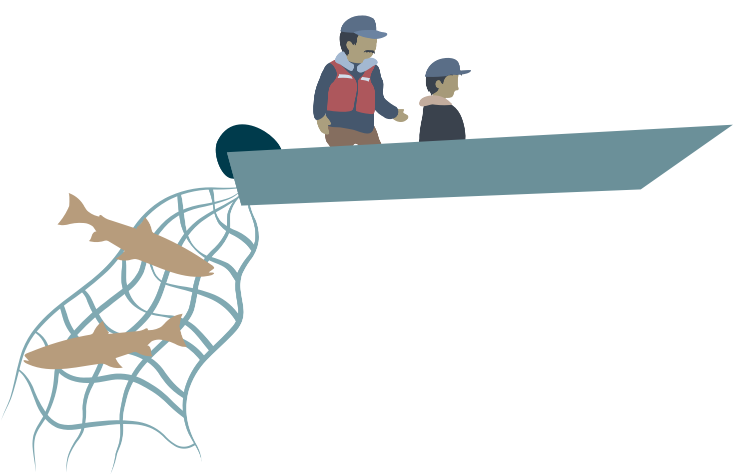
Figure 5: (a, left panel): Tundra "greening" as measured by satellites for the entire circumpolar area[36] and (b, right) in the Kitikmeot Region. GIS projection by Blair Kennedy, ECCC-CWRC, using NASA Landsat (30 m) data.[37]

Optical satellites are showing that the land is "greening," meaning that tundra plants—especially shrubs—are growing more.[19] Figure 5a shows greening around the circumpolar region, and Figure 5b shows greening in the Kitikmeot region of Nunavut. In both cases, greening is widespread, but the rate of change is not the same everywhere. This suggests that all areas are not warming at the same rate. The greening around Bathurst Inlet and Kugluktuk may be caused by sea ice disappearing earlier.[35]

Monitoring by airplane, helicopter, and drone is useful for studying smaller areas, such as a watershed, lake, or bay. Drones provide the most detail: for example, they can show individual cracks in sea ice.

Indigenous environmental observations

Indigenous people have been observing and adapting to Arctic environmental change for millennia, passing knowledge between generations through oral histories and stories. Inuit hold the only long-term and consistent environmental climate record for the Canadian Arctic. This Inuit Qaujimajatuqangit (IQ) is not stored in a database. It dwells in the collective memory of Inuit knowledge-holders, who share their expertise orally. It is a source of climate history that can provide a baseline to assess change and fill gaps in Arctic monitoring.



Inuit in Mittimatalik (Pond Inlet), Nunavut have created sea ice travel maps of hazardous and safe areas for winter, early spring, and late spring.[38] These maps are being used as a sea ice baseline, along with satellite data and ice charts, to show where and when the sea ice is changing. This is very useful for planning sea ice travel.

Some Inuit observations on change in Arctic environments are available in written form. Examples include Voices from the Bay, from the Hudson Bay area;[39] Thunder on the Tundra, about change in the Bathurst caribou herd;[40] and The Earth is Faster Now, which presents knowledge from across the circumpolar North.[41] Through the Coastal Resources Inventory Program of the Nunavut Government's Fisheries and Sealing Department (https://www.gov.nu.ca/in/node/28010), Inuit hunters from all Nunavut communities share their knowledge of the environment, plants, and animals. Environmental observations can now be entered directly into live databases through online tools such as SIKU, which operates in Inuit Nunangat (https://siku.org/reports/publication/62); ELOKA in Alaska and the western Arctic (https://eloka-arctic.org/welcome); and, also in Alaska, the spring Sea Ice for Walrus outlook (https://www.arcus.org/siwo). Community based monitoring provides many benefits; more community-based monitoring networks are needed in the Canadian Arctic.[42]

Indigenous Knowledge Box 3: Community Involvement in Research and Monitoring Across Nunavut (Gjoa Haven, Inuvik, and Clyde River)

Discussions from the Indigenous Knowledge workshop, 7 July 2021

Currently, climate research and monitoring projects are conducted by a combination of researchers coming in and by local and Indigenous peoples. This community-led research is seen as good, but it is important to be aware that some communities may be experiencing research fatigue.

A key way to involve northern communities in research and monitoring efforts is to report research analysis back to the communities. Researchers should understand community concerns and viewpoints on time, place, and scale when making predictions. Sometimes when this is not done there is a disconnect between what the community members expect with respect to research outcomes. A lot of research is high-level and not connected to what the local priorities are.

While it is common for research reports and presentations of findings to be given back to the communities, it would be good to see information be made more accessible. For example, information could be presented as posters, videos, and graphics, which is helpful for those on the internet, with cell phones, or on social media. Sharing information on the radio is good for older generations. Information should also be provided to younger generations and shared with schools. Youth want to be involved and information shared at schools or in their curriculum can help the community be more involved.

There is acknowledgement that community involvement in research can go beyond their Indigenous Knowledge. There is interest in community members being involved in the science of projects and using technology and devices and being partners in research. It was suggested that community members could use technology, such as remote-control drones and sensors for checking thickness of sea ice. Technology could also be used to see data. For example, websites like that of SmartICE that show information from sensors collecting data from local hunting grounds, and showing information in English or Inuktitut, are helpful.

Where are the gaps in our knowledge?

We still have much to learn about the effects of climate change in environments in western Nunavut and eastern NWT. Key indicators can be observed, measured, and monitored. They tell us about the environment and how it is changing over time. For example, sea ice thickness can tell us if the weather over the past winter has been "normal" or different from previous years. Table 2 outlines some of the key indicators that we can monitor to track and understand climate change and shows some of the regional concerns that may relate to each key indicator. Table 2 also shows where there are gaps in our knowledge. More monitoring, both local and regional, is needed in these areas. Monitoring will provide information to help improve our understanding of the key indicators, so that we can give more complete answers to questions about regional concerns. Natural scientists need to work with Indigenous Knowledge holders to better understand these key indicators.

Table 2 Key Indicators of Environmental Change in Western Nunavut and Eastern NWT.

Key Indicator	Regional Concerns	Examples of Monitoring and Observational Knowledge Gaps	Examples of Potential Monitoring Activities
Temperature (Atmosphere)	Less sea ice means more warming of the land, affecting char migration and local/regional weather and climate	Temperature monitoring is often limited to community airports (ECCC)	Establish temperature sensors around communities to monitor and understand changes across the environment
Precipitation (Rain)	Increasing rain-on-snow events that impact caribou grazing and changes in the amount of rain over the growing season	Snow and rain monitoring are often limited to community airports (ECCC)	Set up sensors around communities to measure rain and snow to detect rain-on-snow events and record changes in soil moisture
Snow Cover	Changes in snow are impacting caribou, muskoxen, and small mammals, as well as the long-term sustainability of the drinking water supply	Snow monitoring is often limited to community airports (ECCC) and through satellite imagery, which is difficult to use at community scales	Fund more co-developed, community-led programs that measure snow depth and use Inuit Knowledge and science observations of tundra animals
Permafrost (Soil Temperature)	Slumps and landslides are impacting fish habitat and collapsing ground damages infrastructure	Permafrost monitoring by federal and territorial governments is sparse across the Canadian Arctic	Establish permafrost monitoring sites in communities that link with regional and national networks
Vegetation Change	Vegetation is changing, which impacts important food sources for people and animals	Terrestrial monitoring is limited to specific areas of academic research	Establish long-term vegetation monitoring near communities to track changes in plant cycles and growth
River Discharge	Changes in river flow are impacting fish habitats and near-shore ecosystems	There is not enough information on river outflow for rivers in the Canadian Arctic; more is needed so we can understand how changes in river flow will impact wildlife and the environment	Conduct routine measurement of river discharge and chemistry across the region, covering different drainage basin types
River Nutrients	Increased runoff from the land into the rivers impacts the coastal ocean ecosystem and fish habitat	There is not enough information on water chemistry across the Canadian Arctic to understand long-term change	Conduct routine measurement of river discharge and chemistry across the Arctic, covering different drainage basin types
Lake Ice and Ecosystems	Changes are affecting safe travel (uncertainty about conditions during freeze-up and melt), lake ecosystems, and the safety of drinking water	Lake monitoring is focused mainly on the large lakes (e.g., Great Slave)	Establish monitoring of nearby community lakes of concern

Table 2, continued

Table 2 Key Indicators of Environmental Change in Western Nunavut and Eastern NWT.

Key Indicator	Regional Concerns	Examples of Monitoring and Observational Knowledge Gaps	Examples of Potential Monitoring Activities
Ocean Temperature	Warming coastal waters impact the marine food web	There are not enough long-term records to understand and predict changes in Canadian Arctic Ocean waters	Establish sensors moored in the ocean to constantly monitor deeper waters and surface water during ice-free seasons
Ocean Chemistry	Increased acidity of the ocean is impacting the marine food web		Establish community-led observing in the near-shore coastal region to measure river-to-ocean chemistry
Sea Ice	Changes are affecting safe travel due to uncertainty about conditions during freeze-up and melt	Not enough sea ice observations for some areas and times; satellite images are sometimes hard to understand and difficult to access	Translate satellite and ice chart data into locally relevant sea ice observations and establish community-led observation programs to monitor sea ice thickness and roughness along major routes

Future directions: toward bridging different ways of knowing

How do we fill the gaps in our scientific knowledge to address community concerns and future change in the Kitikmeot, in Ulukhaktok, and across Canadian Arctic? What new tools and methods do we need, especially in communities? What are the best ways that scientists and Indigenous Knowledge holders can work together?[43] As a group of environmental researchers working across the Canadian Arctic, our Working Group came up with the following list of six Emerging Opportunities. These will enable us to collect the observations we need to better understand the effects of climate change in this region. They will build linkages between Indigenous Knowledge and science.

1. Develop research partnerships with northern communities that focus on community-based research needs, and include knowledge sharing and knowledge co-production for all aspects of environmental change research in the region.
2. Develop a new set of environmental indicators with Indigenous rights holders. These would include indicators developed by Indigenous Knowledge holders and scientists and would be included in the research design. The indicators could be adapted for regional and local needs.
3. Establish community-based monitoring initiatives with long-term support that builds capacity in the community and enables the collection of consistent, continuous, and high-quality observations of key environmental indicators.

4. Create opportunities for Inuit youth to participate in monitoring programs and use research tools and educational resources to develop their own youth-led projects.[44]
5. Develop models that predict how climate change will affect each community, to help them adapt.
6. Develop tools for two-way exchange of information that are available to the public and simple to use.

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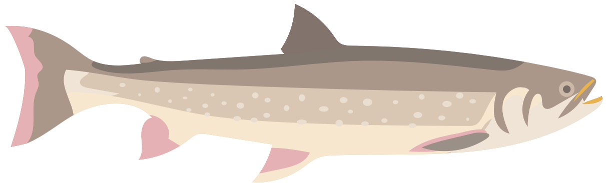
Arctic char in a rapidly changing North



Executive Summary

Fish have been central to Inuit culture, food security, and health for millennia. Arctic char are a staple across Inuit Nunangat. Small commercial char fisheries provide jobs in some communities.

Research has shown that sea ice conditions, temperature, salinity, prey, and possibly predators, can all influence where Arctic char go in the ocean as well as their health. Temperature is among the most important of these conditions. Char may react to warming ocean waters. With a shorter sea ice season, sea-run char may migrate to the ocean earlier and spend longer feeding there. They may stay longer in deeper waters, in the cooler temperatures they prefer. They may spend more time away from the shore as shallow waters near land become warmer.

In warmer waters, char need to eat more. In cooler water, Arctic char need less food. This may be why they move further from shore or into deeper, cooler water later in summer.

Changes in their diet can mean the food available to them is changing. Recent warming and sea ice retreat have brought southern fish species, such as capelin and salmon, to Arctic waters. Community experts are monitoring these new arrivals — some have observed that flesh of char that eat capelin tends to be paler — but it is still unclear how they are affecting Arctic char and other Arctic species. Salmon moving north may affect char living in more southern parts of the Arctic. However, the southern range of Atlantic salmon overlaps with that of char, and the two species do not compete for spawning areas as they spawn in different kinds of habitat. More research is needed to learn how southern fishes moving north affect char.

Earlier ice breakup has improved the condition of Arctic char in some areas, possibly because they have a longer time to feed in the ocean.

The amounts of persistent organic pollutants, such as PCBs, are declining in Arctic char. Mercury, which occurs naturally, can increase in the environment because of dams and mining. This is a concern in Nunatsiavut. Research shows that the levels of mercury in sea-run Arctic char are very low, well below the amounts allowed by commercial sale guidelines. Char that never migrate to the ocean, especially those living in smaller lakes, are more likely to have higher levels.

We need to understand more about the factors that influence the abundance, accessibility, quality, and stability of Arctic char stocks, now and in the future. Through strong and equitable partnerships between researchers, communities, and Indigenous Knowledge holders, we will gain that understanding.

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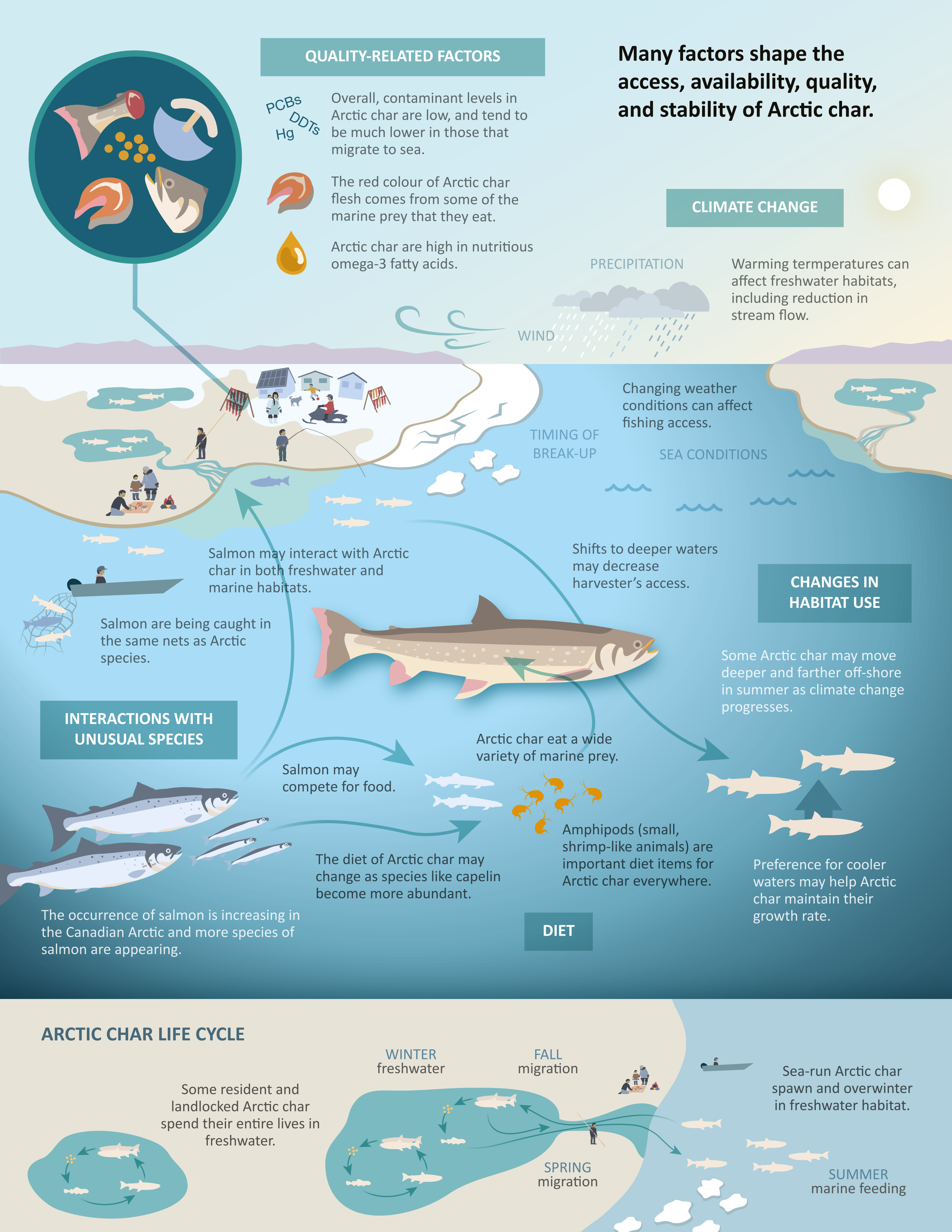

Many factors shape the access, availability, quality, and stability of Arctic char.
QUALITY-RELATED FACTORS
PCBs
DDTs
Hg
Overall, contaminant levels in Arctic char are low, and tend to be much lower in those that migrate to sea.
The red colour of Arctic char flesh comes from some of the marine prey that they eat.
Arctic char are high in nutritious omega-3 fatty acids.
CLIMATE CHANGE
PRECIPITATION
Warming termperatures can affect freshwater habitats, including reduction in stream flow.
WIND
Changing weather conditions can affect fishing access.
TIMING OF BREAK-UP
SEA CONDITIONS
Salmon may interact with Arctic char in both freshwater and marine habitats.
Shifts to deeper waters may decrease harvester's access.
CHANGES IN HABITAT USE
Salmon are being caught in the same nets as Arctic species.
Some Arctic char may move deeper and farther off-shore in summer as climate change progresses.
INTERACTIONS WITH UNUSUAL SPECIES
Arctic char eat a wide variety of marine prey.
Salmon may compete for food.
Amphipods (small, shrimp-like animals) are important diet items for Arctic char everywhere.
The diet of Arctic char may change as species like capelin become more abundant.
Preference for cooler waters may help Arctic char maintain their growth rate.
The occurrence of salmon is increasing in the Canadian Arctic and more species of salmon are appearing.
DIET
ARCTIC CHAR LIFE CYCLE
WINTER freshwater
FALL migration
Some resident and landlocked Arctic char spend their entire lives in freshwater.
Sea-run Arctic char spawn and overwinter in freshwater habitat.
SPRING migration
SUMMER marine feeding

Introduction

Fish have been central to Inuit culture, food security, and health for millennia. Abundant, nutritious, and prized for their flavour, fish – especially Arctic char – are a staple in communities across Inuit Nunangat.

Inuit catch and consume different types of fish including Dolly Varden, Lake Trout, and Whitefish. However, in Nunavut, Arctic char is harvested the most in every community.[1] It is a very important local food source, with high cultural value. Replacing Arctic char with market food would cost about $7.2 million a year.[2] Additionally, Arctic char has a commercial fishery that employs dozens of Nunavummiut and has a quota of about 677,220 kgs. There are 200 other commercial quotas available, but many are not being used. Some communities would like to expand the fishery to provide more jobs.

Arctic char is the world's most northerly freshwater fish. Char living in lakes without access to the ocean are called "landlocked Arctic char." Some, known as sea-run Arctic char, inhabit lakes with ocean access and migrate to the ocean in summer. Others, called "freshwater residents," live in lakes connected to the ocean, but never migrate. In Inuit communities, the sea-run fish are most important for both the subsistence and commercial harvests. In the Arctic, marine waters are more productive (meaning there is more food to eat) than freshwater, so that sea-run fish grow larger.[3] Climate change may increase the amount of food for char in freshwater, and some studies suggest that the number of freshwater residents could increase, while sea-run fish become fewer.[4] This could affect fisheries, as sea-run fish are larger and more valuable.

This paper provides information on some of the recent research on Arctic char, focusing mostly on sea-run char. It addresses thematic questions developed at the *Regional Planning and Knowledge Sharing Workshop* (see Introduction of the Collaborative Assessment). A table at the end shows how ecological information relates to food security.

Arctic char habitat use and how it could change in the future

Northern sea-run Arctic char hatch in freshwater and stay in lakes and streams for 4 to 7 years.[5, 6] Then they migrate to the ocean to feed.[5, 7] Before winter, when the seawater becomes too cold for them to survive, they return to freshwater.[5, 7, 8]

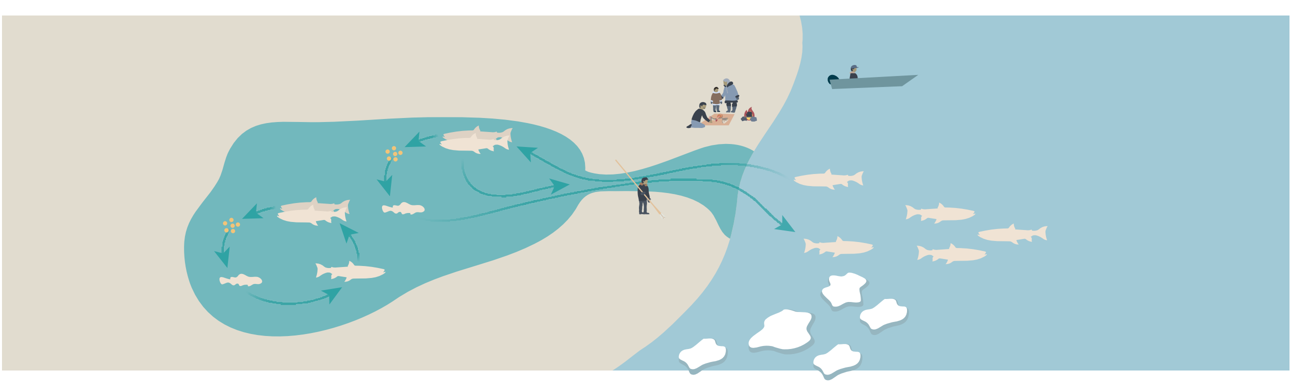
Arctic char migrate like this throughout their lives, and they can live more than 30 years. They spawn many times, unlike their relatives, Pacific salmon, which die after spawning. Arctic char do not tolerate highly salty water well, so they cannot live long in full-strength seawater.

Movement and habitat use in the ocean

Arctic char typically migrate to the ocean when the river ice breaks up in spring, while sea ice is still present. They return to rivers towards the end of August.[9, 10] We have improved our understanding of where Arctic char go by tracking a small number of them with tags, implanted under their skin, which send an acoustic signal.[9] Other studies have tagged hundreds or thousands of fish with plastic ID tags, which have provided valuable information on migration patterns. A few char have been recaptured hundreds of kilometres away from where they were tagged.[11]

This research has shown that sea ice conditions, temperature, salinity, prey, and possibly predators, can all influence where Arctic char go in the ocean.[12, 13] It has also clearly demonstrated these patterns:

- While in the ocean, Arctic char spend most of their time in estuaries (where rivers enter the ocean), often preferring these habitats until the sea ice disappears.[12, 13] In some areas this coincides with the spring tides.
- Char stay close to shore (usually within 1 km) and remain in one estuary for a few days before moving quickly to the next estuary. Scientists are not certain why they prefer estuaries: they may prefer the warmer and less salty water near rivers. There may also be more food in estuaries.
- Arctic char usually stay within 1 to 3 metres of the surface.[14] The top layer of the ocean is warmest and least salty, and most of their prey live there. The fish occasionally dive down below 30 metres, probably to feed on prey in the deeper waters. There the water is colder and saltier, and so the fish soon return to the surface. Later in summer, Arctic char move deeper in the ocean[13] and possibly further from shore.
- Arctic char spend the day further down and come up at night, probably to feed on prey that do the same.[12, 13]



From this information we can predict how Arctic char may react to warming Arctic Ocean waters:

- If rivers break up earlier and freeze up later, the fish may migrate to the ocean earlier and return later, allowing them to spend a longer time feeding there.
- If surface waters warm, they may stay longer in deeper waters in the cooler temperatures they prefer.
- They may spend more time away from the shore as shallow waters near land become warmer.

More long-term studies will improve understanding of how year-to-year changes in the environment influence the way char behave in the ocean as marine waters continue to warm.

The effects of temperature on Arctic char

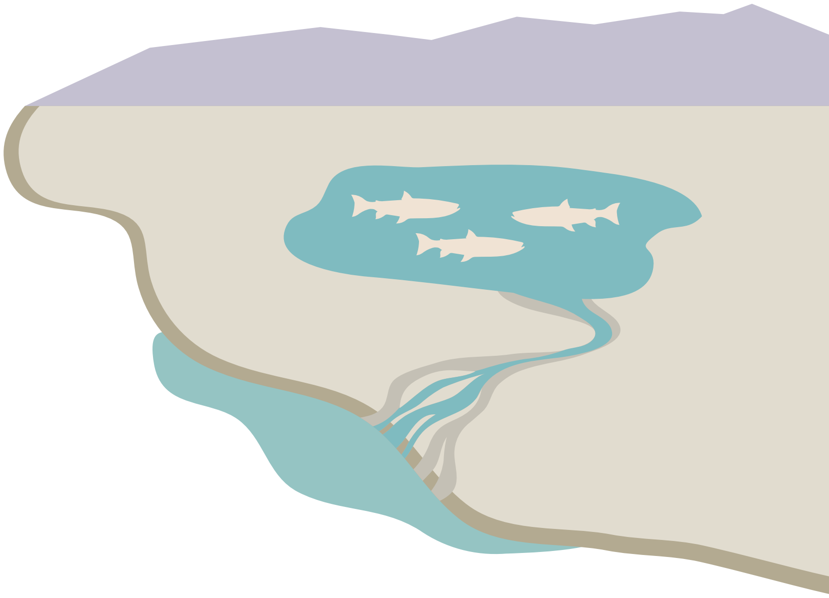
Temperature affects where Arctic char go and how they use their habitats. Temperature also influences their health and metabolism (how their bodies use energy).

Arctic char are a cold-water fish – they can grow at temperatures as low as 0°C – but like all living things they do best in a certain temperature range. In the warmer part of that range their bodies perform better. They grow more quickly, their heart beats more rapidly, and they can swim faster.

When the water warms to about 16°C though, the reverse happens, and their performance decreases.[15] Above 16°C it is harder for them to recover from exercise (like migration). Above 18°C, they can no longer eat, and by 21°C their heart begins failing. At 23°C they cannot stay upright.[15, 16] Arctic rivers are sometimes warmer than 21°C, and this limits where and when Arctic char can successfully migrate.

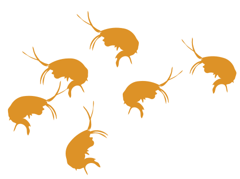
Oceans in the central Canadian Arctic stay well below these temperatures, usually remaining below 12°C. Recent research has shown that warmer summer ocean temperatures and longer ice-free periods are not harming adult Arctic char.[17] Some data suggests that they grow more when the ice-free period is longer.[18]

In warmer waters, the metabolism of Arctic char increases, and they use more energy – which means they need to eat more. Food is often limited though, and by moving to cooler water where they need less energy they can probably grow more quickly. Laboratory studies have shown that in cooler water Arctic char need less food to grow.[19] This may be why the sea-run Arctic char move further from shore or into deeper, cooler water later in summer.



The diet of Arctic char

In winter, when they are in ice-covered lakes, sea-run Arctic char eat very little. They get most of their food in the summer when they are in the ocean.[20] During their short ocean feeding season, they must eat enough to migrate back to freshwater, possibly spawn, survive the winter, and migrate back to the ocean the following year.[5]



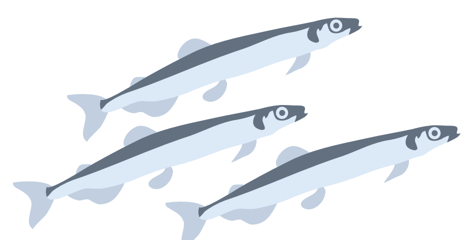
Arctic char feed on many kinds of marine prey. They eat small and large fishes, zooplankton (small aquatic animals), larger crustaceans (amphipods and decapods, and shrimp-like creature such as mysid), and small insects.[12, 21, 22]

Research suggests that Arctic char eat mostly amphipods and mysid shrimps. They also eat copepods, which are small crustaceans. These tiny animals live near shore under sea ice. As the ice disappears, they move deeper and further from shore, and the char follow them.

Fish also make up a large part of the Arctic char diet. They eat Arctic Cod, Sculpins, and occasionally other Arctic char. Recently, they have been eating Capelin and Sand Lance.[23] In the future, they may eat less Arctic Cod, because that species needs to live under sea ice for part of its life cycle. Arctic Cod may become less plentiful in lower Arctic latitudes as a warming climate reduces the amount of sea ice with continued climate change.[24]

Arctic char is a healthy food because of the nutrients, vitamins, and good fats its flesh contains.[25] These come from what the fish eats. The healthy omega-3 fats in Arctic char flesh,[26] come from small Arctic crustaceans. The pigments that give char flesh its reddish colour are beneficial to human health.[27, 28] They come from animals such as copepods that feed on microscopic algae.

Recent warming and sea ice retreat have brought southern fish species such as Capelin, Sand Lance, and Salmon to Arctic waters.[29, 30, 31] Also, earlier sea ice breakup has changed the time of peak production, when marine plants and animals are most plentiful. Both of these factors have affected Arctic marine food webs and char diet. Arctic char can act as a “sentinel species,” meaning that what they are eating shows what prey are available in the environment. Changes in their diet can indicate changes in the marine food web. For example, in the Qikiqtaaluk (Baffin) region, char have recently shifted to eating Capelin – which shows that Capelin are getting more abundant there.[22, 32] In the Kitikmeot region, char are feeding on prey near the surface more than before.[33]



Some indicators of fish quality, such as condition (how heavy it is for its length) and the amount of nutrients they contain, have changed in the past few decades. This may reflect how char are responding to climatic and food web changes. For instance, earlier ice breakup and longer ice-free seasons have improved the condition of Arctic char in some areas.[18, 33, 34] This may be because they have a longer time to feed in the ocean. Some researchers think that changes

The highly variable red colouration of Arctic char skin occurs when they are in spawning condition. Below is a very red char in spawning condition from Naujaat, Nunavut. Photo credit: Laurent Kringayark

in the types of marine prey, caused by climate change, may be influencing the colour of Arctic char and their nutrient and fat content. There is not yet enough evidence to confirm that this is true; but it will be important to understand how changes in Arctic char prey may influence food security and health in northern communities.

Contaminants in Arctic char

Northerners are concerned about pollutants in country foods, including Arctic char. In the early 1990s, the federal government's Northern Contaminants Program (NCP) began to investigate Persistent Organic Pollutants (POPs) in Arctic animals. These include PCBs, used in inks, transformers, etc., and DDT, used to kill insects. Many of these chemicals travelled up from the south on ocean and air currents. Others were used in the north – at former Distant Early Warning (DEW) Line sites, for example.

In the 1950s, after researchers found these chemicals in remote environments and proved they could cause harm (e.g., DDT caused some bird eggshells to become too thin), governments developed regulations to control their use. Bans and restrictions followed in the 1970s. In 2001, 152 countries signed the *Stockholm Convention on Persistent Organic Pollutants*, an international treaty to eliminate or restrict the production of pollutants such as PCBs. This was effective. Industries now use these chemicals much less and they are declining in the environment. Programs such as NCP are monitoring the decline in POPs in Arctic and subarctic animals.

The number of pollutants in traditional foods depends on many factors. Some chemicals build up in an animal over time, so that an older animal can have more in its body than a younger one. An animal's size is also a factor. A small fish like a Sculpin will have less for its size than a large Lake Trout. This is because the pollutants from all the small fish the large fish eats build up in its body. Fish have less pollutants in their bodies than warm-blooded animals. This is because they eat less than warm-blooded animals of the same size, as they do not need as much food to keep warm. Because they eat less, they take in less POPs. Also, these chemicals accumulate in an animals' fat. As Arctic char have very little fat compared to sea mammals, their flesh contains far less contaminants.

From the 1990s to 2010s, NCP researchers worked with communities across the North to measure POPs in sea-run Arctic char.[35] They found that concentrations were very low, even at Cambridge Bay and Saglek, in Nunatsiavut, and where there had been DEW Line sites. These sites had been contaminated with PCBs and later cleaned up. POPs are also declining in landlocked Arctic char in lakes on Cornwallis and Ellesmere islands.[36]

PCBs
DDTs
Hg

Northerners are also concerned about another pollutant, mercury. Mercury occurs naturally in rock, soil, water, and air, and in plants and animals. Human activities like mining and hydro dams can cause it to increase. Like POPs, mercury levels increase with each step in the food chain. This means that fish feeding at the top of food chains (often on other fish) have higher mercury levels than fish feeding lower on the food chain (often on insects or shrimps).

Because sea-run Arctic char grow relatively quickly and feed mostly in the ocean, they tend to have low mercury concentrations. The Canadian Food Inspection Agency (CFIA) measured mercury in char at 35 sites across the North from 1975 to 1994.[37] The amounts were very low, averaging 0.05 parts per million – ten times below the amounts allowed by commercial sale guidelines. More recent studies, from 2004 to 2013, confirmed these low levels.[38]

Scientists have measured mercury in freshwater resident and landlocked Arctic char.[39, 40] Landlocked and resident Arctic char are more likely to have more mercury than sea-run char. This is because fish remaining in freshwater grow more slowly than sea-run fish and because there is more mercury in freshwater food webs than marine food.[20, 41]

The amount of mercury in Arctic char can change over time. Many factors affect this, including the size of the fish, its condition (how heavy it is for its length), how quickly it grows, and the air temperature. Warming in the western Canadian Arctic has caused sea-run Arctic char to grow faster and their condition has improved in some regions.[18] This tends to result in lower mercury levels. Labrador has been warming as well, but researchers have not observed declines in mercury in landlocked and sea-run Arctic char there.[42] Changes over time can also differ among lakes, as smaller lakes can have more mercury than larger ones. Scientists have seen this on Cornwallis Island near Resolute.

Therefore, climate warming may affect mercury levels in Arctic char. Whether the levels increase or decrease depends on many factors. Landlocked and resident fish from smaller lakes are more likely than sea-run char to have levels of mercury above the guidelines for human consumption. Sea-run Arctic char continue to have very low concentrations of mercury.

Parasites are another important indicator of fish quality and their diet. Arctic char can pick up parasites from birds, invertebrates, and other fish. Where the char live (ocean and freshwater) also has an influence. Several different kinds of parasites can infect char. Some are large enough to be visible to the naked eye – such as tapeworm in guts, cysts attached to organs or flesh, worms in the swim bladder, and parasitic copepods on the gills or mouth.

The tapeworm is the only parasite that humans can get from Arctic char.[43] This can only happen by eating uncooked meat with cysts that contain larvae. Medication can treat this safely and effectively (see https://www.cdc.gov/parasites/diphyllobothrium/faqs.html).

Climate change will probably impact the numbers and kinds of parasites in Arctic char habitats, and their ability to infect char. More research is needed to improve understanding of the parasites that infect Arctic char now, and how climate change may affect them in the future.

Species interactions

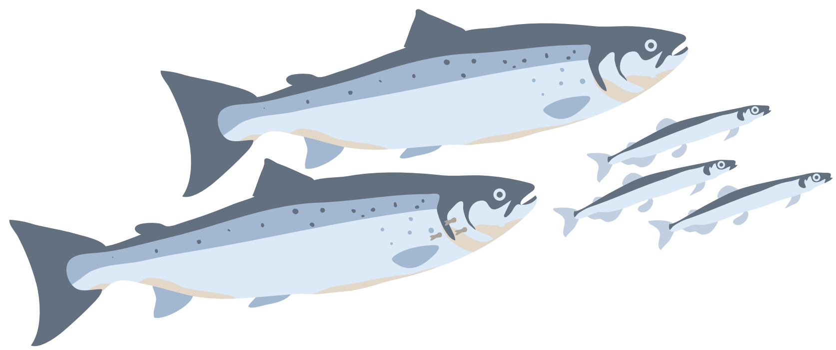
Some subarctic fish species are responding to climate change by shifting northward as waters warm.[44, 45] These fish are appearing in subsistence nets across the Arctic.[46] We do not know much about how subarctic fish are interacting with Arctic char and other Arctic fishes. They may be interacting if they are in the same areas at the same time and if they need similar habitats and food.

Some species, like salmon, spend time in the ocean during summer and spawn in rivers and lakes in the fall, similar to Arctic char and Dolly Varden. For spawning, salmon need places, usually in rivers, that do not freeze to the bottom and that stay warm enough for eggs and juveniles to survive the winter. In the Arctic, these places are usually near groundwater springs. Arctic fishes also use these habitats, so it is possible that salmon and char could interact in both freshwater and marine environments. Researchers are working to understand better how salmon affect Arctic ecosystems and fishes.

In recent years, more salmon are being caught across the Canadian Arctic in subsistence nets set for Arctic char and other fishes.[30, 47, 48] "Arctic Salmon" is a community-based program in the Northwest Territories that is monitoring this in the Mackenzie River and its tributaries (see www.facebook.com/arcticsalmon and www.arcticsalmon.ca).

While there is a long history of Chum Salmon harvests in the Mackenzie River, they are being caught in more places and in greater numbers, especially over the last 10 years.[47, 48]

Pink and Sockeye salmon have also been turning up in nets in recent years, especially in the Beaufort Sea communities. Fishers are catching Sockeye and Pink salmon as far east as Cambridge Bay.[46, 47] Pink Salmon have occasionally been caught elsewhere in Nunavut, in Nunavik, and in Greenland.[30, 46, 49]



Chinook and Coho salmon have appeared in nets in the Northwest Territories, although rarely. Subsistence fisheries in Nunavut also catch the occasional Atlantic Salmon.[50] Scientists expect these fish salmon species to shift northward, possibly impacting southern populations of Arctic char.[51, 52]

There is an area in Nunavik where the northern range of Atlantic Salmon and the southern range of Arctic char overlap.[50] However, the spawning adults and young fish of each species prefer different freshwater areas. Atlantic Salmon generally spawn in rivers, while Arctic char spawn in lakes. Juvenile Atlantic salmon prefer faster water flows, whereas juvenile Arctic char prefer slower waters and pools.[50] It is possible that Arctic char feed on Atlantic Salmon eggs.

Arctic char and Atlantic Salmon do have some similar temperature and habitat preferences, so they may be interacting. To understand this better we need more information on what habitats are available to them, especially in winter.[50]

By assessing locations where the species are normally together, we can learn how northern fishes and southern fishes moving north may interact, and what the effects may be. For instance, both Dolly Varden and Pacific Salmon currently occupy streams in Western Alaska. There, Chum Salmon spawn further downstream, while Dolly Varden spawn further upstream in colder waters near groundwater sources.[51] Salmon benefit Dolly Varden in those locations by adding nutrients to the system and food in the form of eggs and carcasses of spawned salmon, as well as juvenile salmon in both the freshwater[52] and in the estuaries.

More salmon are being seen along the Alaskan North Slope.[53] Warming temperatures may also be improving Pink Salmon production in rivers flowing into the northern Bering Sea.[54] This may mean that more Pacific salmon could move into the Canadian Arctic.

Indigenous Knowledge

The following provides an Indigenous Knowledge perspective on the issues discussed above through interviews and discussions with George Lyall of Nain, Nunatsiavut, NL, Norman Mike of Pangnirtung, NU, and Laurent Kringayark of Naujaat, NU.

The importance of char

Char is an important source of food for Indigenous communities across the Canadian Arctic. Inuit fish char for personal and commercial purposes when weather and ice

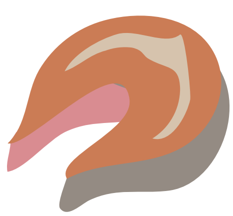
Inuit boat guides transporting gear and researchers from Palik (Byron Bay, NU) to Ikaluktutiak (Cambridge Bay, NU) following the completion of scientific research on the upriver Arctic char migration in late August, 2021. Photo credit: Matthew Gilbert

Fishermen using a long fine mesh net to pull a load of Arctic Char from their weir to shore in Halokvik River near Cambridge Bay, Nunavut. Fish remain an important food source and commercial resource for northern Canadians (Aug. 2017). Photo credit: Matthew Gilbert

thickness permit. In the past, Inuit did not fish much in winter, but better technology, such as nets, has meant that fish can be caught at any time of year.

People fish with rods or nets, from the shore, by boat, or through the ice. The catch is shared widely, as sharing food is part of Inuit culture. The tail goes to the children because it has fewer bones; the middle of the fish goes to adults because it is where all the strength is; and the head goes to elders as this is where the stories are.

In Pangnirtung, Nunavut, char has become the main source of country food. Many people who grew up eating caribou or seal are now eating much more fish. Naujaat, also in Nunavut, has a commercial char quota, but it is never filled. Commercial char fishing is seen as a viable livelihood in places where char are increasing, and a way to provide fish to people who could not get it otherwise.



Life of char

Where a char lives and migrates affects it in several ways, including its colour and condition. The skin and flesh colour may vary from deep red, to orange, to yellow, to white. Most people prefer to eat red or deep orange char, although most agree that the colour alone does not determine the taste. Landlocked or freshwater resident char can also be a different colour, but generally taste the same, though some people may prefer sea run ocean caught char.

Most char migrate from a lake to the ocean and back using the same river. However, around Voisey's Bay, Nunatsiavut, the char swim to the ocean in one river and return by another. Char can live up to 27 years. Older char stop going to the ocean.

It has been observed around Pangnirtung that male fish, *ivashaluk*, appear to protect the eggs in the riverbeds where the females have spawned. There are still male char in the lakes once the females have gone to the ocean.

The colour of migratory Arctic Char (left two) and lake trout (right) flesh can vary anywhere from bright red, to orange, to white, and is influenced by their diet. Photo credit: Matthew Gilbert

Scars are common on char and are generally caused by lice, birds, seals, polar bears (and black bear in Nunatsiavut) or even dolphins who tried to catch them. Parasites have always been common in fish. People generally do not eat fish with a lot of parasites or even feed them to dogs. Landlocked char have more parasites than those that go to the ocean.

Testing for mercury in Naujaat and Pangnirtung has not caused concern, but in Nunatsiavut there is concern about mercury caused by dams.

Climate change and habitat change

Climate change is impacting the marine environment. Freeze-up is later, and ice is thinner and breaks up sooner. This affects the timing and safety of travel on ice to monitor and catch fish.

In recent years, people in Nunatsiavut have observed that fish are getting smaller. Some blame climate change, but no one is certain. They have also noticed that fish are not venturing as far into the ocean and staying near the coast.

While it is now harder to catch fish in winter, more fish are being caught during the longer ice-free season in many places. Capelin are more abundant around Pangnirtung. Char now feed on these and as a result their colour has changed from orange to a whiter shade. Capelin is a new species in the area; Cod, Tom Cod, sculpins, and lump fish are more typical. Salmon, maybe Chinook, are sometimes seen beyond Cumberland Sound.

Pangnirtung has also been experiencing other changes. Ocean water warming from the bottom up and melting permafrost are affecting the levels of rivers or changing lakes. Winds have also changed. East winds, which bring snow, are less frequent. Now winds blow more from the north, and these are dry winds with less snow. New lakes have been forming from melting glaciers; perhaps these new lakes could soon contain char.

Emerging issues and knowledge gaps

Despite significant advances in understanding Arctic char habitat use, behaviour, and diet, many questions remain that could be addressed jointly through collaborative research by Western science and Indigenous Knowledge. First, regarding Arctic char habitat use, it will be important to do additional long-term studies on ocean habitat use to help understand how year-to-year changes in environmental conditions influence Arctic char behaviour in the ocean as marine waters continue to warm. These studies could shed light on why char often inhabit estuaries, which remains a question to be fully answered. Second, in terms of Arctic char diet, there is a need to continue to monitor what char eat in the ocean and whether this is changing due to shifting environmental conditions. Most importantly to communities, we need to assess if changes in char diet, for instance toward subarctic prey, may influence fish quality such as flesh colour, nutrients, and fat content. Conclusive data on this question are not currently available but will be important to understand how changes in char diet may influence food security and health in northern communities. Third, on contaminants in Arctic char and other quality-related issues, a critical research question to tackle will be to study the effects of climate warming on mercury bioaccumulation and levels in char. Furthermore, trends in the presence of parasites and the emergence of new ones remain a knowledge gap to address. Climate change will likely impact parasite dynamics and susceptibility of Arctic char to infections, as well as introduce new parasites through range expansions or introduced species. However, more research is needed to better understand current parasites in Arctic char populations, their prevalence in Inuit Nunangat, the potential influence of climate change on current and new parasites in fish, and the potential risks to human health. This knowledge will be critical to guide public health awareness and responses. In addition, contaminants of emerging concern, such as microplastics, should also be tracked more closely to understand their potential levels in Arctic char. Fourth, on species interactions, continued monitoring of subarctic species expanding their range should continue, as well as research on their interactions with Arctic species including Arctic char. In particular, the potential interactions between salmon species and Arctic char remain an important knowledge gap to tackle, such as studying habitat availability, including in winter, for the two species and whether habitat use may overlap. Overall, continued research on a range of monitoring needs and knowledge gaps — including, but not limited to, char response to climatic changes, parasite dynamics, trends in mercury over time and between different lakes, and new species coming in — will help support communities and organizations of Inuit Nunangat adapt management and policies around Arctic char.

Concluding remarks toward bridging different ways of knowing

We have learned much about Arctic char habitat use, behaviour, and diet, but many questions remain. How will char respond to climate change? Why do they prefer estuaries? How do changes in parasite populations affect them? What are the trends in mercury over time, and how do the differences between lakes influence the fish? It is essential to keep monitoring contaminants and other food safety issues to make sure Arctic char remains safe to eat.

The rapidly changing Arctic challenges our knowledge of Arctic char with new questions, complexities, and uncertainties. We know that temperature is among the most important factors shaping Arctic char distributions and habitat use, and it also affects fish health and metabolism. Changing Arctic conditions will likely affect Arctic char and other fish in many ways, with potential implications for community fisheries and food security (see Table 1).

Knowledge holders in communities across the North are already seeing changes (see Indigenous Knowledge summary). For example, longer ice-free periods could mean longer and better feeding opportunities for Arctic char in the ocean – but these conditions could also make their upstream migrations more difficult. At the same time, longer ice-free periods and thinner ice affect the timing and safety of travel to fishing areas. In Nunatsiavut people are noticing that fish have been smaller over the past few years. Warmer waters also bring new (or more) potential competitors like Pacific and Atlantic salmon, and Lake Trout, as well as new (or more) prey. Communities are monitoring these new arrivals, but it is still unclear how they are affecting Arctic char and other Arctic species. People have already noticed that Arctic char flesh becomes paler when char eat more Capelin.

We need to understand how these and other factors will influence the abundance, accessibility, quality, and stability of Arctic char stocks, now and in the future. Through strong and equitable partnerships between researchers, communities, and Indigenous Knowledge holders, we will gain that understanding.

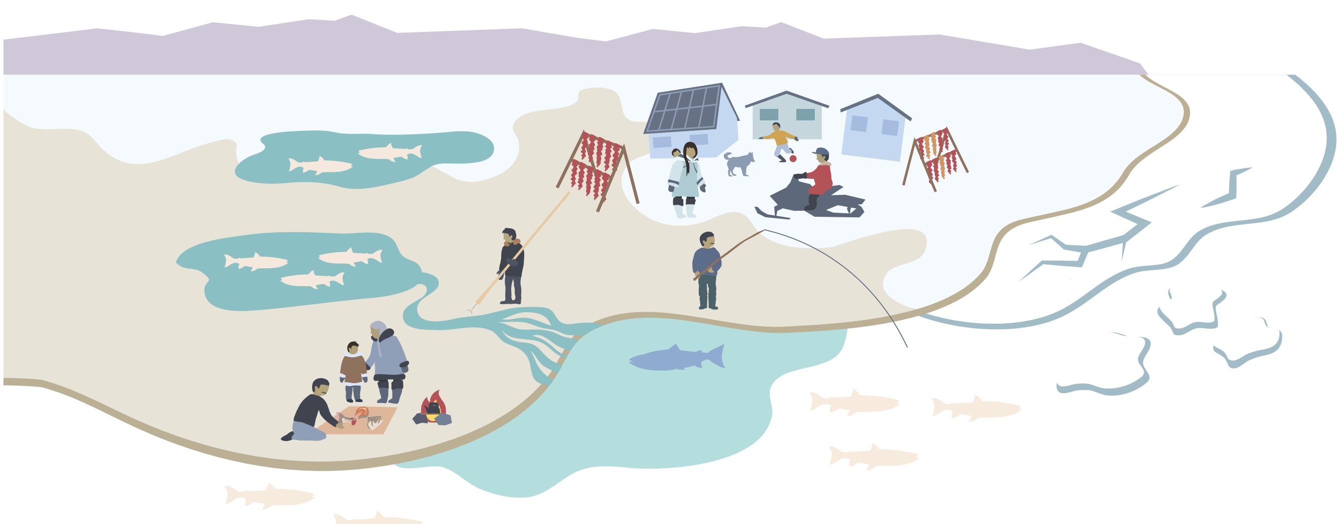


Table 1 Summary of ecological and biological information on Arctic char discussed in this paper and how these relate to the four pillars (Availability, Access, Quality, Safety and Stability) of food security. Also highlighted are Indigenous Knowledge insights on each of the pillars and how the ecology of Arctic char and food security may be altered under changing climatic conditions.

Food security pillar	Example of Arctic char or char-related parameters	Indigenous Knowledge section	Example of possible changes with climate change
Availability The number and size of locally available fish	Fish growth rate, size/condition, and abundance (number)	Some in Nunatsiavut speculate that the size of the fish has decreased	Increase in char growth as the ice-free period becomes longer
		New lakes have been forming from glacial melt and could soon contain char	Increase in number of resident fish as freshwater systems become more productive
Access Factors that impact the ease with which harvesters can access fish	Distribution and habitat use and environmental conditions that impact harvester safety and access to harvest sites	While it is now harder to catch fish in the winter, the number of fish being caught has increased during the longer ice-free season	Early migration to the ocean and longer summer feeding opportunities as rivers break-up earlier and freeze-up later
		Fish are not venturing as far into the ocean and staying near the coast	Preference for deeper waters; more time spent further away from the shore as shallow, near-shore, habitats become warmer and as char follow their preferred temperatures
		Later freeze up, thinner ice conditions, and earlier break up affect the timing, ability, and safety to travel on the ice to fish	

Table 1, continued

Table 1 Summary of ecological and biological information on Arctic char discussed in this paper and how these relate to the four pillars (Availability, Access, Quality, Safety and Stability) of food security. Also highlighted are Indigenous Knowledge insights on each of the pillars and how the ecology of Arctic char and food security may be altered under changing climatic conditions.

Food security pillar	Example of Arctic char or char-related parameters	Indigenous Knowledge section	Example of possible changes with climate change
Quality and safety Composition of nutrients, contaminants, and presence of other food safety concerns, as well as appearance (e.g., colour) of the fish	Nutrient, vitamin, and fat concentrations	Not discussed	Changes in nutrient and pigment concentrations in Arctic char, as fish change their diets to species with different concentrations of nutrients/ pigments as Arctic marine food webs and environments change – for example, the northward expansion of boreal species that char prey on, and change in the timing of peak production (with warming and changes in sea ice)
	Colour (pigments antioxidants)	While there is general agreement that taste is not different based on colour alone, most people prefer to eat red or deep orange char. Char skin and flesh colour may vary from deep red, orange, and yellow to white based on habitat use and diet (for example, char around Pangnirtung are eating Capelin, which have moved into the area); the colour of the char has become paler	
	Mercury concentrations	Testing for mercury in Naujaat and Pangnirtung has not caused concern, but in Nunatsiavut there is concern about mercury caused by dams	Reduced mercury concentrations in some regions as fish experience faster growth and improved condition as waters become warmer
	Parasite infections (particularly those that can be transmitted to humans like tapeworm *Dibothriocephalus dendriticus*, where uncooked meat with larvae are consumed)	Parasites have always been common in fish; fish with a lot of parasites are generally not eaten or even fed to dogs; landlocked char have more parasites than sea-run char	Changes in parasite transmission and infection as new parasites emerge, as parasite dynamics change, and as char become more susceptible to infections through range expansions, introduced species and as char change their habitats
Stability	Consistent and continued availability and access to safe and preferred Arctic Char over time	Not discussed in the IK summary, but the IK workshop highlighted that fish consumption has not decreased; in many cases, the harvest has increased	Increased inter-annual variability in environmental conditions could impact both fish populations (through effects on survival, growth, timing of migrations, or habitat use and movements) and access by resource users to preferred fishing sites and fishing techniques

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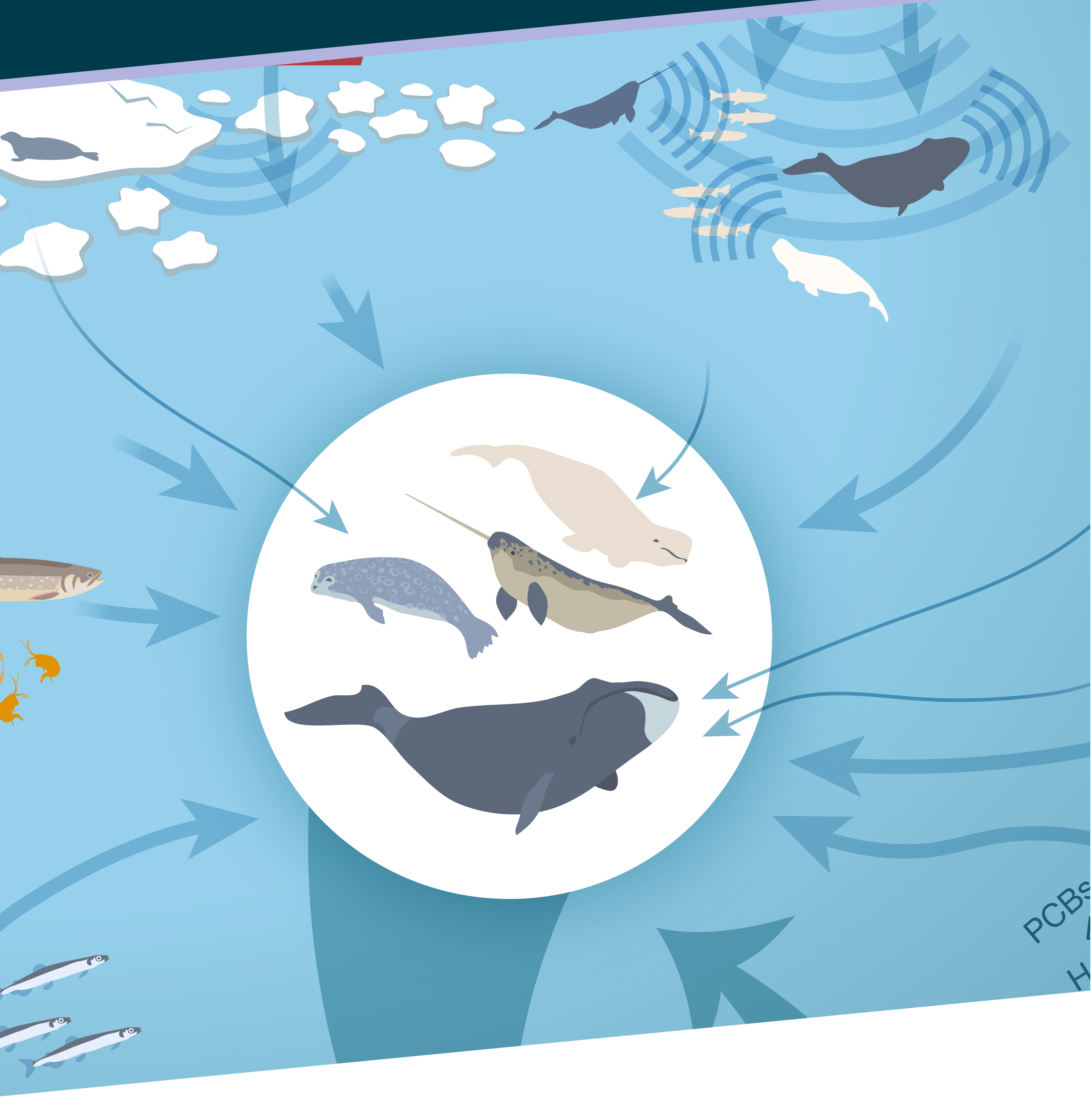

Marine mammals in a changing Arctic Ocean

Executive Summary

Canada's Arctic marine world teems with life. From microscopic plants that live under the ice and power the ecosystem by turning nutrients and sunlight into food, to hundred-tonne Bowhead whales that can break through the ice to breathe, it's an ecosystem like no other — a complex, interdependent web governed by seasonal rhythms of the sea ice.

It's also an ecosystem that's fragile and vulnerable to climate change. As average Arctic temperatures rise, sea ice is forming later in fall, breaking up earlier in spring, and covering less of the ocean. This has consequences for fish and marine mammals, and for the health of the Inuit communities that depend on them for food.

New species are arriving. Not long ago, for example, killer whales were rare in the high Arctic, but Inuit there are seeing them more now. These small whales avoid sea ice as it damages their tall dorsal fins. With more open water they can move north, where they find plenty of prey that is easy to catch. Narwhals, an important source of food in some Inuit communities, have little experience with Orcas and have not learned to be wary of them.

With warming waters, southern fish like Atlantic salmon and capelin are becoming more common in parts of the Arctic. Salmon have appeared in Arctic lakes and rivers and may be spawning there. Inuit in Pangnirtung, Nunavut have observed that beluga whales in Cumberland Sound have shifted their diet from Arctic cod to capelin. During the open-water season, they are seeing new species such as humpback whales, minke whales, and dolphins.

Less sea ice makes it easier for ships to reach the Arctic and lengthens the shipping season. Vessel traffic tripled in the Canadian Arctic between 1990 and 2015, mostly in Nunavut waters. Ship noise stresses whales by masking the sounds they use to communicate with each other, navigate, and find food. More traffic increases the risk of oil spills and of ship strikes, which are often fatal to whales.

Conservation measures, like Marine Protected Areas, can safeguard marine ecosystems and help maintain the food security and economies of communities that depend on them. There are three Marine Protected Areas in the Canadian Arctic. Shipping corridors, speed limits (which reduce ship strikes), and accurate navigational charts to lower accident risk can also help protect whales and other marine life.

Effective Arctic marine conservation requires a thorough understanding of the local environment and the factors that affect it. The most effective way to achieve this is through research that combines the strengths of both science and Indigenous Knowledge.

Inuit must play a direct role in establishing and applying Arctic marine conservation measures, as they have for the three Marine Protected Areas. Communities know they have the most at stake in protecting the Arctic marine environment — because their health depends on it.

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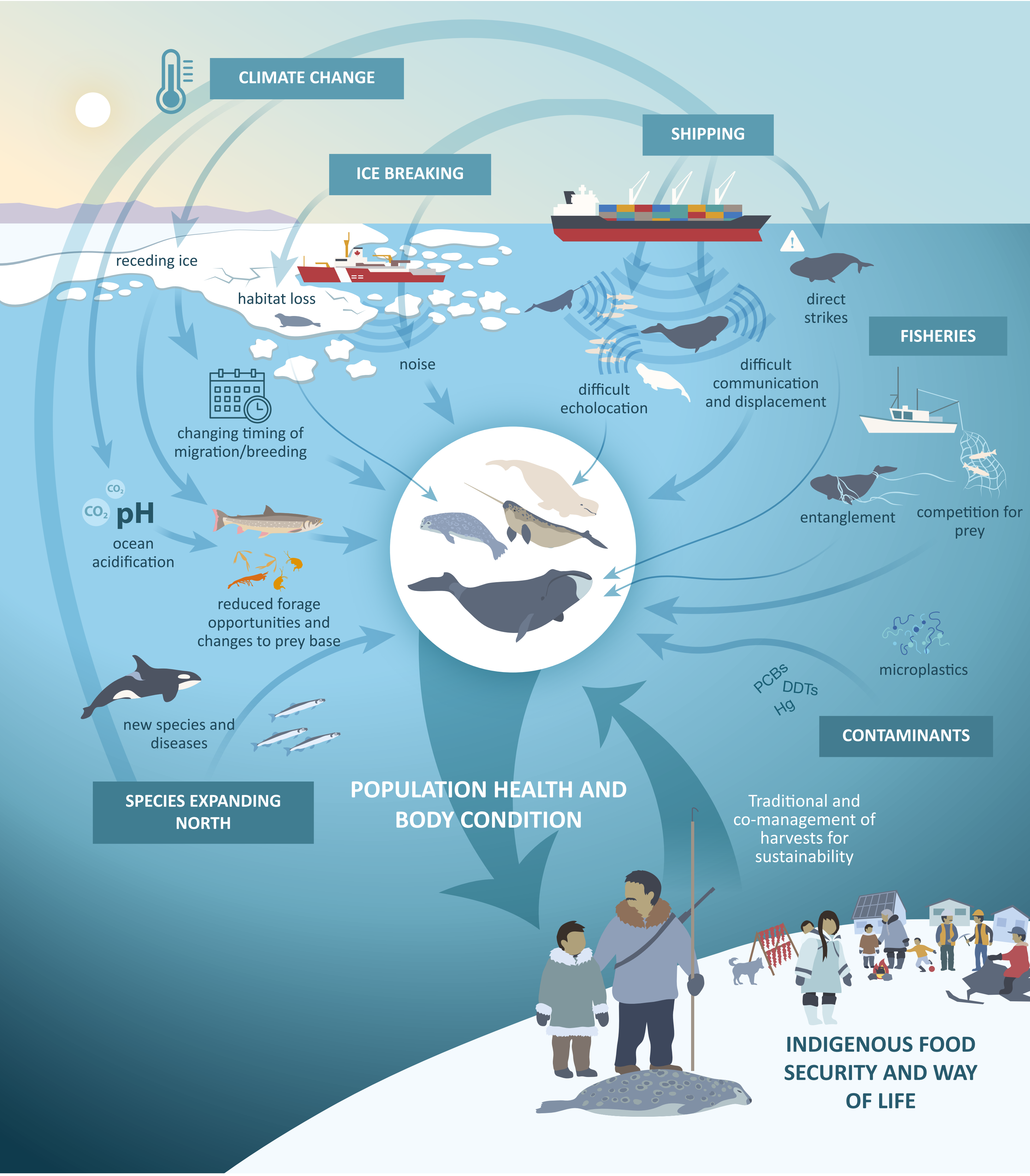
CLIMATE CHANGE
SHIPPING
ICE BREAKING
receding ice
habitat loss
direct
strikes
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communication
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CONTAMINANTS
SPECIES EXPANDING
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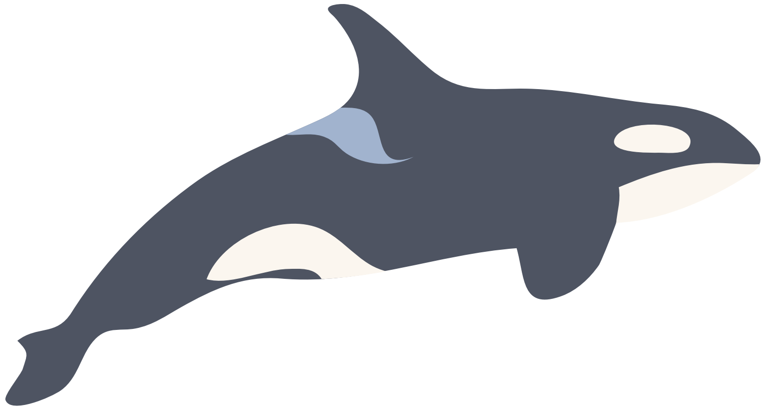


Introduction

The Arctic Ocean is home to thousands of species, from microscopic algae to massive whales. Its unique ecosystem revolves around ice. The Arctic Ocean's biodiversity, and the distribution and abundance of its whales, have changed over the last few decades as the result of ecosystem changes linked with a changing climate, including shifting ice patterns.[1]

Arctic marine mammals are well adapted to the vagaries, fluctuations, and natural cycles of the Arctic Ocean. Climate change is impacting sea ice, posing a risk to Arctic marine food webs and ice-dependent species such as Arctic cod.[2] Large species are more impacted by disturbance and changes in the Arctic Ocean since they migrate long distances and use a variety of habitats.

Human activities also cause change. Oil and gas exploration, new and expanded shipping routes and increased traffic, tourism, and growth of communities have all increased the level of human activity in Arctic waters. As the sea ice season shortens, ships are able to spend more time in the Arctic, as previously inaccessible areas open up due to climate-change driven reductions of sea ice.

This paper shares some of the recent collaborative research on Arctic marine biodiversity, with Indigenous Knowledge is mobilized and included, focusing here on harvested species such as beluga, bowhead, and narwhal. It addresses some of the key questions that participants from Kitikmeot communities and from Ulukhaktok, NT, developed at the *Regional Planning and Knowledge Sharing Workshop in 2020*.

Overview by Indigenous Knowledge holders

Inuit Knowledge and marine management research

Regional co-management boards and game councils, and Hunters and Trappers Organizations, were set up to ensure good, sustainable management of wildlife, including whales. In the Inuvialuit Settlement Region (ISR), there are three distinct beluga whale groups using nearshore waters: one in the Yukon, and two in the Northwest Territories, off Kendall Island and near Tuktoyaktuk, respectively. There are bowhead whales off the coast. There are currently no quotas and approximately

100 belugas are harvested each year. The shallow waters where they are hunted allow hunters to follow them easily, so that each year only one or two of these hunted whales are lost.

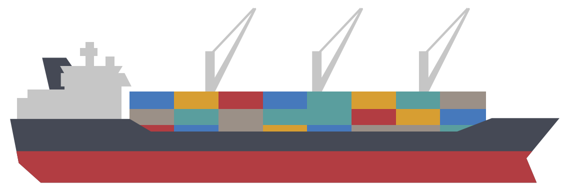
In all northern communities, hunters are the main observers, and they often provide samples from their catches for scientific purposes.

People in Arctic Bay know that beluga and narwhal calve near Resolute Bay. The beluga used to arrive two weeks before the narwhal in the area, but now they come at the same time. Aerial surveys monitor animal and marine mammal populations in some places. These tend to be species-specific projects: narwhal in and around Arctic Bay, planned monitoring around Clyde River, and polar bears in the Inuvialuit region. There has been a lot of research in the Inuvialuit region in recent years, but communities are concerned that the data has not been adequately analyzed and shared with them. Some feel that this research is interfering with wildlife.

Whales and shipping

In the Inuvialuit Settlement Region (ISR), belugas migrate into the shallow waters of the estuaries to breed. For the past decades, the main ship activity has been the sealift for communities and occasional tourist ships. Whales have been observed swimming beside ships but they fear small boats and recognize the sound of their motors. Very few whales are reported struck by ships in the ISR.

Clyde River lies on whale migration and shipping routes. Community members there are seeing fewer whales than in the 1990s and 2000s, and many believe that this is due to increased shipping, especially from the Baffinland mine. Clyde River has a marine monitoring project to get evidence of the impact on marine life of increased shipping, and so far it looks like seals are not affected by Baffinland ships. In Arctic Bay, the community is seeing more belugas, narwhals, and bowheads. This is thought to be because of the Baffinland ships that push the whales more towards the west, away from the shipping routes.



Marine Protected Areas and other protective measures

Marine Protected Areas (MPAs) have been created in the North to help protect whales and to ensure that the communities are able to harvest them. There is a bowhead whale sanctuary near Clyde River, called the Ninginganiq National Wildlife Area. Tallurutiup Imanga National Marine Conservation Area is being established near Pond Inlet. Anguniaqvia Niqiqyuam and Tarium Niryutait Marine Protected Areas, the latter made of up of three areas called Niaqnuunaq, Okeevik and Kitigaryuit, are all located in the ISR. Other protective measures implemented in the Inuvialuit region with co-management board approval include forbidding ships to empty their bilge water, to protect against contamination and invasive species.

In some areas of the Arctic, quotas can be effective if well-developed and adequately managed. Clyde River is considering moving from seasonal quotas to a single quota system that allows carryover of unused tags. This would make it easier to manage harvesting.

Climate change and other environmental impacts

Climate change is causing ice to form later, and break up earlier, in spring. This may be affecting whale migration. In Clyde River and Arctic Bay, hunters must often travel further than they did previously to find whales. Different species are also being seen more frequently: saltwater salmon in Arctic Bay (these arrived over the last 5–6 years); humpbacks and sperm whales near Clyde River; and dolphins near Pond Inlet. Killer whales have been hunting in Arctic Bay for as long as can be remembered, and Inuit often find the partially eaten carcasses they leave behind. In the Inuvialuit region, killer whales are rarely seen, but they are in the Bering Strait.

The biggest environmental concern is from ships: noise, bilge water, and oil spills. Concern is growing at the lack of adequate local equipment, training, and capacity to deal with an oil spill. An oil spill has to be dealt with quickly; relying on the territorial and/or federal government to respond would delay the response. Communities recognize the potential impact of an oil spill and the increased risk from more tourist vessel and mining ship traffic. In areas like Clyde River, where currents and winds are strong and changeable, any contamination would spread extensively, with significant impacts on the marine environment, including fish, birds, mammals, and on Inuit who rely on wildlife for food.

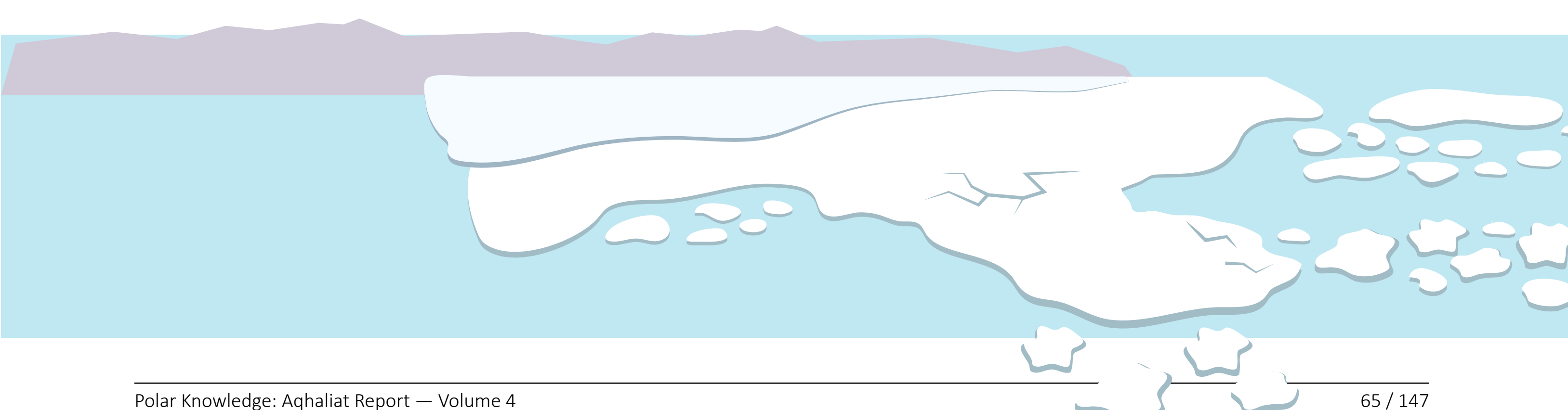
Shifting ice and marine mammals

Arctic Ocean life waxes and wanes with the sea ice. Seasonal changes in sea ice affect the amount and timing of energy available at the base of the food web. The ice directly affects the movements and habitats of many species, from microscopic organisms to whales, creating specialized habitats. Sea ice also interacts with the atmosphere and the ocean through winds[3] and currents.

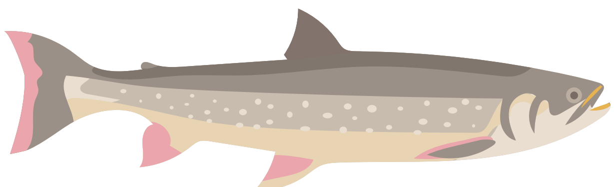
Sea ice is both a physical part of Arctic waters and an ecosystem in itself. It shelters breeding seals and supports the food source of many birds, fish, and marine mammals. Arctic communities use it for travel and hunting.

There are many kinds of sea ice. Seasonal ice forms and melts within a year. Multi-year ice lasts at least two summers. Land-fast ice is attached to the land and stays in place, whereas pack ice, which is further from shore, moves around with winds and currents.

Older sea ice tends to be thicker, less mobile, and more predictable. For example, Tuvaijuittuq (meaning “place that is never without sea ice”), at the north end of Ellesemere Island in Nunavut, preserves more multi-year ice than other places. It will probably be the last area to have summer sea ice. This is because winds bring ice into the area from the central Arctic Ocean. There is more multi-year ice around the



Canadian Arctic archipelago than anywhere else in the Arctic Ocean. Thicker ice lasts longer than younger thinner ice.[4] More land-fast ice leads to a longer ice season,[5] and the formation of stable ice bridges.[6] Prevailing winds, which change in cycles, influence when ice forms and when it disappears. Communities are concerned about changes in this timing because it impacts ice travel safety and the location of marine species.



Sunlight, runoff from rivers, and sea ice all influence the Arctic marine ecosystem. Sea ice plays a key role in how much energy, in the form of nutrients, is available at the base of the food web, and at what time of year. Sea ice affects transfer of energy throughout the entire food web, and species movements and habitats.

A warming Arctic Ocean also influences precipitation, bringing more snow onto the sea ice. Phytoplankton, the microscopic plants that are the primary producers at the base of the food web, need nutrients and light to grow. Snow accumulation limits the amount of light that reaches the water where they live. For production to start, the marine ecosystem needs open water or ponds formed by melted snow on the ice. Both of these let more light into the water than snow does. Ice algae, attached to the bottom of the sea ice, grow first. They contain food for zooplankton (microscopic animals) that are adapted to the timing of ice algae growth. Phytoplankton grow until they use up all the nutrients. When phytoplankton growth is at its maximum, it is called a bloom. These blooms are very important for zooplankton and for species on the seafloor, including the variety of forage species of marine mammals.[7, 8]

Changes to the times when sea ice forms and disappears affects the timing of algae blooms, the prey species that feed on those blooms, and the migration and breeding of marine mammals. In many regions, these blooms are occurring earlier, with more happening under the ice before full breakup.[9, 10] An early or late bloom means phytoplankton may sink to the bottom before the zooplankton has a chance to eat it.[11] In addition, changes in sea ice could mean that marine mammal prey may be getting more energy from pelagic (phytoplankton) rather than ice-associated (ice algae) energy sources. It is still uncertain if the quantity and quality of food for marine mammals is changing with the sea ice, and if this the case everywhere, and how quickly these changes may be happening.

Methods for gathering data on marine mammals

Programs for gathering data on marine mammals work best when scientists and Indigenous Knowledge holders design them together.

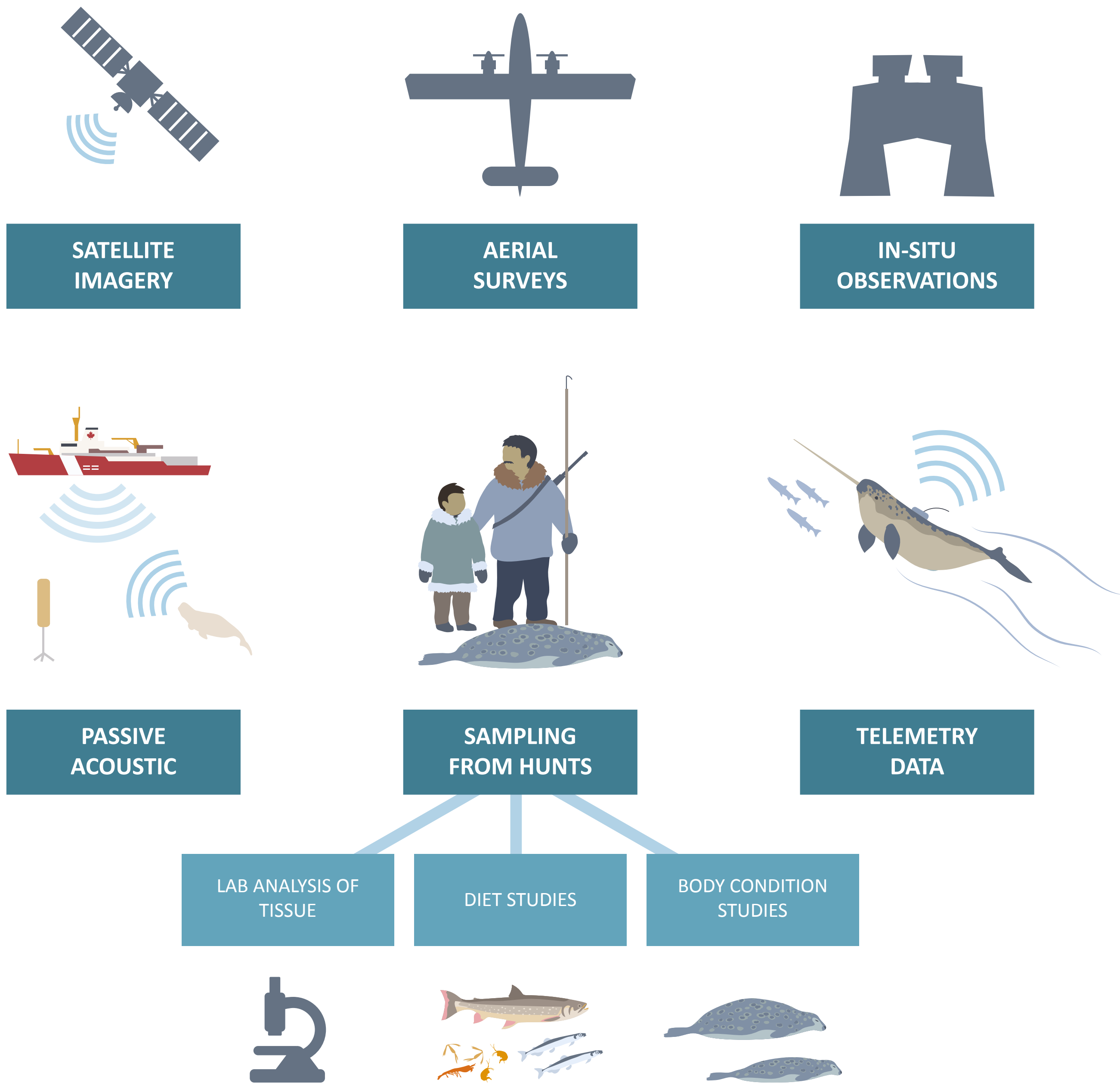


Figure 1: Methods for gathering data on marine mammals, which include satellite imagery, aerial surveys, in-situ observations, passive acoustic, telemetry data, and using samples from hunts, such as lab analysis of tissue, diet studies, and body condition studies.

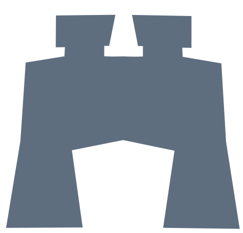
Working together, scientists and Indigenous Knowledge holders design, plan, and study marine mammals through these approaches (see Figure 1):

- Direct observation
- Indirect observation and tracking (done remotely with instruments)
- Collecting tissue samples and measuring harvested animals

Direct observation

Direct observations are done from shore, ice, ship or airplane, by hunters and/or scientists, in-situ. Hunter observations provide important information that complements scientific knowledge.[12] Hunters are skilled and experienced observers who take notice of and rely on such things as the behaviour of animals and their health and body condition; where they are found and when; how abundant they are; and changes in age structure, group structure, and reproduction — over short and long periods, from seasons to decades.

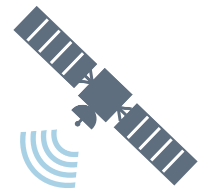
Observations from shore



Observations from the shore, water, or floe edge provide information on marine mammal behaviour and their relative numbers. Shore-based observations have been used to assess the impact of shipping from the Baffinland Mary River mine.

Remote/indirect observation

Tracking data



Satellite telemetry uses tags which are small computers attached to marine mammals that record information such as:

- location of the animal
- how deep the animal is diving
- temperature and the salinity of the water
- sounds the animal makes or that it might hear[13]

Tags are attached to a marine mammal using a crossbow or a pole, or by capturing and temporarily restraining the animal in a net. The knowledge and skill of Indigenous Knowledge holders is critical to doing this safely and successfully. Netting marine mammals is stressful for the animal, but a recent study showed that narwhals returned to their normal behaviour within 24 hours of tagging.[14]

Tagging studies are helping to identify narwhal stocks,[15] determine important habitat in the Pacific Arctic,[16, 17, 18] and study the impact of killer whales on bowhead whales.[19]

Passive acoustic monitoring

Underwater sounds provide information about whales and the sounds in their environment.[20] By recording marine mammal calls, scientists can determine their presence and distribution, estimate their number, and get an idea of their behaviour.

Aerial surveys

Observers flying in aircraft conduct aerial surveys to estimate the distribution, relative abundance, and size of marine mammal populations in the Arctic. These surveys consist of planned flight lines in areas the mammals use. The flight plan is based on:

- information from Indigenous Knowledge holders
- known distribution and relative or expected abundance of marine mammals
- previous surveys

Aerial/satellite imagery

Drones take photographs at lower altitudes that can show the body condition of the whales, their behaviour, and the age and sex composition of their groups.

Photographs taken from airplanes can cover wide areas.

Satellite images can show belugas, narwhals and bowhead whales.[21] Belugas are easiest to detect because their white skin contrasts with the water.

Collecting tissue samples and taking measurements from animals

Tissue samples from the liver, blubber, or skin can show whether the animal's body contains contaminants such as mercury. Blood samples help detect diseases and other health issues, or changes in diet.[22, 23, 24]

Recording the size, age, and sex of animals reveals information about their health and about population growth and dynamics.[25]

Images of belugas taken from a) a drone in the Churchill River at about 16 m altitude, b) a Twin Otter aircraft in Clearwater Fjord (Nunavut), at 600 m and c) a satellite in Clearwater Fjord from space.

Figure 2: Satellite images that show beluga, narwhals and bowhead whales found in a report from Charry et al., 2021.[22] Photo credit A and B: Fisheries and Oceans Canada, © 2020, DigitalGlobe Inc.

Changes in Arctic whale range distribution over time

Beluga whales, including their calves, are well known for spending summer in warm, less-saline waters of specific estuaries. Bowheads tend to use different summering spots, changing their habitat depending on where ocean and ice conditions concentrate their prey. Narwhal normally use deep inlets and fjords as summer calf-rearing habitat, although they are known to change their migration routes in response to annual variation in sea ice.

Whales, being large-bodied, may have more difficulty adapting to and thriving in warmer water temperatures and greater winds and storms that are predicted for the Arctic.

Predators, competitors, and changes in prey affect the distribution of Arctic whales. As sea ice decreases, Arctic whales are more vulnerable to killer whales. Belugas may also lose access to their preferred prey, Arctic cod, which is associated with sea ice.

For millennia, killer whales have migrated each summer to the Arctic and Antarctic, where they find plenty of food. In the past, they did not stay long because they tend to avoid sea ice, which can damage their large dorsal fin. With less ice and longer open water seasons, killer whales are able to spend longer in the Canadian Arctic. A model shows that a population of almost 200 killer whales would need to eat about a thousand narwhal while residing in the Tallurutiup Imanga NMCA (Lancaster Sound) region in summer. It is still uncertain what the true impact of killer whales on narwhal will be during longer ice-free summers, and monitoring will be important. Models estimate that they may eat large numbers of prey not used to killer whales.

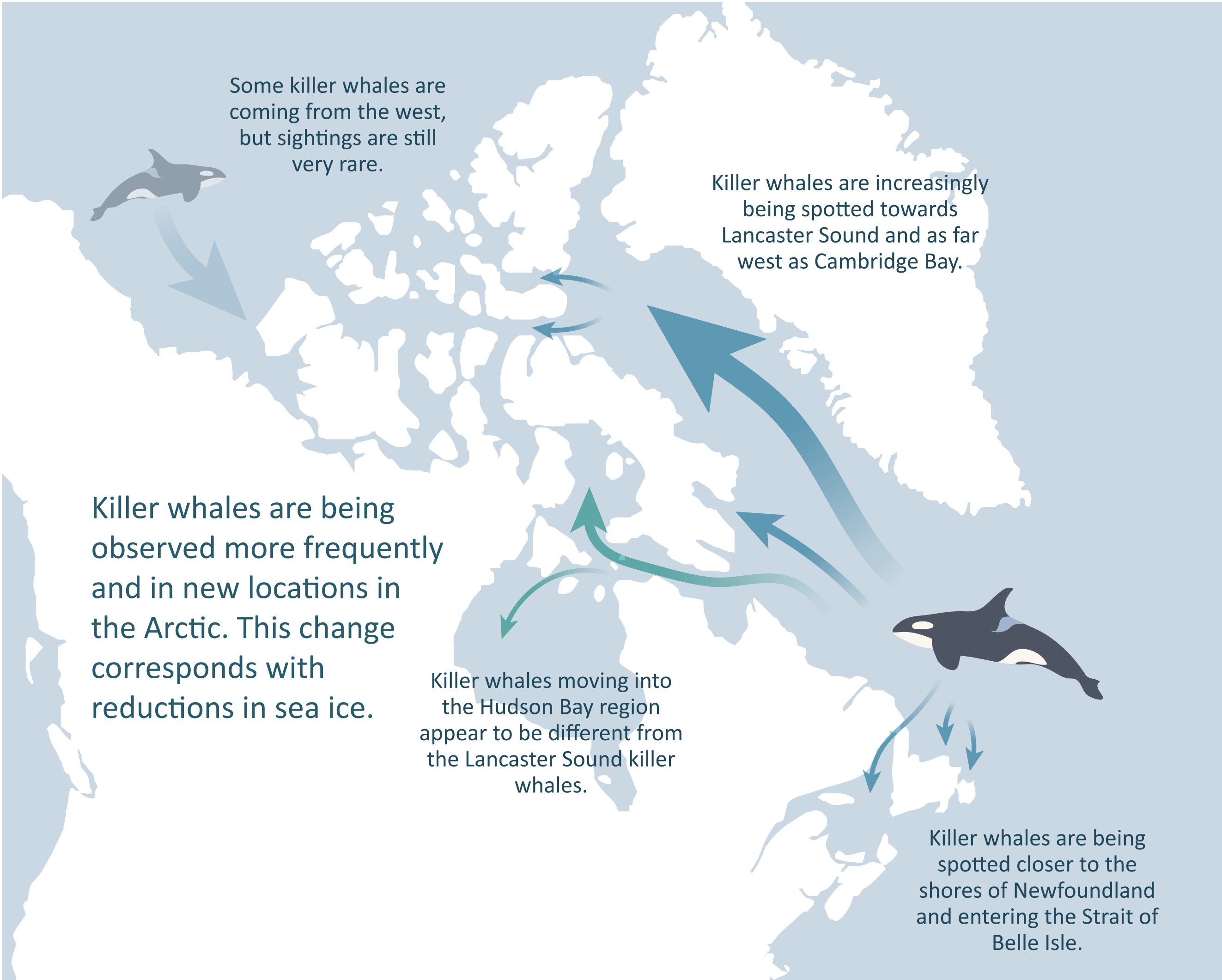


Figure 3: Killer whales are increasingly spotted more frequently and in new locations in the Arctic, seen north and west of the Labrador Sea, moving into Hudson Bay, the Tallurutiup Imanga NMCA (Lancaster Sound) and as far as Cambridge Bay. Whales who are present in the Beaufort Basin can rarely be spotted in the Western Arctic.

The marine ecosystem in the Arctic runs on fat from the ice algae through such species as copepods, shrimp, and especially Arctic cod, which are food for a multitude of wildlife, particularly beluga whales and seals.

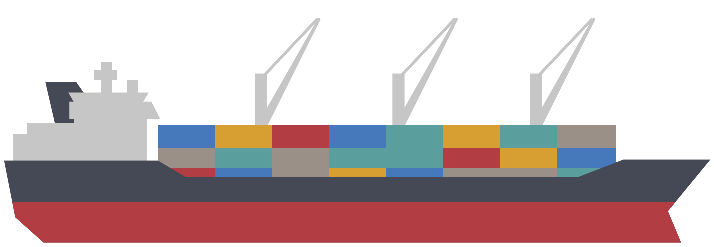
Capelin are also an important forage fish, increasingly so in recent years. They typically live in temperate waters, but have moved northward into Arctic regions with warming ocean temperatures. Capelin are now commonly caught in places where Arctic cod were once predominant.

We do not know how changes to the fish community are affecting Arctic food webs and whales. In Cumberland Sound, capelin have increased with loss of sea ice. Beluga whales have shifted their diet from mostly Arctic cod in the 1990s to capelin in the 2000s. At the same time, harp seals have come to dominate Cumberland Sound during the open-water season, leaving ringed seals to dominate the winter sea ice season. During the open-water season, the region has seen a large influx of new species, including humpback whales, minke whales, and dolphins. Similar changes may occur farther north. The Arctic Archipelago may become the last refuge for endemic Arctic whales, beluga, bowhead and narwhal.

These changes will affect traditional foods in Inuit communities. Communities need information on present and predicted patterns of animal movement and habitat use to help them adapt.

Shipping and vessel impacts

Less sea ice means ships can reach the Arctic more easily and the shipping season becomes longer. Ship traffic tripled in the Canadian Arctic between 1990 and 2015, mostly in Nunavut waters.[30] For marine mammals, ships bring risk of vessel strikes, pollution, and underwater noise which can disturb or displace marine mammals from habitats and migration routes.[31, 32]



Shipping noise impacts

Noise from motorized vessels impacts marine mammal species in a number of ways.

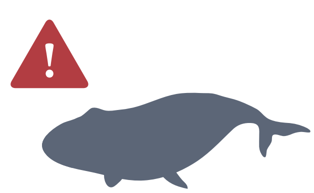
Behavioural disturbance

Marine mammals respond differently to noise. Their reaction may depend on the following:

- past exposure of the individual to the noise
- individuals becoming used to the noise so they no longer see it as a threat
- individual noise tolerance and hearing sensitivity
- age
- sex
- group composition (e.g., the presence of calves)
- the characteristics of the noise
- how sound travels in the habitat
- the normal noise levels in the natural environment of the animal[33]

Some reactions, such as moving away from preferred habitats, not eating, or interrupting nursing, can affect growth, reproduction, and survival.

There are few studies on the impacts of ship noise or icebreaking noise on Arctic marine mammal behaviour Arctic marine mammals.[34, 35] We do not yet know which noise levels cause whales to change their behaviour. We do have evidence that Arctic whales will flee from vessel noise, sometimes when that noise is barely audible.



Signal masking

Communication masking

Ship noise masks the sounds whales make to communicate. Calves are especially vulnerable because their calls are quieter than adults. If a mother does not hear its calf, they may become separated, which is very dangerous for the calf.[36]

Echolocation masking

Belugas and narwhals make clicking noises and use the echoes to find food, navigate, and avoid hazards. This is called echolocation. Ship noise can shorten the distance over which a whale can hear its echoes. This can impair the whale's feeding, navigation, orientation, and hazard avoidance.[37]

Auditory impairment

Ship noise may damage a whale's hearing temporarily or permanently,[38] but we do not know what levels or characteristics of long-duration ship noise would do this, and it would vary among species.[39]

Ship strikes

Whales usually flee from underwater noise and the ships that cause it — but not always. Ship strikes injure and kill whales. Whales are more likely to be hit when they are feeding near the surface, and just below the surface because of the propeller suction effect. Fast ships are most dangerous. There is evidence of ship strikes for only one Arctic whale species, the bowhead.[40, 41]

Oil spills

Shallow waters and poor charts put the Arctic at risk for oil spills. An oil spill there could spread widely and be difficult to clean up because of the following factors:

- the remoteness the Arctic
- the difficulty of reaching a spill far from a community
- the lack of sufficient infrastructure, protocol, and plans to contain and clean up an oil spill
- Sea ice would make it impossible to clean up any spill and would make the oil spread further

Oil can damage an animal's fur or skin and eyes, and block nostrils and blowholes. Swallowing oil can make an animal sick.

Indirect shipping impacts on harvesting of marine mammals

Disturbance from ships can make marine mammals leave an area where Inuit are used to hunting them.

Near the north Baffin community of Mittimatalik (Pond Inlet), shipping traffic increased threefold in 2011–2015 compared with 1990–2000. The ships that increased the most were tourist vessels and ships serving the Baffinland Mary River mine. They passed through an important area for narwhal foraging, mating, and calving[42, 43, 44] and for seal denning. It is essential to understand how shipping may impact these critical life functions, which may in turn affect food security in northern communities. Scientific studies have not looked at this question, although community members have identified this as a concern.[45]

Shipping policies and management measures for reducing impacts

The most obvious way to reduce the impacts of ships on marine mammals is to keep ships out of important areas such as foraging habitat. No-go zones, including formal MPAs (see section on Marine Protected Areas) and shipping corridors that avoid important marine mammal habitat can be effective.[46]

Speed restrictions are also useful: slower ships are quieter and less likely to hit whales.[48]

The best way to reduce the oil spill risk is to lower the chance of an accident by keeping ships away from uncharted waters and by charting those waters.[49]

Tools for conservation of marine species, their prey and their habitats in the Canadian Arctic

Co-management

Co-management refers to agreements between government and the Indigenous Peoples of Canada to jointly make land use and resource management decisions. Co-management boards in areas with settled land claims, and other advisory boards and committees in areas where claims are under negotiation, aim to ensure conservation of species, their prey, and their habitats.

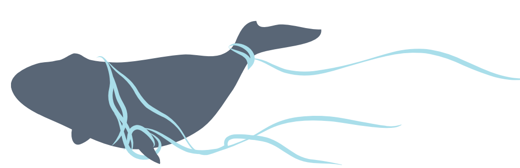
Co-management boards mobilize Indigenous Knowledge from the communities they serve and apply it to marine conservation. They have led the way in developing new approaches that involve Indigenous Knowledge holders in ecological and biological studies in authentic and effective ways.[50]

Types of tools for conservation of marine species

Canada's coastline is the longest of any country in the world. In 2021 the Government of Canada committed to protecting 25% of its marine and coastal areas by 2025, working towards 30% by 2030. To help meet these conservation targets, and to protect against loss of biodiversity and marine habitat, and address the challenges of climate change, the 2021 federal budget included funding of $976.8 million over five years, starting in 2021–2022.

In total, Canada has approximately eight federal and 40 provincial/territorial legislative or regulatory tools for establishing protected areas with a marine component.

Marine Protected Areas are the main tool for marine conservation in Canada. The International Union for Conservation of Nature defines a Marine Protected Area as "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values."



The Canadian government can invoke legislated marine protection in three ways, depending on the Minister that is responsible for its establishment:

- Marine Protected Areas (*Oceans Act*) administered by Fisheries and Oceans Canada
- National Marine Conservation Areas (*Canada National Marine Conservation Areas Act*) under Parks Canada (such as Tallurutiup Imanga NMCA in Lancaster Sound)
- National Wildlife Areas under the *Canada Wildlife Act*, administered by Environment Canada

There are currently 14 *Oceans Act* Marine Protected Areas across Canada, with three in the Arctic:

- Tarium Niryutait (2010)
- Anguniaqvia Niqiqyuam (2016)
- Tuvaijuittuq (2019)

Marine conservation tools known as “Other effective area-based conservation measures” also provide protection but do not meet the International Union for Conservation of Nature definition of a Marine Protected Area. They may apply at certain times, in certain places: for example, to protect fish during spawning or birds during nesting. The Disko Fan Conservation Area is an example of “Other effective area-based conservation measures.” A marine refuge, it protects the unique corals in southern Baffin Bay by restricting the use of commercial fishing equipment that contacts the sea bottom. This site also has conservation benefits for the narwhals, sperm whales, and northern bottlenose whales that use the area. “Other effective area-based conservation measures” are recognized for their value to conservation of species and habitats (biodiversity) and they will likely be used more in the future.

Marine Protected Areas can protect plants, animals, and habitats. They can improve the resilience of ecosystems and benefit areas outside their boundaries. Research shows that they have been effective in improving the local marine ecosystem by:

- increasing biodiversity and species richness
- restoring community structure, and uniqueness
- strengthening the ability of ecosystems to resist, recover from, or adapt to disturbances (such as those caused by overexploitation or climate change)[51]

Marine Protected Areas enhance the economy of coastal communities by providing jobs in conservation and tourism, while protecting subsistence harvesting opportunities.

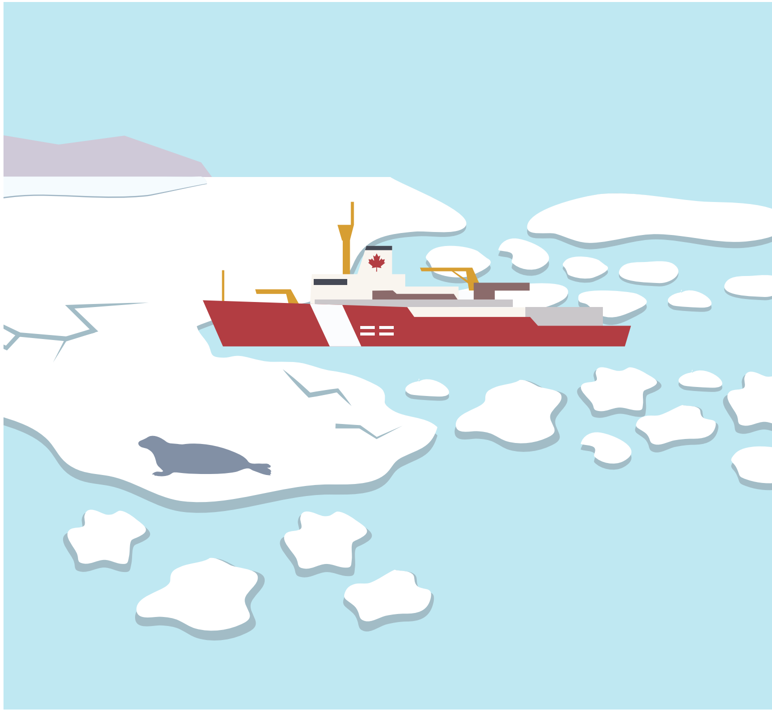


Table 1 Examples of Marine Protected Areas in the Canadian Arctic.

Designation	Regional Concerns	Conservation Objective
Tarium Niryutait MPA	Canada's first Arctic MPA. It was designated under Canada's *Oceans Act* (1996) in 2010. Located within the Canadian Beaufort Sea and the Inuvialuit Settlement Region, it consists of three separate sub-regions covering approximately 1,800 km^2 of Niaqunnaq (Shallow Bay), Okeevik (East Mackenzie Bay), and Kittigaryuit (Kugmallit Bay). Its establishment was a collaborative effort the Inuvialuit Regional Corporation, the Inuvialuit Game Council, the Fisheries Joint Management Committee, and Fisheries and Oceans Canada (DFO).	*To conserve and protect beluga whales and other marine species, their habitats, and their supporting ecosystem.*
Anguniaqvia niqiqyuam MPA (ANMPA)	Canada's second Arctic MPA. It was designated under Canada's *Oceans Act* (1996) in 2016. It is the first MPA in Canada for which both science and Indigenous Knowledge-based Conservation Objectives were developed. Its establishment was also a collaborative effort by the Inuvialuit Regional Corporation, the Inuvialuit Game Council, the Fisheries Joint Management Committee, and Fisheries and Oceans Canada. Located in Darnley Bay, Northwest Territories, in the Beaufort Sea Large Ocean Management Area and the Inuvialuit Settlement Region. It covers an area of 2,361 km^2, and borders the east coast of the Parry Peninsula, about 10 km west of Paulatuk. The community uses the ANMPA for travel, education and other traditional activities, and identifies most of ANMPA as having "Extreme Significance" year-round. ANMPA acknowledged subsistence harvest as a key objective. Through this type of approach, area-based conservation measures strive to maintain key ecosystem services, while also enhancing sustainable Indigenous management practices.	*7. "…to maintain the integrity of the marine environment offshore of the Cape Parry Migratory Bird Sanctuary (MBS) so that it is productive and allows for high trophic level feeding by ensuring that the Cape Parry polynyas and associated sea-ice habitat, and the role of key prey species (e.g., Arctic cod), are not disrupted by human activities."* *8. "…to maintain the habitat to support populations of key species (beluga, char, ringed and bearded seals)."*

Table 1, continued

Table 1 Examples of Marine Protected Areas in the Canadian Arctic.

Designation	Regional Concerns	Conservation Objective
Tuvaijuittuq MPA	This culturally and historically significant marine area lies in the High Arctic off the northwest coast of Ellesmere Island, Nunavut. It is globally, nationally and regionally unique because it has multi-year pack ice. Tuvaijuittuq is the first Marine Protected Area designated by ministerial order under the *Oceans Act* for interim protection in 2019. Under the order, no new or additional human activities will be allowed in the area for up to five years, with the following exceptions: ▪ The exercise of Inuit rights respecting wildlife harvesting as provided for under the Nunavut Agreement ▪ Marine scientific research consistent with the conservation objectives of the MPA ▪ Safety, security and emergency activities ▪ Certain activities carried out by a foreign national, entity, ship or state. The MPA provides interim protection to the area while the Qikiqtani Inuit Association, the Government of Nunavut, and the Government of Canada work with Inuit and northern partners to explore longer-term protection for this area.	*To contribute to the conservation, protection and understanding of the natural diversity, productivity and dynamism of the High Arctic sea ice ecosystem.*

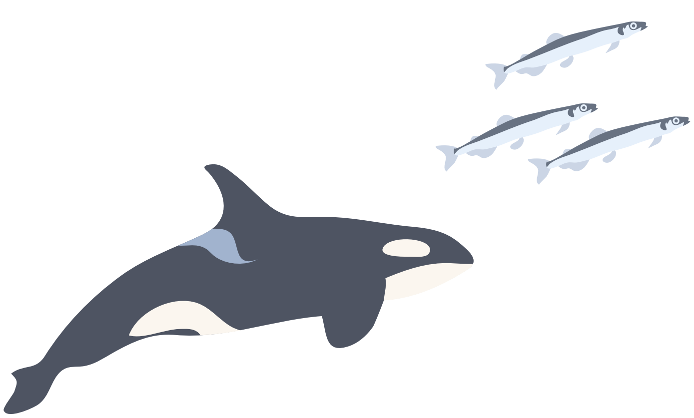
How are these Marine Protected Areas managed?

Local and Indigenous populations can take the first steps to create a Marine Protected Area, and they can manage it once it is established. Three National Wildlife Areas on the northeast coast of Baffin Island were identified as part of the Inuit Impact and Benefit Agreement for National Wildlife Areas and Migratory Bird Sanctuaries in the Nunavut Settlement Area. The Agreement is a collaboration between the Inuit of the Nunavut Settlement Area and the Government of Canada, under the authority of the Nunavut Claim. These agreements require co-management committees to be established for the National Wildlife Areas to advise the federal Minister of Environment and

Climate Change on all aspects of planning and management. Collaborative management with communities and Indigenous Knowledge holders ensures that both Inuit expertise and the best scientific data are combined effectively in all decision-making relating to the MPA.

Investing in marine conservation in Canada

The Arctic is now home to a number of recently established Marine Protected Areas in Canada. The Arctic marine environment is fragile, slow to change, and easy to disturb. It is very sensitive to the effects of climate change and human activities.[53] Marine Protected Areas and other conservation measures can be useful tools in maintaining this unique ecosystem and traditional way of life.



Emerging issues and knowledge gaps / Concluding remarks toward bridging different ways of knowing

Mobilizing Inuit Knowledge for marine conservation, monitoring, management, research and decision-making

There are several knowledge gaps in our understanding of Arctic marine mammals, especially the impact of threats such as climate change. The wealth of knowledge from Inuit complements scientific research and monitoring and it is crucial that it be mobilized and applied to better inform our predictions of the future and protection of marine mammals.

In the past, researchers often considered Indigenous Knowledge as "data," but Indigenous Knowledge is in fact much broader. It is holistic, and includes expertise on culture, society, language, ethics, relationships, practices, and more. Future work would benefit from all researchers having an appreciation and acceptance of Indigenous Knowledge on par with scientific knowledge, and establishing respectful and equitable working relationships with Indigenous experts.[54] It is important that Indigenous Knowledge holders explain what contributions their expertise can make, and how it can be shared and used for monitoring and research.

Indigenous Knowledge about specific places is essential for identifying possible Marine Protected Areas and for other matters concerning wildlife. This is often gathered at workshops, using maps to compile and document information on topics ranging from species location, migration routes, ice edges, harvest areas, and nesting areas, to trails, camp locations, and traditional sites.

Interviews, often at a camp or hunting sites, are another common method. For example, Inuvialuit experts on the behaviour and health of beluga whales have identified indicators of beluga health.[55] These include colour and texture of the *uqsuq* (fat layer), the shape of the body (broad or round back, fat rolls described as 'love handles'), and signs of infection.[56] The indicators have been added to the regular scientific monitoring program.[57]

The results from workshops and interviews are usually compiled into a written document, usually by a researcher who is not an Indigenous Knowledge holder.[58] The original information — whether in the form of audio or video recordings, maps, verbatim transcripts from meetings, or written reports approved by Indigenous Knowledge holders — are preserved. Together, all these records contribute reliable and valuable expertise to inform marine protected area monitoring, and marine mammal management, research, and decision-making.

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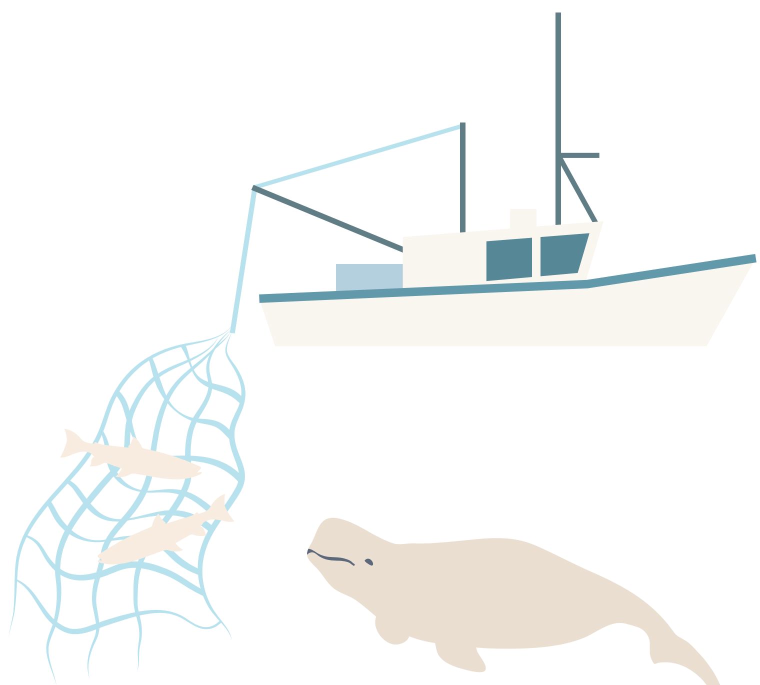

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Caribou – heartbeat of the tundra

Synthesis review of Northern Migratory Caribou – Scientific and Indigenous Knowledge on Porcupine, Bathurst, Qamanirjuaq, and George River caribou herds

Executive Summary

Arctic Indigenous peoples have always relied on caribou for food, clothing, and tools. Their cultures reflect a close relationship with caribou and a profound respect for them. Traditional Indigenous hunting methods are ecologically sustainable and a good starting point for building new co-management systems.

Many caribou herds across the North have declined. Others are maintaining a moderate size. One, the Porcupine herd, has grown large.

Predators and scavengers such as wolves, and grizzly and black bears, depend on barren-ground caribou. Their numbers rise and fall with the size of caribou herds. Research on the calving ground of the Qamanirjuaq and Beverly herds found that predators killed few calves, and mostly weak or sick ones.

Caribou herds grow and shrink naturally over 30 to 65 years. Inuit elders have described how caribou in decline move to find better food. A few caribou find places they can survive. They eventually repopulate areas once the vegetation recovers, which takes about 20 years. Using Indigenous Knowledge to identify, map, and protect these areas is important in helping caribou to recover.

Caribou face modern-day challenges that can prevent or slow recovery, or even cause a decline. Climate change, industrial development, and modern hunting methods are some of these challenges.

Governments require new kinds of development proposals to assess how a project would add to the impacts of existing developments and to the impacts of possible future developments.

Caribou management plans need to protect caribou from disturbance, especially during the calving and post-calving seasons.

There is a lot of data on how caribou cope with their environment. Much of it comes from radio-collar tracking. Biologists use this data with a computer model to understand how climate and development affect caribou numbers.

Hunters and Trappers Organizations (HTOs) have often taken action to conserve caribou during times of scarcity. They have closed sport and commercial hunting while keeping the subsistence hunt open. Management boards have limited harvests, introduced tags, and are recommending more harvest reporting. Some governments have imposed caribou hunting bans until long-term conservation measures can be developed. Others have established natural reserves in areas important to caribou migratory routes and lifecycle stages. These are positive steps, but more work is needed.

Individuals, communities, and Indigenous and scientific knowledge holders, as well as organizations and governments, all want to see healthy caribou herds. Decisions on land use and harvest can either help or hinder the health of caribou herds. Stronger conservation measures, developed through co-management, are needed. We must work together to conserve caribou herds and their habitat.

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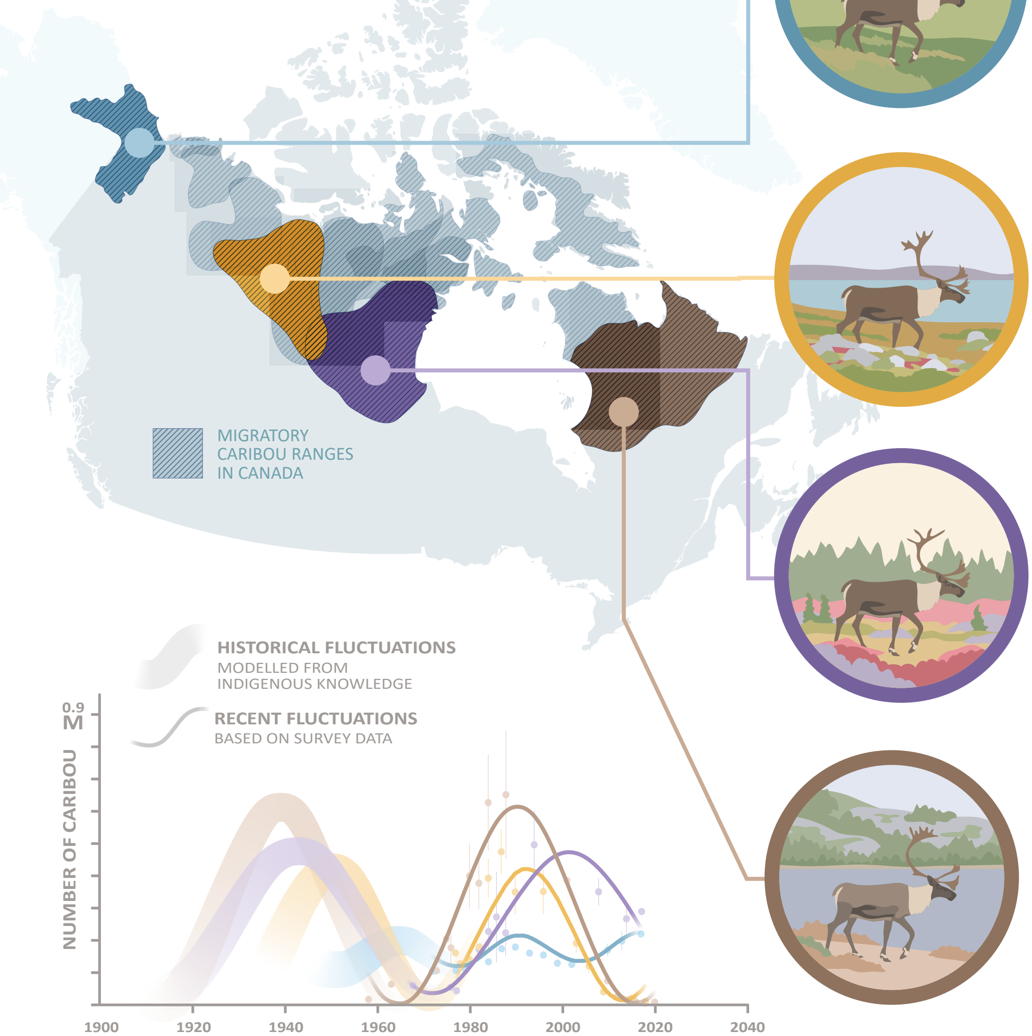
In the past, caribou herds have fluctuated naturally. It is uncertain how new threats will affect caribou in the future.



PORCUPINE

CURRENT TREND
Increasing

MAIN CLIMATE CHANGE IMPACTS
Late spring drought and winter icing conditions decrease food

MANAGEMENT
<2% harvest
Caribou protection: Ivvavik National Park (Yukon), Arctic National Wildlife Refuge (Alaska)

OTHER THREATS
Development poses risk to calving grounds in Alaska

BATHURST

CURRENT TREND
Declining

MAIN CLIMATE CHANGE IMPACTS
Warmer summer decreases food; more insect harassment; freezing rain

MANAGEMENT
Restricted harvest
Caribou Protection: Mobile Core Bathurst Caribou Management Zone

OTHER THREATS
Industrial development, roads

QAMANIRJUAQ

CURRENT TREND
Slow decline

MAIN CLIMATE CHANGE IMPACTS
Warmer summer decreases food; increased shrubification; freezing rain

MANAGEMENT
Moderate harvest
No caribou habitat protection in Nunavut

OTHER THREATS
Industrial development, roads, potential power line corridor (enhances predation)

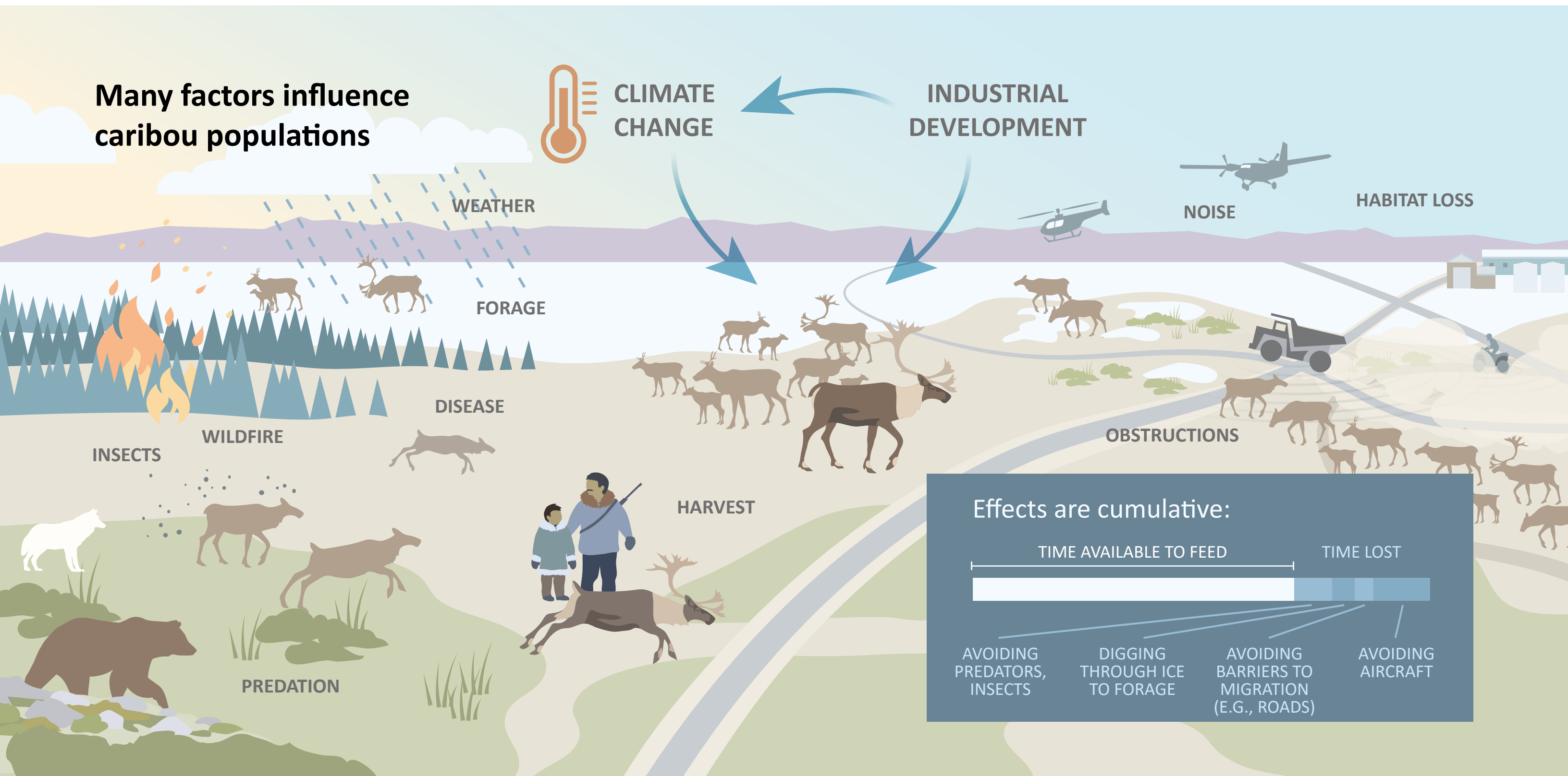
GEORGE RIVER

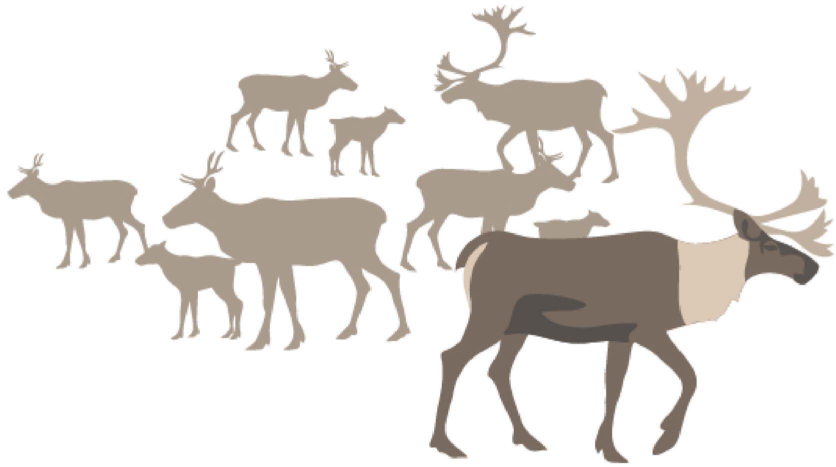
CURRENT TREND
Declining

MAIN CLIMATE CHANGE IMPACTS
Increased summer rains lead to changes in vegetation and more insect harassment

MANAGEMENT
Restricted harvest
Caribou Protection: George River Natural Reserves (Nunavik, Quebec)

OTHER THREATS
Industrial development, roads, power line corridors





Introduction

Caribou have the largest circumpolar range of all the large hoofed mammals. In North America, caribou live as far north as Ellesmere Island, and as far south as the northern United States. They live right across Canada. In Canada there are four different ecotypes of caribou: migratory or barren-ground, woodland, Peary, and mountain. They differ from each other in behaviour, ecology, genetics, and physical appearance.

Arctic Indigenous peoples share an ecosystem with caribou, and have relied on caribou for food, clothing, and tools for millennia. Their cultures reflect a close relationship with caribou and a profound respect for them. Elders emphasize that a hunter must take only what is needed, and use all the animal, without wasting. These practices are ecologically sustainable and a good starting point for building management systems.[1]

Many migratory caribou herds in the Canadian North winter in the boreal forest and migrate north in the spring to calve on the tundra. They migrate to access the high quality and abundant seasonal food resources of the tundra and to avoid the predators of the boreal forest.

These herds continue to display migratory behaviour during periods of abundance or scarcity. Current monitoring reveals that many herds across the North are either declining or at low numbers (e.g., the Bathurst and George River herds). Others, such as the Qamanirjuaq herd, are maintaining a moderate size, though are reported as declining. The Porcupine herd has recently grown to record high numbers (Figure 1).

Indigenous elders know that over long periods caribou herds shrink and grow in population size and they say that “the caribou will come back.” However, human activities that affect caribou have been increasing. These include mining and exploration, roads, highly efficient hunting methods, internet meat sales, and climate change effects. Because of these activities, some worry that caribou may not be able to recover as they have in the past.

This report brings together scientific and Indigenous Knowledge to answer questions raised around caribou abundance and migration at the 2020 Regional Planning and Knowledge Sharing Workshop held at the Canadian High Arctic Research Station in Nunavut, Canada.[2]

Herd movements and distribution – caribou habitat

Knowledge of seasonal range use is a key element in migratory caribou herd and habitat management. Annual range is composed of different seasonal ranges located in the boreal forest, the taiga, and the Arctic tundra. The size and location of the annual range are mainly influenced by the extent of the spring and fall migrations between the herd's summer and winter ranges.

Migratory caribou generally go through nine stages defined both by movements and reproductive events over the course of a year:

- calving
- post-calving
- summer
- late summer
- fall migration (pre-breeding)
- rut
- fall migration (post-breeding)
- winter
- spring migration back to the calving grounds[3]

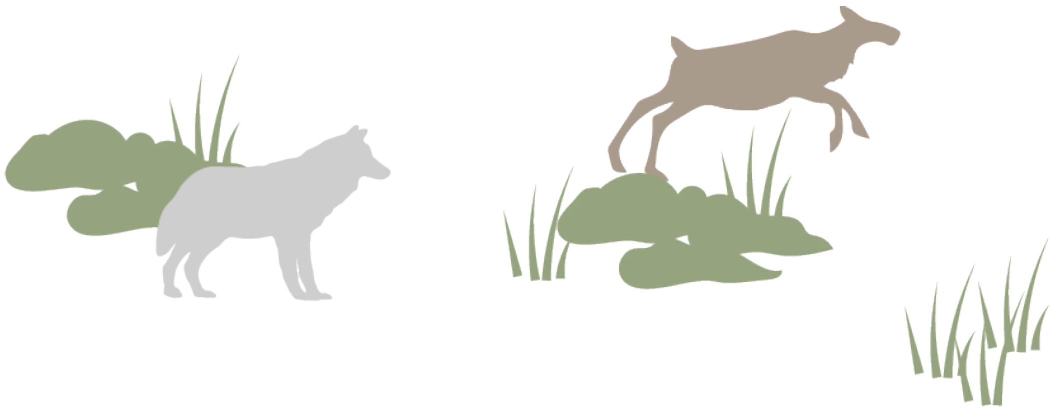
Caribou are vulnerable to disturbance at every stage; but the risk is considered high during calving and post-calving. There are several reasons for this:

- Females need a lot of energy after their young are born. They depend on access to tundra vegetation, which is only available for short periods each year.
- If disturbed, caribou are more likely to flee, because the bond between cows and calves is strongest at this time. Females could avoid areas with too much disturbance leading them to use lower quality habitat with less food for the calf.
- Many cows and calves stay together in a small geographic area, so any disturbance will likely affect more animals.

Caribou management plans need to protect caribou from disturbance at all stages, but the calving, post-calving, and spring migratory seasons are essential to protect.

Migratory caribou usually migrate to the same calving areas year after year. However, occasionally some move to nearby herds or calving areas. In Eastern Canada, tracking data has shown that few George River cows moved to the neighbouring Leaf River herd's calving area between 1990–2000. However, a third of these females returned to the George River herd's calving area in subsequent years. Since 2008, there has been no evidence of cows moving from the George River herd to the Leaf River herd. Current analysis suggests that this movement of caribou is not a significant factor in the documented decline of the George River herd over the last decade.

Photo credit: Aimee Guile from the Wek'èezhìı Renewable Resources Board



Globally, the International Union for the Conservation of Nature (IUCN) re-assessed Rangifer throughout its North American and Eurasian range as vulnerable based on the observed 40% decline over the last 21–27 years.[4] Among North American migratory caribou populations, there is regional variation in the extent and timing of population decline and recovery. For example, in Alaska, three herds peaked between 2003 and 2010, then declined by 53% before, in 2017, two herds started to recover. The Porcupine herd, which is shared by Canada and Alaska, is the only North American herd that increased in the last two decades – by 70% between 2001 and 2017. Other herds, particularly in Nunavut, have exhibited declines over the past decade.

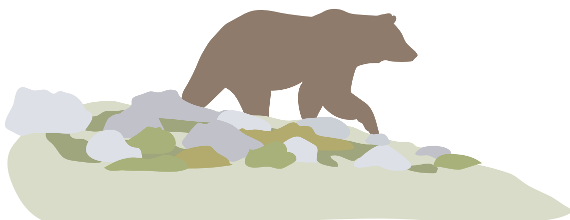
The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) uses IUCN standards to assess endangered species risk in Canada, including caribou. In 2016, COSEWIC assessed Barren-ground caribou on the western Canadian mainland as threatened, because the numbers in nine herds had dropped severely.[5] In 2017, COSEWIC recommended listing Eastern Migratory caribou, which includes the George River and Leaf River herds as endangered under the *Species at Risk Act*. In 2015, Peary caribou were reassessed from Endangered to Threatened,[6] while in 2017, Dolphin and Union caribou were reclassified from Special Concern to Endangered.[7]

Caribou and the ecological system

Caribou have been called the “heartbeat of the tundra” by researchers such as Anne Gunn because of their role in shaping the tundra-taiga ecosystem. Communities and many other wildlife species depend on the seasonal arrival of caribou for their survival and well-being.

Predators and scavengers depend on caribou and for some populations their numbers rise and fall with changes in the size of caribou herds. Predation is a natural part of the migratory caribou’s ecology. Wolves, their main predator, hunt caribou year-round. The survival of wolf pups seems to be linked to caribou abundance.[8] Wolves prefer to den south of the calving ground but still north of the treeline. This strategy is thought to optimize the availability of caribou during migration and post-calving when pups need protein the most.[9] Grizzly bears, and black bears in Eastern Canada, are also important predators of caribou. Many aerial surveys see far more bears than wolves on the calving grounds. Golden eagles are also known to kill newborn calves, but this type of predation is considered minor. Caribou are so important to the landscape that if they were ever removed from it, ecological collapse would result. Caribou are an indicator species for northern ecosystem health and of the impacts of industrial activities and climate change.

Many of the 23 caribou herds across the Canadian North have experienced population declines.[5, 10, 11, 12, 13] Indigenous people expressed concerns that predators (grizzly bears, black bears, and wolves) may be the reason. This prompted a study of predators on the calving grounds of the Qamanirjuaq and Beverly herds between 2010 and 2013. The study found that there was relatively low predation-related calf mortality on the Qamanirjuaq herd, and most of the calves killed by wolves in the Beverly herd represented "compensatory mortality," where wolves preyed on calves already weakened and predisposed to death because of physiological or pathological disorders.[14]



In Eastern Canada, researchers are studying how predators (wolves and black bears) affect the George River and the Leaf River herds. From 2011 to 2021, wolves and black bears were studied to assess their distribution, abundance, and seasonal diet. The black bear population using the George River range appears to be growing. This is supported by recent and more frequent sightings of bears close to Indigenous communities. Since 2011, wolf sightings on the George River range have diminished considerably. This suggests that wolf predation is currently uncommon in the herd's range.

Many previous studies have looked at predators on the calving grounds during the first week of life for calves. Studying the relationship between the caribou and its predators should continue during the post-calving and wintering periods to better understand how predators affect caribou survival through all periods of life.[14]

Other studies have looked to provide further insight into the causes of population decline. One study in particular focused on the decline of Newfoundland's Island Caribou.[15] Insights from the study included:

- The number of animals was unsustainably high in relation to what the environment could handle
- Overabundance resulted in increased competition for food and space, resulting in malnutrition
- Malnutrition caused decreases in female size, survival, and pregnancy rates
- Overgrazing caused caribou to use previously avoided habitats to access food – these areas had more predators
- Undersized calves were at increased risk of predation
- Calf survival became very low (less than 5% in the early 2000s)

More research is needed to determine if a similar relationship between many of the northern migratory herds and their range is a contributing factor to the recent declines.

Population dynamics

The size of migratory caribou herds rises and falls over long periods of time that can span decades.[5, 16, 17, 18] Indigenous oral histories also speak of rises and falls in caribou populations.[19, 20]

The Bathurst and George River caribou populations are currently at extreme lows. The most recent estimate (2021) for the Bathurst herd is about 6,200, a decline from the previous estimates (2018) of about 8,200 and (2015) 20,000. This is down from a population high of about 500,000 in 1986. The George River herd was estimated at 8,100 in 2020. While slightly more than the previous estimate (2018) of 5,500, this represents a decline of almost 99% of its population size of 800,000 in the early 1990s.[21] By contrast, the Porcupine herd is at a high, estimated at 218,000 in 2017. The most recent Qamanirjuaq estimate of 288,000 (2017) suggests that the herd is between its historic maximum (500,000) and minimum (44,000) and in a slow decline.

There is a limit to the number of caribou that their habitat can support. When populations are composed of large numbers of animals, the caribou have a direct impact on their habitat through browsing and trampling. Overuse of the range by the caribou can lead to a decline in its condition. The food they feed on grows slowly and takes time to regenerate. Habitat degradation can lead to poor body condition, reduced female fertility, and reduced calf survival. This may contribute to the rises and falls of populations.

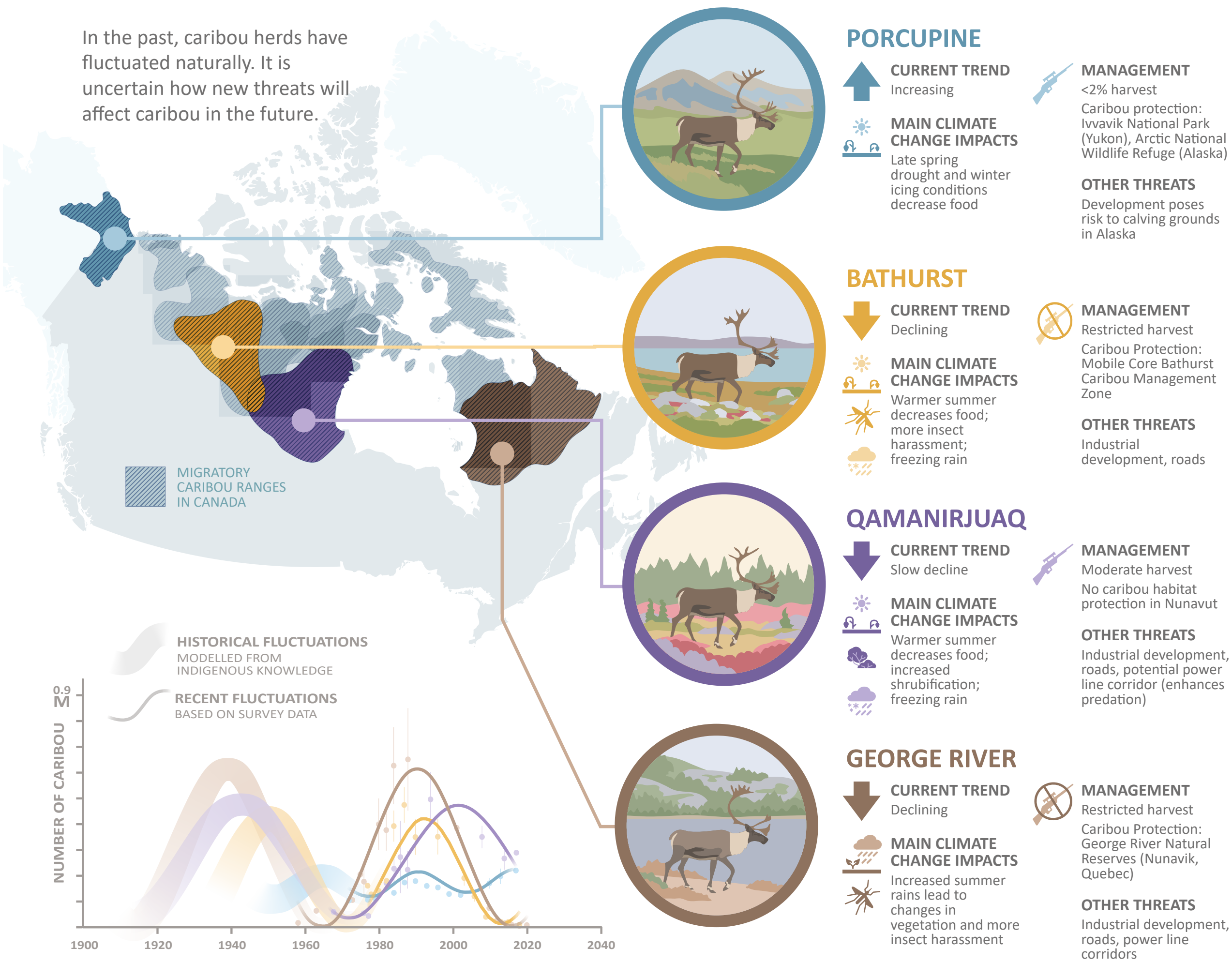


Figure 1: The cyclical nature of northern migratory caribou population fluctuation and status based on scientific surveys and Indigenous Knowledge: Porcupine, Bathurst, Qamanirjuaq, George River caribou herds.

Because herds naturally grow and shrink, communities have had to deal with times when caribou were scarce. Periods of increase and periods of decline can last for decades. It is important to consider both short-term and long-term perspectives on trends in abundance. Short-term trends can help identify current health and status. Long-term trends can help to assess whether the stresses caused by humans, such as development and climate change, worsen the declines, prolong periods of scarcity, or even prevent recovery.

Indigenous Knowledge on caribou population dynamics

Inuit elders from southern Baffin Island shared *Inuit Qaujimajatuqangit* about past changes in caribou distribution and abundance.[19] One cycle takes the lifetime of an elder, with periodic declines after overgrazing. Elders recalled high fluctuation through natural cycles in the island's caribou population, starting with the increase in numbers in the early 1900s lasting for about 20 years and then followed by a rapid decline lasting about three decades. Because "the land had to rest," Inuit continued harvesting caribou during low abundance in the 1950s and 1960s, enabling recovery of lichen forage. From about 1970 to 2000 caribou abundance increased.[19] Based on partial surveys, Ferguson and Gauthier[17] suggested an abundance in the order of 120,000 caribou on southern Baffin Island by 1991. In the early 2000s, Inuit elders predicted another decline. A steep decline occurred through the 2000s and continued to the present-day low of 5,000 caribou on Baffin Island[22]. Inuit participants at a Baffin Island Caribou Workshop in 2014 discussed the scarcity in caribou abundance based on *Inuit Qaujimajatuqangit* and extensive aerial surveys, and cooperative management options.[23]

Elders predict cyclical declines after seeing "too many caribou for too long." Caribou first move to find better food, but their abundance eventually declines. After periods of low

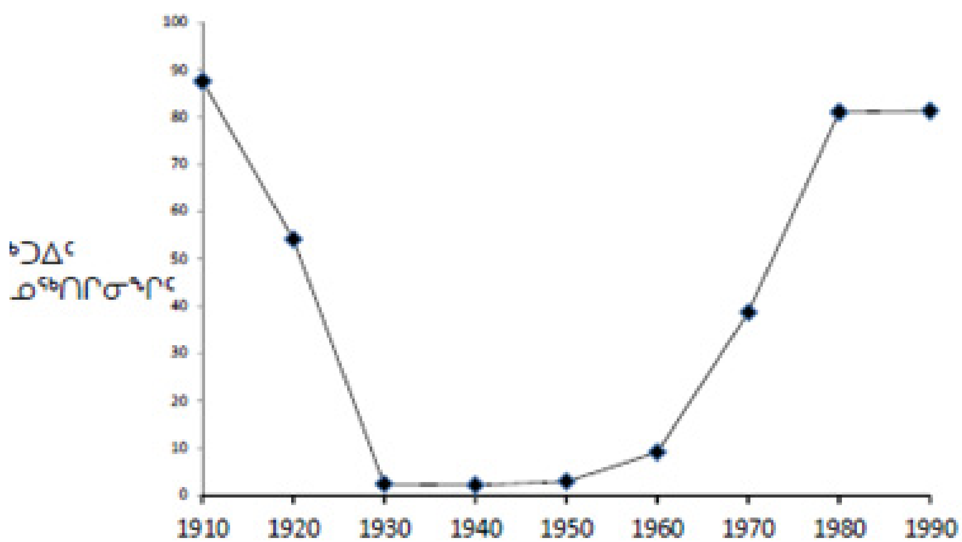


Figure 2: Changes in caribou abundance index over time using *Inuit Qaujimajatuqangit* from Inuit elders on south Baffin Island.[19]

Participants of the caribou *Inuit Qaujimajatuqangit* study (from left to right: Hᐅᓇ ᓚᒃᕿᖅ, ᐊᑲᑲ ᓵᑖ, ᓄᕿᔪᑦ ᐊᐃᐱᓕ,ᔫᓴ ᐅᓂᐅᖅᓴᕋᖅ,ᔫ ᑎᑭᕚᒃ, ᐸᑦᑐᓇᐅᑦᓚᖅ, ᔫᑲᓯᓄᑕᕋᑐᒃ, ᓴᐃᒨᓂᐊᓚᐃᓐᒐ).[19]

abundance, winter forage (lichen) may recover over a period of about 20 years. Elders said, "*We will need to wait until the moss and plants grow over the caribou antlers on the ground before the caribou numbers will increase again*." Elders also described important areas where Inuit find some caribou when there were no caribou anywhere else. From these places, caribou eventually repopulated other areas as habitat recovered. Using Indigenous Knowledge, these and other areas are important for caribou recovery.[19]

We will need to wait until the moss and plants grow over the caribou antlers on the ground before the caribou numbers will increase again.[23] Photo credit: Government of Nunavut

Cumulative effects on caribou

Role of climate

Mainland migratory caribou can endure adverse weather, partly because they seek the best habitats for each season — the boreal forest in winter and the tundra in summer. As well, each herd thrives in its own lands and climate. The Porcupine and George River herds, for example, live in a permafrost landscape, and they benefit from the rich plant growth that warm summers bring there. The Bathurst herd lives on the bedrock of the Canadian Shield, where there is less rain in summer. Soils are shallow, and when they dry out, the food caribou eat grows poorly. In contrast, the range of the George River herd on the Ungava Peninsula gets more rain in summer compared to other ranges, and benefits from warm summers.[24] These conditions favour faster plant growth and increased shrub cover.

To confound the complex effects of climate change, recent studies of Labrador boreal caribou show increased predatory efficiency by wolves in winter as a result of less snowfall.[25] In addition, research conducted at the Northern Plant Ecology Lab in the Yukon Territory[26] suggests a future trend towards the northern encroachment of deciduous aspen and birch forestation. The impact may contribute to a future decline in productivity and habitat suitability for migratory caribou in select southern reaches of their current winter range.

In northern environments, climate change is occurring more quickly than in more southern temperate or tropical environments. Several studies suggest that climate change will result in changes in temperature and precipitation over migratory caribou ranges. A change to temperature and precipitation can affect vegetation growth, biting insects and parasites, and snow conditions. Learning how the climate of each herd's range affects their health, how many calves they produce, and the conditions encountered during their migration will help us understand the impacts of climate change.

Cumulative effects

The world's demand for resources is bringing more roads, mines, and other development to the north. Roads make it easier for hunters and predators to reach caribou herds, and caribou have a harder time finding safe places. Governments require those proposing new developments to explain how the project would affect caribou herds. They must assess its cumulative effects — that is, how the project would add to the impacts of existing developments, and to the impacts of possible future developments. For example, if someone proposes a road into a caribou herd's winter range, they must assess how it would affect wintering caribou, but also how that would add to the existing impacts of other development within the herd's entire range. They must also assess whether building the road would encourage future development.[27] Recent studies of the impact of roads in halting and delaying Qamanirjuaq caribou migration in the Kivalliq region of Nunavut for a period of 5 days as measured by caribou collar information provides important insights into the cumulative effects of barriers to migration to caribou.[28] Unfortunately, the science of cumulative impacts is new and still being understood.

It is challenging to make these assessments, and it requires a lot of knowledge. We need to know how individual caribou react to human disturbance, and what role climate might play in caribou health. We need to relate the impact on an individual animal to the whole herd. Fortunately, there are new studies trying to understand how caribou cope with their environment, and more information is gathered every year. This includes information from tracking collars fitted to caribou.

Computer models are used to bring all this information together. The model shows when, and for how long, caribou will encounter a road, a mine, or other development and incorporates knowledge of caribou food needs, how much food is available, and caribou feeding behaviour to estimate its weight. A heavier cow has a better chance of getting pregnant, and

Bathurst caribou on esker, Contwoyto Lake 2020. Photo credit: Aimee Guile

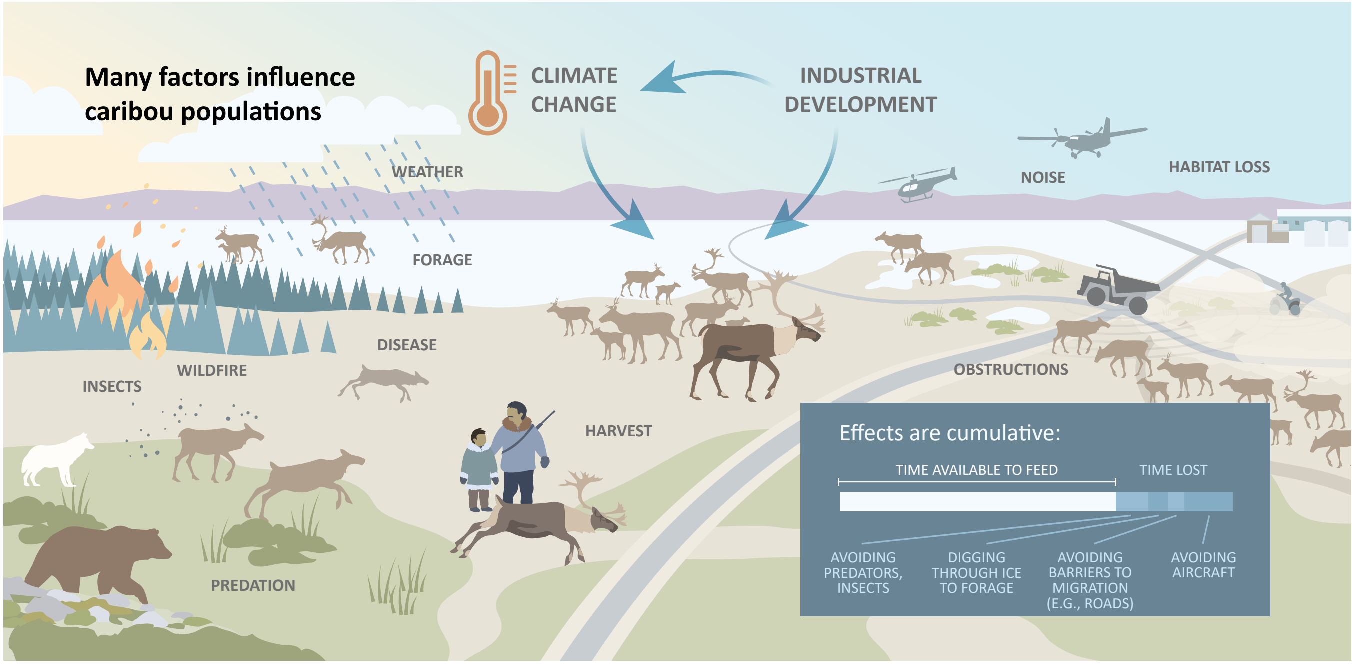


Figure 3: Many factors influence caribou populations, with the effects being complex and cumulative.

a heavier calf is more likely to survive winter. These computer models help us understand how climate and development can affect caribou numbers, but they cannot capture the entire picture.

Scientists have been using computer models to assess potential oil development on the calving and post-calving grounds of the Porcupine herd and to provide information to the Bathurst Caribou Range Plan.

PORCUPINE

CURRENT TREND
Increasing

MANAGED HARVEST
<2%

MAIN CLIMATE CHANGE IMPACTS
Late spring drought and winter icing conditions decrease food

OTHER THREATS
Development poses risk to calving grounds in Alaska

For a description of Indigenous Knowledge related to cumulative effects on caribou please see section on stressors and effects, below.

Harvest management

Hunting caribou is central to the relationship between humans and caribou. Monitoring the caribou hunt is important for caribou management. Harvest data is essential for sustainable management and understanding how hunting is affecting herd size. It is also an opportunity to gather information on caribou health, distribution, and ecology.

Regulations control caribou hunting by non-Indigenous hunters. Indigenous harvest rights are not normally restricted, but in certain areas, when there is a conservation concern, Indigenous harvest rights may be restricted. Caribou harvest reporting is difficult because herds migrate over large areas covering different countries, territories, provinces, and land claims. Harvest reporting works best when hunters trust the agencies collecting the information. Everyone benefits when all governments (including Indigenous – Inuit, First Nations, and Métis) work together to count and manage the caribou harvest.

In different Canadian territories and provinces, HTOs have often taken action to conserve caribou during times of scarcity. In Nunavut, for example, they proactively closed sport and commercial hunting while maintaining subsistence hunting. Sale of caribou meat though social media in and among communities is growing, and this can mean that more caribou are harvested. Stronger conservation measures and harvest reporting developed through cooperative management are needed.

In the Northwest Territories, the Wek'èezhìı Renewable Resources Board (WRRB) severely restricted harvest of the Bathurst herd in 2010. The herd size held steady from 2009–2012, but then dropped again. As a result, in 2016 the WRRB decided to restrict all harvest. This has caused distress and hardship for communities.

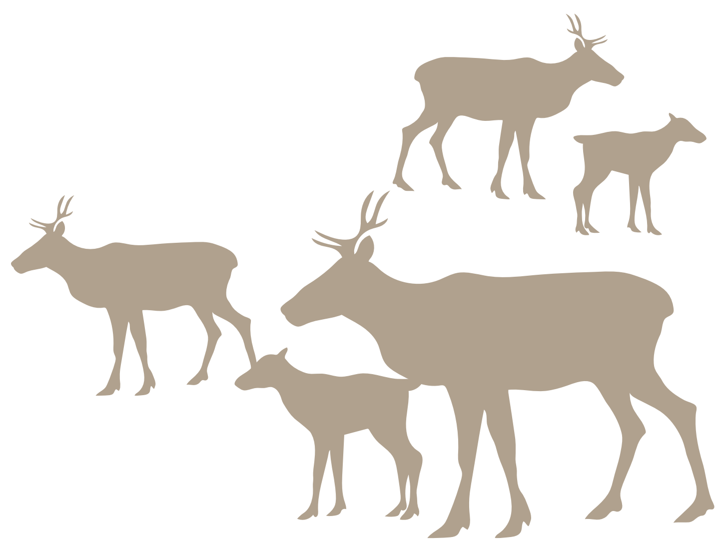
Making the harvest ban work is complicated because the Bathurst herd shares a winter range with the Bluenose-East and Beverly/Ahiak herds. The Mobile Core Bathurst Caribou Management Zone was developed for this reason. Each week, hunters receive a map showing the location of the Bathurst herd, with a buffer zone around it, so that they know where hunting is prohibited. Officers patrol the area to make sure this is respected, but the size and remoteness of the areas make this difficult to enforce. In 2021, the Tłįchǫ Government, Yellowknives Dene, and North Slave Métis Alliance stationed community monitors on the Tibbitt to Contwoyto winter road to keep track of the harvest and provide information to harvesters.

For information on Indigenous Knowledge and harvest management please see the sections on reducing the harvesting stressor and impact on Indigenous peoples' health, below.

Caribou recovery

As caribou move across the land, their hooves leave scars on plant roots. The scars are still visible hundreds of years later, and this helps biologists understand past times of abundance and scarcity.[29] The record they show lines up with Indigenous Knowledge about rises and falls in caribou numbers. It is possible that the peaks are not as high as they once were, and that low numbers have lasted for longer than usual. Also, not all periods of decline are necessarily followed by recovery.

Currently, many herds are at low levels, so caribou management must focus on sustaining or creating the best possible conditions for them to recover. We can know which conditions are related to periods of decline and recovery by



looking at past swings in caribou numbers, and at how their ranges have changed since the last peak.

Biologists measure several factors to help them assess a herd's health. Although each herd is unique, the following are general signs of a healthy, growing herd:

- Good body condition of cows — fat cows are also more likely to be pregnant
- Good calf birth weight and survival (calves make up at least 20% of the herd in October)
- A healthy mix of cows and bulls (approximately 30 calves for every 100 cows in October)
- A high adult cow annual survival rate of 85% and ideally 80% for males (though viable at lower male survival rate)

When herds recover and grow, they begin to expand their range. They may return to areas they have not used in decades, where the vegetation has had time to recover from grazing by caribou. Current and future development activities can interfere with access to seasonal habitats and seasonal travel of caribou.

Many factors affect caribou populations, including predators, industrial developments, roads, hunting, and natural factors, such as fires, weather, and disease. Once herds become small, they will probably decline more quickly. Small populations are especially vulnerable to changes that affect the survival of adults and calves, including harvest, weather and food quality, and availability. As a herd grows, however, it generally becomes more secure. It has enough animals to withstand setbacks like drownings in a river-crossing, or a late spring, which can be deadly for calves. A recovered population needs enough habitat for each part of its life cycle (calving and post-calving, the rut, migrations, and winter ranges), and it must be able to get to these habitats.

Management boards, working together with their many partners — Hunters and Trappers Organizations, regional wildlife organizations, government biologists, traditional knowledge holders, and others — are making recommendations designed to keep caribou habitat healthy over the long term. For example, assessments of the impacts of development on caribou — roads, noise, dust, and other disturbances — must consider the effects of the development over the full span of the natural population highs and lows. This is especially important for habitats that are critical to the sustainability of the herd.

Caribou face modern-day challenges that can prevent or slow recovery, or even cause a decline. Climate change, industrial development, and modern hunting methods can all limit recovery. The trade-offs associated with land use, and harvest decisions that can either help or hinder need to be discussed. Individuals, communities, Indigenous and scientific knowledge holders, and governments, all want to see healthy caribou herds. We must work together to conserve populations and their habitat.

Indigenous perspective

The following provides an Indigenous Knowledge perspective on the issues discussed above through interviews and discussions with George Lyall of Nain, Nunatsiavut, NL, Lars Qaqqaq of Baker Lake, NU, and Johnnie Lennie of Inuvik, Inuvialuit, NWT.

Caribou populations

The Qamanirjuaq herd near Baker Lake, which was once massive, is shrinking. The population cycle for this herd is between 60 and 70 years, but other factors are contributing to the decline. The Beverly herd is also declining, because of changes in their migration route and calving grounds, changes in ice conditions along their route, and other factors.

In Nunatsiavut, the George River herd, once estimated at 750,000, now numbers very few, and the size of Torngat Mountain herd continues to be assessed through aerial surveys. The woodland caribou Red Wine Mountain population is small. Biologists who have examined carcasses have not been able to find the cause of these declines.

In the Inuvialuit region, the Bluenose and Tuktoyaktuk Peninsula herds both appear to be on a low cycle. The Bluenose herd, once a single herd, has split into two. The caribou of the Tuktoyaktuk Peninsula have interbred with reindeer that were imported to the region many years ago. The Porcupine herd is healthy.

Stressors and effects

Caribou have a lot of challenges to overcome. The growth of communities, and the construction of mines and roads, may cause stress and have negative impacts on caribou. Roads make travel on the land easier for hunters. Some may kill more than they need and waste meat. Wolves also wait along the road for caribou. Wolf populations rise and fall when there are more caribou, especially calves.

In the NWT, the government has been paying hunters for wolf carcasses. If this reduces the number of wolves it may help protect the caribou over the short term.

Caribou do not like to cross the power lines in Nunatsiavut and Quebec. This is a concern for some in the Kivalliq region of Nunavut, as a power line has been proposed there. The hydro developments in Nunatsiavut and Quebec have caused stress and other negative effects for caribou. Warmer summers can bring more mosquitos and flies, forcing the caribou closer to water bodies. Climate change has also delayed lake and river freeze-up. Some do not freeze fully, which may affect caribou migration. Rains late in the year and freezing rain on snow creates a crust that caribou must break to reach their food. Calves starve when the ice crust is thick.

Reducing the harvesting stressor

Much is being done to reduce the stress on herds from hunting. Wildlife management boards are doing what they can to manage the harvest to keep it sustainable for communities that depend on caribou. Most use Indigenous Knowledge to develop rules, such as not hunting the lead caribou, which walks ahead of the herd; not hunting pregnant cows or females with calves; and not hunting during rutting season. Wherever herds are in decline (even due to natural cycles), management boards have lowered the number of caribou allowed per household, or reduced hunting in a certain area so that hunters must travel further to get more caribou.

Sport hunting and sales of caribou meat have been reduced or eliminated in some areas of the Arctic, but are a problem in other areas. Inuit are permitted to sell caribou meat to other Inuit in some communities and regions. This can be a concern and is being cautiously monitored. In these places the commercial hunt is reduced when there are not enough caribou to support the food needs of local Inuit.

Where a caribou herd is considered too small to support any harvest, co-management systems may introduce a moratorium as a management tool, only as needed. A moratorium only works if everyone accepts it. Those who continue to hunt can put the herd at risk. It can cause long-term harm to the caribou herd and goes against the interest of Indigenous communities. Hunters who respect the ban feel this behaviour is unfair.

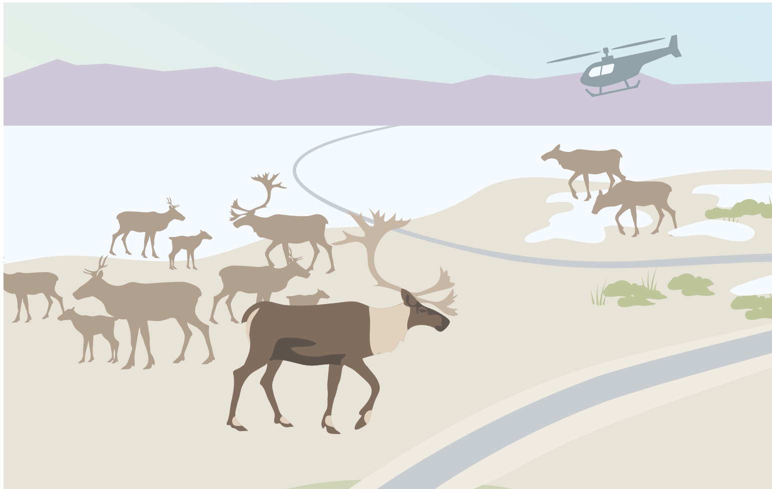
Impact on Indigenous peoples' health

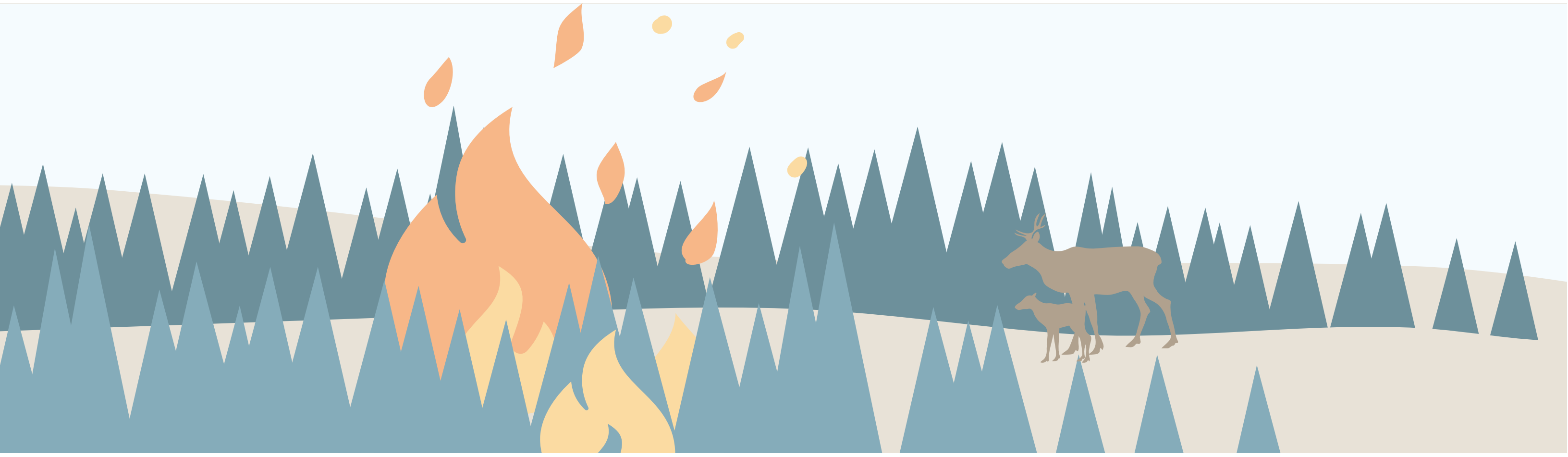
When caribou meat is hard to get or not available at all, people may turn to store-bought food, which is less nutritious and more expensive. Each generation is eating less and less caribou because of limitations and bans.

The Nunatsiavut Government imported caribou and muskox from another region to give their members an opportunity to eat caribou and muskox. (Note: To offset the scarcity of caribou and the lack of country food on Baffin Island, the Government of Nunavut recommended a community hunt of muskox on Devon Island, where a healthy population of these animals is available for harvest by North Baffin communities.[30]

Current and future caribou habitat protection

Government and co-management partners across the North have been working together to develop protective measures for caribou and their habitat. Some have established natural reserves in areas important to caribou migratory routes and lifecycle stages. The Government of Quebec, for example, recently created protected areas that protect part of the ranges of the George River caribou herd. These areas protect part of the seasonal ranges of the annual life cycle of the George River caribou herd. No natural resource exploration or exploitation activity (including mining, energy extraction, forestry) is allowed in these areas.[31] The Porcupine caribou calving and post-calving grounds are currently protected under Canada's Ivvavik National Park and Alaska's Arctic National Wildlife Refuge, although a major portion of the calving grounds are threatened by potential oil development. The Nunavut Wildlife Management Board (NWMB), the territory's main instrument for wildlife management, has developed a list of caribou habitat recommendations for the Draft Nunavut Land Use Plan.[32] This includes a recommendation to





create reserves to protect critical caribou habitat in the Nunavut Settlement Area, specifically:

1. Establishing Protected Areas is generally a more effective conservation action for the protection of core caribou habitat and vulnerable caribou populations than simply establishing protection measures.
2. Particularly considering the currently low population numbers, the high economic, social, and cultural value of caribou and caribou habitat to Inuit, and ongoing exploration and development activities throughout the territory, it is urgent that prompt and effective steps be taken by management authorities to ensure the protection of this irreplaceable natural resource.
3. The establishment under *Nunavut's Wildlife Act of Special Management Areas* and accompanying regulatory safeguards appears to be an effective and appropriate legal action for the protection of caribou and caribou habitat.[32]

Although no protected areas for caribou critical habitat (calving grounds, post-calving grounds and associated migratory pathways and water crossings) have been set aside in Nunavut as of yet, these are positive steps in the right direction. In addition, more work is needed in the development of the Nunavut Land Use Plan to address caribou habitat protection needs. Herds at risk in other parts of the Canadian North may be in need of similar protection.

Emerging issues of research interest

Many of the emerging issues and areas of research interest as they relate to caribou across the North are often complex and intertwined. For example, the world's climate is changing and so is the environment that caribou inhabit. How caribou respond to these changes is of great interest and concern as many could be detrimental. A warmer climate brings changes in the food supply as vegetation communities also adapt to wetter or drier regimes. New parasites and diseases are emerging, along with an increase in numbers and range of insects as longer growing seasons offer a new foothold to completion of complex life stages. Competition for food increases as new species invade a less hostile environment or contribute to an increase in new or existing predators. Drier conditions are expected to lead to more forest fires, which will modify food supply with loss of lichen and landscape structure. Novel research techniques, such as satellite imagery, remote sensing, and blood cortisol monitoring may help researchers understand the impacts of land development, climate change, and cumulative effects of large-scale habitat change and stressors on caribou. While change can be accommodated, it is the pace of change that can be a deal-breaker. Will caribou herds continue to show fidelity to the specific areas? Will they migrate in the same way?

In addition to the emerging issues of climate change, there are many areas of scientific and Indigenous Knowledge research interest that relate to the natural life-history and ecology of caribou across the North. Caribou populations exhibit population highs and lows that can persist for decades. Currently, many populations of caribou are experiencing declines. Key to sustainable management is harvest reporting which could be enhanced for caribou management. Will we see a return to the large numbers (e.g., half a million or more animals in a herd) or will herds fracture and become more dispersed?

Future changes to the land will determine if recovery can rebound to pre-decline levels. Predator-prey dynamics play an important role in caribou ecology as they have shaped the evolution of caribou and their predators over millennia. Whether predation, especially by wolves, can moderate caribou abundance is still uncertain. Abundance limitation by food supply is likely more prevalent, but there may be periods where some processes exert more influence than at other times. Clearly, long-term studies can help answer these questions, but there is an urgency to get answers now, as some herds may be in peril. With the large amounts of data that come with research and monitoring, the development and testing of population models that can be complemented with Indigenous Knowledge spanning decades becomes ever more important. In order to ensure caribou retain a prominent future on the landscape, they will need our collective help to navigate the rapid changes that are occurring. Through collaboration we can work together using both traditional and scientific knowledge to gain a more comprehensive understanding of the complex relationships between humans, caribou, and the land. By working together, caribou can continue to be the heartbeat of the tundra.

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Understanding the effects of climate change on food security in northern Indigenous communities

Executive Summary

Indigenous Knowledge and lived experience, as well as research on northern needs and priorities, are essential to understanding how climate change affects northern food security. This paper describes climate change effects on the different dimensions of food security from the lens of northern Indigenous peoples, acknowledging their strong relationship with land and dependence on country foods for nutrition and community well-being. Bridging evidence from Indigenous Knowledge and research, the multifaceted influence of climate warming and environmental change on food availability, food accessibility, food quality and the need for adaptation are explored. This paper also explores how communities can develop or expand current environmental monitoring programs to focus on a variety of indicators that capture the complex influence of climate change on country food security via a "stressors, states and responses" design. The successes of current community-based monitoring programs are also highlighted and recommendations for enhancing existing monitoring efforts are made with the goal of enabling northern Indigenous communities to remain resilient to change.

Effects of climate change on Country Food: Evidence from the Indigenous Knowledge Working Group. Concept of food security from an Indigenous lens. The connection between food security and cultural identity is why country food security is important to highlight beyond the nutrition factor. The health implications of country food security can't be replaced by store bought food.

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New words are needed to describe new conditions
Intergenerational knowledge transfer must respond to climate-induced changes
Abundance of wildlife and plants
Diversity of wildlife and plants
How do we adapt, by bridging different ways of knowing?
Is there enough?
CLIMATE CHANGE
Affects all aspects of Indigenous food security and ways of life
Do we want to eat it?
Can we get it?
Food quality and safety
Condition of animals
Distribution of animals
Economic barriers
$
Local diets and nutrient intake
Travel conditions

Introduction

Across the North "the land" — which includes land, water, ice, air, plants, and wildlife that live there — has sustained Indigenous Peoples for millennia. Relationships with the land have shaped Indigenous cultures and greatly influenced the ancient knowledge passed down through generations. Now, climate change is altering relations to the land and knowledge of the land. This makes it difficult for northern Indigenous peoples to obtain food from their traditional territories.[1] This affects their food security.

In a Regional Planning and Knowledge-Sharing Workshop held at the Canadian High Arctic Research Station (CHARS) campus (March 10–11, 2020), Indigenous participants expressed concern about how climate change affects their access to country foods. They also spoke of the need for relevant, up-to-date information so they can understand climate change effects, and plan how to adapt.

Indigenous Knowledge and lived experience, as well as research on northern needs and priorities, are essential to understanding how climate change affects northern food security. Indigenous Knowledge and science, working together, will help meet the information needs of northern communities. This information will guide policies and support decision-making to improve resilience and sustainability of northern food systems.

This paper answers the following questions asked at the workshop:

- What are the effects of climate change on the health and availability of country foods?
- Are we doing enough monitoring to understand climate change influences on country food and to plan for the adaptation of northern food systems? If not, what more should be done?
- How can northern and Indigenous knowledge-holders take part in monitoring ecosystem change and what supports do they need?
- What is the role of community-based monitoring in collecting information about climate change and changing wildlife?
- What areas should we focus on for climate change research and monitoring?

Our approach

Polar Knowledge Canada assembled a working group (the co-authors) to develop this paper, based on our diverse experiences working with Northern communities.

Northern organizations, regional governments, and Indigenous governance bodies have conducted their own assessments to identify key issues related to climate change, plan adaptation measures,[2,3,4,5] and create food security strategies.[6,7,8,9] This paper aims to add to these efforts by drawing on both Indigenous Knowledge and scientific knowledge to make recommendations that support community-led responses to climate change impacts on country food.

Climate change impacts country food: evidence from the Indigenous Knowledge Working Group

Harvesting, preparing, and consuming country food (wildlife, fish, berries, and plants) are important cultural practices passed down through generations in northern communities. Climate-driven changes in northern regions have been affecting the ability of communities to harvest and consume country foods. Late freeze-up, irregular spring melt, warmer or colder winters, thawing permafrost, loss of long-term ice, changing precipitation patterns, and coastal erosion — these all affect travel to traditional harvesting areas. In the Inuvialuit region, intense spring melts in the Mackenzie River system force hunters to use newer routes when they return to town, because the usual routes are less safe. The new routes are longer, and hunters use more fuel, which increases the costs of harvest. This is just one example of how changing environmental conditions can affect the safety of hunters and increase costs.

There are also concerns about how climate change affects the quality and availability of country foods. In the Inuvialuit region, some Inuit have noticed that the quality of meat has declined. For example, people have seen worms in lake trout, and abnormal caribou livers. As well, Inuit have learned that reduced annual sea ice means that marine food webs are more exposed to air pollutants, such as mercury, from southern regions. This affects the quality of marine food. Although it is well known that natural cycles can cause the number of animals and their migration routes to change, many Indigenous people are concerned about the added influence of climate change on fluctuations in wildlife abundance. Beluga and narwhal have long been absent from Taloyoak, Nunavut, and knowledge-holders attribute this to climate change and increased ship traffic. In the Inuvialuit region, it is clear that beluga, fish, and caribou are facing climate change impacts. These are significant concerns for those who rely on country foods for their livelihoods.

Climate change also influences Indigenous Knowledge about routes to hunting areas and about meat quality. The combined effects of unpredictable environmental conditions and the changing availability of wildlife complicate the transfer of knowledge between generations. When changing environmental conditions prevent the use of traditional routes, Elders cannot always explain the new conditions. Of equal concern are new toxins and diseases that affect the quality of meat. These are thought to be appearing because of warming temperatures.

It is especially difficult to explain these new conditions when there are no terms for them in the local Indigenous language. Also, when knowledge-holders have not experienced the conditions before, they cannot judge how hunter health or safety will be affected. Without this information, a young hunter may not know how to deal with the conditions and will feel less confident out on the land. These additional pressures compound the climate change anxieties that many northern communities are already facing. This fundamentally disrupts the balance they have developed with their environments over centuries.

Climate change impacts different dimensions of Indigenous food security

Indigenous Knowledge of how climate change is affecting food security can be further explored by examining how climate change impacts the availability, accessibility, and quality of country foods (see Impacts of climate change infographic).

Food availability: Is there enough?

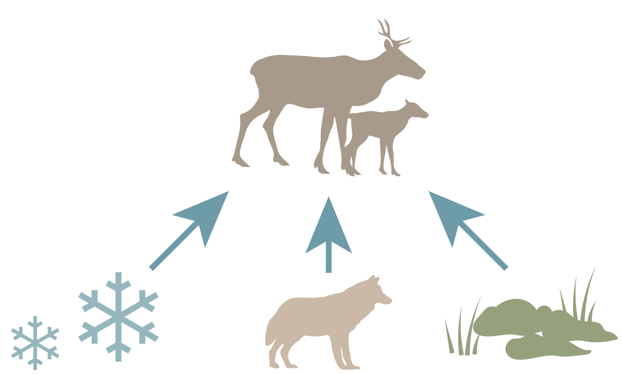
Country food availability is determined by:

- wildlife and plant abundance (the number of individuals of a particular species or herd, or total dry weight of plants)
- wildlife and plant diversity (the presence of different types of country food species)

For country food to be available, wildlife and plants need to be abundant and diverse. Several factors influence the changes in abundance and diversity of Arctic wildlife and plants as the climate warms. These can act in opposition. For example, changes in environmental conditions (thinner ice, deeper snow) can make it harder for caribou to travel and cause them to use more energy during migration. At the same time, longer growing seasons caused by warming can improve the quantity and quality of the plants that wildlife eat. This could provide more energy, which may offset the extra energy used during migration.[10]

Distinct populations of the same species may respond differently to warming because of how they have adapted to local conditions. For example, more Yukon River Chinook may survive an earlier melt of river ice and higher temperatures in the Bering Sea,[11] compared to southern Chinook populations.[12] With warming temperatures, predators such as grizzlies[13, 14] and parasites such as lungworms in muskoxen[15] are moving northward.

Because the influence of warming on country foods is complex, it is hard to be sure how it will affect overall availability. We do know that diversity and abundance of food species are changing faster as the Arctic warms.[1] Ensuring food security requires sharing knowledge and adapting to new opportunities in ways that support and promote Indigenous Knowledge, culture, and wellness.[16]



Food accessibility: Can we get it?

Climate change impacts where country food species are found, and hunters' ability to travel in their traditional territories. It also affects cultural food practices (e.g., food sharing, food choice). Research has shown that climate change:

- challenges hunters' ability to travel safely[17, 18]
- makes harvesting more expensive due to unpredictable weather, increased travel distance, and increased time on the land[18, 19, 20]
- affects the distribution of country food species due to both environmental factors[21] and new predators[18]

Climate change impacts can make it impossible to reach hunting areas when the animals are present.[17, 18] Climate driven environmental conditions that impact food accessibility include the following:

- reduced sea ice extent
- unstable ice conditions
- changing timing and duration of ice freeze-up and break-up
- changing water levels
- more frequent and stronger storms
- unpredictable winds
- changing precipitation pattern
- increasing erosion
- thawing permafrost

These changes can force hunters to harvest another species, such as fish, if they cannot safely reach caribou hunting grounds.[22] Sometimes changing conditions may enable longer fishing seasons.[18, 23, 24]

Unpredictable environmental conditions can also make travel routes that have been used

for generations less reliable and more costly to use. This can make it more difficult to pass on knowledge between generations and therefore harder for elders to help young hunters develop their skills. If hunters are unable to access preferred food species, they may bring home less food, and have less to share with Elders and other community members.[25, 26, 27] This can affect the well-being of individuals and the entire community.[28, 29, 30, 31]

Food quality: Do we want to eat it?

Country food quality refers to:

- nutritional value
- cultural food preferences
- taste, smell, appearance, texture
- safety of foods

Country foods are a major source of essential nutrients. They play a vital role in maintaining health. Climate change impacts on country food access and availability can affect diet and nutrition. For example, if changes force hunters to choose lower quality, easy-to-capture and abundant, species over high quality, hard-to-capture caribou, this can affect the nutrition and health of Indigenous communities.

Climate change is also influencing food safety. Warming temperatures affect the number of contaminants that travel to the north from other areas.[32, 33, 34, 35] This can impact the levels of environmental contaminants in country foods, such as PCBs, mercury, and lead.[35, 36] Environmental monitoring, responsive health advisories, and balanced consumption advice can help limit exposure to these contaminants.[35] Warming temperatures can also decrease food safety and cause foodborne illness. For example, illness from seafood is projected to increase in northern Canada due to warming ocean water.[37]

Climate change affects food preparation and storage practices that depend on cool temperatures. This can reduce food quality and safety. For example, above-ground air-drying of fish and meat, below-ground cold storage on or near permafrost, and fermentation do not work well when it is too warm. Community freezers and cut-and-wrap facilities can help prevent foodborne diseases. It is essential to recognize food safety problems quickly and educate the public, especially in the context of climate change.

Climate change is challenging Indigenous food security; however, regional and community food systems can be and are resilient. These actions are needed:

- study, identify, and respond to climate impacts on access, availability, and quality of country food
- consider how different ways of knowing support and inform the adaptation of northern community food systems to climate change
- develop innovative programming on Indigenous language terminology and knowledge transfer that responds to climate-induced changes and new conditions.

Climate change and wellbeing indicators to monitor

Monitoring relevant indicators over the long term can help track climate change effects on country food security. Climate change influences environmental conditions, wildlife, and plants differently across the North. Local priorities vary as well. While there is no one-size-fits-all solution to developing northern monitoring programs,[38, 39] community-based programs that monitor environmental, social, and economic indicators relevant to people in the region[39, 40, 41, 42] are particularly useful.

Below we provide some key concepts to consider when designing programs to monitor how climate change affects the three dimensions of food security (availability, accessibility, and quality). A "Stressors, States and Responses" design that pairs environmental, social, and economic indicators together can enable the development of holistic monitoring programs (Table 1).

Stressors: Which climate change factors threaten country food species?

Stressors are aspects of the environment that put stress on, or influence change in, country food species. Indicators of stressors can include elements of climate change (e.g., warming annual temperatures, earlier spring temperatures, earlier ice break-up) that influence environmental conditions affecting country food species (e.g., species' habitat, food sources and quality, predation, disease).

States: How is climate change impacting wildlife and plant species?

States refer to how environmental stressors influence wildlife and plant species. Climate can affect the state of a wildlife or plant population in different ways (see "Food availability: Is there enough" above). Indicators of the state of a country food species population might include population numbers, animal health, or behaviour.

Responses: How does climate change impact Indigenous food security?

Responses to climate change include individual or systemic actions, or adaption to policy or practice. Indicators might include harvest levels, the amount of key country food species a community consumes, and levels of food quality or safety.

Table 1 An example of a "stressor-state-response" framework for monitoring climate change impacts on country foods. This table provides some examples of indicators but does not show all potential indicators.

	Stressors	States	Responses
Food availability	Indicator examples: water temperature, salinity, prey availability, ice coverage (habitat), snow depth, predation	Indicator examples: wildlife population size, population structure (males, females, young)	Indicator examples: frequency and quantity of wildlife consumption within communities
Food accessibility	Indicator examples: ice thickness, ice stability, timing of freeze-up, timing of break-up, average air temperature, water levels, storm frequency	Indicator examples: condition of trails and travel routes to harvesting areas, length of harvesting season for key species	Indicator examples: harvest numbers, cultural continuity, transfer of knowledge on food species to younger generations, land-based accidents, provision of harvesting equipment
Food quality	Indicator examples: marine and freshwater temperature, average air temperature, extreme air temperature	Indicator examples: disease-causing pathogens in country food species, levels of environmental contaminants, key nutrients in country foods, community-reported quality (e.g., taste, colour, and texture) of key food items	Indicator examples: frequency and quantity of country food species consumed in communities, occurrence of discarded meat/carcasses, reports of foodborne illnesses, nutrient content, contaminant levels

Community-based monitoring opportunities and successes

Northern Indigenous organizations play an important role in research and monitoring. They identify research questions and lead research at local levels. In Boxes 1 through 4, we highlight examples of community-based monitoring programs that respond to climate change impacts on northern Indigenous food security. These examples show that many different stressors, states, and responses are being monitored across the North. Some common elements contribute to their success, including:

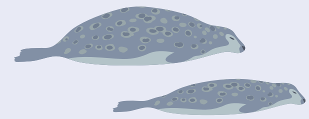
- prioritizing Indigenous self-determination in the design and implementation of monitoring programs
- focusing on culturally important species and their habitats
- working within Indigenous governance structures
- supporting strong community leadership and long-term partnerships to ensure continuity of programs
- engaging Indigenous knowledge-holders to identify relevant indicators and places
- supporting community-based monitoring capacity through youth training and Indigenous guardian programs
- ensuring that monitoring activities are tied to seasonal land use
- recognizing community-based monitoring initiatives as a way of contributing to environmental education, research, conservation, and economic activities
- making monitoring results available within and between communities and regions to support decision-making

These common elements can also help build momentum towards coordinated food-security research and monitoring across the North. It is important to provide opportunities for northerners to share knowledge about program design, data trends, and the technical skills required for research and monitoring.

Community-led research and monitoring programs are inherent to self-government agreements and rights identified in land claims and co-management agreements. Research has not always benefitted northerners or responded to local or regional interests and needs.[44, 45] This is beginning to change. Research and monitoring programs that uphold Indigenous rights and Indigenous self-determination in research can best support local resilience to climate change.[43, 45]

Box #1
Monitoring seal health with SIKU

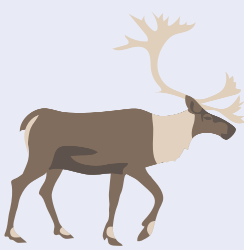
SIKU is the Indigenous Knowledge Social Network (www.siku.org), developed by the Arctic Eider Society (https://arcticeider.com/) and the Hunters and Trappers Association of Sanikiluaq, Nunavut. Involving Inuit hunters from Sanikiluaq and Nunavik communities in the eastern Hudson Bay area, community-based monitoring of the marine environment has been ongoing for many years. This program includes oceanographic and sea ice research, as well as wildlife monitoring programs.



Ringed seals are especially important to food security in the region. A study, based on Elder Peter Kattuk's observations and guidance about changing diets of seals, showed that the seals were eating fewer fish and more shrimp. This study was a key pilot project for the development of the SIKU app both before and after its launch in 2019. With the SIKU app, anyone going out hunting can record important indicators about seals and environmental conditions. In addition, paid environmental monitors use scientific instruments and observations based on Inuit Knowledge to document sea ice, oceanographic, and other conditions. They can record and share this information through SIKU.

Box #2
Monitoring caribou in Nunatsiavut

The George River and Mealy Mountain caribou herds have declined due to climate change and other human-induced impacts in Labrador. The province has banned hunting of both herds. Both herds are vital to Inuit food security and wellbeing.



Community-based research projects have documented Inuit knowledge about these herds. Inuit expressed strong emotions about their loss of connection to the animals. They revealed that caribou are essential to Inuit emotional wellness, identity, and cultural continuity.[29] They worried about permanently losing access to caribou,[30] partly because of climate change. Inuit felt criminalized because of hunting bans. When they shared their views on caribou management, they felt that governments did not listen.[46]

A new caribou monitoring project is bringing academic research and community priorities together. The project aims to reconnect youth to the land and caribou. Young people will join Elders on hunting trips to the wintering range of the George River and Mealy Mountain herds and take photographs of their experiences. Community members will prepare and co-lead trips with the project team. The project assesses the wintering grounds and caribou movements, comparing these with traditional knowledge from past hunting practices. Participants may also assess caribou behaviour or health compared to past observations. This project is an innovative way to keep cultural practices alive and contribute to Inuit well-being.

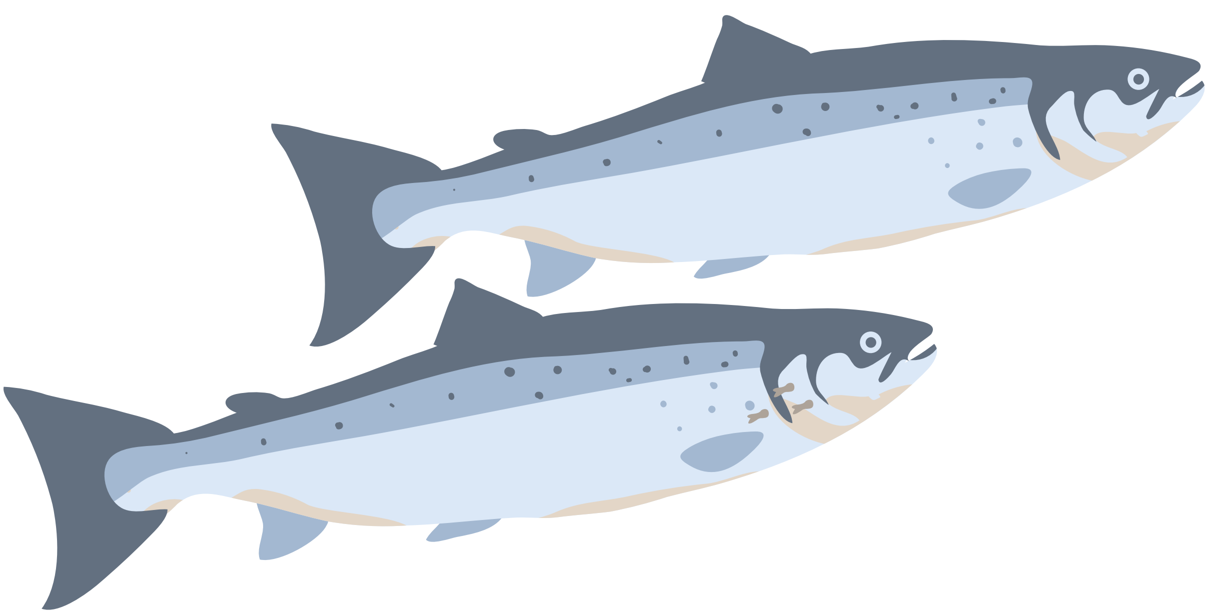
Box #3
Monitoring Chinook salmon in central Yukon

The First Nation of Na-Cho Nyäk Dun (www.nndfn.com) and the Wildlife Conservation Society Canada (www.wcscanada.org) work together to monitor Chinook salmon in the Beaver River watershed. This work joins Indigenous and scientific knowledge in partnership to inform conservation planning.

The Beaver River watershed is home to the Na-Cho Nyäk Dun people and provides habitat for many key wildlife species, including Chinook salmon. A proposed road will cross 48 rivers and streams in the watershed, potentially affecting key salmon spawning habitat. A land-use plan is being developed to protect spawning habitats and reduce the impacts of the road on salmon.

Cultural maps and Indigenous Knowledge of salmon spawning, contributed by Na-Cho Nyäk Dun Elders, guided study design and field work for monitoring salmon numbers, spawning habitat and water quality.

The project identified viable Chinook spawning habitat and key areas to continue monitoring for spawning salmon. It also included training and mentorship for Na-Cho Nyäk Dun staff, who now have the skills to do the surveys themselves and continue the monitoring program. An Elder took part in the monitoring activities and shared Indigenous Knowledge of the land, as well as important insights for conservation. These are captured in a story map shared with Na-cho Nyäk Dun citizens (https://storymaps.arcgis.com/stories/8eba6b85803b4b56b6389abcc74708a8). The results of this work are informing the development of the Beaver River Land Use Plan. Monitoring will continue to support future Chinook salmon and water protection. Future projects in the Beaver River Watershed include monitoring air and water temperature and light conditions.



Box #4
Community-based Collaborative caribou and muskox health surveillance

Caribou and muskoxen health monitoring program were developed collaboratively by community members, academics and government wildlife agencies in response to concerns voiced by the communities of Ulukhaktok, Northwest Territories, and Kugluktuk and Ekaluktutiak, Nunavut. The programs bring Indigenous Knowledge and science together to understand wildlife population health, disease, and zoonoses (diseases that pass from animals to humans). The programs consist of: (i) baseline wildlife health interviews gathering information on stressors; (ii) harvester-based sampling from caribou and muskoxen; and (iii) ongoing annual interviews documenting Indigenous Knowledge on population health and trends.

These approaches bring Indigenous and scientific knowledge together to establish historical baselines and trends. They also document current populations and detect new or emerging conditions, diseases, or concerns. The results are shared with the communities through community presentations, co-management meetings, and reports that are co-authored with key community partners. The results can inform educational, conservation, or public health responses. Co-learning happens through training and knowledge exchange between hunters, monitors, scientists, graduate students, and the general public. Increasingly, local hunter and trapper organizations own and operate these programs, and communities manage data ownership. Scientific researchers and academics serve as external experts to support the programs. This ongoing relationship between community members, government officials, and academic partners brings continued knowledge sharing and builds trust. It also greatly improves the communication network, which leads to more effective wildlife co-management.

Climate change monitoring: Recommendations from the Indigenous Knowledge Working Group

Many ongoing climate change monitoring and research projects focus on a range of wildlife (such as caribou, polar bear, and muskox), marine mammals, and fish. These projects have been positive for communities and have provided added income for hunters as the cost of going out on the land rises. These hunters, including Elders, often know best which areas are most affected by climate change, and share their knowledge about the history of local changes and existing natural cycles with southern researchers.

Monitoring programs must be designed collaboratively with communities so that research and monitoring efforts reflect local priorities and knowledge needs. In some areas, topics important to the community are not being addressed. In other areas, residents are tired of participating in research and no longer want to be involved.

In Taloyoak, Nunavut, several effective projects are monitoring fish populations, but there is no caribou research and more could be done to monitor the growing polar bear population. In the Inuvialuit region, however, there have been many research projects and there is a general feeling that beneficial monitoring projects should be continued. The co-development of projects ensures that monitoring programs are respecting local perspectives on how to collect data ethically. Indigenous peoples want more influence on research methodologies, including the ability to veto methods that they consider harmful to wildlife (e.g., collars on polar bears). They also want to develop local capacity to conduct their own research, including the use of instrumentation.

Adequate funding is needed to enable long-term monitoring, and to integrate research across regions and share knowledge across the North. Inuit Tapiriit Kanatami spearheaded the 2019 Inuit Climate Change Strategy, a helpful framework that communities in the four Inuit regions can use to collaborate and integrate research. Pan-Northern forums generally allow for different communities to share ideas and concerns and unite in their thinking. Program funding needs to be flexible to allow for local innovation in monitoring programs. For example, an Inuvialuit project helped improve country food processing by showing harvesters how to reduce meat wastage for personal and commercial purposes.

Conclusion: Enhancing community-based monitoring of climate change and country food

Relationship with the land is fundamental for northern Indigenous peoples and provides the foundation for local belief systems, identity, knowledge, and livelihoods. Their close connection with the land shapes the way they experience and understand environmental change, and the way they respond to it.

Indigenous communities across the North are experiencing rapid climate change. It is affecting the availability, accessibility, and quality of country food, which is key to Indigenous food security. Monitoring programs and research focused on understanding climate change effects on country foods must consider potential implications for northern Indigenous needs There is a need for integrated research and monitoring that prioritizes the importance of local culture, skills, language, food preferences, and harvest practices to better understand the adaptations required for communities to remain healthy and resilient to change.

The following recommendations support improved understanding of how climate change impacts Indigenous food security. They emphasize culturally relevant and Northern-led approaches.

Recommendations

Consider the relationship between northern food security, culture, health, and climate change

Country foods are critical to northern food security and fundamental to northern Indigenous cultures. Climate change adaptation, nutrition, and health are also part of food security. Understanding how these elements interact will help enable northern communities to strengthen their resilience to climate change.

Promote Indigenous self-determined research on climate change and country food security

There is a need for Indigenous self-determined research that uses multiple perspectives to explore how climate change is affecting northern ecosystems and country food systems. This should include the following:

- research that brings together Indigenous Knowledge, social sciences, natural sciences, and knowledge from different sectors (e.g., linking climate change impacts on wildlife abundance, distribution, and health to impacts on human health and adaptation strategies)
- more support for Indigenous methods, knowledge, values, community-led research, and monitoring for food sovereignty

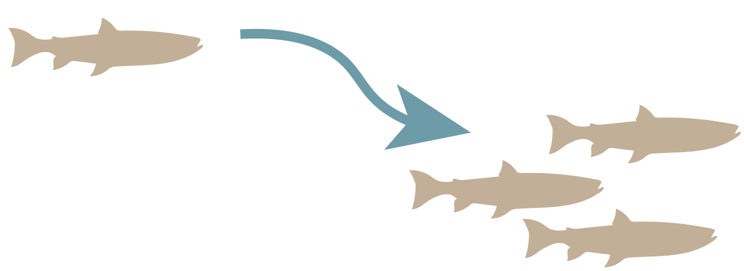
Foster northern leadership and guidance

Northern and Indigenous communities know best what research and monitoring programs they need, and they are the best advocates for these. They can identify key issues of local concern. Indigenous-led programs, or programs that communities and researchers develop together from the start, based on community needs, will foster community interest. These will also foster community involvement in all aspects of research, or as much as local capacity allows.

Focus on critical indicators

Crucial indicators in climate change research and monitoring will vary across the North according to land use, species of cultural value, and Indigenous ways of knowing. This diversity must be supported. To inform broader regional or national decision-making, it is also important to:

- monitor key environmental indicators consistently across regions to contribute to broader assessments of the regional impacts of climate change
- identify and further research how different climate change impacts are connected (e.g., the influence of new predators, habitat change, and local harvesting pressure on species decline)



Encourage co-management-led research

The influence of climate change on country foods needs to be monitored and considered in wildlife co-management processes and policies. There is an opportunity for research partnerships that address critical knowledge gaps. We encourage co-management boards to prioritize, support, and/or lead more climate change research.

Share knowledge among community-based monitoring programs

There is growing interest in storing and sharing knowledge and data among community-based monitoring programs at a national and circumpolar scale. Sharing data will be important for understanding climate change impacts on food security.[47] Important elements include:

- networking and training opportunities within community-based monitoring programs to share ideas and improve coordination
- ways of coordinating and sharing monitoring data that are consistent, secure, and accessible

Provide holistic and coordinated government support for climate change and food security programming

Climate change and food security are connected, but government programs often treat them separately. There is an opportunity for governments to connect their support for food security, climate change, and monitoring through more holistic programs. There is also an opportunity to coordinate successful community-based monitoring programs that address both food security and climate change challenges to enable knowledge exchange, skills transfer, and data sharing.

Increase and sustain investment in community-based monitoring programs

Community-based monitoring programs need consistent and flexible funding for infrastructure, community engagement, and long-term monitoring. This includes expanded support for land-based monitor/guardian programs and monitoring with scientific instruments. Funding must be targeted directly towards communities. It needs to be flexible, so that capacity-strapped northern organizations receive funding when they need it. Funding must also strengthen local capacity to combine research and Indigenous Knowledge.

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Resources

Selected northern organizations and programs doing community-based monitoring across Canada

Organization/Program	Location	Website
Aqqiumavvik Society	Arviat, NU	https://www.aqqiumavvik.com/
Atlas of Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic	Pan-Northern	https://arcticcbm.org/index.html
ELOKA: Exchange for Local Observation and Knowledge of the Arctic	Pan-Northern	https://eloka-arctic.org/
Ittaq Heritage and Research Centre	Clyde River, NU	https://ittaq.ca/
SIKU: The Indigenous Knowledge Social Network	Pan-Northern	https://siku.org/
SmartICE	Pan-Northern	http://www.smartice.org/
Community-based Muskox and Caribou Health Surveillance	Kugluktuk, Ekalututiak, Ulukhaktok	http://people.ucalgary.ca/~kutzrg/Research.html
Nunavut Wildlife Management Board Community-Based Monitoring Network	Nunavut	https://www.nwmb.com/en/about-nwmb/382-english/cbmn/107-community-based-wildlife-monitoring-network
Northwest Territories Cumulative Impact Monitoring Program (NWT CIMP)	Northwest Territories	https://www.enr.gov.nt.ca/en/services/nwt-cumulative-impact-monitoring-program-nwt-cimp
Arctic Borderlands Ecological Knowledge Society	Northern NWT, Yukon, Alaska	https://www.arcticborderlands.org/

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SmartICE community ice monitoring

Can technology, combined with Inuit knowledge, help make sea ice travel safer?

Key messages

- SmartICE connects communities across Inuit Nunangat with ice monitoring technology and satellite imagery. The combination of monitoring technology with Inuit sea ice knowledge allows community members to adapt their travel plans for unprecedented and unpredictable ice conditions.

- SmartICE is a social enterprise that delivers ice information services across Inuit Nunangat that prioritizes community collaboration.

- SmartICE works with northern businesses to demonstrate how its ice information services can help reduce harmful effects of climate change on northern business operations.

- Trained operators working for the benefit and safety of their communities continue to operate SmartICE throughout the COVID-19 pandemic.

Community ice monitoring

This project combines Inuit knowledge of ice travel safety with new community-operated monitoring technology and satellite imagery. SmartICE makes sea ice travel safer by providing near real-time information on ice conditions. It uses automated sensors (SmartBUOYs), set up anywhere on the ice, and operator-run sensors (SmartQAMUTIKs), towed by a snowmobile along trails, to measure and report ice thickness to communities.

Community members can view the data on SIKU (siku.org), a website by and for Inuit, which provides tools and services for ice safety. From its original northern pilot sites in Nain and Pond Inlet, SmartICE expanded to 24 locations across Inuit Nunangat during the 2020–21 ice season. SmartICE is a work-integrated social enterprise that trains and employs young Inuit as producers, operators, and technicians of its technology.

Project leader: Dr. Trevor Bell, Memorial University of Newfoundland, tbell@mun.ca

More information: www.smartice.org

On-ice training for satellite image interpretation of sea-ice features: SmartICE

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(Left) Pond Inlet Community Operator Andrew Arreak surveys the floe edge in Eclipse Sound with the SmartICE mobile sea ice thickness sensor – the SmartQAMUTIK: SmartICE. (Right) SIKU screen view of ice thickness data collected by the Smart QAMUTIK off Iqaluit in January 2020: SmartICE

Community management

With the support of Polar Knowledge Canada (POLAR), SmartICE has been working in partnership with the SmartICE Community Management Committee in Pond Inlet to understand local ice information needs and create technology and services to respond to those needs. A cross-section of sea ice users, from young hunters to elders, sit on the committee. It is self-titled *Sikumiut*, meaning “people of the ice.”

Sikumiut not only manages local SmartICE operations but also coordinates new sea ice projects for the community. For example, the committee has been documenting *Inuit Qaujimajatuqangit* (IQ) of safe ice travel to educate youth in the community.

Community ice mapping

SmartICE is co-designing a program to train local operators to make ice travel safety maps for their communities by combining Inuit knowledge and observations with satellite images. This program builds on the legacy of POLAR’s support in Pond Inlet and operates in the spirit of self-determination. This is the first project to make sea ice maps in a size and time scale that is specific to on-ice travel for communities.

This project is timely, considering the unprecedented and unpredictable ice conditions caused by changing climate. Operators make these maps locally, combining technology and sea ice knowledge, which Inuit trust. Sea ice knowledge uses all aspects of Inuit culture, including values and language. As a result, elders believe these maps will engage the community effectively.

Northern Product on Centre

SmartICE trains Inuit to be the pro-ducers, operators, and technicians of its technology. In 2019, SmartICE launched its Northern Produc-tion Centre in Nain, Nunatsiavut, where Inuit youth trainees learn how to assemble the SmartBUOY for deployment in communities across Inuit Nunangat. Training considers the whole community, is person-centred, and culturally safe.

Characterizing and monitoring permafrost in Kugluk Territorial Park

How do changing permafrost conditions impact ATV trails?

Key Messages

- Ice wedges are numerous in the Kugluk Territorial Park area and are common sites of permafrost decay along the access road and ATV trail.
- Park managers and community leaders are using information from permafrost research and monitoring to prevent terrain disturbances along the ATV route that improves access to Kugluk Territorial Park for Nunavummiut.
- Knowing how the permafrost conditions in the Arctic are changing will help communities build infrastructure that is functional and sustainable.

What we are doing

Researchers, local youth, and other community members are studying permafrost conditions in Kugluk Territorial Park and setting up monitoring sites to record future changes. Their study focuses on the terrain surrounding the access road and ATV trails in the park to understand how changing permafrost conditions affect this important transportation passage for the community of Kugluktuk.

What we have learned

Based on early findings from permafrost coring and ground-penetrating radar, researchers found that the tundra in this area has a high ice content with numerous ice wedges. This makes the terrain sensitive to thawing, erosion, and collapse and has contributed to an increase in both the number and size of ponds in the area. While these processes are occurring naturally due to the climate warming, they are also affected by surface disturbances, such as regular ATV use.

Project Leaders*: Leesee Papatsie, Gary Atatahak and Larry Adjun of Nunavut Parks and Special Places, Government of Nunavut

Researchers, including Kugluktuk youth and park staff, operate a portable earth auger to sample permafrost: POLAR

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Community outreach and participation

Key steps for the success of this collaborative project include:

Community Input

Researchers work together with the Kugluk Community Joint Planning and Management Committee (CJPMC) to set research goals and moni-tor the project's progress.

Knowledge Transfer

Youth, Indigenous Knowledge holders, and researchers learn from each other by participating in youth camps, Nunavut Parks Days activities, and special events.

Training

Project leads invest time and resources in youth engagement and training opportunities throughout the lifespan of the research project.

Mobilizing results

Researchers make results available to community decision makers through public radio interviews, reporting directly to the CJPMC, and participating in conferences.

Why it matters

The results from this study informed a decision to build a new boardwalk ATV trail in Kugluktuk Territorial Park by identifying areas of ice-rich permafrost and patterns of permafrost degradation. The new ATV route decreases negative impacts on the tundra ecosystem. Ongoing community-led monitoring efforts along the new ATV trail will help ensure it remains safe and operational in the long term.

As the Arctic climate continues to warm, changing permafrost conditions will have major effects on the performance, safety, and reliability of northern transportation routes. This research helps build an understanding of how permafrost is changing in the regions, allowing communities to build infrastructure that meets both the needs of the community and the needs of the changing tundra environment.

Ice wedges

Permafrost can contract and crack in cold winter temperatures. When this happens, water from spring snowmelt fills these cracks and later freezes. The resulting vein of ice that appears in the permafrost is known as an ice wedge, which can grow in height, width, and depth over time as this cycle of melting and freezing repeats.

On the ground, ice wedges appear as raised ridges in the landscape. When viewed from above, ice wedges create a distinct polygon landscape pattern.

This aerial photo (above) shows the new Kugluk Territorial Park ATV trail under construction in 2019. Ice wedges, a feature of permafrost, are visible. The permafrost soil sample (upper right), collected along the ATV trail, has high ice content: POLAR

* Science partners: Michael Allard and Marc-André Ducharme, Université Laval; Stephanie Coulombe, Polar Knowledge Canada
Acknowledgements: Community of Kugluktuk; Samuel Bilodeau and Samuel Gagnon, Université Laval; Kugluktuk Joint Planning and Management Committee; Kugluktuk Hunters and Trappers Organization

Canadian Ranger Ocean Watch (CROW)

How can DFO & the Canadian Rangers work together to monitor the southern Northwest Passage?

Key messages

- CROW combines the northern transportation and observation skills of the Canadian Rangers with science from Fisheries and Oceans Canada.

- Canadian Rangers conduct year-round observations of ocean conditions near Kitikmeot communities over a long period of time.

- This project contributes to studies on climate change and marine ecosystems.

- By partnering with the community, this project ensures that local concerns and ocean conditions inform ocean science.

Project leaders*:
Bill Williams and Mike Dempsey,
DFO Institute of Ocean Sciences
bill.williams@dfo-mpo.gc.ca
mike.dempsey@dfo-mpo.gc.ca

Who we are

The team includes scientists and technicians from Fisheries and Oceans Canada (DFO) and Rangers from 1 Canadian Ranger Patrol Group (1CRPG). This project is supported by DFO, Polar Knowledge Canada (POLAR), and the Department of National Defence (DND).

What we do

CROW is a DFO collaboration with 1CRPG to gather baseline data in the southern Northwest Passage. 1CRPG uses specialized instruments supplied by DFO to collect samples of sections of the water, from surface to bottom. Rangers measure temperature, depth, and the amount of salt, oxygen, and plant material in the water. Rangers also measure ice and snow thickness. At a small number of stations, Rangers take zooplankton samples, set up ice temperature buoys, and sample water for dissolved carbon dioxide and nutrients.

How do we do it

DFO supplies scientific equipment, training, and study of ocean information. 1CRPG supplies the services of Canadian Rangers to conduct ocean sampling. The Canadian Rangers provide their on-ice excellence and unmatched observational skills for baseline ocean monitoring.

Baseline monitoring

Although rare, continuous year-round observations are needed in the Arctic to detect changes in the ocean environment that may impact fish, wildlife, and the people that depend on them.

Jimmy Evalik recovers a plankton net through a hole in the ice: Mike Dempsey

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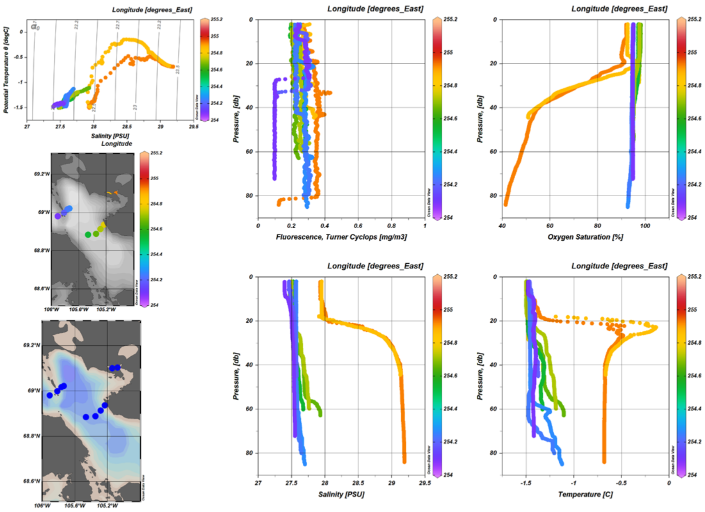
Why this matters

It can be difficult and expensive to conduct observations of ocean conditions in the Canadian Arctic. Until recently, all ocean science was done from large ice-breaking ships in the summer from July to October. CROW enables observations and sampling to continue through the ice-covered months with small projects using snowmobiles. It also enables ocean science to use local and Indigenous Knowledge and expertise.

Year-round observations contribute to studies on climate change and marine ecosystems. 1CRPG members offer their own perspectives on baseline conditions and how things may be changing. Ice and snow measurements are useful for monitoring local conditions. They also help researchers improve their understanding of satellite images according to observations on the ground.

Standard measurements of narrow sections across Dease Strait and Dolphin and Union Strait help researchers understand how ocean water circulates in the Kitikmeot region of the Northwest Passage. Water entering Coronation and Queen Maud Gulfs adds nutrients to the region, which is dominated by freshwater input from mainland rivers.



In 2020, measurements in Cambridge Bay and Dease Strait show how water is well mixed in the strait but layered in the bay. In the deep hole (82 m) in Cambridge Bay, oxygen levels are low, as the water is only lushed out approximately every ive years.

Tommy Epakohak (left) and Ryan Angohiatok pull a CTD instrument up from the ice during CROW 2020 near Finlayson Islands: Mike Dempsey

CTD Instruments

Researchers can observe the layers in the ocean using instruments that measure the amount of salt dissolved in water (conductivity), temperature, and depth. These instruments sometimes have extra sensors to measure the oxygen and plant material dissolved in water. By using many profiles across a strait, researchers can model oceanographic profiles. In other words, they can see how ocean layers form from shore to shore.

Community-based science

People living in a study area have an interest in monitoring the ocean that sustains them. Employment and training opportunities are created by involving the community in research activities. In northern locations, observations made by community participants help to reduce travel costs for southern-based research.

* Associated Researchers: Institute of Ocean Sciences, DFO, Sidney, BC: Bill Williams, Nadja Steiner, Helen Drost, Kristina Brown; Freshwater Institute DFO, Winnipeg, MB: Darcy McNicholl, Karen Dumnall, Tracey Loewen, Christine Michel; DFO, Inuvik, NT: Jasmine Brewster, Connie Blakeston; Joint Secretariat, Fisheries Joint Management Committee, Inuvik, NT: Kayla Hansen-Craik; Environment Canada, Canadian Ice Service, Ottawa, ON: Stéphanie Tremblay-Therrien.

High Arctic Plants and Methane

How do Arctic ecosystems absorb or release greenhouse

Key Messages

• Understanding how arctic ecosystems absorb and release greenhouse gases helps researchers predict the effects of climate change.

• Soil moisture and temperature influence how greenhouse gases are absorbed or released by arctic soils.

• Dry polar deserts are a **methane sink**, meaning they absorb more methane than they release. In contrast, wet soils are a source of methane. Drier sites released less carbon dioxide than wetter sites.

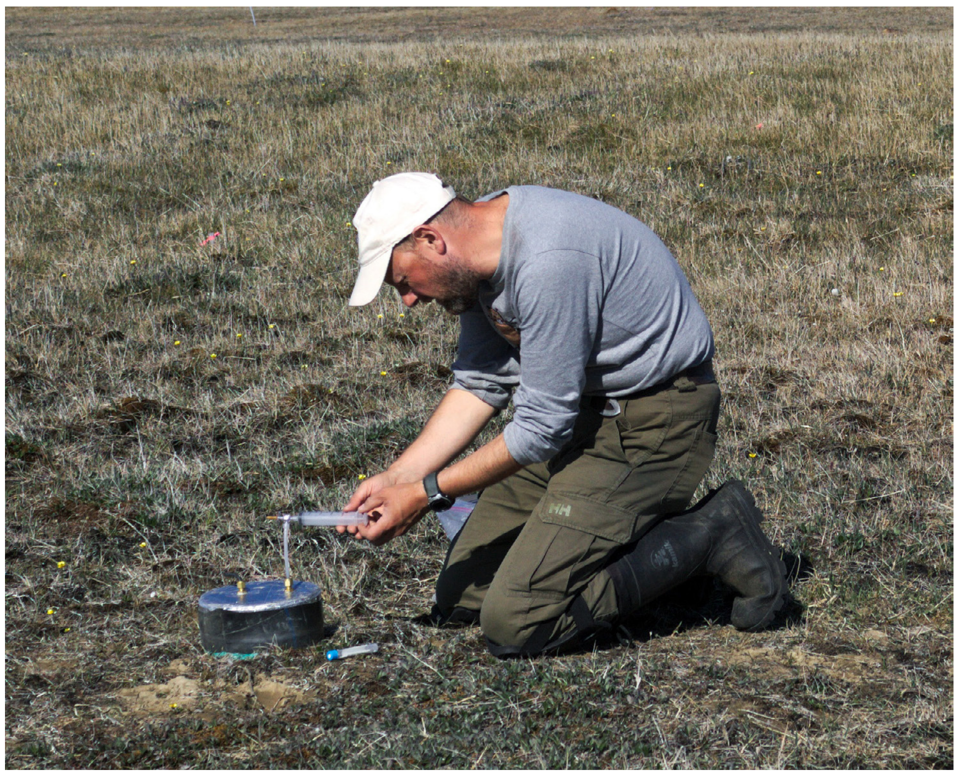
• Past studies likely underestimated how much methane is absorbed by Arctic soils because most studies take measurements in wetter ecosystems.

Research Summary

The research team studied the relationship between moisture, ecosystems, and greenhouse gases in Arctic environments.

At their study site at Cape Bounty on Melville Island, NU, the research team measured greenhouse gases in ecosystems across sites with differing levels of soil moisture. From driest to wettest, their sites included dry polar desert, mesic tundra, and wet sedge meadow (wetland) ecosystems.

The team measured three greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Methane and nitrous oxide are less abundant than carbon dioxide, but they all have powerful warming effects.



POLAR scientist Johann Wagner measures the flows of greenhouse gases in the mesic tundra at Cape Bounty, Melville Island: Johann Wagner

Project leader*: Neal Scott, Queens University, Kingston ON

Read the full research results in the Arctic Journal https://www.nrcresearchpress.com/doi/pdf/10.1139/ as-2018-0018

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Based on two years of observations, the study found that drier sites absorbed methane (CH_4), while wetter sites released methane. Carbon dioxide (CO_2) emissions were lower in dry polar desert sites.

Arctic permafrost soils store a significant amount of the world's carbon. Plant communities, and the soil microbes (tiny organisms) they live with, play an important role in the exchange of gases between the soil and air.

Changes in Arctic ecosystems are important to global climate change. The Arctic is expected to become warmer and wetter with climate change. Since soil moisture and temperature affects Arctic plant communities, climate change will likely lead to changes in the types of plants and their coverage. Understanding how different plant ecosystems absorb and release greenhouse gases helps researchers make better predictions about how the climate might change.

Melville Island Ecosystems

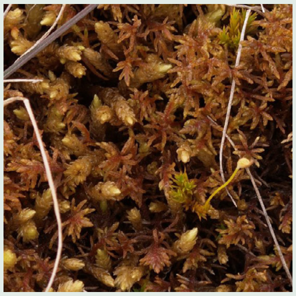
On Melville Island, the permafrost active layer is on average 50 to 90 cm deep, and scattered vegetation only grows at the edges of frost boils in most places. Three important terrestrial Arctic ecosystems are described by the soil moisture and the plants that grow there.

Polar Desert

- Dry soil
- Bare mineral soils cover 80% of the land
- Common plants include purple saxifrage, Arctic poppy, lichens, and mosses
- Most common ecosystem at Cape Bounty, Melville Islands

Mesic Tundra

- Moderate soil moisture
- Organic soils about 3 cm deep
- Common plants include mosses, lichens, grass-like plants, sedges, rushes, and herbaceous flowering plants
- Common ecosystem in other parts of the Arctic



Wet Sedge Meadow (Wetland)

- Wet soil
- Organic soils about 5 cm deep
- Completely covered by vegetation, including cottongrasses, aquatic sedge, Fisher's tundra grass, and alpine foxtail
- Often found downhill from melting icefields

*Additional Collaborators: Johann Wagner, Jacqueline K.Y. Hung, Allison Neil, and Neal A. Scott, Queens University. Funding by NSERC, NSTP, ArcticNet, Government of Canada International Polar Year. Logistical support: Polar Continental Shelf Program. Additional analysis: Agriculture and Agri-food Canada, Carleton University.

Kitikmeot Sea Science Study (K3S)

How do tides, currents, and mixing affect the Kitikmeot Sea marine ecosystem?

Key messages

- The Kitikmeot Sea is a dynamic marine ecosystem influenced by inputs from regional rivers and larger current systems throughout the Arctic Ocean.

- Tidal forces mix the water column in the narrow, fast-flowing straits of the Kitikmeot Sea, which shapes the marine ecosystem and sea ice patterns.

- In winter, mixing action contributes to thin ice or open water in the straits known as '**winter holes.**'

- In summer, mixing delivers nutrients to the surface and supports diverse seabed communities, we call these areas '**summer gardens.**'

What we do

A team of researchers from Canada, the USA, and Norway is gathering baseline data on how water and nutrients circulate in the Kitikmeot Sea and how this affects the marine ecosystem. Researchers collect water and seafloor samples and take measurements from aboard the *R/V Martin Bergmann* in the summer. During the rest of the year, researchers use instruments secured to the ocean floor to measure currents and water properties. These measurements are focused on the narrow and shallow straits of the Kitikmeot Sea.

What we've learned and why it matters

There are faster currents in narrow marine straits throughout the Kitikmeot Sea caused by tides forcing water through the gaps between islands. These currents help to mix the water column and bring nutrients to the surface. This mixing supports plant growth and the marine food web. Inside these passages, soft corals, sea cucumbers, clams, and kelp species take advantage of these nutrients and food particles.

Project leaders:
Kristina Brown and Bill Williams, Fisheries and Oceans Canada,*
kristina.brown@dfo-mpo.gc.ca; bill.williams@dfo-mpo.gc.ca

Yves Bernard (Arctic Research Foundation) and Raphaelle Descoteaux (UiT – the Arctic University of Norway), bring in a sediment box corer on the R/V Martin Bergmann*: Neha Acharya-Patel.*

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Kitikmeot Sea: a unique marine environment

The Kitikmeot Sea is a unique marine environment in the Arctic due to three main features:

Nutrient-rich deep water

Ocean currents deliver salty, nutrient-rich deep water to the Kitikmeot Sea from other basins in the Canadian Arctic Archipelago. Without sunlight, these dissolved nutrients cannot contribute to plant growth that feeds the rest of the food web.

Freshwater input from rivers

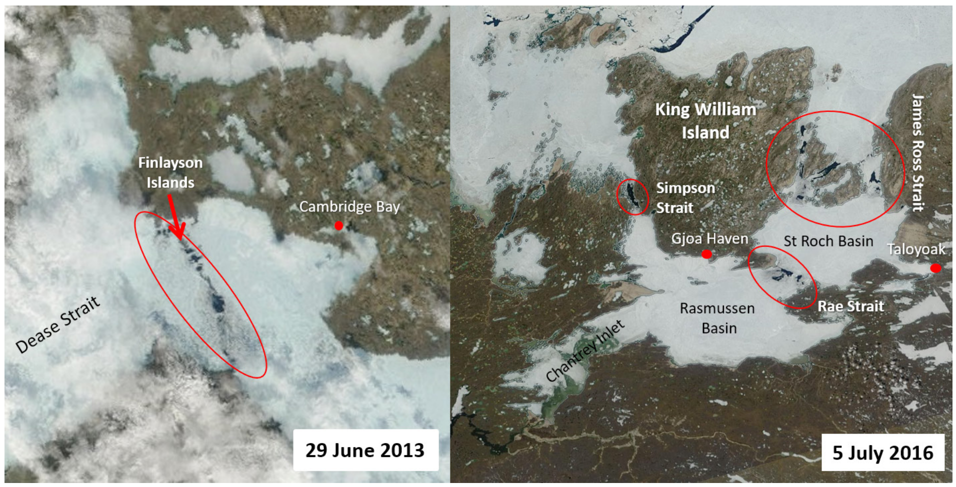
Rivers in the Kitikmeot region deliver massive amounts of freshwater into the Kitikmeot Sea. As freshwater is less dense than salt water, input from these rivers remains at the surface.

Restricted water flow

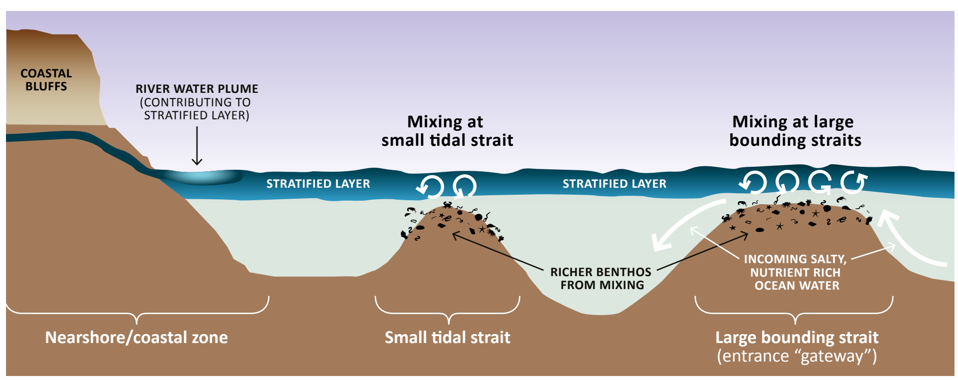
The seabed in the bounding straits of the Kitikmeot Sea is relatively shallow (no more than 30 metres deep),
which limits the exchange of water between the Kitikmeot Sea and other Arctic Ocean basins.

Outside the passages, brittle stars and small marine worms subside on the left-overs. These summer gardens may be important feeding sites for fish or seals. More information on how these straits influence the biological productivity of the greater Kitikmeot Sea region is needed.

In winter, observations by residents and high-resolution satellite imagery show that these same narrow passages are prone to thin ice and early ice breakup, making them dangerous places for winter travel. These winter holes are caused by warmer water, which is brought to the surface by this mixing process due to the tides.



This satellite view shows springtime 'winter holes' created by tidal mixing in the narrow straits: a) Finlayson Islands near Cambridge Bay, NU; and b) Chantrey Inlet, Rassmussen Basin, and St Roch Basin near Gjoa Haven, NU (https://worldview. earthdata.nasa.gov/).



This simplified diagram describes water circulation in the Kitikmeot Sea. Mixing in shallow areas brings salty nutrient-rich deep water to the surface support-ing a diversity of ocean life.

*****Institute of Ocean Sciences, Sidney, British Columbia. **Other project collaborators:** Bodil Bluhm, Department of Arctic and Marine Biology, UiT – The Arctic University of Norway, Tromsø, Norway; Eddy Carmack, Mike Dempsey, and John Nelson, Fisheries and Oceans Canada; Seth Danielson, College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, USA; Donald McLennan, Arctic Research Foundation; Lina Rotermund, Dalhousie University; Adrian Schimnowski, Arctic Research Foundation.

Renewable energy resource assessment

Is renewable energy suitable for all locations?

Key messages

• POLAR aims to help northern communities reduce dependency on fossil fuels for energy generation.

• Local resource assessments are essential to determine if renewable energy sources are suitable for development, for example:

Wind: An average annual wind speed of 3 to 6 metres per second is needed for a wind project to be economically feasible in remote northern communities.

Solar: Due to atmospheric conditions, some areas are subject to better solar irradiance than others. This will dictate the placement of solar panels in suitable communities.

Geothermal: Exploration and deep drilling requirements add significantly to overall project costs to develop this energy source.

Cambridge Bay resource assessment

Wind energy

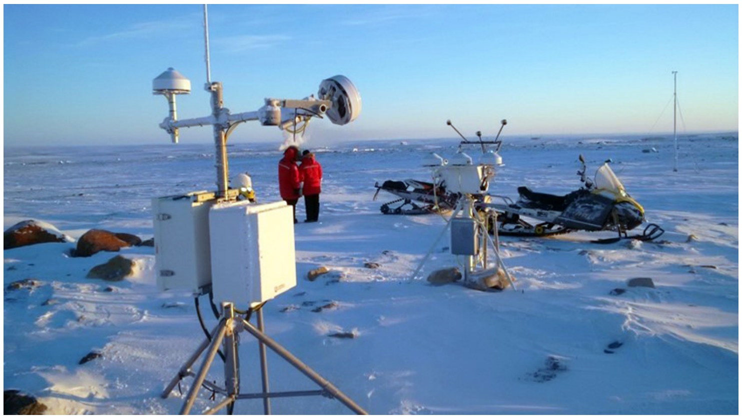
In 2014, POLAR erected a wind tower on the edge of town to measure prevailing wind conditions, in partnership with Natural Resources Canada (NRCan) and the Wind Energy Institute of Canada (WEICan). The study, conducted between 2014 and 2017, showed that a wind project for the community could be technically and economically viable. In 2020, POLAR and WEICan upgraded the sensors on the tower and began wind monitoring again with a view to upgrade data and determine if climate change is having any impact on wind speeds and direction.

Solar irradiance

To evaluate the suitability of solar power for Cambridge Bay, POLAR is conducting solar irradiance monitoring in partnership with NRCan and Campbell Scientific.

POLAR and the Canadian technology provider Spectrafy are collaborating to test and demonstrate direct solar spectral irradiance technology called Solarism. This technology is inexpensive and easy to use, which makes it a viable option for many northern communities. One of seven Solarsim devices was deployed as part of the Build Canada program in Cambridge Bay. The Cambridge Bay project is the most northerly deployment and the only one operating in the Arctic.

Project leader: Rob Cooke, POLAR, info@polar.gc.ca



Water Lake Road Resource Monitoring Site, Cambridge Bay: POLAR

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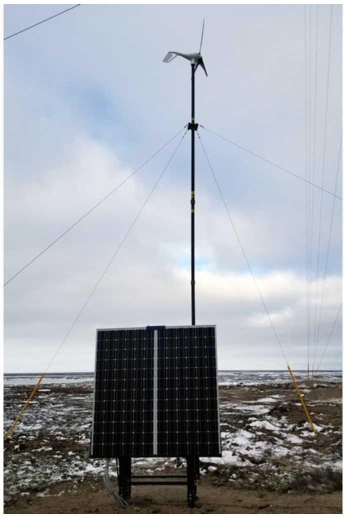
Community resource assessments

POLAR has provided funding to several northern communities to complete small-scale renewable energy projects and has assisted with resource assessments for potential community-scale projects.

Arviat

The Hamlet of Arviat worked with NRStor, an energy storage company, to install both wind and solar monitoring equipment. The community hopes to develop a wind/solar/storage hybrid project to reduce diesel use.



Arviat solar and wind monitoring: NRStor

Tidal study

Changing sea ice patterns, a consequence of climate change, could present an opportunity to use marine energy in the Canadian North. Since 24 of Nunavut's 25 communities are coastal, POLAR and the National Research Council (NRC) are working together to learn whether tidal energy in strategic locations could meet the year-round energy needs of some communities. NRC is investigating five Nunavut communities that showed the greatest potential in table-top studies.

Sanikiluaq

In Sanikiluaq, the Qikiqtaaluk Business Development Corporation (QBDC) relied on community engagement to choose an optimal location to install a wind tower close to the community. The results from this monitoring program allow QBDC to develop a robust business case to support a future 400-kilowatt wind project.

Wind tower positioning in Sanikiluaq, NU: QBDC.

Nunavut metals management demonstration project

Can a regional model for solid waste management maximize local benefits?

Key messages

- Solid waste management through Inuit Development Corporations is viable and adventageous.

- Over 900 batteries, 12 drums of oil waste, and countless mercury switches were removed from the tundra and shipped south for disposal and recycling.

- Community members hired by the municipality completed all on-site work and received over 30 days of on-site training.

- 59% of project funding stayed in the community as wages, equipment, and materials.

Project leader:
Sheldon Nimchuk, Qikiqtaaluk Business Development Corp.,
snimchuk@qcorp.ca

What we did

This project aimed to remove metal waste while employing and training area residents. Metal stockpiles contain old cars, snowmobiles, trucks, and appliances. Each of these contain hazardous waste. Old vehicles contain mercury switches, lead, and various liquid wastes such as oil and gasoline. Old refrigerators contain oils and ozone-depleting gases. Decreasing metal waste stops hazardous waste from contaminating the environment.

The project team protected the environment by removing hazardous materials from metal waste. They also extended the lifespan of the existing dumpsite by compacting the metals into bales. This project helps reduce the need for a larger dumpsite in the future. It also decreases the risk of environmental contamination.

This model of delivering solid waste management through Inuit Development Corporations could be applied to address the metal stockpiles that exist in all Nunavut communities. The project approach was Inuit-led and delivered.

Pitseolak Pudlaq poses near a metal baler: "It is the first time I am seeing this land without old metals all over it. It feels like progress." Over 1,000 metal bales were pro-cessed during this project.

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The project prioritized building Inuit capacity, focusing on social return on investment to deliver on the project. Community members hired through the municipality completed all on-site work. The project team delivered training on site, which was open to other community members. The municipality gained the experience and resources necessary to continue managing their metal dumpsite responsibly, without outside contractors.

Why this matters

Solid waste infrastructure in Nunavut communities is inadequate, outdated, and undersized. Limited budgets and competing priorities at all levels of government have contributed to this challenge. Legacy metal is waste that has been around since before the current regulatory and management frameworks. Most of this legacy waste is scrap metal, including old vehicles, fridges, and building materials. If left as is, the hazardous waste contained in the metal will eventually seep into the environment, pose a risk to human health, and pollute our land, water, and air.

This project showed that future agreements between the Government of Nunavut and Regional Development Corporations in the Qikiqtani, Kitikmeot, and Kivalliq Regions are possible. These agreements can address the legacy metal waste stockpiles across Nunavut while keeping money within the territory and maximizing the benefit to Inuit and communities.

Over 25 end-of-life vehicles were removed from the community core and properly depolluted. "We are pleased to see action toward not only supporting our community with cleaning up the site, but also with providing the training to enable the continued proper management of our waste." — John Hussey, Senior Administrative Officer.

Under Qikiqtaaluk Corporation management, this project:

- Hired six Inuit in Kinngait for two project seasons;
- Provided 30 days of on-site training, including:
  - – safe depollution to remove hazardous waste from vehicles and fridges
  - – metal baling equipment operations
  - – hazardous waste packaging and shipping
  - – health and safety certifications
  - – ozone-depleting substances certification
- Produced and published Nunavut-specific training materials in Inuktitut and English, including:
  - – a guide on removing hazardous waste from metals
  - – a guide on which metals found in a typical Nunavut metal stock-pile can be baled
  - – a guide on how to backhaul hazardous waste

Financial Contributions: Polar Knowledge Canada, Government of Nunavut, Qikiqtaaluk Corporation, Kakivak Association, Municipali-ty of Kinngait. In-Kind Support: Automotive Recyclers of Canada, Municipality of Kinngait, Qikiqtaaluk Business Development Corpo-ration, Government of Nunavut, plusArctic Consulting Ltd., Kudlik Construction.

Waste management technologies

What waste management technologies are useful in Cambridge Bay?

Key messages

- Residents of Canada's remote northern communities want to improve waste management practices and decrease reliance on fossil-fuel-based energy sources.

- Greenhouse gas emissions, black carbon from fossil fuel use, and environmental contamination from overburdened landfills with open incineration negatively impact public health and contaminate land and food chains.

- POLAR has explored several waste management and waste-to-energy solutions. The knowledge gained is helpful to other northern communities considering clean energy alternatives.

Automated Communities System (ACS150)

ACS150 was a collection of technologies, within two sea cans, aimed at meeting the utility needs of a 150-person community. The technologies were grouped so that waste products went in at one end and potable water, heat, and electricity were produced as outputs. This technology demonstration was hosted by Cambridge Bay in 2014, in collaboration with Sustainable Development Technology Canada.

Waste stream analysis

A waste audit of the Cambridge Bay landfill was completed to choose the right waste-to-energy technology for the community. This work was completed in partnership with Concordia University's Institute for Water, Energy and Sustainable Systems. In 2016, workers from the Hamlet, along with PhD student Nathan Curry, spent two weeks sorting 725 kilograms (1,600 pounds) of trash. They held a community meeting at the Elder's Palace and completed formal interviews about waste management. The results showed that the community could benefit from a composting program for food waste and a recycling program for cardboard, plastics, and soda cans.

Project leader: Rob Cooke, POLAR, info@polar.gc.ca

Burning garbage at the Cambridge Bay land ill. Incineration is a common waste management practice in many remote communities: POLAR.

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Micro Automated Gasification System

With results of the waste stream analysis in hand, POLAR partnered with a Canadian waste-to-energy technology provider, Terragon Environmental Technologies Inc., to test and demonstrate its Micro Automated Gasification System (MAGS) within the community of Cambridge Bay. Terragon commissioned and started up the system and provided preliminary training to two operators from the community.

The system operates by batch loading waste products into two chambers. The waste is heated and breaks down to biochar and a gas consisting mostly of hydrogen and carbon monoxide (synthetic gas: syngas). The syngas is used as the fuel for maintaining the process. The overall objective of the project was to assess the MAGS technology in terms of performance, economic feasibility, and operability within a remote northern community.

Technology assessment

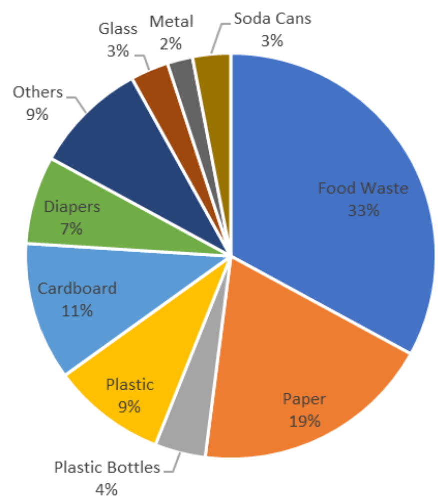
While the MAGS demonstration was running in Cambridge Bay, POLAR engineer Matt Wallace assessed a range of commercially available waste-to-energy technologies. This included heat-recovery technologies, as well as novel solutions to transform waste products into badly needed construction materials or road surface coatings—products that have intrinsic value in remote northern communities. After detailed research, Wallace recommended pursuing a simple incineration system with heat recovery as a starting point for a remote community waste-to-energy system.

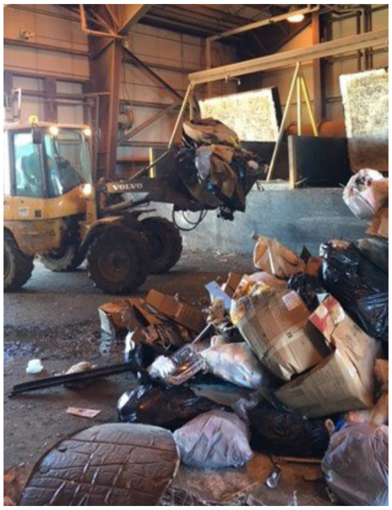
Incineration system with heat recovery

Produced by Dynamis Energy, a Thermal Oxidation System (TOS) is successfully operated by the North Slope Borough in Utqiagvik, Alaska. POLAR and Hamlet personnel travelled to Alaska to view the TOS and meet with company and borough representatives. They concluded that this system would meet the waste management requirements of Cambridge Bay.

Although the population of Utqiagvik is double that of Cambridge Bay, similarities between the two communities support the use of a TOS in Nunavut. Utqiagvik is located north of the Arctic Circle and has a predominantly Indigenous population (i.e., over 60% of residents are Iñupiat). Like Cambridge Bay, Utqiagvik has a polar climate, is supplied mainly by sealift, and maintains strong traditions of harvesting country foods. This comparison helped with assessing wheather the system would meet the needs of Cambridge Bay because Utqiagvik and Cambridge Bay, have similar waste profiles.

The TOS in Utqiagvik has significantly reduced waste going into the landfill. It produces clean emissions and inert ash. It is not, however, making full use of the heat or syngas produced, which reduces the overall economic viability of the system. The Hamlet of Cambridge Bay is now actively seeking funding to install a TOS and intends to use the waste heat either for district heating or greenhousing. POLAR and the Hamlet are both interested in the potential to use syngas for energy generation.





(left) According to a waste stream analysis, a third of Cambridge Bay's trash is food waste. Cardboard and paper make up another third. Data from Nathan Curry, PhD. (middle and right) Utqiagvik TOS in Operation: Matt Wallace.

Wastewater treatment

How can we improve wastewater management in remote communities?

Key messages

- Applied research to improve water and wastewater management is a strong priority for POLAR's northern and Indigenous partners.

- POLAR has led and supported several studies to understand the effectiveness of current wastewater treat-ment practices and to test promising technologies for use in Arctic and northern communities.

- Used water from bathing and laundry is known as **greywater**. It is less contami-nated than **blackwater** (sewage), which includes wastewater from toilets, kitchen sinks, and dishwashers. In many regions of the world where water is not plentiful, people re-use greywater for toilet flushing, irrigation, laundry, and cleaning.

Wastewater management

Many remote communities rely on water delivery with wastewater collection, which is inconvenient and costly. Truck deliveries also add to air pollution through dust and increased greenhouse gas emissions from vehicle exhaust.

In these communities, blackwater and greywater from residences and businesses are mixed in collection tanks, collected by heavy trucks, and dumped into sewage lagoons.

Over time, lagoons deal with the waste effectively but have high potential to pollute the land, local waterways, and food chain.

Polar Knowledge Canada (POLAR) supported a University of Winnipeg study to determine the extent of contamination that is close to remote communities to better understand the effectiveness of sewage lagoons and the potential impacts that effluent runoff has on the environment and food chain.

Project leader: Rob Cooke, POLAR, info@polar.gc.ca

Cambridge Bay's sewage lagoon, as seen in winter: POLAR.

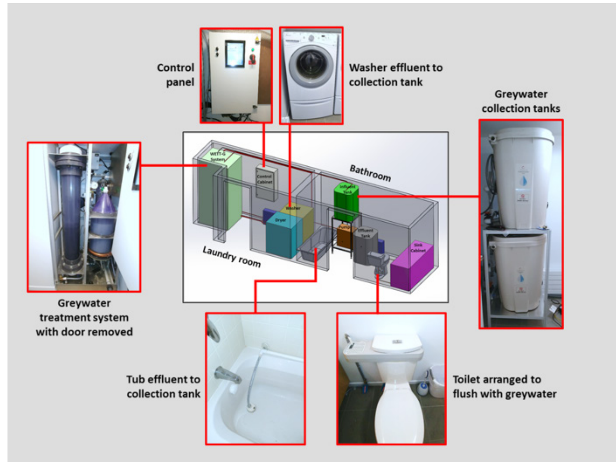
Polar Knowledge Canada   Savoir polaire Canada   Canada

Greywater treatment

Keen to address these problems at their source, POLAR is also studying water conservation through greywater and blackwater treatment technologies.

In 2018, with funding from POLAR, Terragon Environmental Technologies Inc. installed a greywater treatment technology known as the WETT-G on the Canadian High Arctic Research Station (CHARS) campus in Cambridge Bay.

This greywater system relied on automated electrochem-ical technology, which does not require adding chemicals or maintenance-intensive processes. The quality of the treated greywater was comparable to treated municipal water, and the cost of treatment was significantly lower than municipal water rates. This project showed the eco-nomic feasibility and benefits of re-using water through greywater treatment.



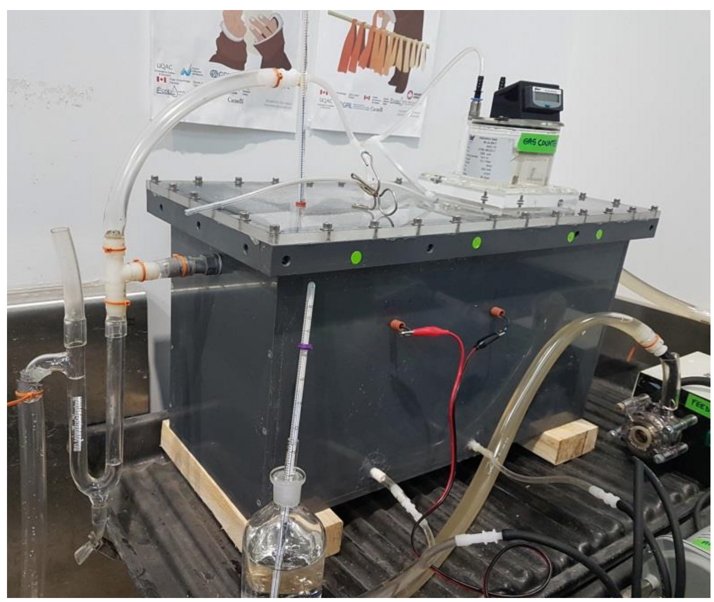
A greywater treatment system similar to the system installed at CHARS: Terragon.

Blackwater treatment: Bioelectrical Anaerobic Sewage Treatment (BeAST)

The National Research Council (NRC) has developed a sewage treatment technology that aims to clean up blackwater before it is sent to a sewage lagoon. The Bioelectrochemical Anaerobic Sewage Treatment (BeAST) system uses microbes to break down waste in a passive flow system. POLAR has partnered with NRC to test this pre-commercial technology at the CHARS campus.

Sewage samples were sent from Cambridge Bay to NRC laboratories in Quebec. Research scientists analyzed the samples and adjusted the BeAST reactor, which was then installed at CHARS. The 30-litre BeAST reactor at CHARS will run for about 12 months.

Initial tests showed that using BeAST allows for much cleaner wastewater to be discharged into sewage lagoons. If further tests are successful, NRC and POLAR will work together to develop and install a larger reactor in residential units in Cambridge Bay.



The BeAST Reactor, similar to one installed at CHARS: NRC.

Did you know? **Methane**, or biogas, is a by-product of the sewage treatment process. This gas can be captured and used for district heating, biofuel production, or to heat greenhouses. Using this gas can significantly add to the economic and environmental viability of this technology.

Kitikmeot wolverine non-invasive and community-based monitoring

How many wolverines are in the Kitikmeot region?

Key messages

- Wolverines in the Kitikmeot region exist at low densities and are being exposed to increasing levels of human activity.

- Knowing the density of the wolverine population in the region can inform future sustainable harvest limits and could support input to impact review processes. This information can also help inform predator research for caribou management.

- This collaborative research project between the Government of Nunavut and the Kugluktuk HTO provided training and employment to HTO members. It also demonstrates the efficiency of joint research projects to inform wildlife management.

Project summary

In 2018 and 2019, Government of Nunavut biologists collaborated with the Kugluktuk Angoniatit Association (Kugluktuk HTO), to estimate the density of the region's wolverine population. This project supports long-term regional monitoring by establishing **baseline information** on the number and density of wolverines in the region.

This research informs predator research for caribou management and could also be used to establish future sustainable harvest limits and support input to Nunavut Impact Review Board review processes.

The research team used non-invasive methods to collect wolverine fur samples northwest of Napaktulik Lake. They placed 154 hair-snag posts, baited with caribou, muskox legs, and scent lures, in a grid across the tundra.

Project leader:
Malik Awan, Department of Environment, Government of Nunavut,
mawan@gov.nu.ca

A wolverine: Thomas Kitchin & Victoria Hurst.

Polar Knowledge Canada Savoir polaire Canada

Canada

Wolverine

The wolverine is one of the larger species in the weasel family. Females usually weigh about 10.5 kilograms (kg) (23 pounds (lb)) while males generally weigh 15 kg (33 lb).

The wolverine is omnivorous and primarily a scavenger. Although it has the strength to kill large game animals, such as deer, caribou, and moose, it only does this occasionally.

In addition to scavenging and preying on big game animals in the winter, wolverines eat eggs from ground-nesting birds, as well as edible roots and berries during the summer months. Wolverines in the study region exist at low densities and are being exposed to increasing levels of human activity.

Baseline data

Baseline data is information that provides a snapshot of what the conditions or situation is now. Data in the future can be compared against this information to detect changes.

The posts were covered with barbed wire, which snagged fur samples from the animals attracted by the lures. Sampling took place over three 10-day sessions from early March through late April 2018 and again in 2019. This is a practical and cost-effective method for monitoring wolverine populations on the tundra.

Project results

The research team studied DNA from the collected hair samples to identify individual wolverines and their sex. The research team identified similar numbers of male and female wolverines. They identified 22 wolverines in 2018, of which 11 were females and 11 were males. In 2019, they identified 27 wolverines, of which 13 were females and 14 were males. Ten wolverines identified in 2018 were recaptured in 2019.

The results showed that there are about three to four wolverines per 1,000 square kilometres (km^2). These estimates apply only to wolverines whose home ranges are centered within the 4,000 km^2 study area near Napaktulik Lake, where the hair-snag posts were set up. Wolverines use the study area in varied ways, which can explain the differences in population density estimates between years.

Wolverines have a large range considering their small size. In 2018, the research team observed a range of approximately 25 km for both males and females. In 2019, the research team observed a consistently larger range for males.

This study demonstrates the importance of joint research projects to inform wildlife management. It also highlights existing opportunities to provide valued training and employment to HTO members through collaborative research projects.

Collaborators/Acknowledgements: Kugluktuk Angoniatit Association, Hunters and Trappers Organization Field team: Malik Awan, GN Department of Environment; OJ Bernhardt, Kugluktuk HTO member; Eric Hitkolok, Kugluktuk HTO member; Perry Klengenberg, Kugluktuk HTO member; Jonathan Niptanatiak, Kugluktuk HTO member. Funding: Government of Nunavut, Department of Environment; Nunavut Wildlife Management Board; Polar Knowledge Canada.

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