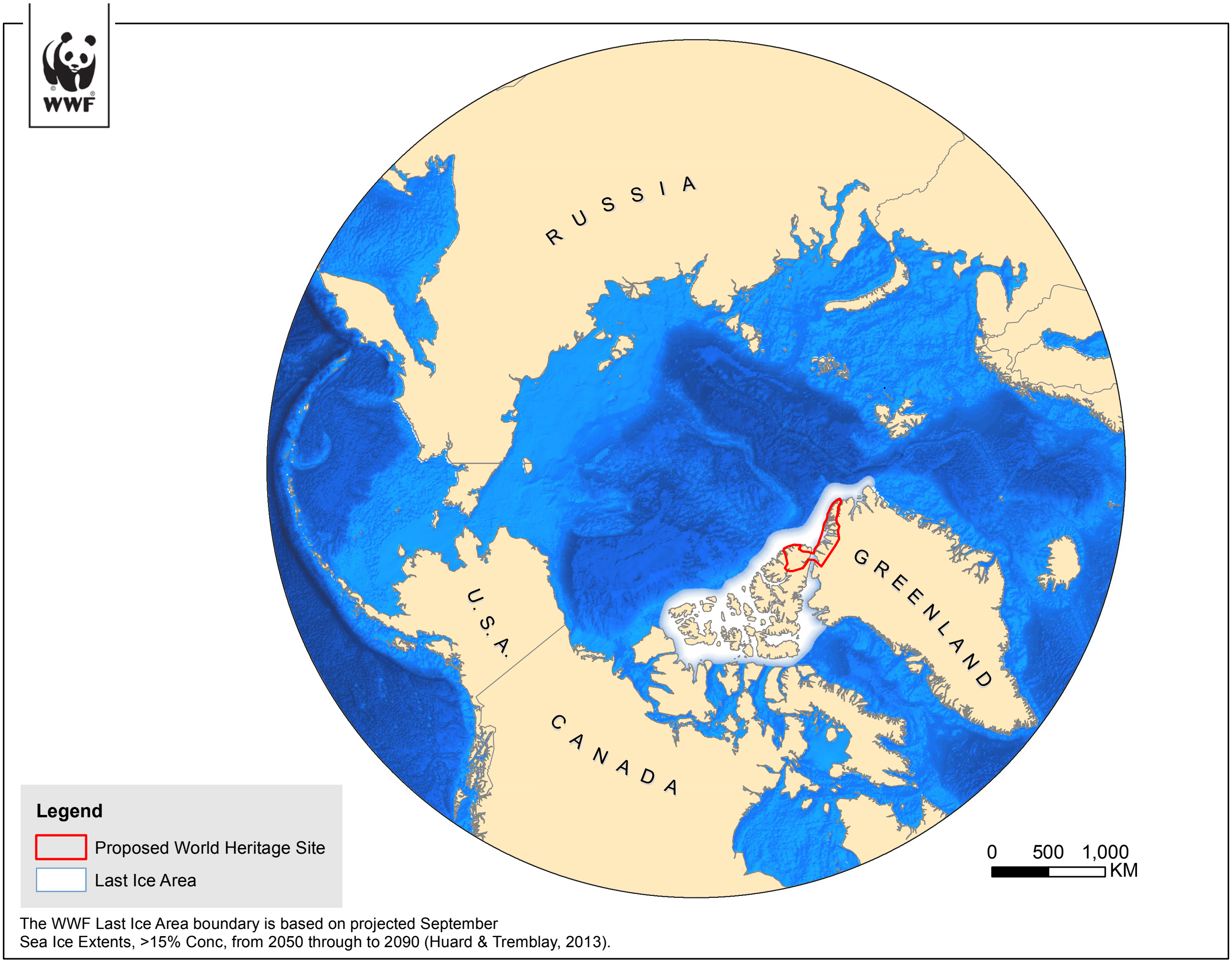
LAST ICE AREA

Potential Transnational World Heritage Property
(CANADA and DENMARK)

Location of the nominated property in the Arctic.



Each State Party to this Convention recognizes that the duty of ensuring the identification, protection, conservation, presentation and transmission to future generations of the cultural and natural heritage situated on its territory, belongs primarily to that State. It will do all it can to this end, to the utmost of its own resources and, where appropriate, with any international assistance and co-operation, in particular, financial, artistic, scientific and technical, which it may be able to obtain.

UNESCO Convention concerning the Protection of the World Cultural and Natural Heritage

INTRODUCTION

This is one of a series of research resources commissioned by WWF to help inform future management of the Area we call the Last Ice Area (LIA). We call it that because the title refers to the area of summer sea ice in the Arctic that is projected to last. As climate change eats away at the rest of the Arctic's summer sea ice, climate and ice modellers believe that the ice will remain above Canada's High Arctic Islands, and above Northern Greenland for many more decades.

Much life has evolved together with the ice. Creatures from tiny single celled animals to seals and walrus, polar bears and whales, depend to some extent on the presence of ice. This means the areas where sea ice remains may become very important to this ice-adapted life in future.

One of my colleagues suggested we should have called the project the Lasting Ice Area. I agree, although it's a bit late to change the name now, that name better conveys what we want to talk about. While much is changing, and is likely to change around the Arctic, this is the place that is likely to change the least. That is also meaningful for the people who live around the fringes of this area – while people in other parts of the Arctic may be forced to change and adapt as summer sea ice shrinks, the people around the LIA may not have to change as much.

As a conservation organization, WWF does not oppose all change. Our goal is to help maintain important parts of the natural world, parts that are important just because they exist, and important for people. WWF does not have the power and authority to impose its vision on people. Instead, we try to present evidence through research, and options for action. It is then up to the relevant authorities as to whether they will take action or not; the communities, the Inuit organizations, and the governments of the Last Ice Area will decide its future fate. We hope you will find the information in these reports useful, and that it will help you in making wise decisions about the future of the Last Ice Area.

In this particular document, we are responding to the lead of the Arctic Council's Conservation of Arctic Flora and Fauna working group, which suggested that a World Heritage site spanning the resilient ice area of Canada and Greenland should be considered by the respective governments, and a discussion document by the Inuit Circumpolar Council that identified a World Heritage Site as an international management option for LIA that would best meet Inuit interests.

Clive Tesar, Last Ice Area lead.

Adopted on November 16, 1972, the Convention concerning the Protection of the World Cultural and Natural Heritage is the most efficient and representative among existing nature conservation conventions and programs. The primary purpose of the Convention is to unite the efforts of the international community to identify, protect and provide comprehensive support to cultural monuments and natural objects of Outstanding Universal Value.

Established in 1976, the World Heritage List represents both diverse regions on our planet and a number of specific properties. Many natural properties of worldwide renown are protected under the World Heritage Convention, including the Great Barrier Reef, Galapagos Islands, Lake Baikal, Grand Canyon, Mount Kilimanjaro, Victoria and Iguazu Falls.

World Heritage status brings with it numerous advantages, both in terms of nature conservation and in garnering comprehensive support for territories inscribed on the World Heritage List. World Heritage Convention offers its States Parties and their inscribed sites broad legal, informational, economic, and networking opportunities, which have been developing and improving for more than four decades.

Benefits of World Heritage Status for Natural World Heritage Sites:

- Additional guarantees of the full preservation and integrity of unique natural areas.
- Increase in the prestige of natural areas and the institutions governing them.
- Increase in the popularity of territories inscribed on the World Heritage List.
- Greater capacity to attract financial support for World Heritage sites.
- Development of alternative types of natural resource use, including ecological tourism and traditional trades.
- Organization of monitoring and inspection of conservation activities in natural areas.

Untouched by economic activities and significant in size, the natural World Heritage properties represent a valuable and important strategic natural reserve of humankind. The fact of a unique voluntary contribution of any state into a joint "bank of nature of humanity" positively affects the state's image (Butorin, 2011).

Figure 1. Polar bear adult and cub tracks. © Vicki Sahanatien / WWF

Canada is currently represented on the World Heritage List by eight cultural and nine natural properties. Canada's natural World Heritage properties are Nahanni National Park, Dinosaur Provincial Park, Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek (transboundary with the United States of America), Wood Buffalo National Park, Canadian Rocky Mountain Parks, Gros Morne National Park, Waterton Glacier International Peace Park (transboundary with the United States of America), Miguasha National Park, Joggins Fossil Cliffs. The total area of Canadian natural World Heritage properties comprises more than 17.7 million ha. Two of natural properties, Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek and the Wood Buffalo National Park, are ranked in the top 10 largest properties worldwide. Work is currently being carried out to present more of Canada's natural and mixed sites for inclusion in the World Heritage List. Atikaki / Woodland Caribou / Accord First Nations (Pimachiowin Aki), Gwaii Haanas, Ivvavik / Vuntut / Herschel Island (Qikiqtaruk), Mistaken Point, and Quttinirpaaq are all included on Canada's Tentative List.

Denmark is currently represented on the World Heritage List by three cultural properties, and one natural property, Ilulissat Icefjord, with the total area of 402 400 ha. Three natural and mixed properties are included on the Denmark's Tentative List: Moler landscapes of the Liim Fiord, Stevns Klint, and the International Wadden Sea (Danish-German-Dutch Wadden Sea).

The booklet contains the materials of the transnational nomination Last Ice Area (Canada and Denmark) developed in 2014 by the following organizations: WWF Canada, Natural Heritage Protection Fund, Institute of Geography of the Russian Academy of Sciences, Likhachev Institute for Cultural and Natural Heritage. The booklet is supported by WWF Global Arctic Programme.

The Last Ice Area is unique amongst potential World Heritage sites, as it is nominated not only for what it is, but for what it will be; a locus of resilience in a rapidly changing world. Sea ice projections show this region within decades will be the only place where year-round Arctic sea ice will remain. This will make it increasingly important for ice-obligate and ice-associated marine mammal species. The nominated area and nearby marine environments provide diverse habitats for a multitude of unique life-forms highly adapted in their life history, ecology and physiology to the extreme and seasonal conditions of this environment. This ice-associated life is important not just in its own right, but for what it provides for adjacent Inuit communities, both in terms of sustenance, and in terms of cultural continuity and resilience.

To this future role as an island of stability in a sea of change, should be added its current attractions as a World Heritage site. A unique character of glacial conditions observed at the nominated property – a kind of "open-air glaciology museum" has no analogues in the world. LIA is unique due to the large-scale of contemporary glaciations and level of glacial relief treatment. There is a rich variety of terrestrial and coastal/marine environments with complex and intricate mosaics of life at various successional stages from 500 m below sea level to 5000 m above.

Nomination LAST ICE AREA

Figure 2. The Arctic Tern, Devon Island.

The First Property
Of the Serial Transnational Nomination

LAST ICE AREA

(CANADA and DENMARK)

Proposal for Inscription on
THE UNESCO WORLD CULTURAL
AND NATURAL HERITAGE LIST

Prepared by:
- World Wildlife Fund (WWF) Canada
- Natural Heritage Protection Fund, Russia
- Institute of Geography of the Russian Academy of Sciences

Supported by:
- World Wildlife Fund (WWF) Global Arctic Programme

2014

1. Identification of the property

1a. Country (and State Party if different)

Canada and Denmark.

1b. State, Province or Region

Canada: Nunavut territory.
Denmark: Greenland autonomous province.

1c. Name of Property

Last Ice Area.

1d. Geographical coordinates to the nearest second

The nominated property is located on the northern coast of Ellesmere Island (the Canadian Arctic Archipelago) and Greenland; it includes the Quttinirpaaq National Park (Canada), and the northern part of Greenland National Park (Denmark).

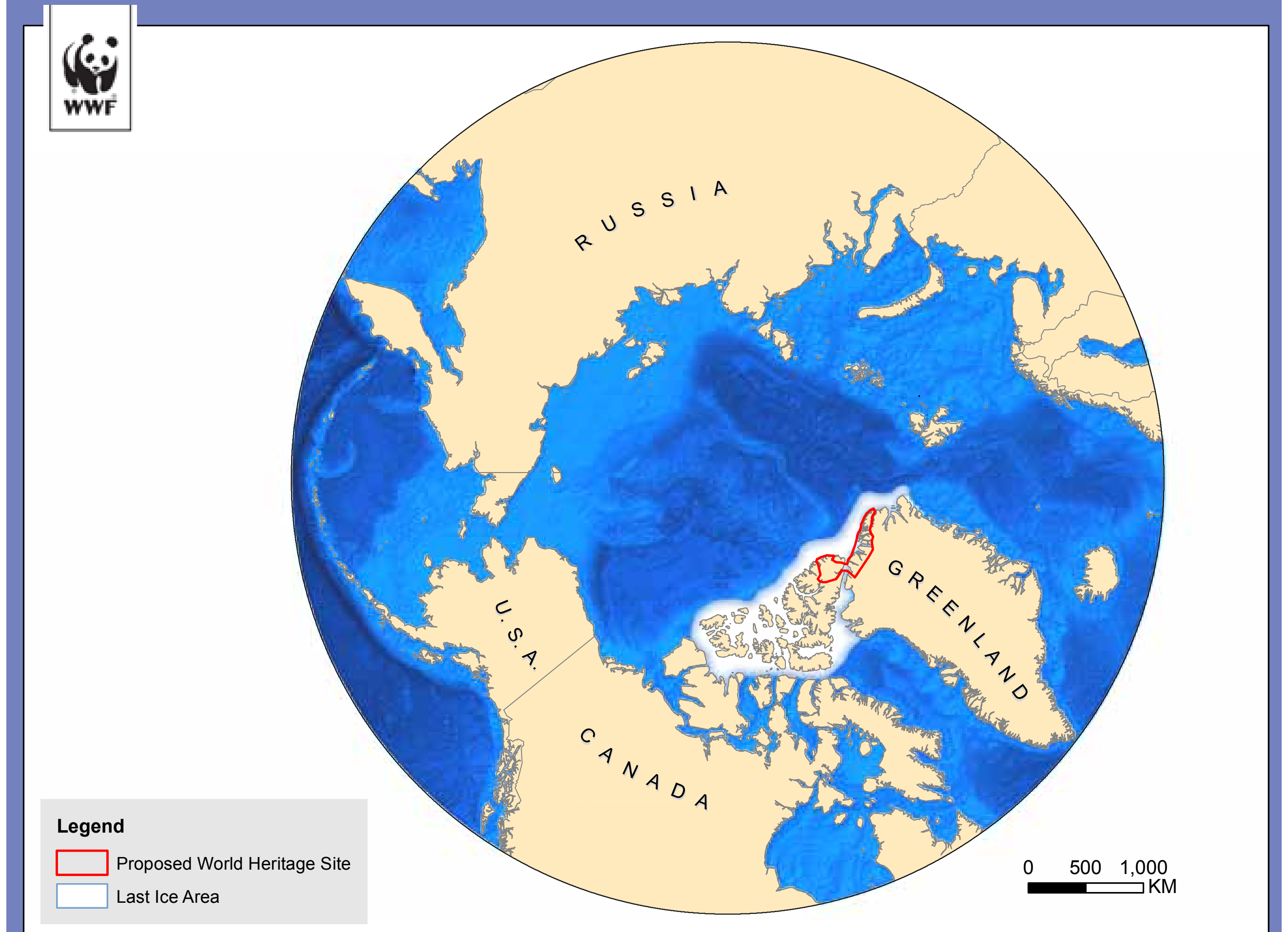
№	Special Protected Area	Coordinates of centrepoint	
		Latitude	Longitude
CANADA			
1.	Quttinirpaaq National Park	82° 7′ 56.424″ N	71° 38′ 53.556″ W
2.	Unprotected waters (Robeson Channel)	81°42′ 27.108″ N	63° 35′ 30.372″ W
DENMARK			
3.	Greenland National Park	82° 20′ 49.128″ N	47° 10′ 6.384″ W
4.	Unprotected waters	81° 39′ 41.04″ N	62° 42′ 20.52″ W

1e. Maps and plans showing the boundaries of the nominated property and buffer zone

1. Location of the nominated property within the limits of the Arctic.
2. Map with the exact indication of the boundaries of the nominated property and its buffer zone.

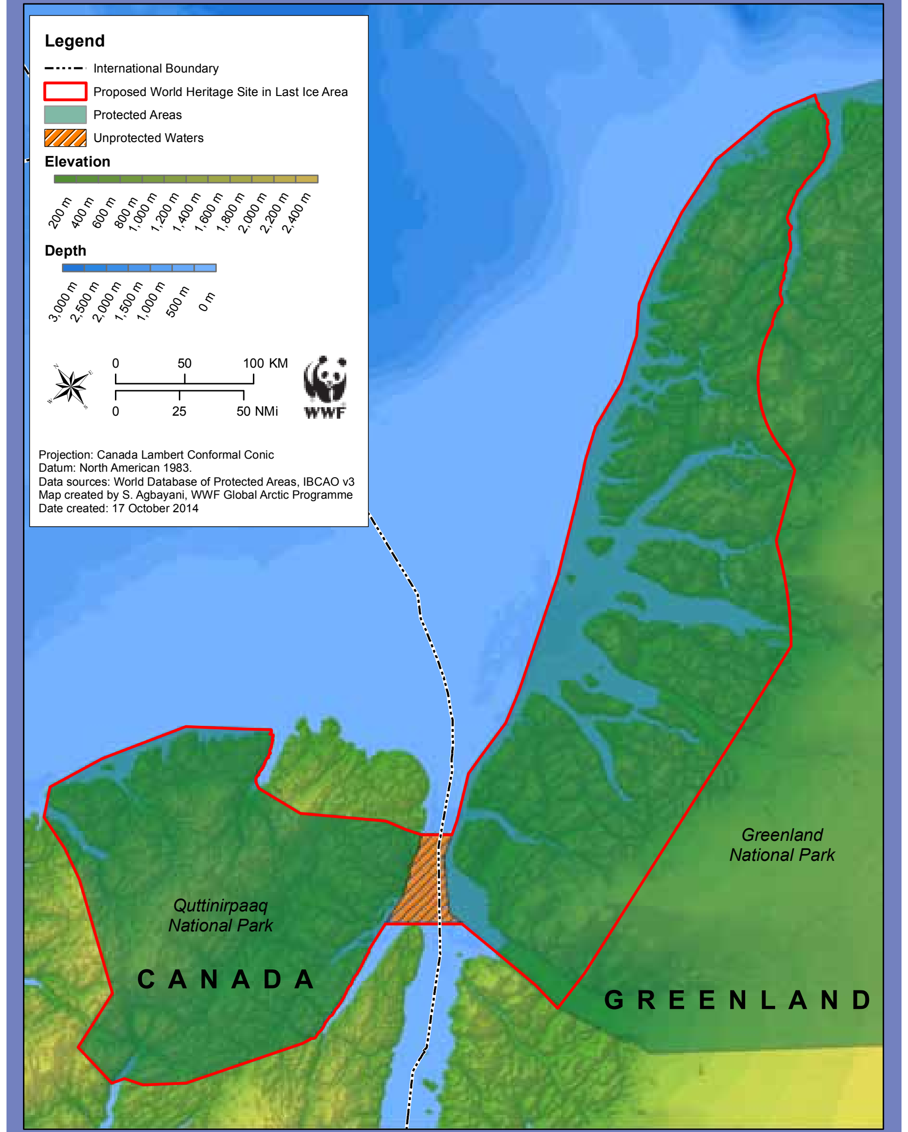
Additional maps and plans:
3. Map of the LIA core area and predicted future sea ice extent.
4. Map of the LIA region with the marine ecoregions and the EBSAs.
5. Map of the LIA region with the terrestrial ecoregions.
6. Seabird colonies in the Canadian and Greenlandic portions of the LIA.
7. Distribution of a) bowhead whales, b) belugas and c) narwhals.
8. Distribution of a) ringed seals (Kelly, 2001), b) bearded seals.
9. Map of location, size and trends of polar bear subpopulations.
10. Protected areas in LIA and its vicinity.
11. Location of current oil and gas rights and potential oil development areas in the Canadian Arctic Archipelago.

Figure 3 . Location of the nominated property in the Arctic.



The WWF Last Ice Area boundary is based on projected September Sea Ice Extents, >15% Conc, from 2050 through to 2090 (Huard & Tremblay, 2013).

Figure 4. Map with the exact indication of the boundaries of the nominated property.



1f. Area of nominated roperty (ha.) and proposed buffer zone (ha.)

№	Special Protected Area	Area, ha
		Nominated property
CANADA		
1.	Quttinirpaaq National Park	4,584,784
2.	Unprotected waters (Robeson Channel)	151,760.8
	Total area in Canada:	**4,736,544.8**
DENMARK		
3.	Greenland National Park	8,152,161
4.	Unprotected waters	39,816.43
	Total area in Denmark:	**8,191,977.43**
	Total:	**12,928,522.23**

The nominated territory is the first component part of the planning serial transnational property which will be further expanded at the expense of other SPAs located within the boundaries of the *Last Ice Area*.

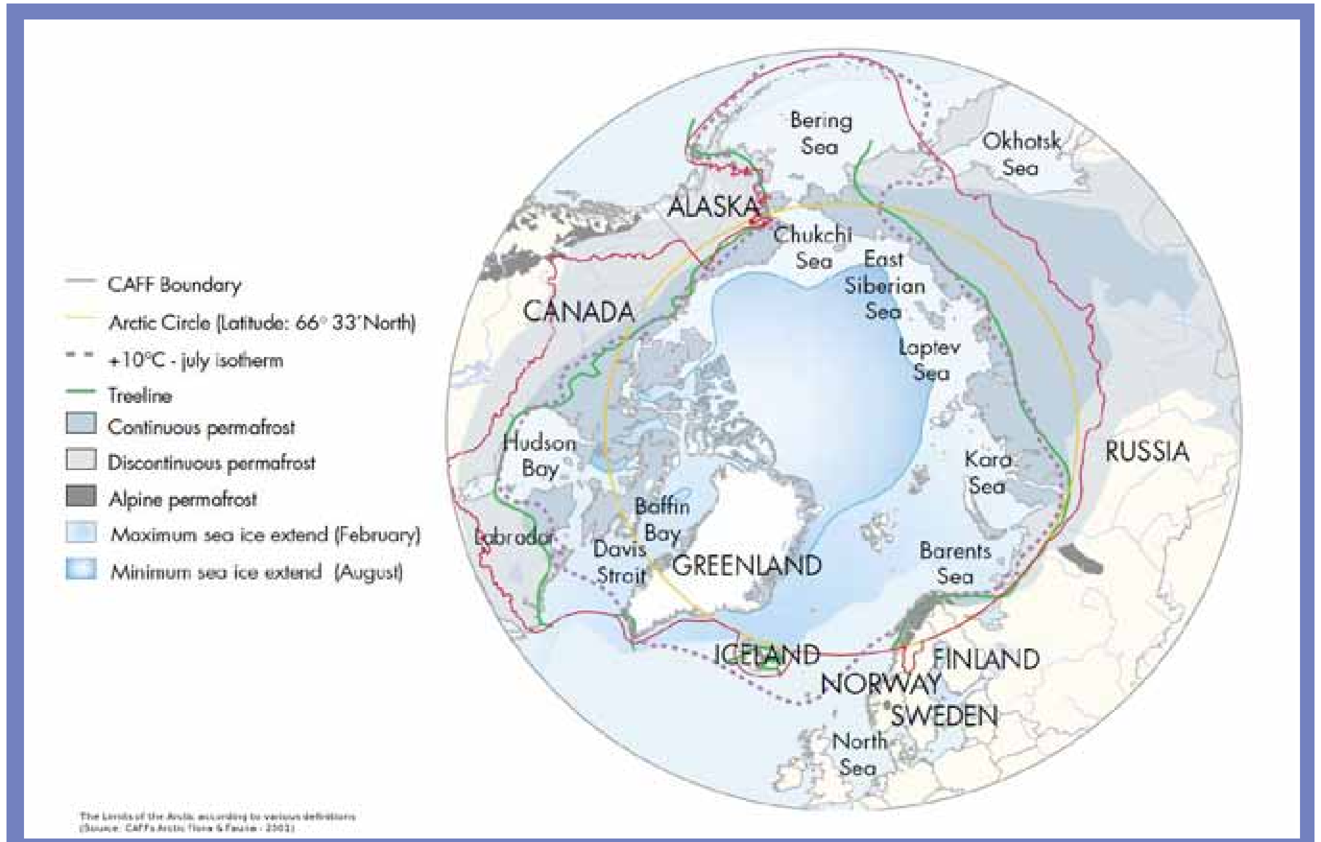


Figure 5. The limits of the Arctic according to different definitions (Arctic Council - CAFF Working Group, 2001b).

2a. Description of Property

Working with Arctic Council definitions of the boundary (Figure 5), the Arctic is a vast region that covers more than 40 million square kilometres, and contains about four million people (AHDR (Arctic Human Development Report), 2004). It consists of the Arctic Ocean and the adjacent terrestrial regions of the United States (Alaska), Canada, Denmark (Greenland), Iceland, Russia, Finland, Norway and Sweden.

The LIA boundaries are fuzzy as they are based on projections of sea ice persistence that are not accurate predictions of the exact location of that ice in the future. Nonetheless, the core of the area of interest includes the Canadian High Arctic Islands (also called the Queen Elizabeth Islands) that are located north of the Parry Channel, and the northern part of Greenland (an imaginary line between the western settlement of Savissivik

Figure 6. Map of the LIA core area, within dash line, and predicted future sea ice extent (WWF, 2011).

and the peninsula Kronprins Christian Land) (Figure 6). The communities included in the LIA area are Grise Fiord and Resolute, in Canada, and Qaanaaq, in Greenland.

Ecoregions

Fifty representative ecological regions, or ecoregions, have been defined within the circumpolar Arctic (WWF, 2012). The objective of designing ecoregions is to plan for conservation and set priorities (Skjoldal et al., 2012). Thirty-seven marine ecoregions were identified based on recognizable species groups of both plants and animals. Each marine ecoregion is an area of relatively homogeneous species composition that is clearly different from adjacent regions (Spalding et al., 2007). These species groupings are likely the consequences of oceanographic or topographic features such as temperature regimes, ice regimes or upwelling, that lead to biological differences (Spalding et al., 2007). The LIA includes five marine ecoregions: Beaufort-Amundsen-Viscount Melville-Queen Maud, Lancaster Sound, High Arctic Archipelago, Baffin Bay (Canadian Shelf) and North Greenland (Figure 8). Within these ecoregions, Ecologically and Biologically Significant Areas (EBSAs) were identified (Skjoldal et al., 2012). These areas were selected based on their ecological importance to fish, birds and mammals, as these species are the most widely studied Arctic groups (Skjoldal et al., 2012). The Beaufort-Amundsen-Viscount Melville-Queen Maud includes one EBSA in Viscount Melville Sound. This area is important for the feeding of belugas and, as a feeding ground and rearing area for polar bears. The Lancaster Sound ecoregion comprises three EBSAs: Lancaster Sound, Wellington Channel and Cardigan Strait/Hell Gate. These three EBSAs are very productive as they each contain a recurrent polynya (area of open water within the sea ice) that is used by seabirds as a nesting, breeding and feeding area, and by walruses as haul-out and wintering grounds. Arctic cod, an important link in the Arctic food web, is abundant in these three EBSAs. Lancaster Sound is also used as a migration corridor for marine mammals such as bowhead, narwhal, beluga, killer whales, and seals, and has the highest known density of polar bears in the world. The High Arctic Archipelago ecoregion comprises six EBSAs. The Archipelago multiyear pack ice is critical as it the largest remaining island pack ice refugium in the world and it supports unique communities. This area is particularly important for under-ice communities, seabirds and polar bears. Norwegian Bay is important for marine mammals and has the most genetically differentiated polar bear population in the world. Ellesmere Island includes three EBSAs: the Ellesmere Island ice shelves (described at section Ice shelves), the Nansen-Eureka-Greely Fiord that supports unique fish communities and aggregations of polar bear and ringed seal and Princess Maria Bay that is used by several seal species, walrus and narwhal. The Arctic Basin pack ice is the EBSA that contains the thickest and oldest sea ice of the Arctic

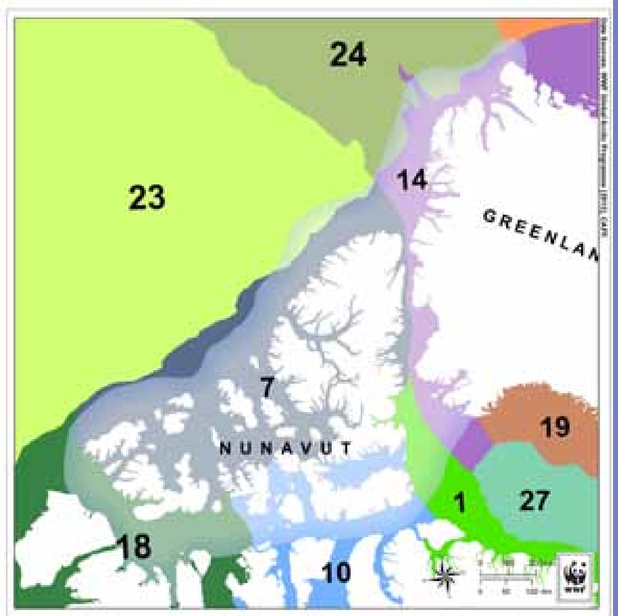


Figure 7. Bylot Island.
© Clive Tesar / WWF

Figure 8. Map of the LIA region with the marine ecoregions and the EBSAs.

Marine Arctic Ecoregions as used in the Rapid Assessment of Circum-arctic Ecosystem Resilience (RACER), adapted from Spalding, et al. (2007).

Marine Arctic Ecoregions

- 1. Baffin Bay - Davis Strait
- 7. High Arctic Archipelago
- 8. Hudson Complex
- 10. Lancaster Sound
- 14. North Greenland
- 18. Beaufort-Amundsen-Viscount Melville-Queen Maud
- 19. West Greenland Shelf
- 22. Fram Strait
- 23. Arctic Ocean – Pacific Basin
- 24. Arctic Ocean – Atlantic Basin
- 27. Davis Strait Basin

and is a unique habitat for under-ice and planktonic communities, and is a significant summer refuge for polar bear. The Baffin Bay (Canadian Shelf) ecoregion includes three EBSAs: the North Water Polynya (see section Marginal ice zones, flaw leads and polynyas), the Eastern Jones Sound that is characterised by an earlier open water feature that joins the North Water Polynya a few months later, and the Northern Baffin Bay that is known as an important seafloor habitat. The North Greenland ecoregion contains Peary Land, an important area for marine mammals and seabirds.

Twenty-three Arctic terrestrial ecoregions were identified based on the variation in plant species groups and communities found in clearly recognizable regions (CAVM Team, 2003). Although many plants grow throughout the circumpolar Arctic, variation in some species groups are informative of glacial histories, topography and other factors that might have contributed to regional differences. Soil type, soil moisture and temperature correspond to the different terrestrial ecoregions. The LIA encompasses three terrestrial ecoregions: Ellesmere-Northern Greenland, Central Canada and, to a small extent, Western Greenland (Figure 10). Tundra, permafrost, ice caps and glaciers, the Greenland Ice Sheet and snow characterize the terrestrial portion of the LIA.

GEOLOGY

Nunavut mineral deposits are mainly associated with Archean basement rocks. The prevalence of Phanerozoic sedimentary strata over igneous rocks of all ages in the Arctic Islands naturally promotes hydrocarbon exploration over mineral exploration. The potential value of know petroleum resources discovered exceeds the value of discovered minerals by a substantial margin (AANDC 2012).

Figure 9. Stream, Ellesmere Island.

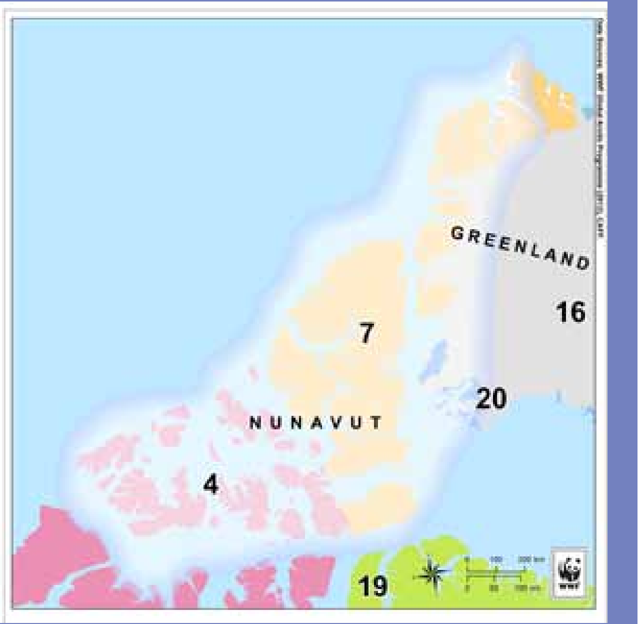


Figure 10. Map of the LIA region with the terrestrial ecoregions.

Terrestrial Arctic Ecoregions as used in the Rapid Assessment of Circum-arctic Ecosystem Resilience (RACER)

- Last Ice Area
- CAFF Boundary
- 4. Central Canada
- 6. Eastern Greenland
- 7. Ellesmere - N Greenland
- 16. Rock and Ice
- 19. West Hudsonian
- 20. Western Greenland

The Arctic Islands are underlain by rocks of the Archean and Proterozoic-aged Churchill, Arctic Platform, Franklinian and younger geological provinces. Paleozoic sedimentary rocks mainly occur in the central and western Arctic Islands. The latest known period of widespread mineralization in the area predates these sedimentary rocks, therefore rocks of this age (Paleozoic) or younger may be discounted as favourable sources of metalliferous deposits. Most of the Arctic Islands fall in this category (Nassichuk 1987).

The east coast of Ellesmere and Devon islands and large portions of Baffin and Somerset islands are geologically favourable to mineralization. The geology of these areas is a continuation of the Rae Domain which contains extensive mineralization on the mainland to the south. The region hosts diverse mineral deposits and occurrences including iron ore, base metals such as lead and zinc, gold, platinum group elements (PGE), diamonds and sapphires (AANDC 2012).

At the present time, parts of eastern Ellesmere and Devon Islands are covered by permanent ice caps that make geological exploration activities difficult. There are minor exposures of Rae Domain Archean and Proterozoic rocks without sedimentary cover in these areas. Greenland's geology is an extension of North America and Northern Europe Archean cratons and Paleozoic sedimentary basins. Greenland is dominated by crystalline rocks of the Precambrian shield, formed during a succession of Archean and early Proterozoic orogenic events which stabilized as a part of the Laurentian Shield approximately 1,600 million years ago.

Major sedimentary basins formed during late Proterozoic time and throughout the Phanerozoic in north and north eastern Greenland, and accumulated sedimentary successions 10 to 15 km thick. Palaeozoic orogenic belts, the Ellesmerian fold belt of North Greenland, and the East Greenland Caledonides disturbed parts of these successions.

Onshore and offshore Upper Palaeozoic and Mesozoic sedimentary basins formed along the continent–ocean margins in North, East and West Greenland and were closely related to continental break-up and the formation of rift basins. Initial rifting in East Greenland in latest Devonian to earliest Carboniferous time and succeeding phases culminated with the opening of the North Atlantic in the late Paleocene. In both central West and central East Greenland sea-floor spreading was accompanied by extrusion of Tertiary plateau basalts.

During Quaternary time Greenland was almost completely encompassed by ice sheets, and the current inland ice is a result of the Pleistocene ice ages. Vast amounts of glacially eroded detritus were deposited on the coastal shelves offshore Greenland

Relief

A mountainous region of continuous permafrost, the region consists mainly of land to 700m above mean sea level. The highest highest point is 2600 m. It has substantial coverage of ice caps and glaciers and exposed carbonate bedrocks/nunataks at high elevation, rising steeply from heavily inundated coastlines. A few low slope hills and plains harbour relatively rich flora and fauna.

Hydrography

The Arctic Ocean consists of a deep central basin (maximum depth of 4,400 m) divided by ridges (i.e. a chain of mountains that form a continuous elevated crest) and surrounded by broad and narrow continental shelves (Figure 5; an interactive map can be visualize at www.arkgis.org). It is the smallest of the world's oceans, but has the highest proportion of continental shelves, with shelf regions covering around 50% of the Arctic marine area (Jakobsson et al., 2004). The continental shelves north of Greenland and of the Canadian Arctic Archipelago extend for a maximum of 300 km off the coast, up to a depth of around 400 m, until they reach the shelf break (i.e. where the slope become very steep). Water depths in the central Canadian Arctic Archipelago are generally shallow (< 100 m) although Lancaster Sound reaches depths of up to 800 m (Niemi et al., 2010). Fiords on the northern coast of Greenland can be very deep (Petermann Fiord is 1,100 m deep (Johnson et al., 2011)) while fiords located on the northern coast of Ellesmere Island are relatively shallower (Disraeli Fiord would be over 300 m deep (Crary, 1956)).

Four sites within LIA are important for lake ecological studies: Cornwallis Island (Char Lake, Meretta Lake, Amituk Lake), Ellesmere Island (Lake Romulus, Cape Hershel ponds), Ward Hunt lake and northern Ellesmere Island meromictic lakes, and Peary land in northern Greenland (Vincent et al., 2008).

Arctic lakes are very diverse. Their salinity ranges from freshwater to hypersaline, and their ice cover can be perennial or seasonal. This diversity leads to different mixing regimes; some lakes mix fully during open water conditions in summer, others mix at spring and fall and stratify strongly during summer (as most temperate lakes), and others never mix (Vincent et al., 2008). These physical differences bring large variations between lake chemical characteristics, such as oxygen concentration, and even within the same lake at different depths or times. Some lake types with unusual features are found exclusively in the polar regions, such as solar-heated perennially ice-capped lakes of northern Ellesmere Island (Veillette et al., 2010), and epishelf lakes. The Arctic also harbours a diversity of streams and river ecosystems, from spring-fed streams to large rivers.

Most Arctic lakes are ultra-oligotrophic and therefore very unproductive, but some are greatly enriched by human activities (e.g. Meretta Lake (Schindler et al., 1974)). Several variables would control biological production in Arctic aquatic ecosystems (Vincent et al., 2008). First, the availability of liquid water is essential for aquatic life. For some ecosystems (e.g. meltwater lakes on ice shelves), this limits biological activity to only a few weeks each year. However, liquid water persists all year round under snow and ice cover for most aquatic ecosystems. Streams and rivers are fed by melting snowpack and glaciers, and their flow is the most important during the peak snowmelt in spring. Second, the reduced irradiance, since the sun is up only during the summer, compounded to the attenuating effects of snow and ice cover on the underwater irradiance strongly limits the annual production in Arctic aquatic ecosystems. However, the primary variable controlling daily primary production by phytoplankton during summer would be nutrient availability (Vincent et al., 2008). Nutrient delivery for biological production to plankton communities in lakes and rivers is low in the Arctic. The release of nutrients from the catchments by soil microbes is limited due to low temperature, low moisture, and freezing. Nutrient recycling rates are also slowed with the low temperature of waters. Also, low temperature would likely slow the metabolic rate and growth of many of the organisms colonizing Arctic aquatic ecosystems. Hence, it is suggested that nutrient supply exert a strong control

Figure 11. Meltwater on ice, Ellesmere Island.

on phytoplankton production with the interplay of light and temperature (Vincent et al., 2008).

Benthic communities of many Arctic aquatic ecosystems flourish and dominate the ecosystem biomass and productivity (Vincent et al., 2008). They take advantage of the more stable environment and of the enhanced supply of nutrients by sedimentation of particles from above and by more active bacterial decomposition and recycling processes, compared to the water column environment. The benthic photosynthetic communities may be more limited by light than by nutrients (Bonilla et al., 2005).

Climate change was identified as the major environmental driver affecting Arctic freshwater ecosystems (Prowse and Reist, 2013). The duration of freshwater ice cover is strongly controlled by climate. The lake ice cover duration in the Northern Hemisphere (1846-1995) has declined: freeze-up becomes later, break-up becomes earlier and the ice cover duration has decreased (Prowse et al., 2011). Rivers are also showing the same trend although there are regional differences (Prowse et al., 2011). The accelerated climate warming occurring in the Arctic has major implications for the lake ice cover as well. In Arctic freshwater ecosystems, the duration of ice cover has decreased by almost two weeks over the last 150 years, with earlier break-ups and later freeze-ups (Prowse and Brown, 2010). Hence, lakes with seasonal ice cover have a longer ice-free season while lakes with perennial ice covers are becoming ice free during summer (Prowse et al., 2011). These reductions in lake ice cover duration modify thermal conditions that may lead to enhanced evaporation and, in some cases, the loss of shallow lakes (Prowse et al., 2011). In addition, these conditions can lead to enhanced mixing, making Arctic lakes becoming sinks for contaminants (Prowse et al., 2011). Loss of ice cover will also likely lead to increased methane emissions and expose the biota to an increased level of ultraviolet radiation (Prowse et al., 2011). Apart from climate change, other environmental stressors are increasingly relevant for Arctic aquatic ecosystems such as pollution (point source and long-range atmospheric transport), altered hydrologic regimes related to impoundment and diversion of freshwater, water quality degradation due to enhanced mining, and oil and gas activities, and anthropogenic introduction of invasive species via more transport in the North (Prowse and Reist, 2013).

Climate

The Arctic climate is challenging for life. It is characterized by extreme seasonality; air temperature vary from glacial to temperate, the winter polar night is followed by the summer midnight sun, and snow and ice covers fluctuate significantly between seasons. Precipitations are generally low and some particularly arid regions are classified as "polar deserts". The climates of specific locations within the Arctic are likely to vary since this is a vast region and specific features such as the topography or the distance to the coast, can influence local conditions (Figure 12). For instance, Alert (located on the northern coastline of Ellesmere Island) is influenced by cold air advection from the Arctic Ocean and the blocking of solar radiation by frequent low clouds and fog, while Eureka (located on the coastline of a fiord on Ellesmere Island but not exposed to the Arctic Ocean) is subject to the rain shadow effect of surrounding mountains (Maxwell, 1981).

Normals for the period 1981-2010 are available for five stations in the Canadian portion of the LIA region (Table 1).

A long-term station south of the LIA region, Upernavik (72.78°N, 56.13°W), has a mean daily temperature of -7.1 °C for 1981-2010 (Cappelen, 2011). Also, the north drainage basin of Greenland, which include the LIA region, has a mean daily temperature of -21.3°C and a total of precipitation of 182.5 mm (Lucas-Picher et al., 2012). In Greenland, there are sharp differences in temperatures from the coasts to the fiords (Cappelen, 2013). In summer, drift ice and cold water along the coast make the fiords warmer places. In winter, the situation is reversed and coastal areas are warmer. Ellesmere Island and the north of Greenland are therefore very cold. Nevertheless, unusual very warm temperatures have been recently recorded, such as a maximum of 20.5°C at Ward Hunt Island (83°N, 74°W) in summer 2008 (Vincent et al., 2009).

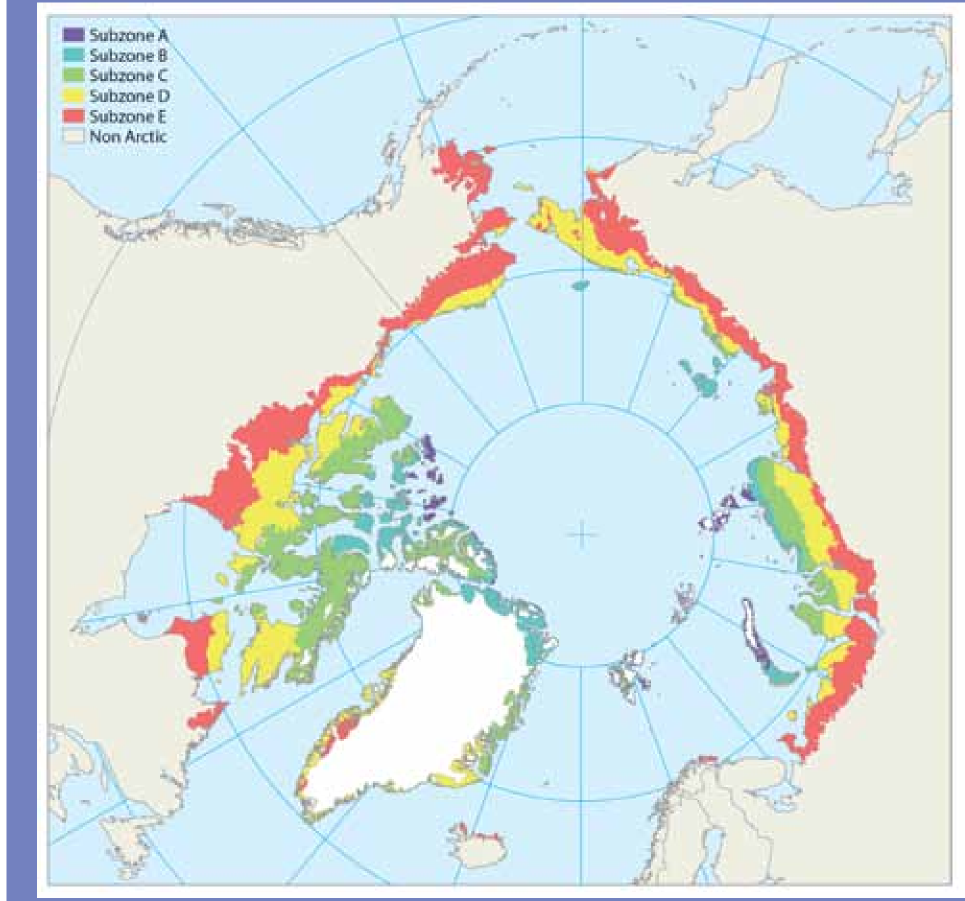


Figure 12. Bioclimate subzones of the circumpolar Arctic based on the Circumpolar Arctic Vegetation Map. Mean July temperature of zone A is 0-3°C, for zone B, 3-5°C, for zone C, 5-7°C, for zone D, 7-9°C, and for zone E, 9-12°C (CAVM Team, 2003).

Table 1. Location and climate data for Canadian weather stations located in the LIA region or in its vicinity from 1981 to 2010. Data were obtained from the Government of Canada (Government of Canada, 2013a). Lat.: latitude, Long.: longitude, Temp.: mean daily temperature, Days > 0°C: days with daily maximum temperature > 0°C. Precipitation, rainfall and snowfall are all total. NA: not available.

	Lat. (°N)	Long. (°W)	Temp. (°C)	Days > °C	Precipitation (mm)	Rainfall (mm)	Snowfall (cm)
Alert	82.52	62.28	-17.69	80.62	158.29	17.43	184.64
Eureka	79.98	85.93	-18.75	98.95	79.07	32.53	60.30
Resolute	74.72	94.97	-15.67	92.90	161.20	59.47	111.21
Pond Inlet	72.69	77.97	-14.56	119.62	189.01	91.02	131.90
Clyde River	70.49	68.52	-12.58	122.67	NA	63.29	194.74

Snow

Snow is an important and dominant feature of Arctic terrestrial landscapes and marine icescapes, with cover present for eight to ten months of the year. Its extent, dynamics, and properties (e.g. depth, density, water equivalent, grain size, and changes in structure throughout its vertical profile) affect climate (e.g. ground thermal regime), human activities (e.g. transportation, resource extraction, water supply, use of land, and ecosystem services), as well as infrastructure, hydrological processes, permafrost, extreme events (including hazards such as avalanches and floods), biodiversity, and ecosystem processes (Callaghan et al., 2011b). Air temperature and precipitation are the main drivers of regional-scale snow cover variability over the Arctic region, with local-scale variability in snow cover related to interactions with vegetation cover and topography through processes such as blowing snow and sublimation (when water changes directly from solid to vapor form without thawing) (Callaghan et al., 2011b). Impurities in the snow (e.g. leaf litter and organic and black carbon) contribute to local (landscape) and regional (circum-Arctic) differences in how much of the sun's energy is absorbed which influences spring season melt rates (Callaghan et al., 2011b). In contrast to temperate regions, most of the Arctic snowmelt during spring occurs over a very short period of time.

Snow provides important denning habitat for several Arctic species such as polar bears and ringed seals (Callaghan et al., 2011b). For instance, female ringed seals give birth to their young in snow dens on the sea ice. The snow cover provides protection from cold temperatures and predators. These snow dens are especially critical when pups are nursed from late March to June. To successfully rear young, ringed seals in the central Arctic need on-ice snow depths in April of at least 50 cm. Such snow depths are usually found as snow drifts next to sea ice ridges but can be present on flat landfast ice (Hezel et al., 2012). Thus, the period over which snow accumulates on ice is considered to be the primary factor influencing the quality of ringed seal breeding habitat (Smith and Lydersen, 1991). Inadequate snow depths increase pup mortality through exposure and predation (Ferguson et al., 2005).

Snow cover on sea ice controls the underwater light availability by strongly attenuating light penetration. Snow cover influences the timing of the early spring under ice productivity in the Arctic Ocean, since primary production is initiated by the growth of ice algae as soon as a critical amount of light reaches the ice-water interface in spring. If the snow cover persists during the summer, it will also reduce the light available for photosynthesis by the phytoplankton. The huge importance of snow cover in attenuating light penetration of ice-covered aquatic ecosystems was demonstrated by a field experiment that removed the snow cover from an area of a perennially ice-covered lake. Removing the snow greatly increased light that was available at the ice-water interface (Belzile et al., 2001). This study also showed the much greater role of the snow cover compared to the ice cover in attenuating light penetration (Belzile et al., 2001).

People of the Last Ice Area

While there are no permanent human settlements within the proposed World Heritage Site bouandaries, people do live in communities along the fringes of the Last Ice Area. In Canada, the communities of Grise Fiord and Resolute are on the southern fringe of the Last Ice Area, while across Lancaster Sound, the communities of Arctic Bay and Pond Inlet would also be considered adjacent to the LIA. In Greenland, the community

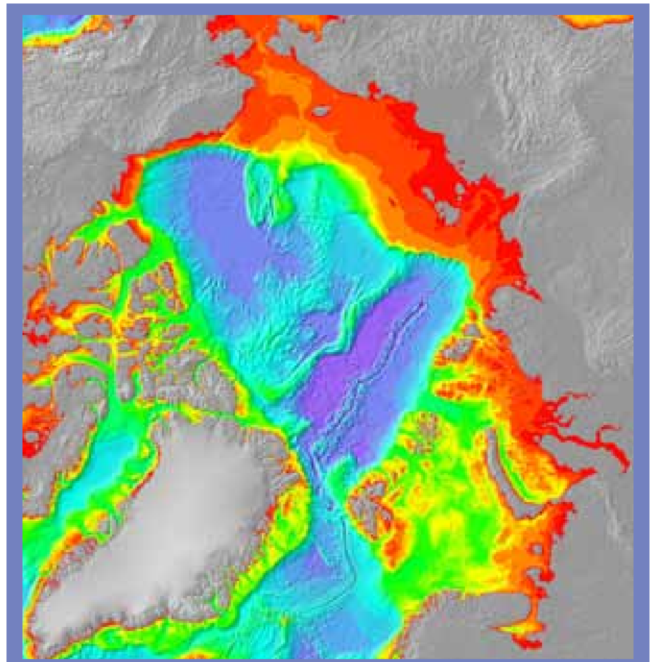


Figure 13. Bathymetry of the Arctic Ocean (Jakobsson et al., 2012).

of Qaanaaq borders the Greenlandic portion of the Last Ice Area. Indigenous peoples have used this area for thousands of years, with habitation of Ellesmere Island traced back as early as 2000 B.C.E. Current use includes hunting over much of the Last Ice Area (ICC 2013).

Inuit in the region are concerned by the changes they are seeing in sea ice, particularly as these may limit their access to traditional food sources. They are also concerned about potential and current industrial activities also having a negative effect on their ability to harvest traditional foods such as caribou and whales (ICC 2013). For a people that has such a close link to the sea ice, the continued existence of a healthy sea ice ecosystem could be considered an essential element of cultural resilience.

The marine environment

The Arctic Ocean is unique. It has the most extensive continental shelves of all oceans: they cover 50% of its total area. It is the most extreme ocean in regard to the seasonality of light, large riverine inputs and its predominant ice cover.

In addition, Arctic marine productivity and biodiversity are shaped by connections to the Pacific and Atlantic oceans, and a strong stratification (layering of water with different temperatures and salt levels).

Physical oceanography

Bathymetry

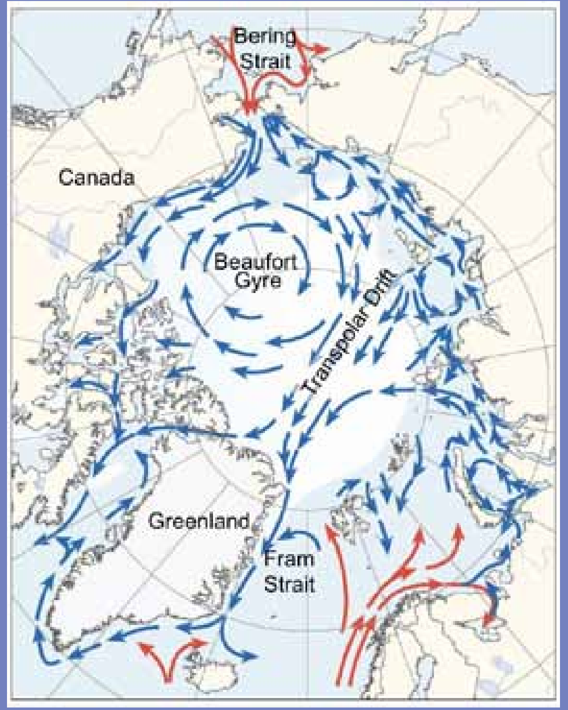
The Arctic Ocean is a nearly landlocked ocean and receives large amounts of freshwater from large rivers such as the Ob, Lena, Yenisey and MacKenzie. The Arctic Ocean consists of a deep central basin (maximum depth of 4,400 m) divided by ridges (i.e. a chain of mountains that form a continuous elevated crest) and surrounded by broad and narrow continental shelves (Figure 13; an interactive map can be seen at www.arkgis.org). It is the smallest of the world's oceans, but has the highest proportion of continental shelves, with shelf regions covering around 50% of the Arctic marine area (Jakobsson et al., 2004). The continental shelves north of Greenland and of the Canadian Arctic Archipelago, part of the LIA, extend for a maximum of 300 km off the coast, up to a depth of around 400 m, until they reach the shelf break (i.e. where the slope is very steep). Water depths in the central Canadian Arctic Archipelago are generally shallow (< 100 m) although Lancaster Sound reaches depths of up to 800 m (Niemi et al., 2010). Fiords on the northern coast of Greenland can be very deep (Petermann Fiord is 1,100 m deep (Johnson et al., 2011)) while fiords located on the northern coast of Ellesmere Island are not well known, except that Disraeli Fiord is about 450 m deep (D. Antonaides, pers. comm.).

Currents and water masses

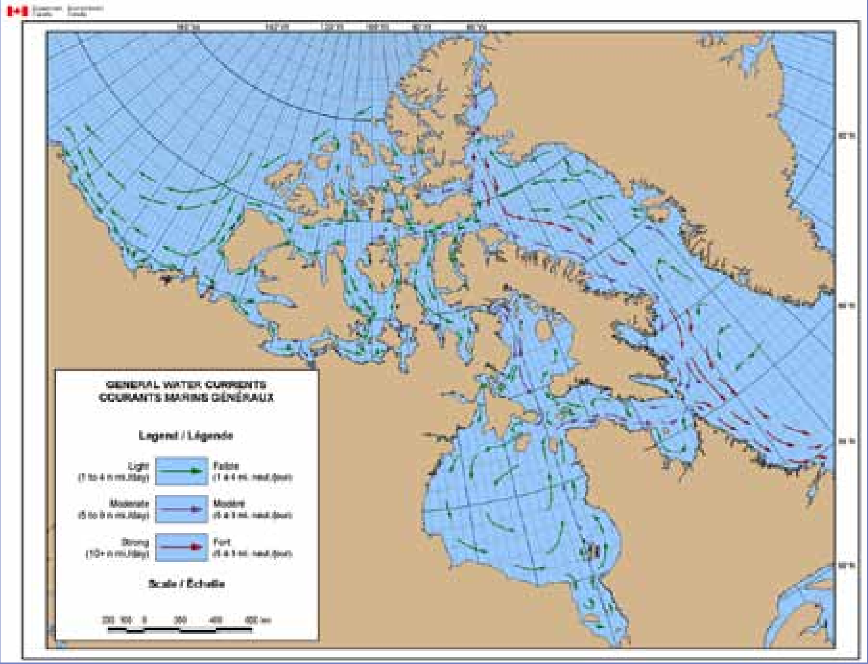
The circulation of surface waters in the Arctic Ocean flows predominantly from the Pacific to the Atlantic Ocean (Figure 14). The flow to the Atlantic Ocean is through several routes in the Canadian Arctic Archipelago, mainly in Lancaster Sound/Barrow Strait and in Nares Strait, and through Fram Strait, down the east coast of Greenland. The Pacific Ocean water is characterized by a low salinity (less than 33 ‰) and is nutrient-rich compared to the Atlantic Ocean water. The Pacific waters are therefore less dense and form a layer on top of the Atlantic water mass. Freshwater from sea ice melt and river discharges add to this surface layer and contribute to the stability of the water column. A consequence of these high freshwater inputs is the permanent stratification of the central Arctic Ocean with a surface salinity of 32 ‰ and a deep water salinity of 34 ‰ (Gradinger et al., 2010). Surface waters become rapidly depleted in nutrients due to the blooms in primary productivity but the underneath layers remain nutrient-rich. The interplay between the winds and the stability of the stratification determine the vertical supply in nutrients by mixing deep waters into the surface layers (upwelling).

Water masses of the Arctic Ocean are found to vary in temperature, salinity and position from year to year. These changes, apart from modifying water stratification and mixing regimes, may affect nutrient concentrations, and the distribution of plankton, fish larvae and larger invertebrates. Arctic marine biodiversity is therefore linked to the dynamic pattern of oceanic conditions (CAFF, 2013b).

The wind-driven surface circulation in the Arctic Ocean also determines the movement of sea ice. The clockwise Beaufort Gyre controls the movement of the Arctic pack ice off the northern coast of Greenland and along the northwestern margin of the Canadian Arctic Archipelago (Figure 14). By recirculating ice, the Beaufort Gyre produces the thickest and oldest ice in the Arctic Ocean (Lee et al., 2012). Moreover, the Transpolar Drift moves ice from the Siberian coast region across the Arctic Ocean towards and eventually through Fram Strait (National Snow and Ice Data Centre, 2013a). As a result, on a basin-scale, the thickest sea ice (mean thicknesses of 4 to 6 m) is located off the northern coast of Greenland and along the northwestern margin of the Canadian Arctic Archipelago, and is the region covered by the LIA project.



A)



B)

Figure 14. Surface ocean currents in A) the Arctic Ocean and B), the Canadian Arctic Archipelago. In A), blue arrows indicate cold currents and red arrows, warm currents (modified from (Arctic Council - CAFF Working Group, 2001a)). In B), green arrows indicate light currents, purple arrows, moderate currents and red arrows, strong currents (Environment Canada - Canadian Ice Service, 2013).

Figure 15-16. Photos showing examples of the different sea ice types: on the left, first-year is shown (http://ice-glaces.ec.gc.ca/App/WsvPageDsp.cfm?ID=10975&Lang=eng) and, on the right, multiyear sea ice is illustrated (worldcomplex.blogspot.ca/2010/08/blowing-up-arctic_12.html).

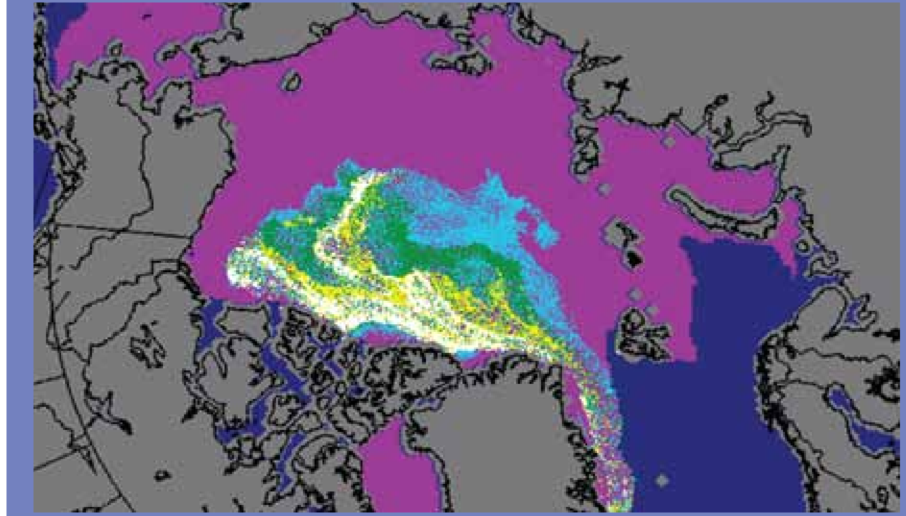


Figure 17. Arctic sea ice ages at the end of March 2013 (NSIDC courtesy J. Maslanik and M. Tschudi, University of Colorado). Areas cover by first-year ice (< 1 year old) are represented in magenta, ice of 1-2 years old in blue, ice of 2-3 years old in green, ice of 4 years old in yellow, and ice older than 4 years in white.

Sea ice

Sea ice is frozen ocean water and it is found throughout the Arctic and around the Antarctic. Different types of sea ice are found and they have distinct properties (Figure 15, 16). First-year ice is floating ice of no more than one year's growth. Its thickness ranges from 0.3 to 2 m. This ice type is generally level but ridges that occur are rough and sharply angular (National Snow and Ice Data Centre, 2013a). As sea ice forms, it expels salt into the ocean water by the formation of brine (droplets of highly saline water) that is trapped in pockets between the ice crystals. Another way that salts are expelled on new seasonal ice is by the forming of frost flowers on top of it (Barber et al., 2012a). When sea ice becomes multiyear ice (ice that has survived at least two summer melt seasons (Parkinson and Comiso, 2013), it becomes fresh as the salts have been expelled and all than remains is frozen water. Multiyear ice is therefore stiffer and it is harder for icebreakers to navigate through it (National Snow and Ice Data Centre, 2013a). Extensive multiyear ice forms in the Arctic Ocean as it is land-locked

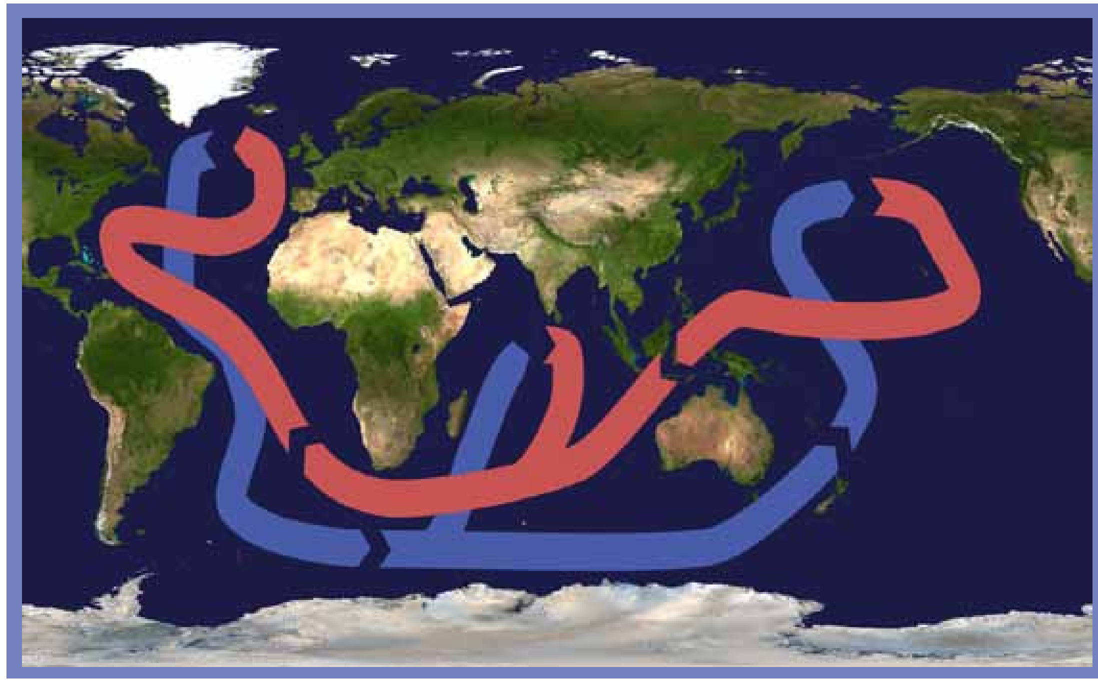


Figure 18. The thermohaline circulation (wikimedia commons).

(Figure 17) (National Snow and Ice Data Centre, 2013a). Perennial ice is defined as ice that has survived at least one summer melt season (Parkinson and Comiso, 2013). Landfast ice is defined as ice that grows out from the shore (Vincent et al., 2011).

The roles of sea ice

Sea ice is the most dominant feature of the Arctic marine environment. It influences the climate locally and globally. Sea ice has an impact on albedo, ocean circulation via brine expulsion, and ice melting influences the transport of cold and low salinity waters with ice drift. In addition, ice cover controls atmospheric-ocean exchanges.

Sea ice albedo is an important positive feedback process for the global climate. Albedo is a unitless measure of how well a surface reflects solar energy. A white surface has a high albedo (i.e. 1) while a black or transparent surface has a low albedo (i.e. 0) since most of the light it receives is absorbed and converted into heat. Arctic sea ice has an albedo of around 0.7 while ocean open water albedo is around 0.06 (Huard and Tremblay, 2013). Climate warming causes the sea ice cover to melt and increases the open water area. This results in the reduction of the surface albedo and decreases the amount of solar energy (light and heat) that is reflected back to space. Areas of open water absorb more solar energy and contribute to further warming and more sea ice melt. This process contributes substantially to the Arctic amplification of climate change.

Sea ice also affects the movement of ocean waters. When sea ice forms, brine is pushed into the ocean water just underneath the ice. This water has a high concentration of salt and is denser than surrounding ocean water, thus sinks. By this process, sea ice contributes to the ocean's global thermohaline circulation (Figure 18). Changes in the amount of sea ice formed can disrupt normal ocean circulation, thereby leading to changes in the global climate. In contrast, when the sea ice cover melts in the Arctic Ocean or in Fram Strait, it creates a layer of freshwater on top of the ocean water. Since freshwater is less dense than seawater, it tends to stay at the top of the ocean. This lower density discourages the normal process of sinking at high latitudes that supports the thermohaline circulation.

Ice cover also controls atmosphere-ocean exchanges. It isolates the upper ocean from direct wind forcing which physically protect the surface water from mixing and damps surface wave motion. Ice cover also protects the coasts from erosion by bigger wave heights leading to greater coastal erosion and recessions. It also serves as an efficient thermal insulator. The Arctic's atmosphere is very cold during the winter while the ocean is relatively warmer. The sea ice cover prevents the heat in the ocean from warming the overlying atmosphere. Nonetheless, heat can escape from leads and polynyas. As the ice melts, energy and moisture move out of the ocean to the atmosphere resulting in more storms such as cyclones (cells of air that rotate in a counter-clockwise direction), characterized by high winds and precipitation.

The sea ice cover also plays important roles for the Arctic marine ecosystem. Similar to the snow cover, the ice cover influences how much light will penetrate to the under ice ecosystems and affects the timing and extent of ice algal and phytoplankton production. The recent thinning of the sea ice cover contributes to an increase in light transmission, which is mirrored in greater primary production by phytoplankton (see section Arctic marine food webs and productivity (Arrigo et al., 2012)). The different components of Arctic marine biodiversity use and depend on sea ice in different ways. Sea ice cover is the substrate for organisms that thrive within it (see section Biodiversity in the sea ice). Two fish species use the sea ice cover as habitat, protection from predators and a place to spawn (see section Fish). Marine mammals that live in the Arctic all year long rely on sea ice as a platform for resting, hunting or breeding (see section Marine mammals). Loss of Arctic sea ice will push these organisms to adapt their life cycle in order to survive, and the sea ice diversity will change as multiyear ice is replaced by first-year ice. The impacts of a reduced sea ice cover for species that use sea ice occasionally (e.g. seabirds, whales present in the Arctic only during summer) is less clear. The decline in the sea ice cover implies that islands will be separated by open water longer during summer and will prevent terrestrial animals from migrating easily between habitats.

Other impacts of a reduced sea ice cover will be more indirect. Navigation through the Northwest Passage will be easier. This could result in shipping impacts, including spills of bunker fuel oil, or hazardous cargoes (Arctic Council, 2009). Subsistence harvesting practices will have to change in some communities, as traditional over-ice routes become unstable during shoulder seasons, and prey change their patterns.

Marginal ice zones, flaw leads and polynyas

Some features of the sea ice environment are of particular ecological significance since they are highly productive: marginal ice zones, flaw leads and polynyas (Figure 19).

Marginal ice zones

The marginal ice zone is the transition area from ice-covered seas to open water, where sea ice is significantly influenced by the action of waves. Waves are responsible for the break-up of ice floes (drifting pieces of sea ice)

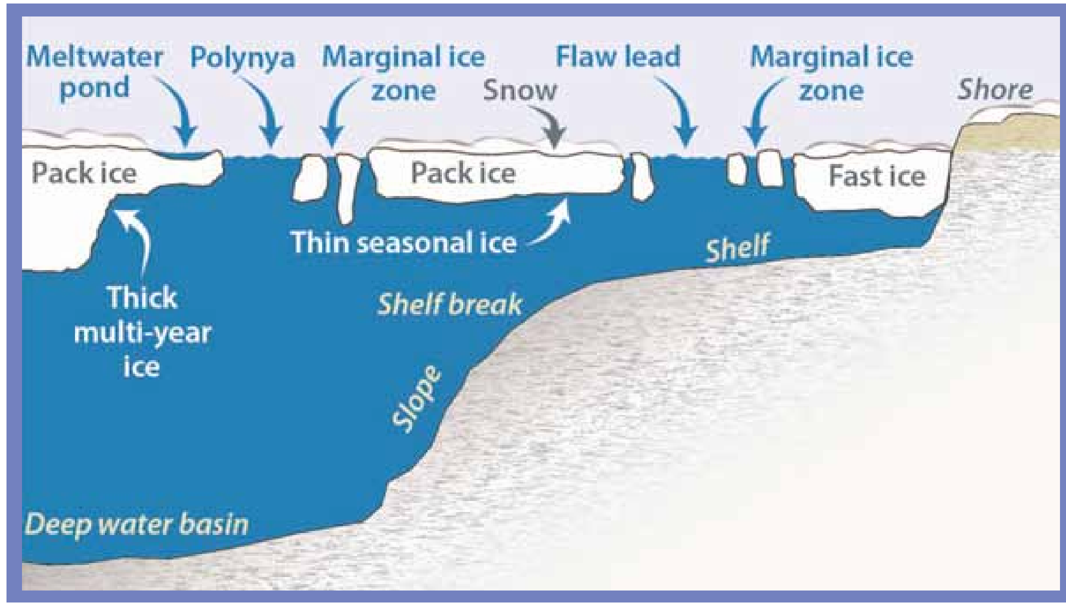


Figure 19. Some features of the sea ice environment (CAFF, 2013b).

and determine the extent of the marginal ice zone. They represent narrow zones that are 25-100 km wide (Dumont et al., 2011). These areas are complex and variable sea ice environments. Swells and waves are lower as they enter the marginal ice zone. Typical marginal ice zone conditions are found along the southern edges of the ice pack in the Bering, Greenland, Chukchi, and Barents Seas, and in Baffin Bay (Roed and O'Brien, 1983).

Marginal ice zones are recognized as biologically productive regions, where large numbers of phytoplankton, zooplankton, seabirds and marine mammals converge. In the Arctic, this is due to upwelling occurring at the sea-ice edge (Smith et al., 1987). Upwelling is the process by which deep, nutrient-rich waters rise to the surface due to the action of the winds or currents. Arctic surface waters are typically reduced in nutrient concentrations and the water column is highly stratified, which limit the growth of phytoplankton. Upwelling, created by the action of the wind on the open water, inject nutrients into the surface waters.

A significant implication of the recent decrease in sea ice extent has been the retreat of the ice edge away from the coast and continental shelves (Lee et al., 2012). At the end of the summer, when sea ice extent reaches its minimum, the marginal ice zone is located above the deep ocean which was until recently perennially ice covered (Lee et al., 2012). As an example, the recent decrease in sea ice extent has resulted in the production of a substantial marginal ice zone in the deep Beaufort Sea (Lee et al., 2012). Extending open water conditions in the marginal ice zone permit more direct connection with the atmosphere and can have implications for the upper ocean structure and sea ice evolution.

The LIA as described in Figure 6 does not include marginal ice areas but these areas will be increasingly present in the LIA as sea ice extent decreases.

Flaw leads

Flaw leads are areas of unconsolidated ice or ice-free waters between the mobile multiyear pack ice and the fixed coastal fast ice (Deming and Fortier, 2011). The circumpolar flaw lead is a perennial feature of the Arctic observed throughout the winter (Figure 20). It consists in a large crack in the ice at the periphery of the Arctic Ocean, along the coastlines of the shallow seas that surround the deep Arctic Ocean basins (Deming and Fortier, 2011). The circumpolar flaw lead in the LIA area is relatively narrow since multiyear landfast sea ice is still substantial in this area even during the summer. In some areas, the circumpolar flaw lead widens significantly in spring and summer and

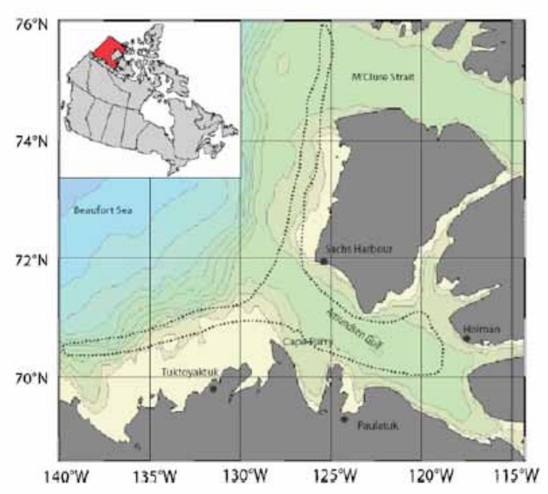


Figure 20. Map of the circumpolar flaw lead (indicated by the grey dashed line) in the Beaufort Sea and local communities (Barber et al., 2012b).

forms recurrent polynyas where biological productivity is increased (Deming and Fortier, 2011). Flaw leads are also areas of high ice production (Dethleff et al., 1998).

The ice edges of a flaw lead are areas of high biological productivity (Barber et al., 2012a). Upwelling is caused by strong winds which mixes water layers and introduces deeper water replete with nutrients close to the surface, making them available for biological growth (Barber et al., 2012a). As the sea ice cover and volume are decreasing with a warming climate, the open-water season at the periphery of the Arctic Ocean is lengthening and the circumpolar flaw lead is projected to enlarge and to last longer (Deming and Fortier, 2011). Ecosystem-wide enhancements in productivity are expected in these areas (Barber et al., 2012a).

Polynyas

Polynyas are large areas (10 - 90,000 km2) of permanently or frequently open water surrounded by thick sea ice (Barber et al., 2001b). Polynyas are generated by warm water input from below or by the action of strong winds that move away sea ice as soon as it is formed (Barber et al., 2001a; Tremblay and Smith Jr, 2007). Similar to the flaw leads, polynyas produce a lot of sea ice.

Polynyas are highly productive areas and hotspots of diversity compared to other ice-covered areas of the Arctic Ocean

Figure 21. Location of the Northwater Polynya between Greenland and Ellesmere Island in Baffin Bay in May/June (map from Campbell et al., 2005).

(Barber et al., 2001a). In most Arctic waters, low winter sun and a thick ice cover limit primary production. However, the open waters associated with polynyas permit phytoplankton blooms in early spring and, this increased algal production is reflected in high densities of zooplankton (Arrigo and van Dijken, 2004). They are a very important habitat for high densities of birds and mammals that use these areas for feeding, mating, spawning and over-wintering grounds (Barber et al., 2001b). This high productivity at all trophic levels is mirrored by a great export of carbon and nutrients to the seafloor at the end of the bloom season (Grant et al., 2002). Polynyas are also of special significance for air-breathing Arctic organisms (Heide-Jorgensen and Laidre, 2004). They form breathing holes for narwhal, beluga, walrus and seals species. Areas adjacent to polynyas can form suitable hunting ground for polar bears because of the aggregation of seals. Also numerous seabirds use polynyas for hunting and major winter bird colonies in the Canadian islands are located adjacent to polynyas (e.g. the North Water Polynya). Upwelling and vertical mixing of water masses entrain nutrients from below into the surface waters that can become rapidly exhausted in nitrate during blooms (Tremblay and Smith Jr, 2007). Polynyas are often described as polar oases. Archaeological records also show that Inuit used the shores of polynyas as a predictable food source since prehistoric times as Inuit settlements are often found in the vicinity of persistent polynyas (Henshaw, 2003; Pedersen et al., 2010).

The largest polynya in the LIA region is the North Water Polynya (NOW) in northern Baffin Bay between Canada and Greenland (Figure 21). This polynya forms each spring and is the largest and most productive recurring polynya in the Arctic (Deming et al., 2002; Dumont, 2012). Its formation is due to a combination of factors: strong northerly winds blow the ice downstream of an ice bridge that forms at the constriction point between Greenland and Ellesmere Island, leaving behind an area of open water (Dumont et al., 2010). The former Northeast Water polynya (NEW), off the northeast coast of Greenland, is no longer considered a polynya due to changed ice conditions (Kovacs and Michel, 2011). The NEW polynya was only moderately productive due to little replenishment of nutrients (Schneider and Budeus, 1995). Several polynyas smaller than the NOW can be found within the LIA region (Niemi et al., 2010).

Polynyas are dynamic features that vary in timing, extent and duration from year to year (Dumont, 2012). Moreover, a warmer climate associated with a reduction in thick sea ice cover may affect polynyas in different ways, although it is expected that they will more commonly decrease in duration (Smith Jr and Barber, 2007). For instance, trends over the last 4 decades show that the NOW polynya is occurring less frequently and break-up earlier. Also, its formation is due to the presence of thick sea ice and a slightly warmer Arctic winter could lead to its demise (Dumont, 2012). In contrast, the Wrangel Island polynya, located in the Chukchi Sea, has more than doubled in extent over the last 30 years (Moore and Pickart, 2012). New polynyas could be generated at other sites (Ingram and Carmack, 2006). Species reliant on polynyas will need to adapt where they go and when if they are to remain connected to these areas. Alternatively, they will have to adapt to less productive habitats (Ingram and Carmack, 2006).

Ice shelves

Ice in bays and fiords can become very thick since less dynamic conditions in wind and current, compared to offshore, have permitted ice growth over periods lasting from tens to thousands of years. Ice shelves are defined as thick (> 10 m) ancient ice attached to the coastline (multiyear landfast sea ice) and floating on the sea (Veillette et al., 2008). Ice shelves are in hydrostatic equilibrium with the ocean and hence, only 10% of their total thickness is emerging above sea level (freeboard) (Mortimer, 2011). Ice shelves are a predominant feature of the Antarctic, where they border 55% of the coastline (Dowdeswell and Jeffries, 2011), but they are also present in the Arctic (Eurasian High Arctic, Greenland

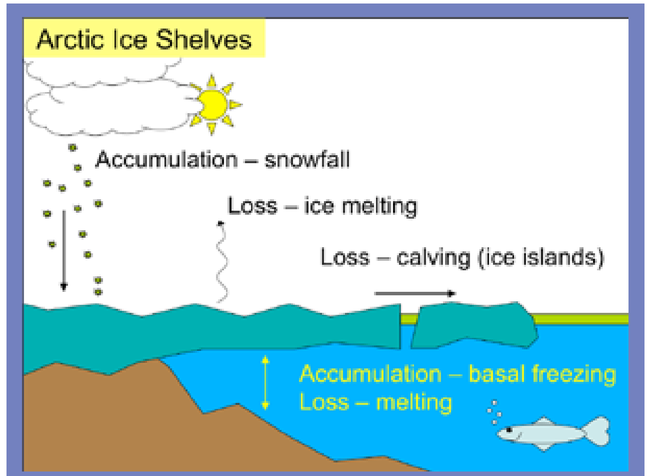


Figure 22. The formation and loss processes of most Canadian Arctic ice shelves (figure courtesy of Derek Mueller).

and the Canadian High Arctic) (Dowdeswell, 2011). In the Canadian High Arctic, ice shelves are found on the northern coastline of Ellesmere Island. These are formed, on the underside, by the accretion of basal ice and, on the upper side, by the accumulation of ice from snow and rain precipitations. Ice shelves loss processes include melting and calving events that create ice islands (Jeffries, 2011; Figure 22). In Greenland and Antarctic, however, ice shelves are composed of the floating extensions of glaciers floating off the continents (Williams and Dowdeswell, 2001).

Ice shelves along the northern coastline of Ellesmere Island have undergone rapid attrition of more than 90% in extent over the last decades. At the beginning of the 20th century, a single ice shelf covering around 8,900 km2 was reported to fringe this coastline (Vincent et al., 2001). This ice shelf subsequently deteriorated into several smaller ice shelves and accelerated major changes occurred since 2000 (Mueller et al., 2008; Vincent et al., 2011). At the end of the summer of 2008, there were four remaining main ice shelves in Canada, totalling an area less than 675 km^2 (Figure 23; Mueller et al., 2008; Vincent et al., 2011). In addition, the Ward Hunt Ice Shelf, the largest of the four, has undergone substantial fractures during the summers of 2010 and 2011 (W. Vincent, pers. comm.). Milne Ice Shelf is now the thickest in Canada with a maximum thickness over 90 m and a mean thickness of 55 m (Mortimer, 2011). Warmer air temperature, by controlling ice melt, is playing a role with the numerous calving events and the disintegration of the remnant ice shelves. Offshore winds also move fractured ice away from the coast and no longer provide a barrier to the waves that batter the ice shelves (Copland et al., 2007; Mueller et al., 2008; Veillette et al., 2008). The decline in the number, thickness and area of Canadian ice shelves may be irreversible given the current and projected climate warming and that multiyear landfast sea ice is also decreasing along the northern coastline of Ellesmere Island (Copland et al., 2007).

Ice shelves provide the physical structure for unique ecosystems. Cold-tolerant microbial communities occur in association with sediments on the ice shelves' surface (Mueller et al., 2006). The surface morphology of ice shelves is characterized by undulations parallel to the coast that would be caused by the alongshore winds (Figure 24; Hattersley-Smith, 1957). During the summer, meltwater flows in the troughs of these undulations and creates long (up to 15 km), thin (10-20 m), and shallow lakes (maximum of 3 m)

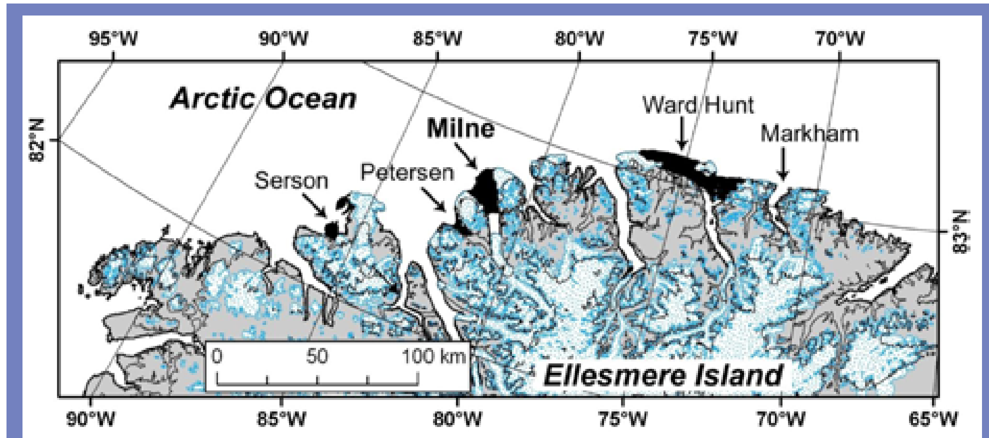


Figure 23. Map of the northern coastline of Ellesmere Island showing the location of the 4 remnant ice shelves at the end of summer 2008 (note that Markham Ice Shelf is completely lost)(figure courtesy of Warwick Vincent).

Figure 24. The Ward Hunt Ice Shelf in August 2008 when the characteristic undulations were clearly visible (proto credit: J. Veillette).

that are also characterized by their microbial mat communities (Mueller et al., 2006). DNA profiling demonstrated that the mat microbial communities were composed of all three domains of life (Bacteria, Archaea and Eukarya) and viruses (Varin et al., 2010, 2012). Moreover, when an ice shelf completely dams a fiord or an embayment, a lake called "epishelf" may be formed on the landward side (Veillette et al., 2008). These ice-dammed lakes are highly stratified since a layer of freshwater from snow and ice melt floats on top of sea water. These waters do not mix because of their different densities, and because the perennial ice cover stops wind from mixing them (Veillette et al., 2008). There is currently only one known remaining Arctic epishelf lake, in Milne Fiord (Veillette et al., 2011). Ice shelves and their associated epishelf lakes are vulnerable Arctic ecosystems that have become extremely rare and will likely become extinct in the coming decades (Veillette et al., 2011).

MARINE BIODIVERSITY

The Arctic Ocean provides diverse habitats for a multitude of unique life forms highly adapted in their life history, ecology and physiology to the extreme and seasonal conditions of this environment. The logistical challenges imposed by the harsh Arctic environment limit our knowledge of the marine biodiversity. This is especially true for the High Arctic where biological data are sparse and almost nonexistent for some habitats (e.g. the benthos) (Piepenburg et al., 2011).
Arctic marine food webs and productivity

This section first presents information on Arctic marine food webs and productivity. Then, the biodiversity of the different Arctic Ocean habitats (in the ice, in the water column and on the seafloor) is discussed. The biodiversity of fish, marine mammals and seabirds, and the description of key species is then presented. Finally, the impacts of climate change for marine biodiversity are tackled since they are likely to affect all Arctic life on top of, within and beneath the ice, and also in the open water and on the ocean floor. A special emphasis is placed on the LIA region.

Overall, it is predicted that there will be more life but that it will be less diverse (Fortier et al., 2012). Only organisms that are adapted to low temperatures, strong seasonality, a perennial or seasonal ice cover, limited nutrients in the stratified surface layer of the water column and a pulsed annual cycle of primary production have survived in the extreme climate of the Arctic over the last 3.5 million years. These Arctic specialists are now being challenged by more productive southern species that will migrate north. This is because individuals can inhabit areas within their preferred metabolic temperature tolerances. The southern generalists grow faster, are more fertile and achieve higher survival rates since they never had to adapt to the hostile Arctic conditions. It is predicted that these generalists will outcompete the native, specialist species (Fortier et al., 2012). Relationships among species are changing too, with new predation pressures and shifts in diets recorded for some animals.

ARCTIC MARINE FOOD WEBS AND PRODUCTIVITY

Structure of Arctic marine food webs

Arctic marine food webs comprise the interconnections between microbes, algae and animals (Figure25). Primary producers (ice algae and phytoplankton) support the base of the Arctic marine food web. They convert the energy from the sun into food energy. Then, zooplankton, such as copepods, and bacteria graze on these primary producers. In turn, carnivorous zooplankton, fish (Arctic cod) and whales feed on zooplankton. Arctic cod are the main food source of seals. Top predators such as humans, polar bears, seals and whales are then generally feeding on a combination of different species. Detritus, which typically includes the bodies or fragments of dead organisms as well as fecal material and nutrients, sink to the sediments where they support invertebrates and microbial communities. The relatively short growing season implies that consumers have a narrow window of opportunity to grow and accumulate energy reserves for winter survival and/

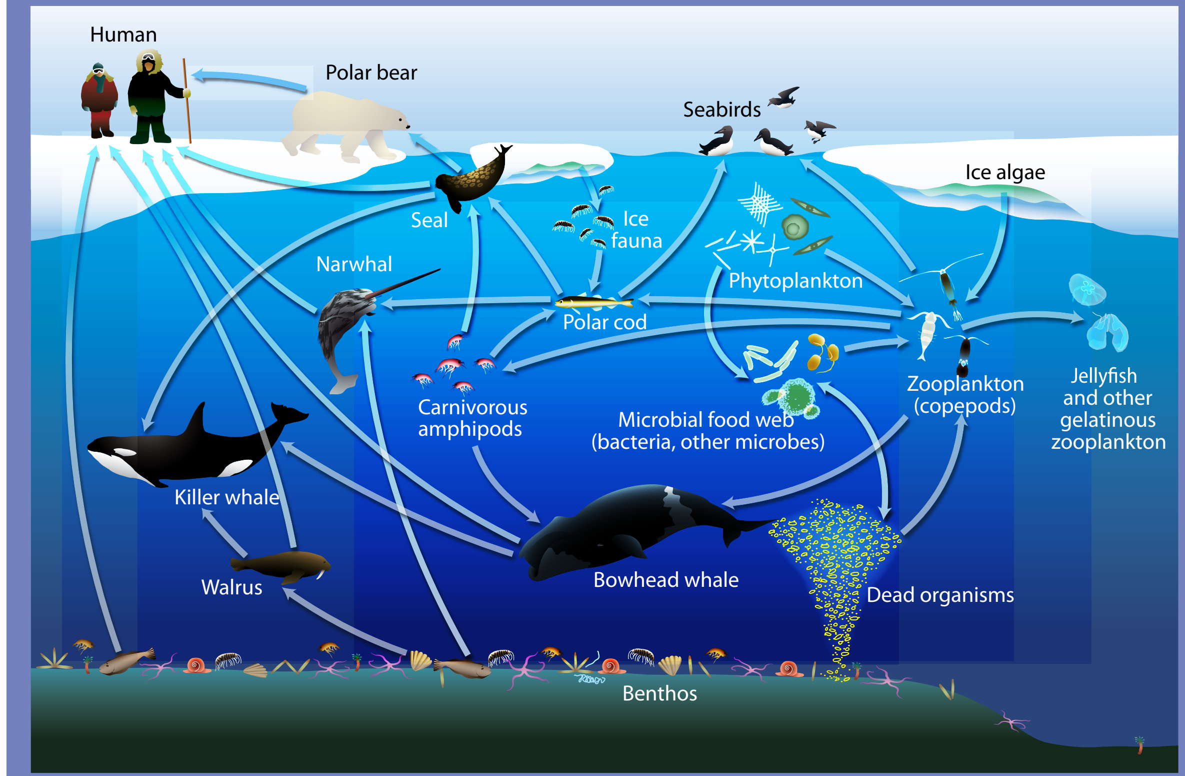


Figure 25. Representation of an Arctic marine food web (Darnis et al., 2012)

or reproduction. Arctic marine food webs involve numerous pathways but are not considered complex compared to the food webs of more temperate systems. These food webs are considered vulnerable to perturbations (de Santana et al., 2013).

Primary production

Primary production determines the amount of food that is available to consumers. Also, primary producers, by fixing the greenhouse gas CO_2, help to reduce its burden in the atmosphere since sinking algae and detritus remove carbon from the surface waters (a process known as the biological pump). Primary production in the Arctic Ocean depends on light and nutrients (i.e. nitrate is usually limiting). It starts with the growth of ice algae as soon as a critical amount of light reaches the ice-water interface in spring. Since snow cover strongly attenuates light penetration, it influences the timing of ice algal growth. Ice algal production then blooms and ice algae synthesize fats. At the onset of ice melt, fat-rich ice algae are released in the water column and provide high energy food for the zooplankton, and eventually to the seafloor, at a time when little food is available (Tremblay et al., 2012). Phytoplankton then take over as the dominant primary producers. The intensity of the late spring or early summer phytoplankton bloom is controlled by the availability of nutrients, which are readily depleted from the surface layer. The surface layer derived from ice melt is relatively less dense and restricts the mixing with nutrient-rich water from deeper waters. The primary production declines during summer and until the ice forms in the fall. A second bloom can occur in polynyas where ice growth is delayed (Tremblay and Smith Jr, 2007).

This classical view of the annual cycle of primary productivity in the Arctic Ocean, presented in the above paragraph, is challenged by some works that report phytoplankton blooms under the ice cover over continental shelves in Barrow Strait in the Canadian Arctic Archipelago (Fortier et al., 2002) and in other seas (Arrigo et al., 2012; Mundy et al., 2009; Strass and N thig, 1996). The recent thinning of the ice cover and the proliferation of melt ponds increase light transmission and make it possible for the required amount of light to reach underneath the ice (Arrigo et al., 2012). This suggests that under-ice phytoplankton blooms may be more widespread over nutrient-rich Arctic continental shelves and that satellite-based estimates of annual primary production in these waters may be underestimated by up to 10-fold (Arrigo et al., 2012).

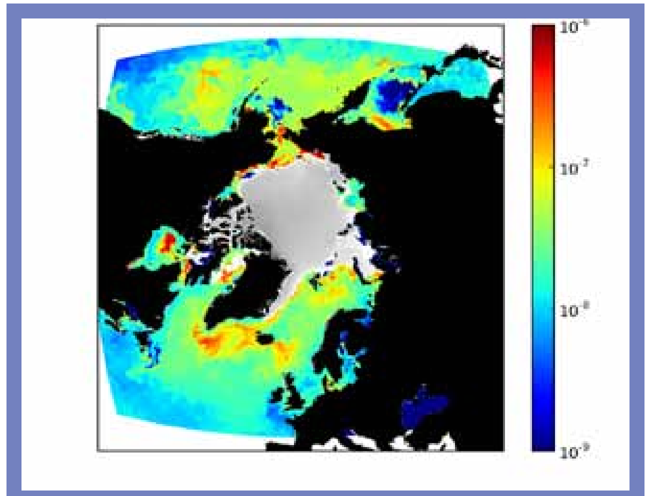


Figure 26. Annual pan-Arctic primary production taking into account the subsurface peaks in primary production (i.e. depth integrated primary production) using SeaWiFs based model for 1998-2007 (Hill et al., 2013).

Primary productivity is low in the Arctic Ocean and in the Canadian Arctic Archipelago compared to other oceanic environments located at lower latitudes (Niemi et al., 2010). This is explained by the reduced availability of light since the sun is up only during the summer and, the sea ice cover controls the amount of light that reaches the water column. Snow on the ice cover also contributes to reduce light penetration. Primary productivity is also extremely variable among different areas of the Arctic Ocean. Figure 26 illustrates the depth integrated primary production from 1998 to 2007. Depth integrated primary production is used since vertical profiles of primary production at many sites in the Arctic Ocean revealed persistent subsurface peaks during most of the summer period (Hill et al., 2013). Coastal seas account for 75% of annual integrated primary production while the central basin and Beaufort northern sea were the regions with the lowest annual integrated productivity, due to persistently stratified, nutrient-depleted and ice-covered conditions. The highest primary production is located in the northern Bering Sea and southern Chukchi Sea, and this is explained by the more nutrient-rich waters of the Pacific Ocean compared to the Atlantic Ocean. The overall LIA region is moderately productive with the NOW polynya being a hotspot of primary productivity (Figure 26). This variation in primary productivity in the Arctic Ocean is influenced by latitude, seasonal and multiyear sea ice and snow cover, depth and stability of the surface mixed layer, discharge of inorganic sediments (causing light attenuation) and nutrients from rivers and water circulation patterns (Gosselin et al., 1997; Pabi et al., 2008). Ice algae contribute around 60% of the entire primary production (sea ice and water column) in the central Arctic Ocean but only 3% in the coastal seas (Gosselin et al., 1997). However, primary productivity within and under the sea ice may increase with higher light transmission through thinning sea ice (Boetius et al., 2013). Primary productivity in the coastal seas and in the deep central basin are also very different in terms of timing and composition (Tremblay et al., 2012).

BIODIVERSITY IN THE SEA ICE

The sea ice cover is a dynamic living system. It is a substrate for diverse and abundant organisms that thrive in sea ice (Figure 27; Krembs and Deming, 2011). The sea ice biota consists of a complete food web and observed taxa include viruses, archaea, bacteria, protists, and multicellular organisms (worms and crustaceans small enough to navigate the brine channels) (Bluhm et al., 2011b). Microorganisms, nutrients and other constituents are incorporated into sea ice as the ice is formed. Larger organisms are selectively scavenged from the water column into the sea ice at the time of its formation (Kovacs and Michel, 2011). Sea ice organisms are assumed to be the founding members for the development of the ice-algal bloom that occurs in spring with the seasonal increase in solar radiation.

Multiyear and first-year sea ice communities differ substantially (Bowman et al., 2012). First-year ice supports more organisms than multiyear ice. This is due to the greater presence of pores and brine channels that offer more habitats than does multiyear ice (Kovacs and Michel, 2011). Dramatic decreases in the extent of Arctic multiyear ice suggest that this environment may disappear in the next decades and be replaced by ecologically different first-year ice (Bowman et al., 2012). This may result in higher biomass of sea-ice associated organisms available for upper trophic levels before light reaches the surface waters in spring (Poulin et al., 2011).

Sea ice is important as a habitat for photosynthetic algae. They can be present on the upper and lower surfaces of the ice as well as within it. However, in the Arctic, sea ice algae flourish mainly at the ice-water interface (Kovacs and Michel, 2011). Ice algal communities in the Canadian Arctic Archipelago are diverse (Michel et al., 2006). Marine single celled eukaryote (algae and other non-autotrophic organisms) associated with sea ice were recently surveyed and the authors

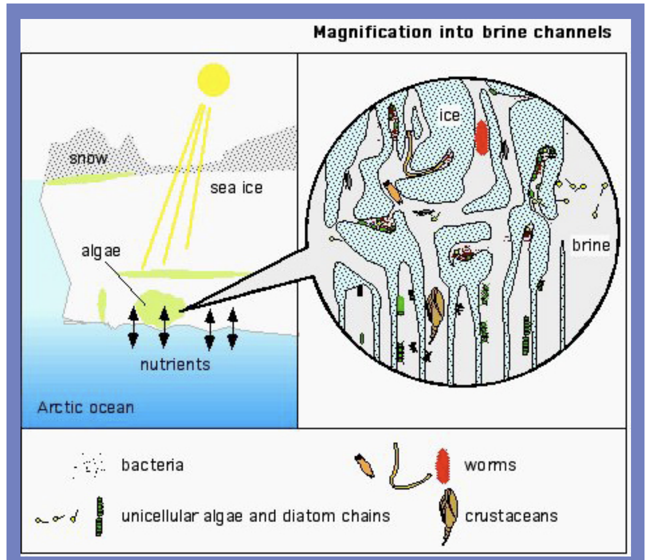


Figure 27. The flourishing life within the briny habitat of sea ice. The ice specific ecosystem includes bacteria, viruses, unicellular algae, diatom chains, worms and crustaceans (from www.arctic.noaa.gov).

reported 1,027 taxa (Poulin et al., 2011). Many of the invertebrates within the ice feed on ice algae. Invertebrates and fish feed on ice algae on the underside of the ice when the water column does not support phytoplankton growth. Ice algae are grazed by zooplankton when they are released from the ice cover and by benthic communities if they sink to the sediments. Some algal species, such as the diatom *Melosina arctica,* grow meter-long filaments that are not used as food by zooplankton and sink rapidly to the seafloor. A recent cruise reported widespread deposition of this ice algae to the deep seafloor of the central Arctic basins and feeding by opportunistic megafauna (Boetius et al., 2013).

WATER COLUMN BIODIVERSITY

The open water of the Arctic Ocean harbours a multitude of habitats that include coastal and oceanic regions, downwelling or upwelling areas and polynyas. The water column food web is composed of phytoplankton, zooplankton, bacteria and archaea, and other tiny organisms such as various animal larvae and other floating animals like jellyfish. "Plankton" describes the organisms that are drifting with the currents in contrast to other pelagic organisms that are able to propel themselves (e.g. fish and whales). "Phytoplankton" comprises single-celled algae that mostly photosynthesize and other protists between 0.2 and 200 µm (Poulin et al., 2011). "Zooplankton" are small animals that feed on other zooplankton, phytoplankton or particles of organic matter. Many common phytoplankton and zooplankton species are not Arctic specialists and are also found in other oceans (Bluhm et al., 2011b).

Phytoplankton

A recent pan-Arctic assessment of marine phytoplankton reported 1,874 single-celled types (Poulin et al., 2011). This number is indicative of a well-diversified group of organisms (Poulin et al., 2011). Pennate and centric diatoms, dinoflagellates and prymnesiophytes are the most frequently reported marine phytoplankton groups in the Arctic (Poulin et al., 2011). The vast majority of the identified micro-organisms consist of large cells (>20 µm) because of the magnification capability of light microscopy. Recent major technological advances in molecular biology permitted identification of most major groups of marine microbes in the three domains of life (Bacteria, Archaea and Eucarya) in Arctic marine waters (Lovejoy et al., 2011). Communities of phytoplankton are dynamic and change with the seasons (Terrado et al., 2009).

Climate change has already had impacts on phytoplankton communities. The warming and freshening of the surface layer lead to increased stratification and nutrient depletion. Small picoplankton, being very small (<2 µm diameter), have a large surface-area-to-volume ratio that provides effective acquisition of nutrients as well as hydrodynamic resistance to sinking. Hence, these small cells are thriving and displace the larger cells (Li et al., 2009). Increased ice-free conditions may also favour and extend northwardly the intrusion of Atlantic phytoplankton species (Hegseth and Sundfjord, 2008).

Zooplankton

Zooplankton communities are much better characterized than phytoplankton communities. Despite a relatively low sampling effort, they reveal a surprisingly high diversity (Darnis et al., 2012). The inventory of Arctic metazoan (multicellular) zooplankton is around 350 species with nearly 200 species largely restricted to the shelves and 174 listed from the central basins (Bluhm et al., 2011b; Kosobokova et al., 2011). Arctic crustaceans dominate in terms of species number with copepods being the most diverse group, followed by the Cnidaria. However, zooplankton diversity of the Arctic has not been exhaustively characterized (Archambault et al., 2010). As climate change modifies oceanographic conditions, the number of zooplanktonic species will likely increase in this region (Archambault et al., 2010).

Large suspension feeders, such as the copepods Calanus glacialis and Calanus hyperboreus, dominate the biomass of zooplankton in the Arctic (Darnis et al., 2012). These species feed on large phytoplankton and build huge lipid reserves that are essential for all animals, making them key drivers of the transfer of energy through Arctic marine ecosystems. These species perform long-range seasonal vertical migrations to depths of several hundred meters where the late developmental stages overwinter (Darnis et al., 2012). Small, numerically dominant copepods (Oithona similis, Triconia borealis, Pseudocalanus spp., and Microcalanus spp.) are active year-round and feed opportunistically throughout the winter on variable food sources (Darnis et al., 2012).

SEAFLOOR BIODIVERSITY

The benthos is the community of organisms dwelling on the seafloor. Arctic benthos ranges from unicellular life in the spaces among sediment particles to large invertebrates (Figure 28). The Arctic seafloor presents a multitude of habitats that include intertidal areas, fiords, estuaries, an expanded shelf zone, and the deep sea with several basins separated by deep sea ridges (Josefson and Mokievsky, 2013). At smaller scales, benthic areas contain different sediment habitats such as sand and mud as well as harder substrates like boulders and bedrocks. Nearshore locations are affected by ice scouring and present impoverished benthic diversity. Macroalgae (seaweed) are found in shallow waters.

Much remains unknown about what species are found in the Arctic benthos, particularly in deep waters, where new species are still being described and where half of the species were observed at only one or two locations (Bluhm et al., 2011a). An inventory of benthic species colonizing the central Arctic deeper than 500 m resulted in 1,125 species (Bluhm et al., 2011a). Crustaceans, foraminifers, annelids and nematodes dominated this inventory. A recent study on macrofauna (large enough to be retained on sieves with a mesh size of 0.5 mm, mostly fauna that live in the mud) and megafauna (larger than 1 cm, mostly live on the surface of the substrate and are visible on seafloor images) colonizing the seafloor of Arctic shelves suggest an intermediate biodiversity (Piepenburg et al., 2011). A total of 2,636 species were listed and the highest species numbers were for crustaceans, annelids, molluscs and echinoderms (Piepenburg et al., 2011). The authors of this work also estimated that the entire benthic macro- and megafauna (excepting fishes) of the Arctic shelves could number

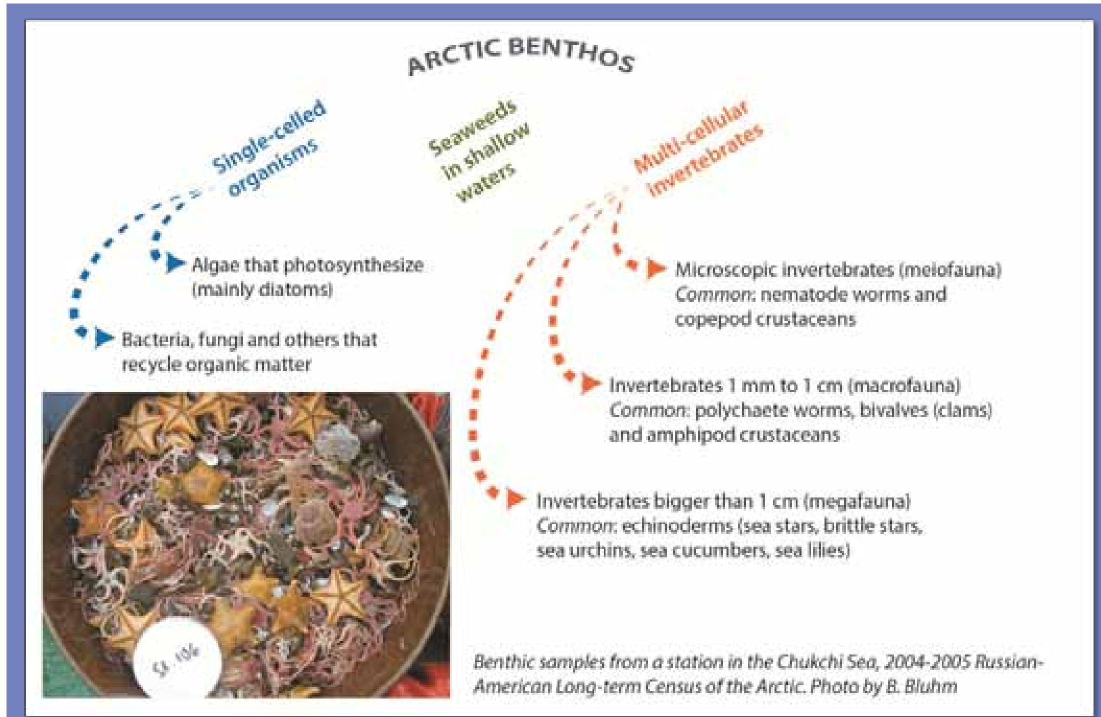


Figure 28. Arctic seafloor diversity (CAFF, 2013b).

up to 4,700 species (Piepenburg et al., 2011). It is worth noting that the number of reported benthic species is influenced by the sampling methods and the sampling frequency. Bacteria and algae (in shallow waters) are also present on the seafloor (Bluhm et al., 2011b).

Most benthic communities are supported by the food supplied from the water column. Plankton, ice algae, and organic matter sink through the water column and fuel benthic food webs. Amounts of phytoplankton and zooplankton production and the timing of algal blooms and peak zooplankton production are important to determine the coupling of the benthic and pelagic communities (see section Arctic marine food webs and productivity). The location, timing and duration over which food from the water column drifts to the seafloor affects the distribution and biomass of benthic communities. For instance, the NOW polynya has high primary production and tends to be associated with enriched benthic biomass due to a longer period over which the benthos receive food (Darnis et al., 2012; Grant et al., 2002). The macrofauna and megafauna of the Arctic shelves provide major feeding grounds for fishes, mammals and seabirds.

It is expected that the benthic fauna may show increased diversity, due to a combination of anticipated increased food availability and immigration of faster-growing species adapted to warmer waters in the southern areas of the Arctic (Josefson and Mokievsky, 2013). Moreover, fisheries of commercially relevant species might become more important in the LIA. Commercial shrimp fisheries for Northern (*Pandalus borealis*) and striped (*Pandalus montagui*) shrimp began in the late 1970s off Baffin Island and expanded southward to the area of Resolution Island (Hudson Strait) in the mid-1990s, where the main fishery remains to date (DFO, 2008). The Northern shrimp is the most important marine resource in Greenland, and represents 70% of the total fisheries revenues (Dahl-Jensen et al., 2011). The snow crab fishery is also important in Greenland (Boertmann et al., 2009).

FISH

Nearly 250 marine fish species are known from the Arctic Ocean, but this number rises to 633 fish species if the adjacent Arctic seas are included (Christiansen and Reist, 2013). These 633 species represent 2.2% of the fish species on the

Figure 29. Arctic cod, Boreogadus saida.

planet (Christiansen and Reist, 2013). Of these, 63 species are restricted to Arctic waters (Christiansen and Reist, 2013). Hence, polar seas are considered species-poor compared with more temperate latitudes. Most Arctic marine fishes are living on or closely associated with the seafloor (benthic and demersal fish respectively).

Two species can at times be closely associated with sea ice, using it as ha bitat, protection from predators and a place to spawn: Arctic cod (*Boreogadus saida*, also called polar cod) and ice cod (*Arctogadus glacialis*) (Christiansen and Reist, 2013). Arctic cod is considered as a keystone species and is particularly abundant and widespread in marine waters throughout the Arctic (Christiansen and Reist, 2013). It is the dominant fish on the Arctic shelves and the central element of the pelagic food web of the Arctic Ocean (Welch et al., 1992). They feed mainly on copepods, amphipods and mysids (small shrimp-like animals), and they play a key role in the diet of many Arctic marine mammals, seabirds and fish. The distribution of Arctic cod varies seasonally in habitats ranging from coastal brackish waters to regions deeper than 200 m, and from just above the seafloor to under sea-ice habitat. They can occur in a dispersed state all year round but schools often appear in nearshore waters during summer (Welch et al., 1992). Large schools of Arctic cod are present at the productive ice edge during late spring-early summer where they would hide from predators (Gradinger and Bluhm, 2004) and to feed on zooplankton and other ice-associated taxa (Bradstreet and Cross, 1982). Northward shifts in marine boreal fish distribution have already been documented as a consequence of climate warming (Renaud et al., 2012). The native Arctic cod is therefore starting to be challenged by more productive southern species on its territory. Arctic cod is also dependent on zooplankton for food. The changes in sea ice will likely affect the developmental life cycles of zooplankton and thereby, influence the diet composition of Arctic cod. The ice cod is much less abundant and it primarily found in fiords and Arctic shelves (Christiansen and Reist, 2013).

Other common marine fish species include the Greenland halibut (*Reinhardtius hippoglossoides*), sculpins (Cottidae) and the Greenland shark (*Somniosus microcephalus*). The Greenland halibut is a Subarctic and Arctic species and occurs in deep water along continental slopes. It is a flatfish but it lives and feeds mainly in the water column. Sculpins are benthic fishes that occur in many types of habitats and they are found mostly in shallow waters. Their pectoral fins (i.e. fins located on each side of the body) are smooth on the upper edge and webbed with sharp rays along the lower edge, which make them well adapted for gripping the seafloor substrate. Sculpins are a important food source for other fishes but are not consumed by humans. The Greenland shark is the northernmost species of shark and is native to the North Atlantic Ocean and waters around Greenland and Iceland. This shark species is large (up to 7 m in length). It feeds mostly on other fishes but also sometimes on seals. Greenland sharks occupy deep environments where the temperature is cold and they swim very slowly. The flesh of this shark is poisonous unless it is boiled in several changes of water, dried or fermented.

Herring and Greenland halibut are important for subsistence fishing in the Canadian Archipelago (Niemi et al., 2010) and essential to the economy of Greenland (Tejsner and Frost, 2012). There is commercial fishery adjacent to the LIA. Greenland halibut is fished commercially since 1986 in Cumberland Sound (in southwest Baffin Island) (see references in Niemi et al., 2011) and around Greenland (Kovacs and Michel, 2011). This Arctic species is expected to decline in response to warming temperatures (Albert and H ines, 2003). Atlantic cod (*Gadus morhua*) is also fished around Greenland (Kovacs and Michel, 2011). This species is a former boreal species and has been observed in increasing densities recently (Berge et al., 2008). As the sea ice retreat and ocean waters warm, this species will likely spread northwards and may lead to greater populations and enhanced fisheries values (Christiansen and Reist, 2013; Drinkwater, 2005). Newly opened waters will become accessible for commercial fishing. The LIA region may become more important for several marine fish species. However, while enhanced primary productivity could result in increased fish harvests for Northerners, it will probably be insufficient to sustain large-scale commercial fisheries in the Canadian Arctic (Tremblay et al., 2012).

The impacts of climate change and of Arctic fisheries on Arctic marine fish will act in concert. New commercial fisheries in the Arctic are imminent and they will affect species of boreal origin that are already commercially harvested, and fishes native to Arctic waters (Christiansen and Reist, 2013). A warmer ocean will cause shifts in fish distribution as they are very sensitive to changes in water temperature, although different species and life stages will respond in different ways (Christiansen and Reist, 2013). Nevertheless, the invasion of boreal fish species into Arctic waters has already started (Renaud et al., 2012). There are currently 59 species that are fished in the Arctic and sub-Arctic waters (Christiansen and Reist, 2013). Demersal fish are collected by bottom trawls, affecting significantly the sea bed and producing considerable bycatch of non-targeted fish (species and sizes not desirable by the industry) (Christiansen and Reist, 2013).

Seabirds

Seabirds are birds that frequent coastal waters and the open ocean. Loons, petrels, cormorants, jaegers/skuas, gulls, terns and auks are all seabirds. Seabirds are important components of Arctic ecosystems, and are culturally and economically important for local communities. They are also frequently used as indicators of environmental changes. The Arctic is an important region for seabird diversity. Forty-four species of seabirds breed in the Arctic (Gaston, 2011). Twenty-three occur in the High Arctic and forty-one in the Low Arctic. Fifteen species have a circumpolar distribution. West Greenland (24 species) and eastern Canadian Arctic (Nunavut, northern Quebec and Labrador, 22 species), are recognized as biodiversity hotspots (Gaston, 2011). Many seabirds are very conservative in their breeding sites. The 42 species can be found within LIA.

Large breeding colonies of seabirds can be found on cliffs and islands and some are associated with highly productive areas such as the North Water Polynya. Major breeding seabird colonies of the Canadian portion of LIA include Prince Leopold Island (murres, kittiwakes, fulmars and guillemots), Coburg Island (Thick-billed Murres and Black-legged Kittiwakes), Cape Hay and Cape Graham on Bylot Island (thousands of seabirds and geese), Hell Gate and Cardigan Strait (Black Guillemot, Northern Fulmar, Common Eider), eastern Devon Island (Ivory Gull, Iceland Gull and Glaucous Gull colonies), Hobhouse Inlet on Devon Island (Northern fulmar), Cape Liddon and Radstock Bay on Devon Island (Northern fulmar), Baillie-Hamilton Island (Black-legged Kittiwakes), and Browne Island (Black-legged Kittiwakes) (Figure 30). Breeding seabird colonies are present in northwest Greenland (Figure 30). Melville Bay (just south of the core area of LIA), has been explored in detail for breeding seabird colonies and this area revealed low density of breeding colonies and low numbers of breeding seabirds (Boertmann and Huffeldt, 2012).

Most Arctic seabirds have large population sizes and many species are represented by millions of individuals (Gaston, 2011). One exception is the ivory gull (Pagophila eburnea), an iconic seabird that inhabits the Arctic Ocean throughout the year, with less than 12,000 breeding pairs globally (Gilchrist et al., 2008). However, most Arctic seabird populations have shown declining trends in recent years (Gaston, 2011). Stressors to Arctic seabirds include overharvesting, fisheries activities, pollution and climate change (Gaston, 2011). The contribution of climate change to the decline in population

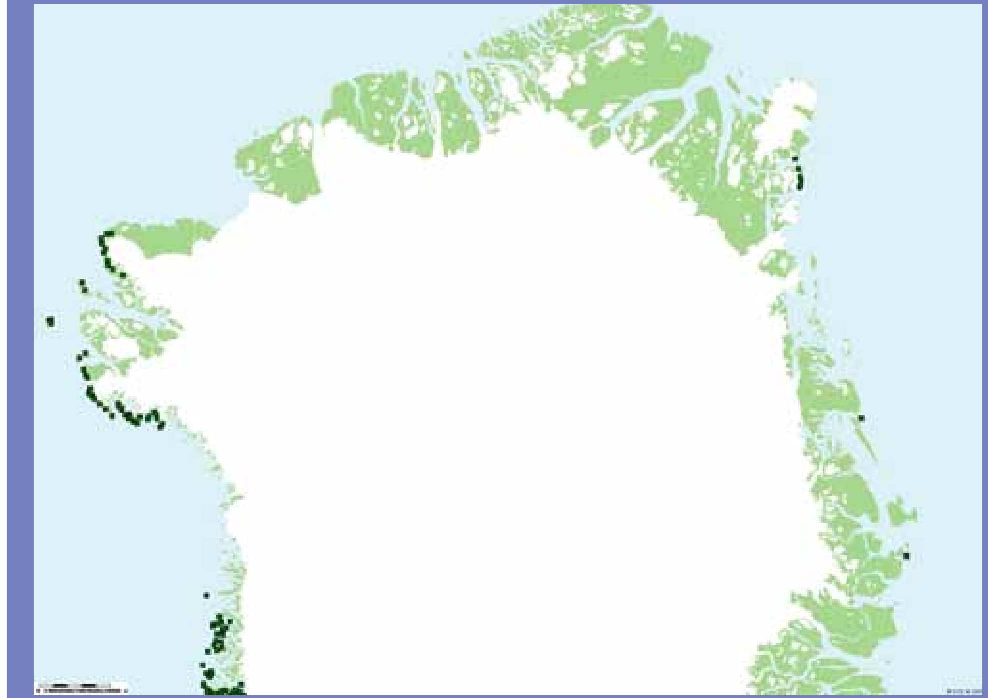


Figure 30. Seabird colonies in the Canadian and Greenlandic portions of the LIA.

Figure 31. Bird colony.

trends is generally linked to the food chain as seabirds rely on ice edges and polynyas as key foraging locations (see references in Gantner and Gaston, 2013). The timing of breeding initiation with seasonal peak food (mainly fish and invertebrates) is influencing the reproductive success. Changes in sea ice cover conditions also allow northward spread of predominantly temperate or Low Arctic species (see references in (Ganter and Gaston, 2013)) at the expanse of High Arctic species. Sea ice is also used as a platform for social activities and to escape from marine predators and for resting.

MARINE MAMMALS

Seven marine mammals species (three whales, three pinnipeds (fin-footed marine mammals) and polar bears) live in the Arctic all year long and many other species occupy Arctic waters seasonally. Arctic marine mammals use several specific types of ice habitats and feed on diverse food sources (Table 2). Changes in the Arctic climate may challenge the adaptive capacity of these species. Sea ice plays a crucial role for these animals either as platform, marine ecosystem foundation and barrier to non-ice-adapted marine mammals and human commercial activities (Moore and Huntington, 2008). A clear example is that reduction in sea ice cover removes the hunting platform of polar bear and likely reduces the survivorship of its primary prey, the ringed seal. The fitness of Arctic marine mammals is therefore influenced by sea ice effects on ecosystem structure and prey availability.

One approach to quantify marine mammal resilience to climate change is to classify them in regard to the species relationship to the ice (Moore and Huntington, 2008). Polar bear, walrus, bearded seal and ringed seal are classified as ice-obligate species since they are reliant on sea ice as a platform for resting, breeding or hunting. Harp seal, hooded seal, ribbon seal, spotted seal, beluga, narwhal and bowhead whale are ice-associated species since they are adapted to marine ecosystems of which ice is predominant. Fin, minke, humpback, gray and killer whales are seasonally migrant species that encounter sea ice in parts of their migration. Ice-obligate species are especially vulnerable to changes in the sea ice cover. The scenario for ice-associated species is harder to predict but decreases in the sea ice cover will have negative impacts on these species, except perhaps reduced risk of sea ice entrapment. The five migrant whale species are likely to benefit from loss in sea ice since the pelagic system will be more accessible.

Another approach to assess the sensitivity of marine mammals to climate change is to use an index that

Table 2. The diversity of ice habitats and prey items for Arctic marine mammals species (from CAFF, 2013).

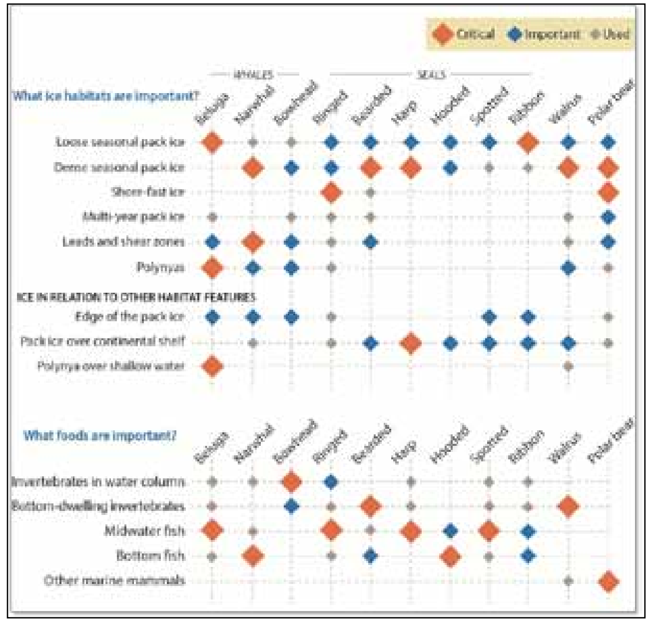


Figure 32.
© Clive Tesar / WWF

Figure 33. Bowhead whale.
© naturepl.com M. Homes / WWF

Figure 34. Beluga.
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Figure 35. Narwhal.
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includes the species narrowness of distribution and specialization of feeding in addition to the seasonal dependence on sea ice and reliance on sea ice as a platform to access prey and predator avoidance (Laidre et al., 2008). This index suggests that the hooded seal, the polar bear, and the narwhal are the three most sensitive Arctic marine mammal species, primarily due to reliance on sea ice and specialized feeding. The least sensitive species were the ringed seal and bearded seal, primarily due to large circumpolar distributions, large population sizes, and flexible habitat requirements.

Overall, climate change is forecast to have serious negative impacts on Arctic marine mammals by altering the seasonal patterns, the extent and the quality of sea ice habitat. Species seasonally occupying the Arctic might stay north longer, and compete for food resources with existing Arctic species. Also, temperate marine mammals are expanding their distribution northward, which is likely to cause competitive pressure on Arctic endemic species and to put them at greater risk of predation, disease and parasite infections (Kovacs et al., 2011).

Since the LIA is predicted to hold the last remaining ice during summer, the area is considered likely to become increasingly important for ice-obligate and ice-associated marine mammal species. This is why WWF is in discussion with Inuit and governments located in the LIA region in order to plan the future management of this area to help ensure the resilience of all life forms dependant on sea ice. This need has been recognized by the Arctic's pre-eminent intergovernmental forum, the Arctic Council. A recommendation of the Arctic Biodiversity Assessment (CAFF, 2013a) states the importance of developing and implementing mechanisms to conserve Arctic biodiversity under the deteriorating trend of sea ice, glaciers and permafrost.

Whales

Only three whale species live year round in the Arctic (as defined by the boundary developed by the Arctic Council's working group, the Conservation of Arctic Flora and Fauna). These are the bowhead whale, a large baleen whale, and the narwhal and the beluga, which are middle-sized toothed whales. The bowhead whale and the beluga have a circumpolar distribution while the narwhal only occupy the Atlantic sector of the Arctic (Figure 36; Reeves et al., 2013). Thirteen other whales species (baleen whales: blue, fin, sei, humpback, minke, North Atlantic right and gray whales; toothed whales: sperm, Sowerby's beaked and killer whales, Atlantic white-sided and white-beaked dolphins, and harbour porpoise) seasonally occupy Arctic and Subarctic waters. The loss of summer sea ice cover is allowing an increasing number of killer whales to use the Canadian High Arctic as a hunting ground (Darnis et al., 2012). The stronger presence of this apex predator species will likely affect the populations of the bowhead whale, the narwhal and the beluga. The three Arctic whale species are described in the following paragraphs.

Bowhead whales (*Balaena mysticetus*) measure between 15 and 18 m and weigh up to 100,000 kg. They live in Arctic waters during summer but migrate to Subarctic seas during winter (Laidre et al., 2008). This whale species occurs within the LIA region in Baffin Bay and on the eastern side of the Canadian Arctic Archipelago (Figure 36). The global population size of bowhead whale would be over 20,000 individuals. The pre-whaling population of bowhead whales has been estimated at about 50,000 individuals (COSEWIC, 2009). Commercial whaling ended around 1910 having reduced the population to less than 3,000 animals. The bowhead whale is listed as "least concern" on the IUCN Red List, since the population appears to be increasing (Reilly et al., 2012). This whale species is well adapted to ice-covered waters and can move through areas of nearly solid ice cover. They prefer areas of low ice coverage in winter, presumably to reduce risk of ice entrapment while remaining within the ice (Ferguson et al., 2010). In contrast, during summer, these whales select high ice coverage regions to reduce risk of killer whale predation while providing enriched feeding opportunities (Ferguson et al., 2010). Bowhead whales also inhabit polynyas and the marginal ice zone during winter and early spring (Laidre et al., 2008). The bowhead whale is feeding on zooplankton throughout the water column including near the bottom (Laidre et al., 2008).

Belugas (*Delphinapterus leucas*) or white whales occur in estuaries, at the continental shelves and in deep ocean basins. They measure between 4 and 6 m and weigh between 900 and 1,300 kg. Belugas are divided in discrete populations around the Arctic, depending on their summering (fiords or estuaries, to which they show high fidelity) and wintering (shallow or coastal areas) grounds (see references in Laidre et al., 2008; Figure 36). DNA studies have indicated genetic differences between some of the populations (de March and Postma, 2003). The world wide population estimate is well over 150,000 animals and has been divided into 29 different populations (or stocks) by the International Whaling Commission (Jefferson et al., 2012a). This species is listed as "near threatened" on the IUCN Red List because there is large uncertainty about population numbers and trends over parts of the species range, and because its survival relies on na-

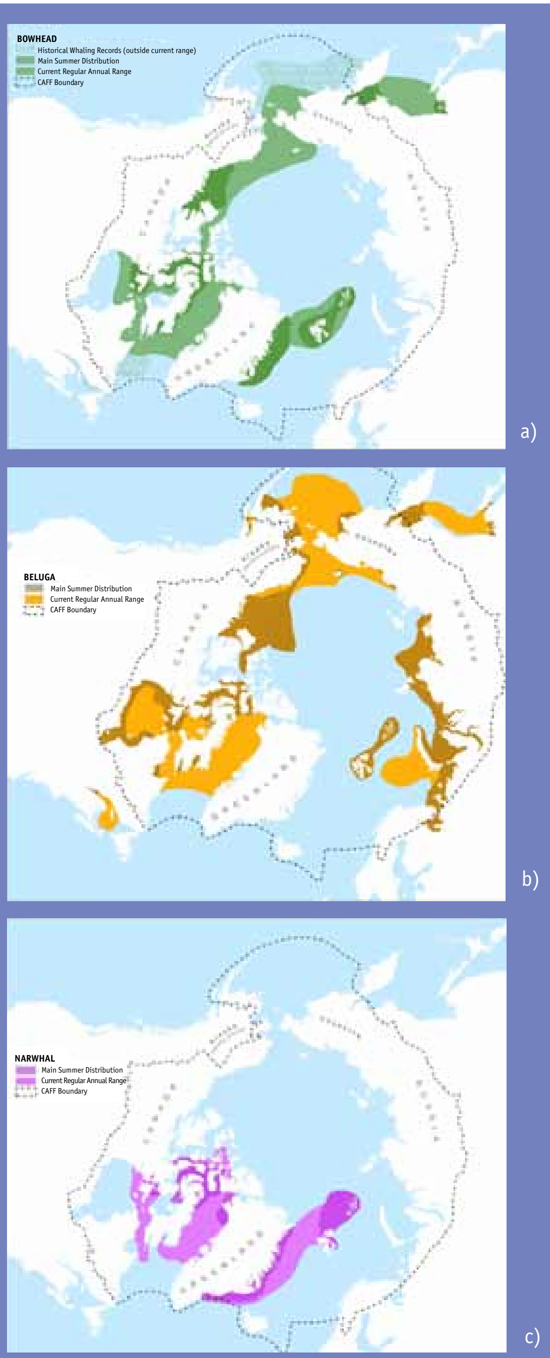

Figure 36. Distribution of a) bowhead whales, b) belugas and c) narwhals (Reeves et al., 2013).

tional and international conservation programs that monitor and manage hunting (Jefferson et al., 2012a).

The different populations of belugas are subject to different levels of threat which call for individual assessments (Jefferson et al., 2012a). Two populations are present within the LIA for at least parts of the year: the North Water winter (North Baffin Bay) stock, with an estimated population size of 21,213 belugas based on 1996 surveys (Innes et al., 2002) and the West Greenland winter stock, with an estimated population size of 7,941, based on 1998 and 1999 surveys (Heide-J rgensen and Aquarone, 2002). Ice edges serve as important feeding grounds for belugas as their predominant prey is Arctic cod.

Narwhals (*Monodon monoceros*) are medium sized (4 to 6 m, 1,600 kg) toothed whales that occupy waters of the eastern Canadian Arctic Archipelago, West and East Greenland, Svalbard and Franz Joseph Land (Figure 36). They are widely present in the LIA region. It is the Arctic whale with the most restricted distribution. Narwhals perform annual migrations over long distances. During summer, narwhals spend approximately two months in High Arctic ice-free shallow bays and fiords. They overwinter in offshore, deep, ice-covered habitats along the continental slope in more southern locations (Heide-J rgensen and Dietz, 1995). Narwhals feed mainly during winter on benthic organisms and Greenland halibut in offshore deep ocean basins (Laidre et al., 2008). The narwhal is listed as “near threatened” on the IUCN Red List, although there is uncertainty about numbers and trends in large parts of the species range and evidence of decline for specific subpopulations (Jefferson et al., 2012b). The total population is great-

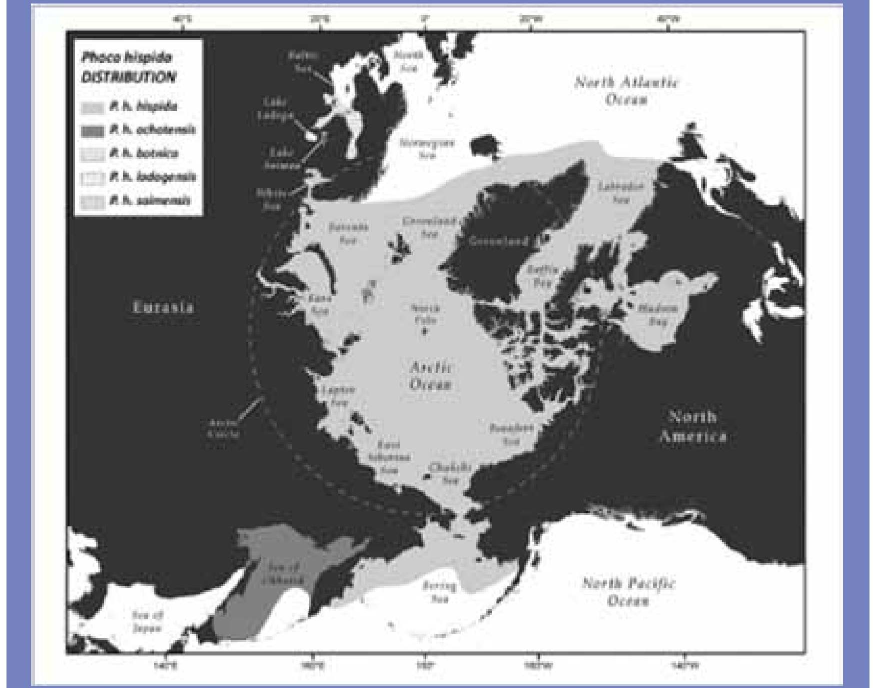

Figure 37. a)

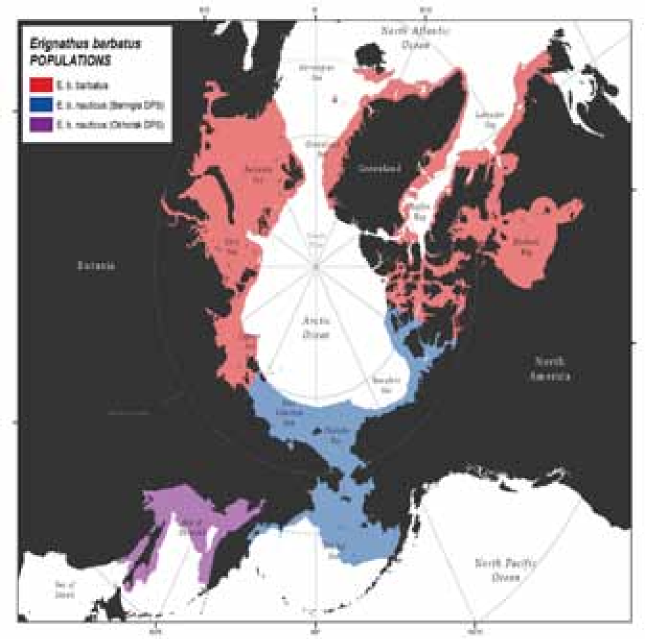

Figure 37. b)

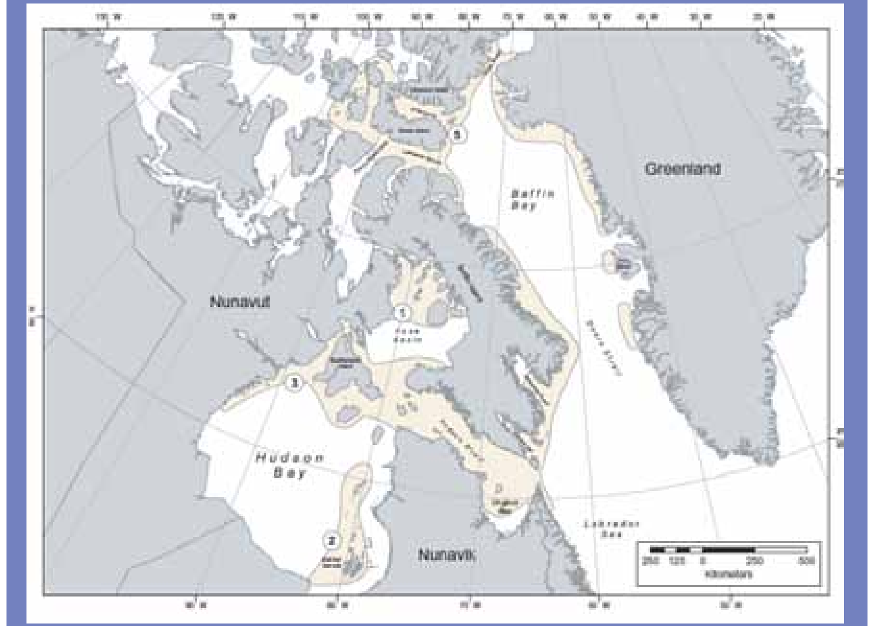

Figure 37. c)

Figure 37. Distribution of a) ringed seals (Kelly, 2001), b) bearded seals (Cameron et al., 2010) and c) walrus (Stewart, 2008).

Figure 38. Ringed seal.
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er than 80,000 individuals (Jefferson et al., 2012b). Narwhals are the most ice-associated whales: they are found in dense pack ice and are highly dependent on leads and cracks in the ice during migrations (Laidre et al., 2008).

Pinnipeds

Arctic ice-obligate pinnipeds with a circumpolar distribution are the ringed seal, the bearded seal and the walrus (Laidre et al., 2008). Other seal species that can be found in Arctic waters are the spotted seal, the common seal, the harp seal, the ribbon seal and the hooded seal (Greenland Institute of Natural Resources, 2012; Laidre et al., 2008). These latter species depend on sea ice only for some parts of their life cycle, especially for birthing, molting, mating and resting during spring. In contrast to Arctic ice-obligate species, they are not year round in the Arctic and they rely on sea ice only seasonally. The ribbon seal and the spotted seal only occur in the Bering, Chukchi and Okhotsk seas while the common seal, the harp seal and the hooded seal occur only in the North Atlantic (Greenland Institute of Natural Resources, 2012; Laidre et al., 2008). The three Arctic ice-obligate seal species found year round in the Arctic occur within the LIA region, but only ringed seals are reported to occur along the northern coastline of the Canadian Archipelago and Greenland (Figure 37). These are briefly described in the next paragraphs.

The ringed seal *(Pusa hispida*) is the most common and widely dispersed marine mammal of the Arctic. It is the smallest of the seal species (up to 1.65 m and up to 70 kg) and they get their name from the light-coloured circular patterns that appear on their darker grey back. The species has a circumpolar distribution (Figure 37)

Figure 39. Bearded seal.
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Figure 40. Walrus.
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and is the only seal species that is able to occupy large areas of consolidated sea ice, since they are able to maintain breathing holes (Norwegian Polar Institute, 2013). They are dependent on sea ice for all aspects of their lives: for giving birth, as a staging area for breeding, for moulting, resting and aquatic predator avoidance (Norwegian Polar Institute, 2013). Landfast ice over the continental shelves would be their favoured habitat for breeding and giving birth (Laidre et al., 2008). The ringed seal is listed as "least concern" on the IUCN Red List (Kovacs et al., 2008). Five subspecies are recognized: Arctic Ringed Seal (*P. h. hispida*), Baltic Sea Ringed Seal (*P. h. botnica*), Lake Ladoga Ringed Seal (*P. h. ladogensis*), Lake Saimaa Ringed Seal (*P. h. saimensi*), and Sea of Okhotsk Ringed Seal (*P. h. ochotensis*). The global population estimate would be between 3 and 8 millions but the population size of the different subspecies varies greatly (Kovacs et al., 2008). Climate change, contaminants and by-catch in fishing gear are the current threats to this species (see references in Kovacs et al., 2008). Ringed seals feed on Arctic cod and a variety of large zooplankton (crustaceans) under the ice or in the first 50 m of the water column (Laidre et al., 2008). Ringed seal are a keystone species in the Arctic since they compose the majority of the polar bear diet, especially in spring, and they are a major food source for Arctic communities (Norwegian Polar Institute, 2013).

The bearded seal (*Erignathus barbatus*), named so because of their long whiskers, measure between 2.0 and 2.5 meters and weigh between 260 and 360 kg. They have a circumpolar distribution and two subspecies of bearded seals are widely recognized: *E.b. barbatus* in the Atlantic sector, and E.b. nauticus in the Pacific sector (Figure 37). Only the subspecies *E. b. barbatus* can be found in the LIA. A minimum estimate for Canadian waters of 190,000 animals was suggested (Cleator, 1996) and no clear population numbers are available for the Greenlandic waters. The species is listed under the category of "least concern" on the IUCN Red List (Kovacs and Lowry, 2008). Bearded seals are found mainly over the shallower waters of the continental shelves and usually in association with moving ice or leads and polynyas (Laidre et al., 2008). The seasonal movements and distribution of bearded seals are linked to seasonal changes in ice conditions. The seals generally move north in late spring and summer, as the ice melts and retreats, and move south in the fall, as sea ice reforms to remain associated with their preferred ice habitat. Bearded seals are closely associated with sea ice, particularly during the critical life history periods related to reproduction and moulting, and they can be found in a broad range of different ice types (see references in (Cameron et al., 2010)). Ice provides a platform on which the seals haul out, bear and nurse pups, and rest and moult. Bearded seals feed primarily on benthic organisms that include epifaunal (are attached to substrates) and infaunal (live in the substrate/ soft sea bottom) invertebrates and demersal fishes (fish that live near the seafloor). Polar bears and walruses are the main predators of bearded seals (Laidre et al., 2008).

Walrus (*Odobenus rosmarus*) is the largest species of pinniped in the Arctic, measuring between 3.0 and 3.6 meters and weighing between 600 and 2,000 kg. Walruses have a discontinuous circumpolar Arctic and Subarctic distribution (Figure 37). Three subspecies are distinguished: the Atlantic walrus (*Odobenus rosmarus rosmarus*), the Pacific walrus (*Odobenus rosmarus divergens*) and the Laptev walrus (*Odobenus rosmarus laptevi*), although the taxonomic status of the latter is uncertain. Only the Atlantic subspecies is found within the LIA. The population estimates that are available have a low precision (Lowry et al., 2008). Nevertheless, the Atlantic population would be around 18,000 individuals, the Pacific, around 200,000 individuals and the Laptev, around 5,000 individuals (WWF, 2013b). The walrus was once threatened by commercial hunting but today the biggest danger it faces is climate change. The walrus is listed under the category of "data deficient" in the IUCN Red List (Lowry et al., 2008).

Walruses in the Atlantic display sex-specific distribution and movement patterns. Females with young and males move to separate areas during summer but they occupy the same areas during winter (see references in Laidre et al., 2008). Walruses show high fidelity to their terrestrial haul-out sites (beaches on islands or remote stretches of mainland coastlines) and wintering areas from year to year (Laidre et al., 2008). They can overwinter close to polynyas that provide access to seafloor food resources. All subspecies of walruses are found in relatively shallow continental shelf areas and seldom occur in deep waters (maximum of 200 m). Walruses are benthic feeders and shallow divers; they generally feed on molluscs and other invertebrates in depths around 20-30 m.

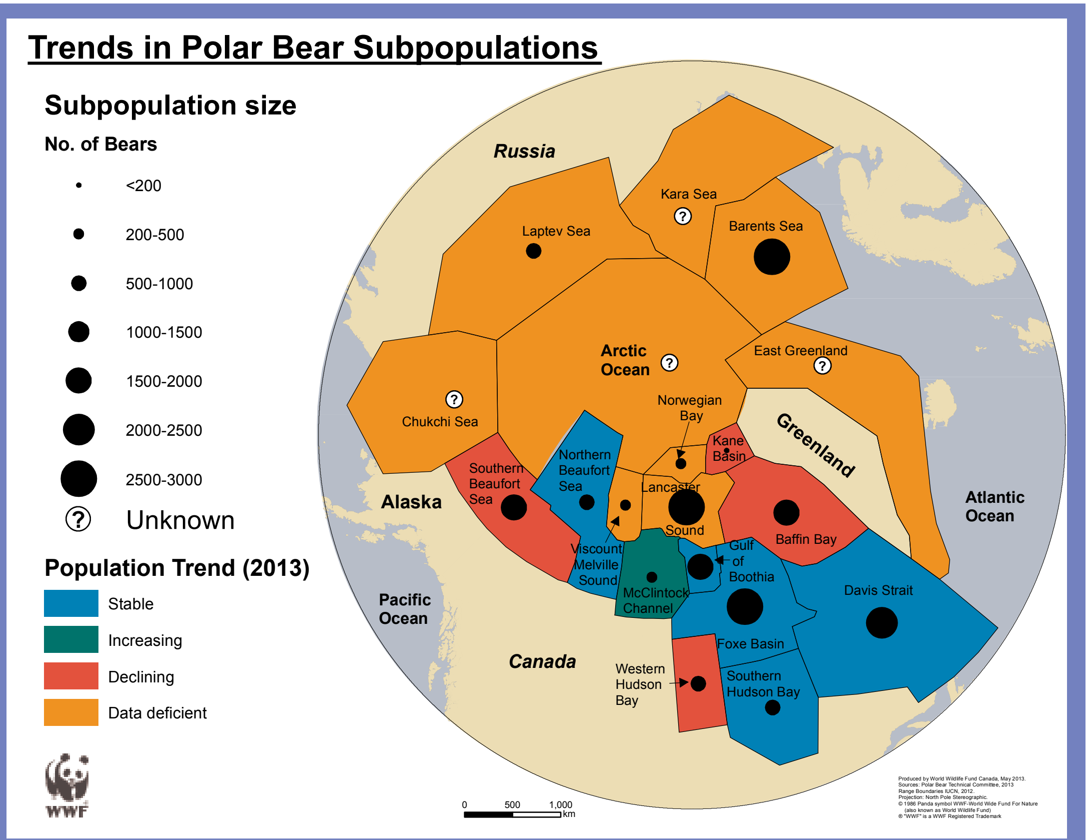
Polar bear

Polar bears (*Ursus maritimus*) are an iconic Arctic species. They are considered marine mammals because they live predominantly on the sea ice throughout the Arctic. They are an ice-obligate species, using the sea ice as a platform for hunting seals. Polar bears are 2-3 m in length and can weight up to 680 kg. They have a circumpolar distribution (Figure 42) and are found mainly in areas of annual ice cover over the continental shelf and the inter-island channels of various archipelagos. Polar bears prefer to forage on seasonal sea ice but will also use multiyear sea ice. In more southern locations, such as Hudson Bay and Davis Strait, where annual ice melts completely, bears spend up to several months on land waiting for the ice to freeze again. Polar bears have annual movement patterns within their home ranges and they show high fidelity to denning and spring feeding areas (Laidre et al., 2008; Lone et al., 2013). Sea ice also facilitates, but is not essential, for seasonal movements, mating, and in some cases, maternal denning (Laidre et al., 2008). They feed mainly on ringed and bearded seals but they also eat belugas, narwhals and walruses (Laidre et al., 2008). They also feed on land, eating eggs, berries, and whatever they can scavenge.

Figure 41. Polar bear.
© Gert Polet / WWF

The worldwide polar bear population is divided into 19 subpopulations (Figure 42) and four ecological regions have been described (Figure 43; Amstrup, 2011). This species is listed as "vulnerable" on the IUCN Red List with an estimated global number of 20,000 to 25,000 (Schliebe et al., 2008). In 2008, the polar bear was listed as Special Concern under the Federal Species at Risk Act of Canada (Government of Canada, 2013c). Out of the 19 subpopulations, four are considered to be declining in numbers (IUCN PBSG 2013). The main threat to the polar bears long-term survival is the loss of sea ice habitat (Stirling and Derocher, 2012). The critical feeding time occurs in late spring and early summer, when they feed on ringed seal pups that are born in early April and weaned about six week later. At that time, pups are up to 50% fat, naïve about predators and

Figure 42. Map of location, size and trends of polar bear subpopulations.



accessible from the surface of the ice. After the ice break-up, seals are mostly inaccessible to the bears. A reduced extent in sea ice and an earlier sea ice break-up in spring results in less time to access prey, longer periods of fasting, less healthy body condition and lower survival of cubs (Rode et al., 2010; Stirling and Derocher, 2012). While all bear species have adapted to changes in their environment in the past, the adaptive capacity of polar bears is limited since they are highly specialized for life in the Arctic, and they exhibit low reproductive rates with long generational spans. Moreover, the pace of Arctic sea ice habitat loss may be too fast for polar bears to adapt. Projections of polar bear habitat losses for this century are the greatest in the southern seas of the polar basin (e.g. Chukchi and Barents seas) and least along the Arctic Ocean shore included in the LIA region, from Banks Island to Greenland (Durner et al., 2009). On the basis of these projected losses in essential habitats and if climate warming continues, a research team argued that polar bear could disappear from two-thirds of their current global habitat by 2050 (Amstrup et al., 2008). The LIA is likely to be a large chunk of remaining prime habitat. A global coordinated monitoring framework of polar bear subpopulations is proposed as this would provide a better circumpolar understanding of ongoing patterns and future trends in polar bear subpopulations, and would improve the monitor of the effects of stressors on polar bears (Vongraven et al., 2012).

LIA is home to six polar bear subpopulations (Table 3). The populations of Baffin Bay and Kane Basin are listed as "in decline", even if sea ice is still extensive in these regions. Harvest pressures from both Canada and Greenland in Baffin Bay and Kane Basin are held responsible for this decline and an agreement between both parties signed in 2009 should help making harvest sustainable (CBC News, 2009). Within LIA, thick multiyear ice will be replaced in part by annual ice, which is associated with greater productivity, and may create more favourable habitats for polar bears over the short term (in the next three to four decades), acting as potential refugia. However, if warming continues at its present rate, this region is also projected to become ice-free during summer in the foreseeable future. Nevertheless, LIA will remain the best habitat available for polar bears as this region will retain the most ice for the longest period. The long-term viability of polar bears is uncertain (Stirling and Derocher, 2012).

The terrestrial environment

The LIA is composed of many landscapes. Towering mountains with peaks over 2,000 m are found in the eastern islands of the Canadian Arctic Archipelago (Ellesmere, Axel Heiburg and Devon). The higher land on these islands is commonly covered by ice caps. Spectacular fiords and glaciers are also part of the landscape. The central and western islands of the

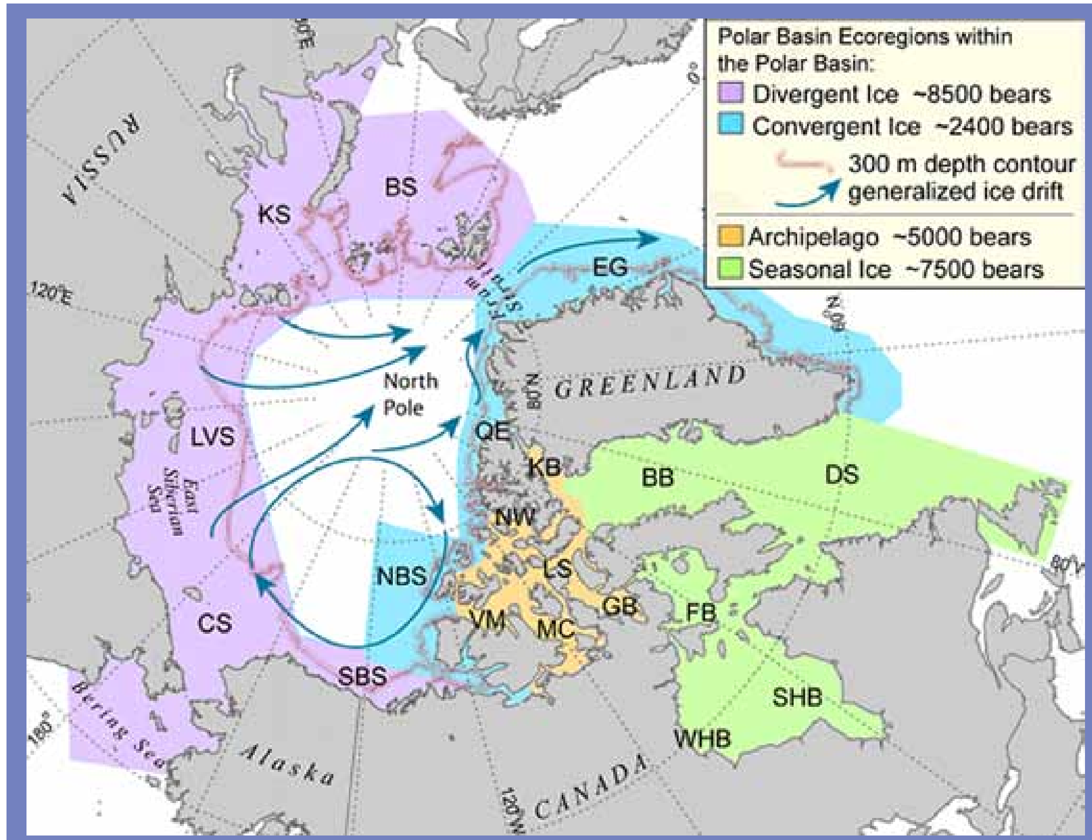


Figure 43. Ecoregions used in analysis of the future global status of polar bears. Ecoregions include the 19 Polar Bear management units (black initials) as defined by the IUCN Polar Bear Specialists' Group, and blue lines represent general ice flow patterns (Amstrup, 2011).

Table 3. Numbers and trends of the polar bear subpopulations found in the LIA region (data are from Vongraven and Richardson, 2011).

Ecoregions	Subpopulation	Number (year of estimate)	Trend
Seasonal ice	Baffin Bay (BB)	1546 (2004)	Decline
Archipelago	Kane Basin (KB)	164 (1998)	Decline
	Norwegian Bay (NW)	190 (1998)	Decline
	Lancaster Sound (LS)	2541 (1998)	Decline
Convergent Ice	Arctic Basin	Unknown	Data deficient
	East Greenland (EG)	Unknown	Data deficient

Canadian Arctic Archipelago are generally flat with low relief (less than 200 m). Greenland is the largest island and 85% is covered by an ice sheet nearly 3,000 m thick. Fiords and islands characterize the Greenlandic coastline.

The Arctic terrestrial environment is characterized by numerous lakes that dot the landscape and by the predominance of snow and ice in the form of glaciers, ice caps, ice sheets and permafrost (permanently frozen ground).

Lakes and Rivers

The Arctic contains an abundant and wide range of freshwater ecosystems, including lakes, rivers, ponds, streams and a complex array of wetlands and deltas. These aquatic environments are habitats for diverse biological communities (see section Aquatic biodiversity) and are important for hunting and fishing by indigenous communities. They also provide drinking water supplies to communities and are a key resource for industries such as transport and mining. Moreover, Arctic aquatic environments have global significance as sentinels of climate change, as sources of greenhouse gases, and large rivers bring major inputs of freshwater and organic materials to the Arctic Ocean (Vincent et al., 2008). Four sites within LIA are important for lake ecological studies: Cornwallis Island (Char Lake, Meretta Lake, Amituk Lake), Ellesmere Island (Lake Romulus, Cape Hershel ponds), Ward Hunt lake and northern Ellesmere Island meromictic lakes, and Peary land in northern Greenland.

Arctic lakes are very diverse. Their salinity ranges from freshwater to hypersaline, and their ice cover can be perennial or seasonal. This diversity leads to different mixing regimes; some lakes mix fully during open water conditions in summer, others mix at spring and fall and stratify strongly during summer (as most temperate lakes), and others never mix (Vincent et al., 2008). These physical differences bring large variations between lake chemical characteristics, such as oxygen concentration, and even within the same lake at different depths or times. Some lake types with unusual features are found exclusively in the polar regions, such as solar-heated perennially ice-capped lakes of northern Ellesmere Island (Veillette et al., 2010), and epishelf lakes (see section Ice shelves). The Arctic also harbours a diversity of streams and river ecosystems, from spring-fed streams to large rivers.

Most Arctic lakes are ultra-oligotrophic (have very low levels of nutrients) and are therefore very unproductive, but some are greatly enriched by human activities (e.g. Meretta Lake (Schindler et al., 1974)). Several variables would control biological production in Arctic aquatic ecosystems (Vincent et al., 2008). First, the availability of liquid water is essential for aquatic life. For some ecosystems (e.g. meltwater lakes on ice shelves), this limits biological activity to only a few weeks each year. However, liquid water persists all year round under snow and ice cover for most aquatic ecosystems. Streams and rivers are fed by melting snowpack and glaciers, and their flow is the most important during the peak snowmelt in spring. Second, the reduced irradiance, since the sun is up only during the summer, compounded to the attenuating effects of snow and ice cover on the underwater irradiance strongly limits the annual production in Arctic aquatic ecosystems. However, the primary variable controlling daily primary production by phytoplankton during summer would be nutrient availability (Vincent et al., 2008). Nutrient delivery for biological production to plankton communities in lakes and rivers is low in the Arctic. The release of nutrients from the catchments by soil microbes is limited due to low temperature, low moisture, and freezing. Nutrient recycling rates are also slowed with the low temperature of waters. Also, low temperature would likely slow the metabolic rate and growth of many of the organisms colonizing Arctic aquatic ecosystems. Hence, it is suggested that nutrient supply exerts a strong control on phytoplankton production with the interplay of light and temperature (Vincent et al., 2008).

Lake floor communities of many Arctic aquatic ecosystems flourish and dominate the ecosystem biomass and productivity (Vincent et al., 2008). They take advantage of the more stable environment and of the enhanced supply of nutrients by sedimentation of particles from above and by more active bacterial decomposition and recycling processes, compared to the water column environment. The lake floor photosynthetic communities may be more limited by light than by nutrients (Bonilla et al., 2005).

Climate change is the major environmental driver affecting Arctic freshwater ecosystems (Prowse and Reist, 2013). The duration of freshwater ice cover is strongly controlled by climate. The lake ice cover duration in the Northern Hemisphere (1846-1995) has declined: freeze-up comes later, break-up comes earlier and the ice cover duration has decreased (Prowse et al., 2011). Rivers are also showing the same trend although there are regional differences (Prowse et al., 2011). In Arctic freshwater ecosystems, the duration of ice cover has decreased by almost two weeks over the last 150 years, with earlier break-ups and later freeze-ups (Prowse and Brown, 2010). Hence, lakes with seasonal ice cover have a longer ice-free season while lakes with perennial ice covers are becoming ice free during summer (Prowse et al., 2011). These reductions in lake ice cover duration modify thermal conditions that may lead to enhanced evaporation and, in some cases, the loss of shallow lakes (Prowse et al., 2011). In addition, these conditions can lead to enhanced mixing, making Arctic lakes sinks for contaminants (Prowse et al., 2011). Loss of ice cover will also likely lead to increased methane emissions and expose the biota to an increased level of ultraviolet radiation (Prowse et al., 2011). Apart from climate change, other environmental stressors are increasingly relevant for Arctic aquatic ecosystems such as pollution (point source and long-range atmospheric transport), altered hydrologic regimes related to impoundment and diversion of freshwater, water quality degradation due to enhanced mining, and oil and gas activities, and anthropogenic introduction of invasive species via more transport in the North (Prowse and Reist, 2013).

Glacier Ice

Arctic glacier ice comprises mountain glaciers (i.e. ice bodies whose shape and size are controlled by bedrock topography), ice caps (i.e. dome-shaped ice bodies that entirely submerge the underlying rock) and the Greenland Ice Sheet (i.e. an ice sheet is an ice cap). If all glaciers, ice caps and the Ellesmere Ice Sheet were to completely melt, the global sea level would rise by 7.9 m (Dahl-Jensen et al., 2011; Sharp et al., 2011). 250,000 km3 of ice is locked up in mountain glaciers and ice caps (Sharp et al., 2011). The LIA region contains glaciers and ice caps in the mountains on Devon and Ellesmere islands, which are nourished in part by moisture from the NOW polynya, and glaciers at the periphery of Greenland (these glaciers are not connected to the Greenland Ice Sheet). These glacial features drain ice mass away from the accumulation areas, where snowfall exceeds surface melt, to ablation areas where melting exceeds accumulation. Where the ablation areas of ice reach the ocean, icebergs are calved. The Greenland Ice Sheet is a massive ice cap of nearly 3,000 m thick. It is the largest body of freshwater ice in the Northern Hemisphere; it is composed of 2.93 million km3 of ice (Dahl-Jensen et al., 2011). The Greenland Ice Sheet gains ice by snow falling onto its surface, and loses ice either at the surface, where it is melted by warm air and winds, or from the edge, where it breaks off as chunks of solid ice or flows into the ocean as meltwater. In contrast to sea ice, glacier ice is formed on land but may end up in the ocean. Glaciers and ice sheets contribute to the river and lake systems of the Arctic to which they provide freshwater while melting. Nutrients and sediment are carried with the melting ice into rivers, lakes and the ocean.

Similar to trends observed for sea ice, lake and river ice cover, glacier ice is also rapidly declining (Dahl-Jensen et al., 2011; Sharp et al., 2011). Almost all Arctic glaciers have retreated over the past 100 years and the rate of loss has increased during the last decade across most regions (Sharp et al., 2011). The Greenland Ice Sheet is also losing ice in a series of fast-flowing glaciers that discharge to the ocean through fiords along the coast. These glaciers have increased their rate of flow and discharge an increased volume of ice (Dahl-Jensen et al., 2011; Nick et al., 2013). The warming of the ocean water that is in contact with the outflowing end of these glaciers would play a role in these rapid changes. The total loss of ice from Arctic glaciers and ice caps since 2000 (150 Gt/y) is in the same range as the ice loss estimated from the Greenland Ice Sheet (~200 Gt/y) (Dahl-Jensen et al., 2011; Sharp et al., 2011). However, the volume of the ice sheet is almost 12 times larger than the global volume of glaciers and ice caps.

Permafrost

Permafrost, or permanently frozen ground, is soil, sediment, or other rock material that remains at or below 0°C for two or more consecutive years (National Snow and Ice Data Centre, 2013c). Permafrost underlies the vast majority of the surface of the terrestrial Arctic and it can occur beneath offshore Arctic continental shelves (National Snow and Ice Data Centre, 2013c). At the soil surface, there is an active layer that freezes and thaws seasonally. Under this active layer, a transient layer can remain frozen in some summers and, underneath it, there is permafrost (Callaghan et al., 2011a). Taliks, unfrozen zones within permafrost, can occur, for example, under large water bodies (Callaghan et al., 2011a). Terrestrial permafrost thickness ranges from less than 1 meter to greater than 1,500 meters in the north of the Arctic region (National Snow and Ice Data Centre, 2013c). The active layer thickness is influenced by climate and local factors and vary from less than 0.5 m in vegetated, organic terrain to more than 10 m in areas of exposed bedrock (Callaghan et al., 2011a). The proportion of the landscape underlain by permafrost becomes greater with increasing latitude from the southern limits of the permafrost zone to the High Arctic (Callaghan et al., 2011a). The LIA is located well north of the continuous (90-100% of area) permafrost boundary.

Permafrost is intimately linked with biodiversity and ecosystem processes in the Arctic (Callaghan et al., 2011a). On one hand, permafrost influences soil temperature, drainage, nutrient availability, rooting depth and plant stability. It also provides a habitat for viable ancient microorganisms that live within permafrost. On the other hand, vegetation moderates ground surface temperature by insulating and protecting permafrost directly or indirectly by trapping snow. No species are dependent on permafrost and no ecosystems are limited by the presence of permafrost, as tundra can be underlain by permafrost or not. However, the presence of permafrost is playing a key role in plant species composition as it restricts the types of plants that can grow.

As a result of increased air temperature, the permafrost is degrading rapidly in most Arctic regions (IPCC, 2013). Temperatures in the permafrost have risen by up to 2 °C over the last three decades, although there are large regional variabilities (Callaghan et al., 2011a), and the southern limit of permafrost has moved northward in Russia and Canada (Callaghan et al., 2011a). This thawing trend is projected to continue and by 2100, the area currently underlain by permafrost near the surface (upper 3.5 m) would decrease by 37-81% (IPCC, 2013).

Permafrost thawing is having drastic impacts on the built and natural environments (Callaghan et al., 2011a). Arctic infrastructure (e.g. schools, hospitals, roads, airports) is greatly damaged and the design of any future development will need to take into account the instability of the permafrost. Also, permafrost thawing on mountain slopes can lead to rock slope instability and landslides. In addition, coastal erosion is enhanced since the Arctic coastline is composed of unconsolidated material rich in ice. With permafrost thawing during summer, the coasts are especially sensitive to the action of waves and experience high annual erosion rate. Moreover, the outcomes of thawing permafrost are at the opposite for hydrology; landscape dryness is increasing in the boreal forest and ponds are drying, while waterlogging occurs in some flat areas of the Subarctic. This is because permafrost degrades in a continuum from rising temperatures in frozen ground (which increases the unfrozen water content and reduces the load-bearing strength of the ground) to complete thawing of ice-rich ground (which causes the surface to subside and creates depressions in the ground, termed 'thermokarst'). Biodiversity and ecosystem processes on land and in aquatic ecosystems are being affected by these changes in hydrology. Finally, permafrost thawing has a critical impact in greenhouse gases emissions. Recent research have demonstrated that permafrost soils (both terrestrial and beneath continental shelves) hold large pools of carbon, mostly in the form of methane (CH_4) and nitrous oxide (N_2O), and that the emission of these two powerful greenhouse gases from thawed permafrost could greatly increase radiative forcing and trigger abrupt climate change (Callaghan et al., 2011a).

TERRESTRIAL BIODIVERSITY

This section examines Arctic terrestrial biodiversity. Soil microbial biodiversity, vegetation and animal biodiversity for terrestrial ecosystems (except aquatic ecosystems) are first described, then, aquatic biodiversity is presented.

SOIL MICROBIAL BIODIVERSITY

Arctic soils are generally shallow and not very productive. The heterogeneity of the soil cover is substantial and greatly influences the distribution of the soil biota occurring in relation to the small-scale topographic variations (Callaghan, 2005). The soil biota comprises invertebrates, fungi and prokaryotes (bacteria and archaea). Despite the critical role that these organisms play for the functioning of ecosystems by being responsible of carbon and nutrient fluxes, they are still poorly understood in the soil of the tundra compared with other species (Callaghan, 2005).

Recent progresses in molecular ecology have rarely been applied to Arctic terrestrial studies. Nevertheless, a molecular technique investigated the upper limit for variation of prokaryote diversity as compared with other systems. This technique revealed that Arctic polar desert and tundra soils contain a considerable level of prokaryote diversity; similar to boreal forest soils and much higher than arable soils (Callaghan, 2005). However, conventional inventories reveal that species number of all groups of soil microorganisms is lower in the Arctic than further south (Callaghan, 2005). Most groups of prokaryotes and fungi are represented in the soil of the tundra but some that are common elsewhere are rare or absent in the tundra. Soil microbial communities in the tundra vary seasonally; it is dominated by fungi during winter while certain bacteria become more important during spring, summer and fall, and the importance of fungi declines (Buckeridge et al., 2013). The soil nutrient status and environmental differences between winter and the other seasons explain these community differences (Buckeridge et al., 2013). Also, Arctic soils hold large reserves of microorganisms. The harsh Arctic climate limits the metabolic activity of Arctic soil microorganisms.

Microorganisms are highly adaptive, tolerant of most environmental conditions and have short generation times that help to adapt to changes in environmental conditions. The main impact of climate change on Arctic soil microorganisms will likely be an increase in metabolic activity, to a similar level as the one of the boreal soils (Callaghan, 2005). Warmer temperatures, increase in atmospheric CO2 concentration and a higher availability of nutrient will likely contribute to this. Increased in microorganisms activity implies accelerate soil organic matter decomposition (Koyama et al., 2013).

VEGETATION

Vegetation in the Arctic

Environmental and climatic conditions are extreme for Arctic vegetation and control the plant communities that can grow. Summer temperature is the most important factor that influences Arctic vegetation (CAVM Team, 2003). The mean July temperatures are near 0˚C on the northernmost Arctic islands. At these low temperatures, plants are at their metabolic limits, and small differences in the total amount of summer warmth make large differences in the amount of energy available for maintenance, growth, and reproduction. Higher summer temperatures cause the size, horizontal cover, abundance, productivity, and variety of plants to increase. Environmental factors such as landscape, topography, soil chemistry, soil moisture, and the history of plant colonization also influence the distribution of plant communities in the Arctic (CAVM Team, 2003). Most plants found in the Arctic are dwarf shrubs, herbs, lichens and mosses that grow close to the ground, and they cover the land surface that is not ice-covered (5.05 millions km2 are covered by vegetation out of 7.11 millions km2 of total land surface) (Walker et al., 2005). With decreasing latitude (moving from the High Arctic to the Low Arctic), the amount of warmth available for plant growth increases significantly, allowing the size, abundance, and variety of plants to increase as well (CAVM Team, 2003).

The circumpolar Arctic is subdivided along latitudinal subzones (Figure 10) and longitudinal floristic provinces (Figure 44). The latitudinal north-south axis reflects the present climate and vegetation gradient divided into five different subzones. A, B and C delineate bioclimate subzones of the High Arctic, while D and E are located in the

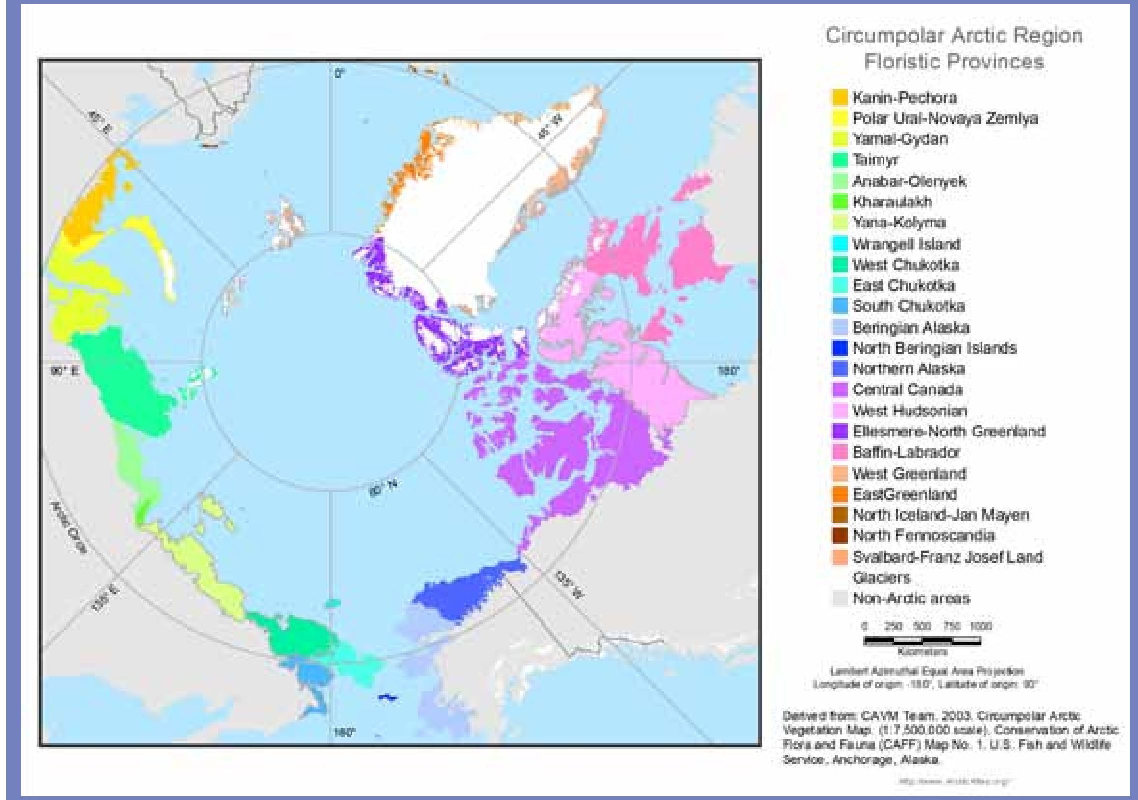


Figure 44. The floristic provinces of the circumpolar Arctic region (CAVM Team, 2003).

Table 4. Vegetation properties in each bioclimate subzone from CAVM Team (2003). Note that the subzone A is also known as polar desert, subzone B as Arctic tundra, subzones C and D as typical tundra and, subzone E as southern tundra. Alternatively, subzone A can also be named the Arctic herb subzone (absence of sedges and woody plants); B, the northern Arctic dwarf shrub subzone; C, the middle Arctic dwarf shrub subzone; D, the southern Arctic dwarf shrub subzone and E, the Arctic shrub subzone.

Subzone	Mean July Temp[1] (°C)	Summer warmth index[2] (°C)	Vertical structure of plant cover[3]	Horizontal structure of plant cover[3]	Major plant growth forms[4]	Dominant vegetation unit (see Detailed Vegetation Descriptions for species)	Total phyto-mass[5] ($t\ ha^{-1}$)	Net annual production[6] ($t\ ha^{-1}\ yr^{-1}$)	Number of vascular plant species in local floras[7]
A	0-3	<6	Mostly barren. In favorable microsites, 1 lichen or moss layer <2 cm tall, very scattered vascular plants hardly exceeding the moss layer	<5% cover of vascular plants, up to 40% cover by mosses and lichens	b, g, r, cf, of, ol, c	B1, G1	<3	<0.3	<50
B	3-5	6-9	2 layers, moss layer 1-3 cm thick and herbaceous layer, 5-10 cm tall, prostrate dwarf shrubs <5 cm tall	5-25% cover of vascular plants, up to 60% cover of cryptogams	npds, dpds, b, r, ns, cf, of, ol	P1, G1	5-20	0.2-1.9	50-100
C	5-7	9-12	2 layers, moss layer 3-5 cm thick and herbaceous layer 5-10 cm tall, prostrate and hemi-prostrate dwarf shrubs <15 cm tall	5-50% cover of vascular plants, open patchy vegetation	npds, dpds, b, ns, cf, of, ol, ehds* * in acidic areas	G2, P2	10-30	1.7-2.9	75-150
D	7-9	12-20	2 layers, moss layer 5-10 cm thick and herbaceous and dwarf-shrub layer 10-40 cm tall	50-80% cover of vascular plants, interrupted closed vegetation	ns, nb, npds, dpds, deds, neds, cf, of, ol, b	G3, S1	30-60	2.7-3.9	125-250
E	9-12	20-35	2-3 layers, moss layer 5-10 cm thick, herbaceous/ dwarf-shrub layer 20-50 cm tall, sometimes with low-shrub layer to 80 cm	80-100% cover of vascular plants, closed canopy	dls, ts*, ns, deds, neds, sb, nb, rl, ol *in Beringia	G4, S1, S2	50-100	3.3-4.3	200 to 500

[1] based on Edland (1996) and Matveyeva (1998).
[2] Sum of mean monthly temperatures greater than 0°C, modified from Young (1971).
[3] Chernov and Matveyeva (1997).
[4] b - barren; c - cryptogam; cf - cushion or rosette forb; deds - deciduous erect dwarf shrub; dls - deciduous low shrub; dpds - deciduous prostrate dwarf shrub; g - grass; ehds - evergreen hemiprostrate dwarf shrub; nb - nonsphagnoid bryophyte; neds - nondeciduous erect dwarf shrub; npds - nondeciduous prostrate dwarf shrub; ns - nontussock sedge; of - other forb; ol - other lichen; r - rush; rl - reindeer lichen; sb - sphagnoid bryophyte; ts - tussock sedge. Underlined codes are dominant.
[5] Based on Bazilevich, Tishkov and Vilcheck (1997), aboveground + belowground, live + dead.
[6] Based on Bazilevich, Tishkov and Vilcheck (1997), aboveground + belowground.
[7] Number of vascular species in local floras based mainly on Young (1971).

Low Arctic (Table 4). Very steep bioclimate gradients occur in mountains and these areas are therefore mapped as elevation belts (CAVM Team, 2003). There is a clear increase in species numbers from the northernmost High Arctic subzone A (102 species) to the southernmost Low Arctic subzone E (2180 species) (Daniëls et al., 2013). The longitudinal east-west axis reflects different conditions in the past such as glaciations, land bridges and north-south trending mountain ranges (particularly in Asia). These influences have limited the exchange of species between parts of the Arctic (Daniëls et al., 2013). Species numbers per floristic province vary widely from approximately 200 species for the heavily glaciated and northern floristic province Ellesmere – North Greenland to more than 800 species for Beringian Alaska (Daniëls et al., 2013).

Approximately 3% (~5900 species) of known plant species occur in the Arctic (Callaghan, 2005). Vascular plants (2,218 species), bryophytes (mosses and liverworts; 900 species) and lichens (1,750 species) are the main structural components of terrestrial vegetation and ecosystems (Daniëls et al., 2013). Vascular plants and bryophytes are the two main groups of terrestrial plants and as primary producers, they perform photosynthesis and support all organisms of higher trophic levels. Vascular plant diversity of the Arctic is relatively poor. Approximately 2,218 vascular plant species are recognized in the Arctic which represent less than 1% of the known vascular plant species in the world (Daniëls et al., 2013). The majority of these Arctic vascular plant species have a circumpolar distribution (Daniëls et al., 2013). Bryophytes cover less land surface than vascular plants in the Arctic (Schofield, 1972) and they strongly differ in life cycle, structure and physiology (Daniëls et al., 2013). Turfs dominate the bryophyte growth form in the Arctic (Schofield, 1972). Bryophyte diversity is moderate in the Arctic

Figure 45. The floristic provinces of the circumpolar Arctic region (CAVM Team, 2003).

although species number could increase in the course of future studies. The estimated species number of Arctic bryophytes is 900 species, significantly less than 1,750 lichen species and 2,218 vascular plants (Daniëls et al., 2013). High Arctic sites have fewer species of bryophyte than Low Arctic areas (Daniëls et al., 2013). Also, almost 80% of these species have a circumpolar distribution (Daniëls et al., 2013). Bryophytes contribute to vegetation biomass in stable, wet-to-moist sites, and they add to species richness of many vegetation types in other habitats as very few vegetation types in the Arctic occur without bryophytes (Daniëls et al., 2013). Single shoots occur almost everywhere, and particularly in the High Arctic (Daniëls et al., 2013). Vascular plant endemism is well developed in the Arctic as 5% of the Arctic vascular plant species are endemic to the Arctic (Daniëls et al., 2013). Interestingly, the relative percentage of vascular plant species endemic to the Arctic decreases from the High Arctic to the Low Arctic (Daniëls et al., 2013). In contrast, Arctic endemism is not strongly pronounced for bryophytes (Daniëls et al., 2013). No species in the Arctic are currently considered as invasive, although some are at risk of becoming it with increasing human traffic combined with climate change (Daniëls et al., 2013).

Plants have always played a central role in the lives and cultures of Arctic indigenous peoples (Daniëls et al., 2013). Vascular plants are consumed and used for medicines. The use of bryophytes is little known and therefore, probably very restricted.

Vegetation in the LIA

The LIA region encompasses three bioclimate subzones. Islands between the Peary Channel and the M'Clure Strait, at the northwestern margin of the Canadian Arctic Archipelago, are characterized by subzone A, the northern coast of Ellesmere Island and Greenland, and territories on each shore of the Parry Channel, by subzone B, and the interior of Ellesmere Island and Devon Island, by subzone C. Two floristic provinces are found within LIA. Northern Greenland, Ellesmere Island, Axel Heiberg Island and Devon Island are part of the Ellesmere – North Greenland province. The other islands of the Canadian Arctic Archipelago north of the Parry Channel are included in the central Canada province.

Terrestrial fauna

Terrestrial fauna of the LIA

Terrestrial mammal species reported for LIA are listed at Appendix I. The terrestrial predator community of the LIA consists of Arctic wolf (*Canis lupus arctos*), Arctic fox (*Vulpes lagopus*), (red fox, Vulpes vulpes, on Devon Island) and stoat (*Mustela erminea*). Aerial predators in the LIA are rough-legged hawk (*Buteo lagopus*), gyrfalcon (*Falco rusticolus*), peregrine falcon (*Falco peregrinus*), snowy owl (*Bubo scandiacus*), jaegers and skuas (Stercorariidae), gulls (Laridae) and raven (Corvidae). There are many species of shorebirds that prey on invertebrates and molluscs on land, shorelines and tidal mud flats. Polar bears are summer season terrestrial predators and scavengers in the seasonal sea ice regions.

Figure 46. Arctic wolf (*Canis lupus*).
© Staffan Widstrand / WWF

Caribou

Rangifer tarandus is called caribou in North America and reindeer in Europe. It is a conspicuous Arctic terrestrial species with a circumpolar distribution in the tundra and taiga zones of northern Europe, Siberia and North America (Figure 48). They have supported many cultures for thousands of years through meat and fat, and skins for clothing. Caribou is found throughout LIA; the subspecies Peary caribou (*Rangifer tarandus pearyi*) is found on the islands of the Canadian Arctic Archipelago and coastal northwestern Greenland (Government of Canada, 2013b; Jensen and Christensen, 2003). This subspecies is small (males measure 1.7 m in length on average), have relatively short legs, they are almost completely white and they have small antlers (Government of Canada, 2013b). Peary caribou migrate seasonally between islands to maximize their use of the available habitat. During summer, they feed on dense vegetation in the slopes of river valleys and upland plains, while during winter they occur in areas where the snow is shallow. Caribou is an important prey species for many Arctic carnivores such as wolves and polar bears. The caribou is listed under the category of 'least concern' of the IUCN Red List due to a wide circumpolar distribution and presumed large populations (Henttonen and Tikhonov, 2008).

The number of mature individuals of Peary caribou in the population of the Queen Elizabeth Islands is 2100 (Government of Canada, 2013b), the Inglefield/Pruhoe Land population and the Olrik Fiord population in Greenland had an estimated population size of 2,300 in 1999, and an unknown number, respectively (Greenland Institute of Natural Resources, 2013). The best current estimate of the total Peary Caribou population, including calves, is 7890 (Government of Canada, 2013b). The Peary caribou population is declining; the total population has declined by 72% since 1980, and the population on the Queen Elizabeth Islands has declined by about 37% (Government of Canada, 2013b). The Peary caribou has been assessed as endangered under both the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Species At Risk Act (SARA) (Government of Canada, 2013b). The main threat to this caribou population would be winters with heavy and persistent snow accumulation, in association with freezing rain and warm periods that cause the formation of ice crusts over vegetation. For this reason, climate change could lead to the disappearance of this population (Government of Canada, 2013b). Industrial development is still absent in the Queen Elizabeth Islands and northwestern Greenland. However, future industrial operations could hamper seasonal migrations and cause disruptions during critical periods of their life cycle (Government of Canada, 2013b). Certain Peary caribou herds are characterized by low number and low genetic diversity, which reduce their ability to adapt to environmental stresses (Government of Canada, 2013b).

Figure 47. Two young Peary caribou (*Rangifer tarandus pearyi*).
© Paul Nicklen/National Geographic Stock / WWF-Canada

Figure 48. Distribution of caribou (Ultimate ungulate.com, 2012, compiled from Burt and Grossenheider, 1976; Whitehead, 1993)

Lemming

The Northern Collared (or Arctic) lemming (*Dicrostonyx groenlandicus*) is an important species in the High Arctic ecosystem and it is widely distributed throughout the LIA. It copes with the severe winters by positioning its nest and tunnels under the snow. The Arctic lemming feeds on wil-

Figure 49. Muskox on tundra, Ellesmere Island.

low and grasses while it is the most important prey species for Arctic fox, stoat and snowy owls. Skuas, jaegers, gyrfalcon and raven also feed on lemmings. The lemming population follows a cyclical pattern and crashes at times, which influences especially the population of stoats. As an example, two races of Arctic foxes occur in Greenland: the white Arctic foxes are found primarily inland, and the blue Arctic foxes are associated with the coastal zone (Jensen and Christensen, 2003). The white Arctic foxes feed on lemmings and show much greater population fluctuations than the blue Arctic foxes that feed on stable food sources (Jensen and Christensen, 2003).

Musk ox

Musk ox (*Ovibos moschatus*) have lived in the Arctic for many thousands of years and they are survivors of the last ice age. They live in the Arctic tundra in Canada, Alaska, and Greenland (throughout LIA). These animals are well adapted to the Arctic climate with their long thick, shaggy fur that keeps them warm. Additional adaptations to the harsh Arctic climate are

Figure 50. Muskox (*Ovibos moschatus*).

short legs and large, rounded hooves that allow them to move easily through shallow snow. These large mammals (up to 360 kg) feed on roots, mosses and lichens and they supplement their diet with Arctic flowers and grasses during summer. Musk ox live in herds of two to three dozen animals and they use cooperation to deal with predation by wolves and dogs. When they are threatened, they form a circle, protecting their young in the middle, and they show their sharp horns outward. They are an integral part of the Inuit lifestyle as they provide large quantities of meat, and warm versatile insulating fur.

AQUATIC BIODIVERSITY

Arctic aquatic biodiversity

Aquatic biodiversity is known to decrease with increasing latitude, likely reflecting the increasingly harsh conditions (Prowse and Reist, 2013). Also, Arctic aquatic environments often have a simplified food web structure compared to temperate latitudes (Vincent et al., 2008). They range from simple with flagellates, ciliates and rotifers at the highest trophic level, to more complex with well-developed zooplankton and fish communities (Vincent et al., 2008). Shallow lakes and ponds exhibit extreme seasonality in temperature, water levels and light conditions, which preclude the presence of higher trophic levels (Prowse and Reist, 2013). The level of nutrients available in the lake (if it is oligotrophic, mesotrophic or eutrophic) and biogeography would likely influence the food web structure and diversity (Vincent et al., 2008). The microbial water column diversity of some Arctic lakes was reported to be very rich despite their extreme locations (Charvet et al., 2012; Comeau et al., 2012).

At the base of the food web, phytoplankton in polar lakes include bacteria, eukaryotic algae and ciliated protists (Lizotte, 2008). Between 20 to 150 species of phytoplankton are found per lake in the Arctic and species number was found to be correlated with latitude, altitude or water temperature (Moore, 1979; Prowse and Reist, 2013). Species composition would be mainly determined by water chemistry (Forsstr m et al., 2009). Chrysophytes were reported to dominate the phytoplankton communities of High Arctic lakes (Charvet et al., 2012). However, picocyanobacteria could be the most abundant cell types in these waters (Van Hove et al., 2008). Zooplankton are important components of Arctic lakes as they represent the highest trophic level of the foodweb in lakes without fish. Their abundance is therefore only controlled by food supply and their ability to survive in cold conditions (Rautio et al., 2008). Rotifers, copepods, cladocerans, fairy shrimps (Anostraca) and mysids are the main components of the zooplanktonic community of Arctic lakes and ponds (Rautio et al., 2008). The distribution of zooplankton species in Arctic lakes is largely dependant on geographic location and correlates with the distance from locations that escaped glaciation in the Pleistocene period (Rautio et al., 2008). Zooplankton feed preferably on phytoplankton but they can also feed on benthic microbial mats in shallow lakes (Rautio et al., 2008). Some species live on the edge of their environmental tolerance while others have adapted to life at low temperatures, short growing season, long periods of ice cover, and low food supply (Rautio et al., 2008). In lakes with fish, predation controls the zooplankton community, as fish are size-selective in their feeding. Zooplankton therefore tends to be small and transparent in order to escape predation in these lakes (O'Brien et al., 2004; Rautio et al., 2008). Different species of fish have different impacts on the zooplanktonic community (O'Brien et al., 2004).

Arctic lakes display low fish abundance and diversity. Within the Arctic, eastern Canadian Arctic and Greenland are the regions with the lowest diversity because they were deglaciated last during the last ice age and that they still retain large ice sheets (Christiansen and Reist, 2013). Five fish families (carps and minnows, trouts and salmons, sculpins, perches, and lampreys), out of the 17-19 present, comprise most of the Arctic freshwater diversity (Christiansen and Reist, 2013). Some lampreys, and some trouts and salmons are anadromous, meaning that they undertake regular migrations between marine waters, to benefit from the productive marine coastal environments for feeding, and freshwater for reproduction, juvenile growth and over-wintering. These species are especially important for subsistence fisheries by local communities. About 127 species of fish occur in freshwater Arctic and sub-Arctic environments, which represent around 1% of the global fish estimate on the planet (Christiansen and Reist, 2013). Nonetheless, this estimate certainly underestimates Arctic freshwater fish diversity, as it does not consider the important diversity that occurs below the species level. Out of these 127 species, 83-85 are obligate freshwater forms, 39 are anadromous and 2 species are catadromous (fishes which migrate from freshwater into the sea to spawn) (Christiansen and Reist, 2013). Arctic char (*Salvelinus alpinus*) is the freshwater fish the most northerly distributed as it is the only species to occur north of 75°N latitude, and in the LIA (Christiansen and Reist, 2013). Lake A, a coastal lake located at 83°N on the northern coast of Ellesmere Island contains an anadromous Arctic char population (Veillette et al., 2012). This fish species is widely distributed throughout many habitats and exhibit different life-history strategies that vary with latitude, resulting in high adaptability (Power et al., 2008). Some populations are resident in lakes and they show complex variety of life-history tactics: they vary in growth and feeding patterns, and occupy distinct niches. Other populations are anadromous. Lake char (Salvelinus namaycush) is also present in many lakes in the south of the Canadian Arctic Archipelago (Power et al., 2008).

The well-developed benthic microbial mats at the bottom of Arctic lakes, streams and ponds are dominated by cyanobacteria, but other algal groups such as chlorophytes and chromophytes are also present (Jungblut et al., 2009). The benthic invertebrate community is abundant in Arctic lakes and is mostly composed of insect larvae (chironomids), oligochaete worms, snails, mites and turbellarians (Rautio et al., 2008). The only macrophytes present in Arctic lakes are benthic mosses (Jungblut et al., 2009).

Figure 51.
© Clive Tesar / WWF

Figure 52. Walrus.

2b. History and development

History of geological development

There is no history of geological development within the proposed area. There is the potential for a lead-zinc development to the east of the proposed boundary in the Greenland portion at a property known as Citronen Fiord. There are no current or proposed geological developments in the immediate vicinity of the proposed area.

History of land use

The most northerly districts of both Nunavut and Western Greenland have historically been sporadically occupied, with a few permanent communities currently settled in the region. Dorset (300 BC) and Thule archeological evidence points to use of the northern areas of both Nunavut and western Greenland. It is presumed that camps found throughout the Arctic are remnants of early Inuit harvesting activity centred around whales while they were plentiful. When whales were no longer plentiful, Inuit changed their harvesting activities to make use of other more abundant species, such as seals, which led to a more nomadic existence (Riewe, 1975)

Pre-Dorset people inhabited Ellesmere Island as early as 2000 B.C.E. Over time the Thule people replaced the pre-Dorset. Remnants of Thule villages can still be found in many of the inlets and fiords of Ellesmere Island. Thule were no longer occupying the area by the 18th century, although hunting parties from Greenland and Arctic Bay sometimes visited Ellesmere Island (Riewe, 1975)

The settlement of Grise Fiord is located on the north shore of Jones Sound on the southern tip of Ellesmere Island, the most mountainous island in the Arctic Archipelago. The terrain is harsh and the surrounding mountains provide limited support for wildlife. The sea is frozen 10 months of the year with break-up occurring in mid-August. From May to August the sun never sets, while the dark season lasts from October to mid February (Riewe, 1975).

In western Greenland, the communities of Qaanaq (formally a town), Savissivik, Moriusaq, Qeqertat, and Siorapaluk comprise Qaatsuitsup municipality (all formally settlements) and are the northernmost communities. Qaasuitsup Kommunia (municipality) covers all land and communities from the Ilulissat area (http://www.qaasuitsup.gl/en/Om-kommunen/Cities-and-settlements). In Nunavut, Grise Fiord and Resolute are the northernmost communities established by the Government of Canada to assert sovereignty over the High Arctic in the 1950's. Inuit refer to Grise Fiord as "the place that never thaws" (Aujjuittuq) (Hamlet of Grise Fiord, 2012) and Resolute (also referred to as Resolute Bay) is known as "place with no dawn" (Quasuittuq) (Unknown, 2012).

Inuit from Grise Fiord hunt caribou and polar bears on the East Coast of Ellesmere Island. Qaanaq, Siorapaluk and Qeqertat residents are active hunters in Northwest Greenland.

Additional stressors

Although the Arctic is still sparsely populated, it is experiencing pressure from numerous sources. Climate change is a prominent driver affecting the entire Arctic. The climatic impacts for marine and terrestrial environments, and their related biodiversity, have been addressed throughout the different sections of this report. Additional important factors that threaten the integrity of Arctic ecosystems are enhanced mining and oil and gas activities, increased shipping, and contaminants by local pollution or long-range transport. These anthropogenic stressors are also likely to interplay and have cumulative effects. A companion report by WWF on the non-renewable resources of the LIA looks more closely at the economic probability of exploitation of these resources.

Oil and gas development in the Canadian Arctic began in the Beaufort Sea in the 1970's. Wells were drilled from artificial islands. Seismic exploration was also realized in the Lancaster Sound region of the Canadian Arctic Archipelago during the 1970's (Niemi et al., 2010). At the moment, the highest known oil and gas potentials of the Canadian Arctic Archipelago are in the Sverdrup Basin and Lancaster Sound (Figure 53).

The Canadian portion of LIA does not hold any major mineral project at the moment (Aboriginal Affairs and Northern Development Canada, 2012b). However, the Po-

Figure 53. Location of current oil and gas rights and potential oil development areas in the Canadian Arctic Archipelago (Aboriginal Affairs and Northern Development Canada, 2013).

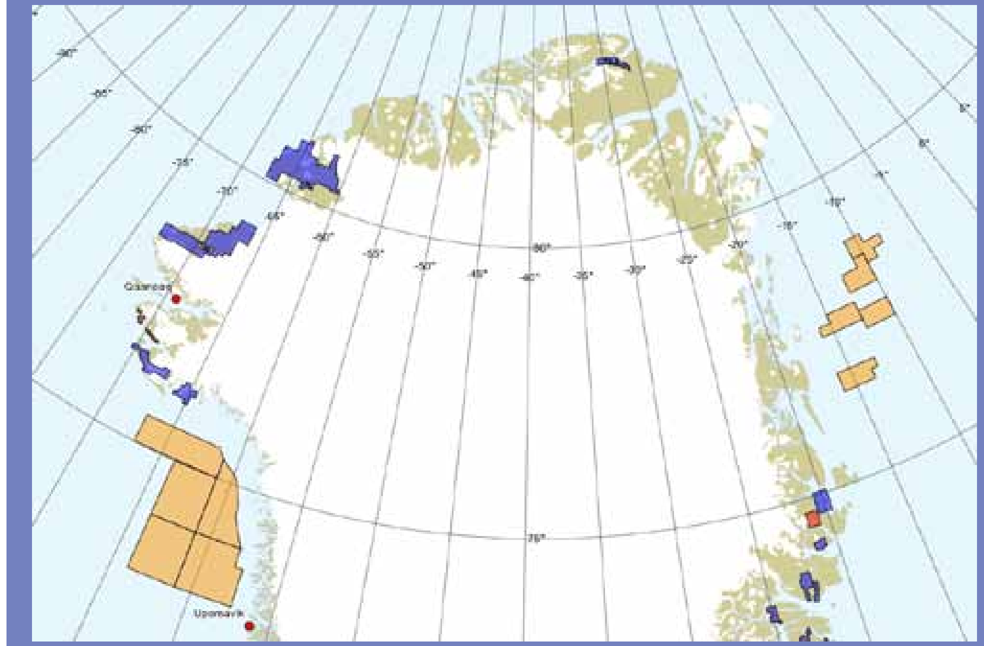


Figure 54. Mineral and hydrocarbon licences in North Greenland (Government of Greenland - Bureau of minerals and petroleum, 2013).

Figure 55. Two long-tailed ducks sit together on sea ice.

laris zinc mine was an underground zinc mine located on Little Cornwallis Island. This mine closed in 2002 following over 20 years of production. On nearby Baffin Island, the Nanisivik Mine was a zinc-lead mine located in the community of Nanisivik. This mine was opened in 1976 and closed in 2002 due to low metal prices and declining resources. The Mary River Property is a proposed iron ore mine located on Baffin Island. It is one of the largest and richest undeveloped iron ore projects in the world and involves the construction, operation, closure and reclamation of an open pit mine. Mineral activities in Greenland have grown rapidly in the past 10 years and this trend would continue in the future (Tejsner and Frost, 2012). Exploration licences for minerals in the Greenlandic portion of the LIA are located in Northwest Greenland and Northeast Greenland (Figure 54) and companies target iron, gold, lead, zinc, copper and rare earth elements.

Recent conservation history

There are several protected areas in LIA and its vicinity, which cover terrestrial and marine environments (Figure 56). Moreover, Canada is currently in the process of establishing a national marine protected area near Lancaster Sound (Parks Canada, 2013a). Lancaster Sound is the eastern entrance to the Northwest Passage, the sea route through Canada's Arctic Archipelago. This area is crucial for marine mammals including seals, narwhals, belugas, bowhead whales, walrus and polar bears. Lancaster Sound is also bordered by huge seabird breeding colonies, with populations in the hundreds of thousands. In addition, Qausuittuq is a proposed national park

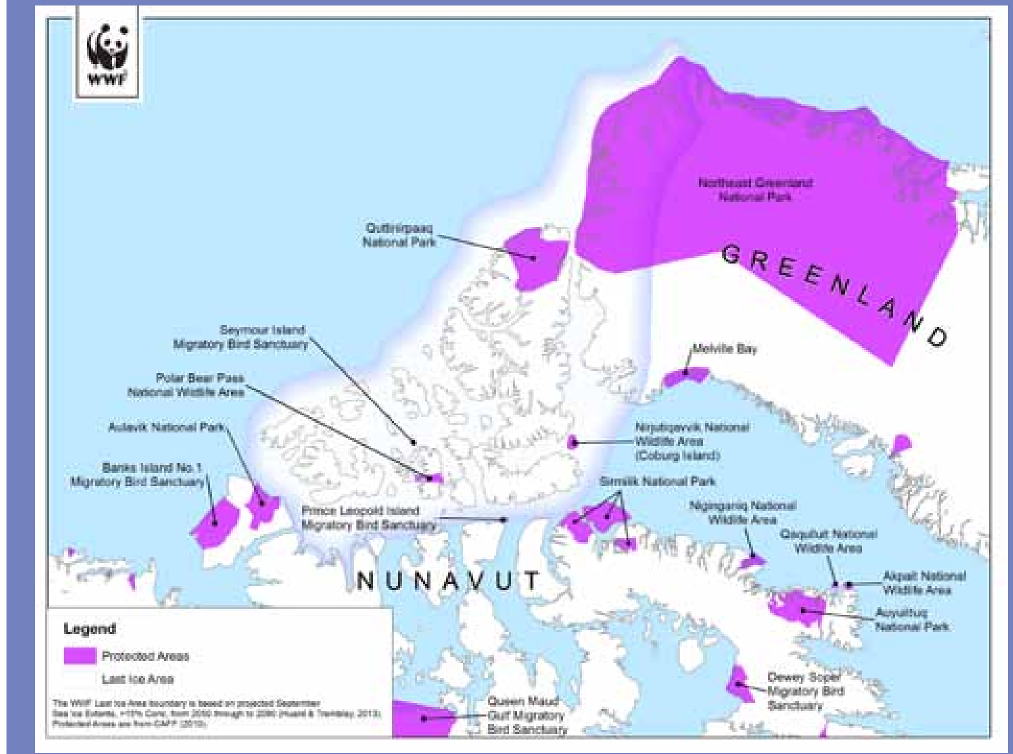


Figure 56. Protected areas in LIA and its vicinity (Protected Planet, 2013).

that includes most of Bathurst Island and a number of islands west of Bathurst Island, and is north of the Polar Bear Pass National Wildlife area (Parks Canada, 2012). This area has been chosen to represent the Western High Arctic Natural Region. This park would help to protect the endangered Peary caribou and other wildlife. The following paragraphs briefly describe each of the protected areas located in the LIA.

North-East Greenland National Park

The North-East Greenland National Park is the largest (with an area of 972,000 km2) and most northerly national park in the world. It extends three nautical miles into the adjacent sea. The Greenland Government established it in 1992, 15 years after it was appointed a UNESCO biosphere reserve. Mineral exploration is possible within this park (Tejsner and Frost, 2012). It is the only national park in Greenland and it encompasses the entire northeastern coastline of 18,000 km, and interior sections of Greenland. The Sirius Dog Sledge Patrol, Danish Navy, monitors the coastline of the park and is stationed at Daneborg, located in the National Park. Also, the research station Zackenberg is located within the park. There are no permanent Inuit settlements within the park.

Quttinirpaaq National Park

The Quttinirpaaq ("top of the world" in Inuktitut) National Park is located on the northeastern part of Ellesmere Island, only 720 km from the North Pole. It is the northernmost park in Canada and the second largest, after Wood Buffalo National Park. It covers 37,775 km2, of which 2,670 km2 are marine (Wood, 2007). It was established as Ellesmere Island National Park Reserve in 1988, and the name was changed to Quttinirpaaq in 1999, when Nunavut was created, and became a national park in 2000 (Parks Canada, 2013b). Quttinirpaaq is pending an application as a UNESCO world heritage site (UNESCO, 2013). Most of Quttinirpaaq National Park is classified as an Arctic desert.

The park consists of sedimentary mountains, ice caps, glaciers, ice shelves and fiords. The park borders on the Arctic Ocean and rises to Mount Barbeau (a nunatak), at 2 616 m the highest mountain in eastern North America. Much of the park, including the Hazen Plateau, is a polar desert receiving less than 2.5 cm of annual precipitation. Some areas of highly productive sedge grasslands occur, which support a range of Arctic wildlife including muskox, arctic hare, wolves and the endangered Peary caribou. Lake Hazen is one of the largest freshwater lakes in the circumpolar region, and has attracted great scientific interest as a thermal oasis in a polar desert. Unique physical features are the ancient deposits of 80 m-thick freshwater ice shelves that extend several kilometres out over the Arctic Ocean. The major valleys of the park are central to one of the routes by which early Aboriginal peoples moved from the Canadian Arctic to Greenland. The route contains three major axes of contact during the early Palaeo-Eskimo period (4500-3000 years ago). All pre-contact cultural groups known to have occupied High Arctic Canada, including Independence I (4500-3000 years ago) and Independence II (ca. 3000-2500 years ago), Late Dorset (ca. 1300-800 years ago) and Thule (ca. 900-300 years ago), are represented by archaeological sites in the park. The park has one of the highest concentrations of pre-contact sites surveyed in the High Arctic, including sites associated with the earliest documented human inhabitants of this remote region.

Melville Bay Nature Reserve

This reserve borders with LIA. It is a large bay off the coast of northwestern Greenland. It is located to the north of the Upernavik Archipelago and opens to the southwest into Baffin Bay. It was established in 1977. Melville Bay Nature Reserve has an area of 7,957 km2, of which 5,193 km2 are marine (Wood, 2007). The Greenland Government is currently drafting a new regulation for the nature reserve with a clearer definition of activities allowed within the reserve (e.g. traditional hunting) (Tejsner and Frost, 2012).

Figure 57. Muskox on tundra, Ellesmere Island

Sirmilk National Park

Located near Pond Inlet, Sirmilik ("the place of glaciers" in Inuktitut) National Park is composed of three separate areas at the north end of Baffin Island: most of Bylot Island, the area between Oliver Sound and Paquet Bay, and the Borden Peninsula east of Arctic Bay. Sirmilik National Park represents the Northern Eastern Arctic Lowlands Natural Region and portions of the Lancaster Sound Marine Region (Parks Canada, 2013c). This park was created in 2001 and has a global area of 22,252 km2. Although this park does not include a marine portion, it is surrounded by ocean.

Aulavik National Park

Aulavik ("place where people travel" in Inuvialuktun) National Park is located on Banks Island and was established in 1992. This park protects 12,274 km of Arctic Lowlands (Environment Canada, 2013a). This park encompasses a variety of landscapes from fertile river valleys to polar deserts, is home to the Peary caribou and has the highest density of musk ox in the world.

Nirjutiqavvik National Wildlife Area (Coburg Island)

Nirjutiqavvik National Wildlife Area includes Coburg Island and its surrounding marine areas, and is located between Ellesmere Island and Devon Island. It was established in 1995. It encloses 1,650 km2, including a marine portion with intertidal components of 1,283 km2. This national wildlife area is one of the most important seabird nesting areas in the Canadian Arctic. It supports around 385,000 seabirds, predominantly Thick-billed Murres and Black-legged Kittiwakes. Northern Fulmars, Glaucous Gulls, Black Guillemots and Atlantic Puffins also nest on Princess Charlotte Monument Island (Environment Canada, 2013b). This area is also important for polar bear, walrus, ringed seal, bearded seal and migrating beluga and narwhal (Environment Canada, 2013b).

Polar Bear Pass National Wildlife Area (Bathurst Island)

Polar Bear Pass National Wildlife Area is located on Bathurst Island, in the heart of the Canadian Arctic Archipelago. It has an area of 2,636 km2 (including 214 km2 of marine environments) and was created in 1985. This protected area was created because it supports significant wildlife populations and important archaeological sites (Environment Canada, 2013c). Polar Bear Pass National Wildlife Area supports more than 54 species of birds including 30 breeding species (mostly waterfowl and shorebirds), Arctic fox, Arctic wolf, lemmings, musk ox, the Peary Caribou, and polar bears travel through the area in spring and summer.

Figure 58. Arctic hare. Kane Basin.
© Vicki Sahanatien / WWF

Prince Leopold Island Migratory Bird Sanctuary

This migratory bird sanctuary is located on Prince Leopold Island within Lancaster Sound, at the junction of Prince Regent Inlet and Barrow Strait. It was established in 1992 and covers 311 km2, including a marine portion of 243 km2. This area is host to huge seabird colonies of murres, kittiwakes, fulmars and guillemots and its surrounding waters represent a major seabird feeding area (Environment Canada, 2013a).

Seymour Island Migratory Bird Sanctuary

This bird sanctuary is part of the Berkeley group of islands and is located approximately 30 km north of Bathurst Island. It was designated in 1975 and this protected area is small (28 km2 including a marine portion of 20 km2). The island is approximately 3 km long, and raised beaches cover most of the island. Seymour Island supports the largest Ivory Gull colony in Canada. The Ivory Gull is an endangered species (Environment Canada, 2013a).

3. JUSTIFICATION FOR INSCRIPTION

3.1.a Brief synthesis

LIA property with a total area of 12,928,522.23 ha is located on the northern coast of Ellesmere Island (the Canadian Arctic Archipelago) and Greenland; it includes the Quttinirpaaq National Park (Canada), and the northern part of Greenland National Park (Denmark).

LIA property is a unique example of present-day glaciers, from heavy domes to thick outlet tongues, and various glacial relief forms: winding U-shaped fjords having dissected the coastline, monumental through valleys and cliffy nunataks, concurrently being the highest North American mountains to the east of the Rocky Mountains. It is ornamented by prominent alpine-type ridges – traces of former large-scale glaciations. So far, LIA is a platform for active glacial processes development. Severe glacier calvings trigger large-scale iceberg formation, in such moments ice movement speeds are the highest. LIA's adjacent waters are also unique. This is the only distribution area of the disappearing perennial sea ice cover, which remains for the whole summer only in this region of the world. A unique character of glacial conditions observed at the nominated property – a kind of "open-air glaciology museum" has no analogues in the world. LIA is unique due to the large-scale of contemporary glaciations and level of glacial relief treatment. The region is one of a few places in the world where a full range of ice-formation zones can be observed: from snow and firn to the ice ones. The activity of cold-type glaciers with soles frozen to the underlying surface drastically differs from more southern "warm" glaciers. According to the data of deepwater drilling, the Greenland ice sheet has been continuously developed for the last 18 mln years, which makes LIA property even more valuable and unique as a source of information related to the Earth development during this period. LIA property will contribute for the diversity of environmental conditions in the region, especially, areas of present-day glacial processes development in the Arctic.

The LIA includes two marine ecoregions defined within the circumpolar Arctic (WWF, 2012): High Arctic Archipelago and North Greenland. Within these ecoregions, Ecologically and Biologically Significant Areas (EBSAs) were identified. These areas were selected based on their ecological importance to fish, birds and mammals, as these species are the most widely studied Arctic groups. The High Arctic Archipelago ecoregion multiyear pack ice is critical as it the largest remaining island pack ice refugium in the world and it supports unique communities. This area is particularly important for under-ice communities, seabirds and polar bears. Ellesmere Island includes three EBSAs: the Ellesmere Island ice shelves, the Nansen-Eureka-Greely Fiord that supports unique fish communities and aggregations of polar bear and ringed seal and Princess Maria Bay that is used by several seal species, walrus and narwhal. The Arctic Basin pack ice is the EBSA that contains the thickest and oldest sea ice of the Arctic and is a unique habitat for under-ice and planktonic communities, and is a significant summer refuge for polar bear. The North Greenland ecoregion contains Peary Land, an important area for marine mammals and seabirds.

3.1.b Criteria under which inscription is proposed (and justification for inscription under these criteria)

Criterion viii

LIA area is a unique natural region which present-day appearance has been largely influenced by glacial processes and the influence is still relevant. The glacial shell covering significant part of the area is being developed here under specific and harsh conditions of the Arctic desert. Within the region, picturesque ice domes and caps can be seen, with their width exceeding 900 m, and the age being more than a hundred thousand years. The ice and sheets of correlated glacial deposits concentrated along the seashore keep the memories of the Earth development history, being the source of valuable scientific data related to the climatic conditions observed during this long period. Large outlet glaciers (e.g. Petermann Glacier dewatering the Greenland ice sheet, being 70 km in length and 15 km in width) are highly dynamic. They not only tend to shrink progressively due to the global warming, but are also characterized by such a phenomenon as pulsation. Due to instantaneous glacier calvings, numerous icebergs float in the ocean, age-diverse morainic ridges are formed, conditions for new ecosystems development – primary settlements in the territories that have been previously covered with a glacier shell – are produced. Only a short time ago, in the beginning of the 20th century, marine tidewater glaciers drifted along the entire northern seashore of the archipelago. At present, the Ward Hunt glacier – a fragment of the monolithic ice shelf – is a unique example of a contemporary continental shelf glacier in the Arctic which is still breaking up with the tabular icebergs formation. The northern coast of the Canadian Arctic Archipelago and Greenland is the only region on Earth where the perennial sea ice cover remains stable for the whole summer. Ice packs cause damage to the recurring polynyas, they are separated from ice shelves by tide cracks or shore ice – areas of high biodiversity and key elements in the development of marine ecosystems. The glacial relief of LIA is also very diverse characterized by an unrivalled combination of deep trough valleys, coastlines heavily dissected by fjords and alpine-type ridges and massifs. Peaks or nunataks protruding above the ice domes are the highest ones in the Canadian Arctic (Barbeau Peak, 2616 m) and form a typical impressive relief of steeple-roofed rocky residuals.

U-shaped glacial valleys that are now turned into sea inlets not only determine a specific coastline appearance, but are also of paramount importance for island and marine ecosystems connections. Most part of the territory which at present is not covered by eternal ice due to extremely bad moisture conditions in the region has evident traces of more thick covers related to the Quaternary period.

Criterion ix

The property may provide valuable evidence on the impacts of climate change to large-scale natural arctic ecosystems if proper monitoring and research take place. There is a rich variety of terrestrial and coastal/marine environments with complex and intricate mosaics of life at various successional stages from 500 m below sea level to 5000 m above.

Due to the surface circulation of the Arctic Ocean, the ice that remains at the minimum sea ice extent is mostly located within and north of the LIA. Sea ice plays several roles such as influencing local and global climates, affecting the albedo and ocean circulation and, determining atmospheric-ocean exchanges. This area is changing at one of the most rapid pace on the planet and there is a pressing need to learn more about its biodiversity before it vanishes.

Criterion x

The nominated area and nearby marine environments provide diverse habitats for a multitude of unique life forms highly adapted in their life history, ecology and physiology to the extreme and seasonal conditions of this environment. Arctic marine food webs involve numerous pathways, are relatively simple and vulnerable to perturbations.

Since the LIA is predicted to hold the last remaining ice during summer, the area may become increasingly important for ice-obligate and ice-associated marine mammal species. Seven marine mammals live in the Arctic all year long and many other species occupy Arctic waters seasonally. The Arctic is an important region for seabird diversity and large breeding colonies are found on cliffs and islands.

The nominated area is a habitat of endemic, rare, and increasingly threatened (with shrinkage of their sea ice habitat or other climate-related impacts) species including polar bears, ice-associated whales and seals and Peary caribou. Species listed on the IUCN Red List are polar bear (vulnerable) and narwhal (near threatened).

Two thirds of the global polar bear population could disappear by 2050 if climate warming continues (Amstrup et al., 2008). For the other third, the LIA is likely to be prime habitat. LIA is home to six polar bear subpopulations. The populations of the Archipelago and Baffin Bay are in decline, even if sea ice is still extensive in these regions. Within LIA, thick multiyear ice will be replaced by annual ice, which is associated with greater productivity, and may create more favourable habitats for polar bears over the short term, acting as potential refugia. LIA will remain the best habitat available for polar bears as this region will retain ice the longest.

Some features of the sea ice environment are of particular ecological significance since they are highly productive: marginal ice zones, flaw leads and polynyas. The largest polynya in the LIA region is the North Water Polynya (NOW) in northern Baffin Bay between Canada and Greenland. This polynya forms each spring and is the largest and most productive recurring polynya in the Arctic.

The Arctic contains numerous freshwater ecosystems of different types (glaciers, lakes, rivers, ponds, streams, wetlands). Within LIA, glaciers and ice caps are present on Devon and Ellesmere islands, and at the periphery of Greenland. The Greenland Ice Sheet spreads up to the northern part of Greenland. The microbial water column diversity of some Arctic lakes was reported to be very rich despite their extreme locations. Lake Hazen is one of the largest freshwater lakes in the circumpolar region, and has attracted great scientific interest as a thermal oasis in a polar desert.

3.1.c Statement of Integrity

Integrity substantiation has been in accordance with the "Operational Guidelines for the Implementation of the World Heritage Convention":

Paragraph 88:

(a) The nominated property is a whole nature complex with its main components inseparably tied with each other by the common origin, history and the dynamics of natural development, and includes all elements necessary to express its Outstanding Universal Value.

(b) By its size (129285.2 km^2) the nominated property is enough to support the functioning of nature complexes of the Last Ice Area and to ensure the complete representation of the features and processes which convey its significance.

(c) Climate change is a prominent driver affecting the entire Arctic. Additional important factors that threaten the integrity of Arctic ecosystems are enhanced mining and oil and gas activities, increased shipping, and contaminants by local pollution or long-range transport. These anthropogenic stressors are also likely to interplay and have cumulative effects.

These additional stressors are currently minimal in the nominated area ecosystems. There is currently no hydrocarbon development and any major mineral project in the nominated sector of the LIA. The complex of specially protected areas is not subject to economic impact. Bearing the status of the National Park – the highest nature conservation status in Canada and Denmark, the whole nominated territory (with the exception of part of the Robeson Channel) provides protection and the following natural development of representative complex of ecosystems. The territory is extremely hard to access, which gives it supplementary guarantees of integrity and safety.

Paragraph 90:

The biophysical processes and landform features of the nominated area are intact.

Paragraph 93:

The nominated property contains all of the key interrelated and interdependent elements of Arctic ecosystems in their natural relationships.

The northern coast of the Canadian Arctic Archipelago and Greenland is the only region on Earth where the perennial sea ice cover remains stable for the whole summer. The glacial relief of the nominated sector of the LIA is very diverse characterized by an unrivalled combination of deep trough valleys, coastlines heavily dissected by fjords and alpine-type ridges and massifs. Peaks protruding above the ice domes form a typical relief of steeple-roofed rocky residuals.

Paragraph 94:

Due to its sheer size, the nominated property contains all necessary elements to demonstrate the key aspects of processes that are essential for the long term conservation

Figure 59. Multiyear Ice.
© Kathryn Hansen / Credit NASA

of the Arctic ecosystems and the biological diversity they contain. There is a rich variety of terrestrial and coastal/marine environments with complex and intricate mosaics of life at various successional stages from 500 m below sea level to 5000 m above.

Paragraph 95:
The property contains the most critical habitats essential to ensure the survival of viable populations of many endemic, rare and disappearing flora and fauna species.

The nominated sector of the LIA is a very illustrative site that demonstrates the classical marine Arctic ecosystem with the typical "trophic pyramid" consisting of all the main links (marine mammals, fish, aquatic invertebrates, zoo- and phytoplankton, microorganisms, as well as seabirds and polar bear, the largest land predator found in the Arctic that is the top of this pyramid).

3.1.e Protection and management requirements

Nowadays the status of the National Park (which meets the requirements of the II IUCN category) ensure the conservation and further natural development of the unique ecosystem complex. Any economical or business activities are prohibited on the territory of the SPAs and restricted within their buffer zones. Such activities as hunting, mining operations, commercial building and transport routes construction are prohibited. Thus, territorial and functional integrity is achieved within such a vast territory of the natural complexes.

Eastern part of the nominated property, the North-East Greenland National Park, in 2007 was appointed a UNESCO Biosphere Reserve.

The special protected areas within the nominated territory possess enough financial and administrative resources for long-term conservation of the property`s Outstanding Universal Value. The Sirius Dog Sledge Patrol, Danish Navy, monitors the coastline of the North-East Greenland National Park and is stationed at Daneborg, located in the National Park. Also, the research station Zackenberg is located within the park.

Integrated coordination system of transboundary property management is being developed at the moment. WWF scientists are in discussion with Inuit and governments located in the LIA region in order to plan the future management of this area to ensure the resilience of all life forms dependant on sea ice. A recommendation of the Arctic Biodiversity Assessment (CAFF, 2013a) goes in that sense and states the importance of developing and implementing mechanisms to conserve Arctic biodiversity under the deteriorating trend of sea ice, glaciers and permafrost.

3.2 Comparative Analysis

**LAST ICE AREA (LIA)
IN THE GLOBAL
BIOGEOGRAPHICAL CONTEXT**

Global analysis of distribution of the World Heritage Sites shows that among all the biogeographic realms distinguished according to the well-known M. Udvardy's scheme of biogeographical regions (1975) relatively few UNESCO sites are located in the Nearctic region. This area is vast and includes the USA, Canada, Greenland, and northern Mexico (see Fig. 60). Most natural heritage sites are concentrated in western USA and Canada. Meanwhile, the entire north-eastern Nearctic region is the area with an obvious lack of World Heritage Sites, while being a vast territory comparable to the entire Western Europe in terms of its area.

The same conclusion can be drawn if one deals with this problem in the context of individual biomes (i.e., at the lower taxonomic level): the addition of this site, in the northestern Canadian Arctic Archipelago and northern Greenland, to the world map of UNESCO sites is extremely topical. Indeed, an analysis of the sites that have already been inscribed on the World Heritage List shows that the following 5 biomes, or habitat types, are the most common ones in it: wetlands, tropical moist and dry forests, coasts, and mountains. Meanwhile, the Arctic tundra and deserts, which are abundant in the northeastern North America, turn out to be least covered.

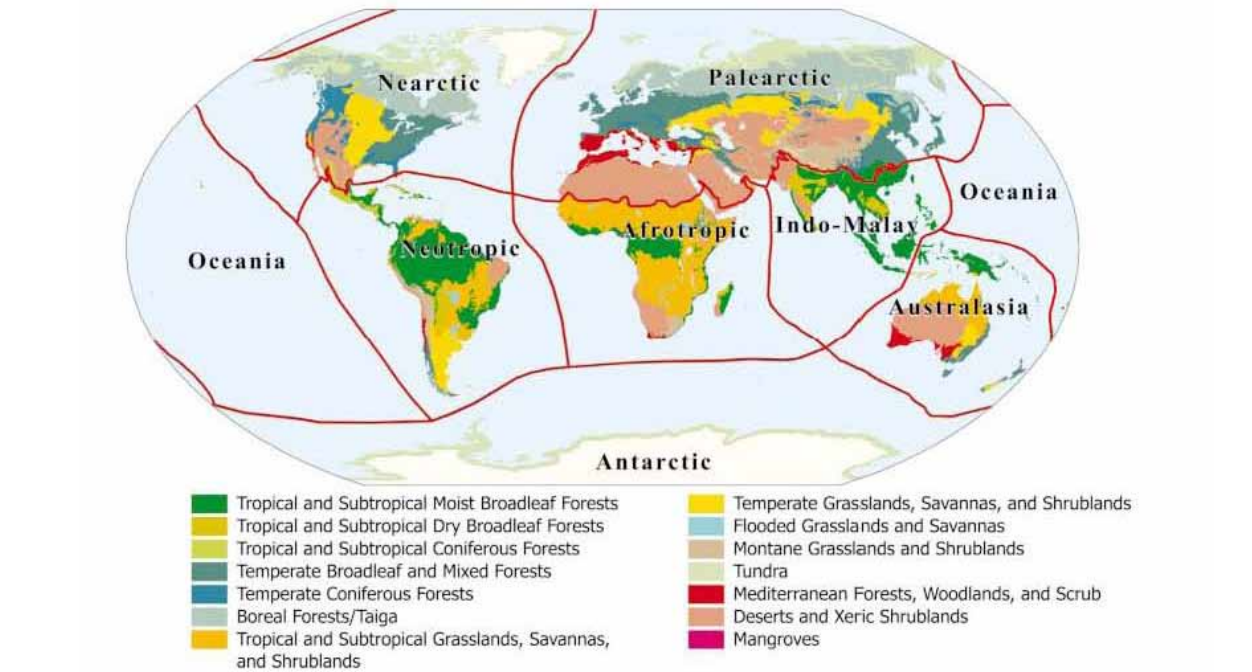


Figure 60. Terrestrial biomes, terrestrial and freshwater biogeographic realms, and marine biogeographic realms (sensu Dasmann, 1974; Udvardy, 1975).

Thus, from this viewpoint, awarding the world heritage status to the site under study (Last Ice Area) is extremely relevant, since it would make the distribution of the UNESCO sites more uniform. This fact would fully comply with the policy of the World Heritage Center and the Global Strategy that has been being fulfilled since 1994 to make the World Heritage List more well-balanced and adequate so that it fully displays the natural and cultural diversity of the world and comprises all the main geographical zones of the Earth.

**LIA AND OTHER ARCTIC AND SUBARCTIC
NATURAL WORLD HERITAGE NOMINATIONS**

Today, only a few Natural World Heritage Sites are located in the Arctic and Subarctic region, Wrangel Island being the northernmost of them (N 71). Hence, it was reasonable to add the northern portion of the temperate zone, together with the Natural World Heritage Sites lying in this zone, to a comparative analysis. In this case, the number of possible analogues is eight (Table 5). The analogues are compared below in terms of the key parameters related to criteria viii, ix and x (Tables 6, 7 and 8).

The Southern Hemisphere also contains three Natural World Heritage Sites located in the circumpolar zone: "The New Zealand Subantarctic Islands", Australia's Macquarie Island and the Heard Island and McDonald Islands. However, the circumpolar zone in the Southern Hemisphere is known to differ drastically from that in the Northern Hemisphere, so it is rather difficult to draw an analogy in this case.

A comparison of the nominated property with other natural sites that have already been inscribed on the UNESCO World Heritage List reveals a number of unique features. This fact gives grounds for claiming that this region of the Arctic has global value in the context of three criteria highlighted by the UNESCO Convention, namely: **criterion viii** – "to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features"; **criterion ix** – "to

Table 5. World Heritage Sites located in the Arctic, the Subarctic, and the northern portion of the temperate zone.

Name of the World Heritage Site	Country	Criteria and year of inscription	Area	Brief description	Geographic coordinates
LIA	Canada/ Denmark (Greenland)	Proposed criteria: (viii) (ix) (x)	>12 928 520 ha	The Arctic. The northeastern portion of the Canadian Arctic Archipelago (Queen Elizabeth Iislands), northeastern Greenland.	N 82° 7′ 56.424″ W 71° 38′ 53.556″ N 82° 20′ 49.128″ W 47° 10′ 6.384″
Ilulissat Icefjord	Denmark (Greenland)	(vii) (viii) 2004	402 400 ha	The Arctic/the Subarctic. The ice fjord in southwestern Greenland.	N69 7 60 W49 30 0
Surtsey	Iceland	(ix) 2008	3 370 ha	The Subarctic. A small island of volcanic origin south of Iceland.	N63 18 11 W20 36 8
Laponian Area	Sweden	(iii) (v) (vii) (viii) (ix) 1996	940 000 ha	The northern portion of the temperate zone. Ancient mountains with lakes, glaciers, and Alpine relief, submontane swampy taiga	N67 19 59.988 E17 34 59.988
Virgin Komi Forests	Russia	(vii) (ix) 1995	3 280 000 ha	The northern portion of the temperate zone. The western foothills of the Northern Urals covered with virgin taiga, high-mountain zone with alpine relief.	N65 4 0.012 E60 8 60
Putorana Plateau	Russia	(vii) (ix) 2010	1 887 251 ha	The Subarctic. The vast basalt plateau in the northern part of Central Siberia.	N69 2 49 E94 9 29
Wrangel Island	Russia	(ix) (x) 2004	1 916 300 ha	The Arctic. The large mountainous island with the adjacent basin. The island is covered with tundra forest and rock fields.	N 71 11 20 W179 42 55
Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek	USA/ Canada	(vii) (viii) (ix) (x)	9 839 121 ha	The Subarctic/the northern portion of the temperate zone. Alaska. The mountain and glacial zone with coastal areas covered with moist coniferous forests.	N 61 11 51.3 W140 59 31.1
Nahanni	Canada	(vii) (viii)	476 560 ha	The Subarctic. The picturesque montane river flowing in giant canyons.	N 61 32 50 W 125 35 22

be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals"; and **criterion x** – "to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation."

These criteria are further developed for this site as follows:

Criterion viii: Variety of glaciological forms: types of ice (glaciers), forms of glacial relief, glaciological processes.

Criterion ix: Combination of various Arctic ecosystems: marine (from shallow water areas to the areas several hundred meters deep), coastal (including fjords), and insular ones (from small subpolar islands to giant Greenland);

Criterion x: The presence of globally endangered species inscribed in the International Red List.

CRITERION VIII: an outstanding example of significant geomorphic or physiographic features of the relief.

Variety of glaciological forms: types of glaciers, glacial forms of relief, and glaciological processes.

The nominated property is a combination of scenic glaciers, deep trough valleys and coastlines dissected by fjords. Under the influence of ancient and contemporary glaciations the relief of mountains has acquired Alpine features even at comparatively low altitudes. Summits rising above ice caps, or nunataks, create distinctive spectacular landforms of peaky cliffed residual mountains. Outlet glaciers descending into the ocean form a vast number of icebergs (from smaller to the largest ones) carried by streams up to the middle of the North Atlantic. There are still unique ice shelves extensively shrinking for the last two centuries along the coast which provide the ocean with tabular icebergs. The northern coast of Greenland and Canadian Arctic Archipelago is projected to become the only area on the Earth where the lasting sea ice sheet stays intact during the entire summer period. Polynyas breaking the pack ice and flaw leads separating them from ice shelves are zones of high biodiversity and essential elements of natural ecosystems' functioning. The LIA area is a unique combination of the traces of ancient larger-scale glaciation, manifestation of contemporary glaciological processes and the only large distribution area of summer sea ice projected to last.

Up to 36 % of the nominated Canadian territory on Ellesmere Island is covered with glaciers. They are mostly situated in the north, in the mountains of the Grant Land, at the altitudes of over 1100 m above sea level. More than half of these mountains the highest in the Canadian Arctic are covered with ice. There is no solid ice cap like in Greenland due to the relatively small amount of precipitation. The area is dominated by flat-summit glaciers and small ice caps over a hundred thousand years old. The depth of the glaciers in the onshore part of the park reaches 900 meters (for example, Gilman ice dome with the height of 2743 m above sea level.) The glaciers are of cold type, i.e. they are iced to the underlying surface. This is one of those few places on the planet where you can find an entire range of ice-formation zones: from snow and firn zones to ice ones. Summits protruding over the ice sheet, or nunataks, can be over 2500 meters (there is Barbeau Peak rising over M'Clintock glacier, 2616 meters high, it is the highest mountain in Nunavut, and there is Whisler Mountain, 2590 meters high, further north.)

Outlet glaciers originate from large firn fields. They may end up onshore feeding rivers and lakes (the largest non-saline receiving basin is Lake Hazen), or they may fall into the sea breaking along the front and forming numerous tidewater glaciers. While the former gradually reduce their length and depth and retreat which is thought to be a result of the global warming, the latter may dramatically change their sizes due to one-time calving glaciers, which cannot be the evidence of a regional climate change, but only shows the complex internal dynamics of the glaciers (E. Garankina, 2014). The largest glaciers include Dryas, Henrietta Nesmith, Blister, Turnstone, Abbe, and Turnabout. The Hazen Plateau situated further south is not covered with glaciers at the moment (two residual ones are Murray Ice Cap and Simmons Ice Cap), but it is dissected by the network of ancient glacial trough valleys. It goes down to a sea with steep 600-meter cliffs in the east.

In the early twentieth century maritime continental glaciers lined nearly the entire northern coast of Ellesmere Island. However, by the beginning of the twenty-first century there were only fragments of the single ice shelf left (Ward Hunt and Markham). They are 80 meters high, may be partially covered by water at high tide, actively produce tabular icebergs and continue to deteriorate. The ice-free coastal strip has the traces of more extensive quaternary glaciation.

The northern coast of the Canadian Arctic Archipelago and Greenland is also the only area on the Earth where the lasting sea ice sheet stays intact during the entire summer period. Pack ice is broken by recurring polynyas (for example, North Water polynya) and they are separated from ice shelves by tide cracks or flaw leads which are zones of high biodiversity and essential elements of natural ecosystems' functioning.

In Greenland the nominated property occupies the coastal strip dissected by deep fjords, along which outlet glaciers descend to the sea from the trough valleys. The coastline dissection with fjords is related to the overdeepening of river valleys during the glacial age and their flooding at rising of the sea level in the post-glacial period. Only one, situated farthest to the south, Petermann Glacier drains the Greenland ice sheet, falling into a large fjord. The glacier is 70 km long and 15 km wide, and its thickness varies from 600 m to 30-80 m at its front, where large blocks of ice often split off it. The Greenland ice sheet has continuously developed for the past 18 million years, experiencing periods of intense shrinkage and, on the contrary, adsorption. The rest of the nominated property is mountainous, free from ice sheet and it bears only

Table 6. World Heritage Sites in the Arctic, Subarctic, and the northern portion of the temperate zone: diversity of ecosystems and forms of natural processes.

Name of the World Heritage Site	Glacier types (continental, maritime, mountain, outlet, icebergs)	Glacial forms of the relief (trough valleys, cirque landforms, corries, karlings, fjords, moraines, outwash plains, etc.)	Glaciological processes (exaration, calving glaciers, formation of icebergs, cracks in glacier masses)
LIA	+ Ice caps, flat-summit glaciers, outlet glaciers, icebergs, pack ice	+ trough valleys, cirque landforms, fjords	+ Exaration, calving glaciers, formation of icebergs, cracks in glacier masses
Ilulissat Icefjord	+ outlet glacier	+ Fjord, trough valley	+ Rapidly moving glacier, calving glaciers, icebergs
Surtsey	-	-	-
Laponian Area	+ Mountain-valley glaciers	+ Outwash plains, U-shaped valleys, cirque landforms, moraines, monad-nocks, screes, drumlins, erratic blocks	+ Rapidly moving glaciers, exaration
Virgin Komi Forests	+ small corrie and niche glaciers	+ trough valleys, cirque landforms, cor-ries, mountain terraces, moraines	+ Exaration
Putorana Plateau	+ small corrie and niche glaciers	+ Trough valleys, corries, fjords	+ Exaration
Wrangel Island	-	-	-
Kluane / Wrangell-St. Elias / Gla-cier Bay / Tatshenshini-Alsek	+ ice field, outlet glaciers, Malaspina glaciers	+ Trough valleys, fjords, moraines, hang-ing valleys	+ Exaration, calving glaciers, formation of icebergs, cracks in glacier masses, moraine deposits
Nahanni	-	-	-

mountain glaciation (ice caps at the Roosevelt Range.) This is the ice-free land area located farthest to the north which is qualified as a polar desert due to very low precipitation.

If you look at Table 6, you can see that only few properties can partially compare to the LIA area, including the Ilulissat Icefjord, Laponian Area, Virgin Komi Forests, Putorana Plateau, Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek. These areas have considerable contemporary glaciation or abundant traces of past glacial periods.

Ilulissat Icefjord can be considered a partial analogue to the LIA area as it is one of the few outlet glaciers connecting the Greenland ice sheet with the sea. Other similarities with the nominated area include a receiving fjord where icebergs are actively formed and its location at the border of the Arctic and Subarctic. Nevertheless, the Ilulissat Icefjord is a very limited area, which does not provide such a variety of types and forms of glacial relief as the LIA area enormously exceeds it in size. Therefore, they cannot be considered similar in every way.

The Laponian Area is a region with strong alpine type relief, abundance of corries, trough valleys, kursu valleys and contemporary mountain-valley glaciers with a rich zone of

accumulative glacial relief (outwash plains, moraines.) However, this area is located further south, in the northern portion of the temperate zone, therefore, there are no elements of transection or semi-continental glaciation (ice caps, flat-summit glaciers), which are so characteristic and unique of the LIA area, there are no fjords connected to the coast or outlet glaciers either. The main volume of glaciation here took place much earlier, during the periods of wider mountain and continental glaciation, whereas the LIA area is the scene of the widespread recent glacial activity.

The Virgin Komi Forests and Putorana Plateau bear the traces of powerful glacial processes, but at the moment only small residual corrie and niche glaciers are observed here. In the first case, exaration processes are concentrated in the most elevated axial zone of the Ural mountain range (the area of Mount Narodnaya, Telposiz mass) where large corries with morainic lakes, alpine type ranges and karlings, tunnel valleys are prevailing. In the second case, glaciers had a significant impact on the entire mass, as a result of which numerous valleys dissecting it have a trough-like outlook, and their mouths filled with large lakes resemble typical fjord coasts. Partially, this relief of the Putorana Plateau corresponds to the features of the Hazen Plateau affected by glaciers in the southern part of the Quttinirpaaq National Park on Ellesmere Island, with its 600-meter high cliffs and a dense network of troughs. However, the location of both properties, the Komi Forests and Putorana Plateau, in the northern portion of the temperate zone and Subarctic, respectively, implies almost complete lack of recent glacial activity, therefore, they cannot be considered similar to the LIA area.

The Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek are the areas where heavy glaciation is combined with alpine relief. The world's largest ice field outside the Arctic Circle is situated here. Remarkable tectonic activity in the area provides for the active interaction of glaciers with the relief. The high dynamics of their sizes and depths results in the formation of large trough valleys and hanging valleys connected to them, which are the traces of more powerful glaciation. Due to the increased hydration, one of the longest outlet glaciers in the world is formed here, and the largest Malaspina glacier is preserved here, as well. And still, these two so different areas of glacial activity cannot be compared due to all their peculiar features. It is the development in the conditions of increased hydration and high tectonic activity which results in overly intense glaciation in the uncharacteristic area (in the Subarctic to temperate zones.) On the contrary, adverse dry weather conditions of the LIA area allow us to trace the typical formation of

Table 7. World Heritage Sites in the Arctic, Subarctic, and the northern portion of the temperate zone: diversity of ecosystems and forms of natural processes.

Name of the World Heritage Site	Ter-restrial ecosys-tems	Coastal ecosys-tems	Insular ecosys-tems	Marine ecosys-tems	Conti-nental ice sheet	Fjords, lakes
LIA	-	+	+	+	+	+
Ilulissat Icefjord 402 400 ha	-	+	-	-	+	+
Surtsey 3 370 ha	-	-	+	+	-	-
Laponian Area 940 000 ha	+	-	-	-	-	+
Virgin Komi Forests 3 280 000	+	-	-	-	-	-
Putorana Plateau 1 877 250	+	-	-	-	-	+
Wrangel Island 1 916 300	+	+	+	+	-	-
Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek 9 839 120 ha	+	+	-	+	-	+
Nahanni 476,560 ha	+	-	-	-	-	+

Figure 61. Arctic Fox.

glaciers and slow transformation influenced by them of the relief into arctic deserts that are so widespread in the northern sector of the Nearctic and virtually not included in the UNESCO World Heritage sites.

The other areas shown in Table 6 cannot be compared with the LIA in terms of relief glaciation. They were either not affected by the last glaciation at all (the mountainous Wrangel Island, because of its extreme eastern position and small amount of precipitation, the Nahanni River area due to its rather southern location), or they were formed in suitable conditions (the Subarctic), but fairly recently (the volcanic island of Surtsey was formed only half a century ago), therefore, they have not been under an active glacial impact yet.

Thus, it is fair to say that the LIA is a unique "open-air museum of glaciology". Here, you can observe both spectacular glaciers of various types: large ice caps, small flat-summit glaciers, thick outlet glaciers, and diverse glacial relief forms: meandering deep fjords, which are numerous in the north-west coast of Greenland, U-shaped trough valleys widespread on the both sides of the Nares Strait, rocky nunataks that are also the highest peaks in North America to the east of the Rocky Mountains. The areas bearing no contemporary glaciation have clear traces of its wider distribution in the past – the colorful alpine landforms. Also, there are active glacial processes in progress in the area. Thick calving glaciers significantly reduce the size of the glaciers and cause massive formation of both larger and smaller icebergs. The speed of moving ice in the calving period can be enormous. The adjacent waters still bear a disappearing lasting sea ice sheet.

All of this allows us to speak about the unique glaciological conditions of the nominated property which can be considered similar in every way to none of the sites already included in the World Heritage. Only the areas of Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek and Ilulissat Icefjord can be considered partial analogues in terms of the contemporary glaciation scale, and the Laponian Area, Virgin Komi Forests, Putorana Plateau are partially similar to it as far as the scale of glaciation is concerned. However, nearly all of these areas are located in the northern part of the temperate zone or in the Subarctic, consequently, even existing glaciers are developing in the conditions absolutely different to those of the LIA area. The amount and variety of contemporary glaciation and glacial relief forms in the LIA area are similar and even greater than those of the other regions it has been compared to. Therefore, it appears that the inscription of the LIA in the World Heritage List by criterion viii will significantly expand the diversity of its natural environment, in particular, the areas of contemporary development of glacial processes in the Arctic.

CRITERION IX: an outstanding example of current ecological and biological processes in evolution and development of terrestrial and freshwater ecosystems.

The combination of various Arctic ecosystems (insular, coastal, and marine ones).

The statement "to be an outstanding example representing significant on-going ecological and biological processes in the evolution and development of terrestrial, coastal and marine ecosystems" is valid about the LIA property.

Table 7 shows that among all the analogues that have already been inscribed on the World Heritage List, the broadest range of Arctic ecosystems can be found within the nominated property. Thus, the continental properties in the Subarctic and the northern portion of the temperate zone (Laponian Area, Virgin Komi Forests, Putorana Plateau and Nahanni) cannot compete with LIA for the diversity of ecosystems as they contain neither coastal nor marine ecosystems. Furthermore, these properties lie south of LIA (N 61–69), thus there is no ice cover. Although Surtsey and Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek include terrestrial, coastal, and insular areas, they are also located further south than

Table 8. World Heritage Sites in the Arctic, Subarctic, and the northern portion of the temperate zone: species diversity in the most representative groups of living organisms.

Name of the World Heritage Site	Mammals: the approximate total number of species	Birds: the approximate total number of species
LIA	Approximately 20 species, almost half of them are marine animals (whales, seals, the walrus, and the polar bear), the rest being terrestrial species (arctic fox, muskox, reindeer, lemming, wolf, etc.). Almost all marine animals have been inscribed in the IUCN Red List of Endangered Species where they are attributed to different categories.	Approximately 40 species of seabirds forming large colonies. Many species have been inscribed in the IUCN Red List of Endangered Species.
Ilulissat Icefjord	10-12 species	The total number of seabirds: no data available Near the fjord: 10 seabird colonies
Surtsey	No data available	Appr. 90
Laponian Area	Appr. 25	Over 150
Virgin Komi Forests	Appr. 40	Over 200
Putorana Plateau	Over 30	Appr. 140
Wrangel Island	Appr. 20	Appr. 170
Kluane / Wrangell-St. Elias / Glacier Bay / Tatshenshini-Alsek	Appr. 30	Over 200
Nahanni	Appr. 25	Over 120

LIA (N 61–63), in the northern portion of the temperate zone. Two Arctic World Heritage Sites, Ilulissat Icefjord (N 69) and Wrangel Island (N 71), are the ones most similar to the property under consideration. However, the former site focuses on coastal ecosystems, while Wrangel Island, although being very similar to LIA in terms of Arctic ecosystems presented there, does not have continental glaciation (which is the key phenomenon for our analysis) and is located in the geographically opposite sector of the Arctic.

The diversity of glacial forms (sea ice: marginal ice zones, flaw leads, polynyas; ice shelves, glacier ice), which are highly dynamic under conditions of current climate changes, is the aspect highly relevant for criterion ix.

Thus, one can claim that the nominated part of the LIA area is unique because there is a combination of various Arctic ecosystems, as opposed to the other high-latitude circumpolar Natural World Heritage Sites.

– ecosystems of large islands, including montane, flatland, and coastal ones (Northwest Greenland, North of Ellesmere island);
– ecosystems of small islands (e.g., Hendrick, John Murray, Sverdrup, Hazen land islands);
– coastal landscapes, including such unique relief form as fjords, are common (e.g., St. George, Victoria, Koch, Frederick Hyde fjords);
– the nominated property contains vast water areas of the Arctic ocean, including both shallow-water and deepwater zones;
– continental glaciers, various forms of sea ice.

CRITERION X: The area contains the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species.

The presence of globally endangered species inscribed in the International Red List.

The LIA area is a very illustrative site that demonstrates the classical marine Arctic ecosystem (starting with the shallow-water zone to the zones several hundred meters deep), with the typical "trophic pyramid" consisting of all the main links (marine mammals, fish, aquatic invertebrates, zoo- and phytoplankton, microorganisms, as well as seabirds and polar bear, the largest land predator found in the Arctic that is the top of this pyramid). In terms of this aspect, the LIA site has no analogues. In none of the other UNESCO sites located in the Subarctic and Arctic water the marine ecosystem is represented so completely and is characterized by such high biodiversity.

However, the value of the site under consideration is associated with the fact that a number of species inscribed in the IUCN Red List of Threatened Species are found here.

Thus, one of the key local species, the polar bear, is referred to as a "vulnerable species" in the IUCN Red List of Endangered Species, which makes it necessary to pay special attention to the problem of its conservation. The total population of polar bears in the Arctic is estimated at 20–25 thousand; a declining trend is observed in many Arctic regions. In particular, it is true for the significant portion of the area under study (LIA), where 6 local subpopulations of the polar bear have been found. However, the polar bear is a relatively abundant species here so far. In terms of its contribution to conservation of this vulnerable species, the LIA area can be compared only to Wrangel Island (Russia), which is known to be the largest "birthing center" of polar bears in the world. The predator is rarely seen in Ilulissat Icefjord and is not found at all in the areas of other potential analogues since they lie south to its natural habitat.

Another feature of LIA (if one compares this area to other high-latitude World Heritage Sites) is the crucial role played by various marine animals (cetaceans and pinnipeds) in the ecosystem. These animals account for approximately the half of the entire species composition of the mammalian fauna in the area under study. Many of them have been inscribed in the IUCN Red List of Endangered Species (different categories) . Only two other Arctic Natural World Heritage Sites can be compared to LIA in this respect: Ilulissat Icefjord and Wrangel Island, both containing a significant water area (in particular in the latter case).

Thus, the water area adjacent to Wrangel Island is known to be the feeding grounds of the gray whale (this species migrates to this area from the direction of California, from the Mexican nature reserve El Vizca no). Other cetaceans (the bowhead whale, the humpback whale, the finback whale, the orca, and the beluga whale) are also found here. Along with the walrus, other pinnipeds also inhabit this area: the ringed seal, the bearded seal, the spotted seal, and the ribbon seal. A number of these species are globally endangered. Although some marine animal species are found in both these regions (LIA and Wrangel Island, which are located in the geographically opposite areas of the Arctic), the uniqueness of each region is obvious.

The other Natural World Heritage Sites discussed as possible analogues do not contain such vast water areas: they are either continental (e.g., the Putorana Plateau), or border with sea or ocean coasts (e.g., Alaska site), or are individual islands (Surtsey Island). Hence, they cannot significantly contribute to conservation of endangered marine mammal species.

Let us mention the fauna of seabirds: approximately 40 seabird species inhabit the LIA area; many of them have been inscribed in the IUCN Red List of Endangered Species. In this aspect, LIA is one of the other Arctic and Subarctic marine World Heritage Sites where large congregations of seabirds are observed, including globally endangered species (bird colonies in Surtsey Island, along the coast of Ilulissat Icefjord, on the Alaskan coastline, and on Wrangel Island).

Thus, a conclusion can be drawn that LIA is not inferior to other Arctic and Subarctic sites that have already received the status of Natural World Heritage properties in terms of the main aspects related to criterion x (faunistic diversity of species, the presence of globally endangered species). This fact is particularly important if one takes into account the high-latitude location of the area, harsh climate, and high degree of ice cover: one would not expect to have abundant flora and fauna under such extreme conditions.

Nevertheless, the area under study can be tentatively referred to a certain "polar oasis", where the combination of local factors forms the ecosystem rich in Arctic marine species, which is rather typical and representative of the high-latitude areas of the Western Hemisphere. This region is of the greatest significance for conservation of the polar bear, cetaceans, pinnipeds and colonial seabirds.

Summarizing the comparative analysis, we would like to mention that two UNESCO properties (Ilulissat Icefjord in southwestern Greenland and Russia's Wrangel Island in the Chukchi Sea) are the ones most similar to LIA with respect to individual parameters.

The Greenland's fjord and LIA are similar in terms of their geographic proximity (they both belong to the same super-island, Greenland), similar composition of biota, some common features of glacial landscapes and glacial processes. However, due to its vast area (being ten times as large as that of the fjord), the LIA region has a wide range of Arctic landscapes, both terrestrial and marine ones, including several dozens of large, medium-size, and small fjords.

Although LIA and Wrangel Island have some features in common (mostly due to the presence of islands and vast water areas in both properties), there is a number of fundamental differences as well. These differences include different types of biota, climate, recent glacial activity in the LIA area and its complete absence even in the past on Wrangel Island because of the fact that both properties are separated by several thousands of kilometers, thus lying virtually at the opposite "poles" of the Arctic zone of the Earth; hence, they cannot be regarded as obvious analogues.

No obvious analogues of LIA have been identified among the promising Natural (and Cultural-Natural) World Heritage properties in the region under study (the Arctic and Subarctic) that have been included in the Tentative Lists of the corresponding countries (Canada, USA, Iceland, Denmark, Sweden, Norway, Finland, Russia). Quttinirpaaq National Park, a part of the nominated area, is pending an application as a UNESCO World Heritage site in 2013.

Canada:
– Ivvavik / Vuntut / Herschel Island (Qikiqtaruk) – Mixed World Heritage Site, N 68.
– Quttinirpaaq National Park – Mixed World Heritage Site, N 82.

Denmark: Greenlandic inland and coastal hunting area – the cultural landscape showing the history and traditions of Eskimo hunting activity, western Greenland.

Island:
– Vatnaj kull National Park shows the glaciation and volcanic processes, N 64.
– Torfaj kull Volcanic System – the unique volcanic landscape, N 63.
– Brei afj r ur Nature Reserve – cultural landscape, Mixed World Heritage Site, N 65.

Finland: Saimaa-Pielinen Lake System – N 61–63.

Norway:
– The Lofoten islands – Mixed World Heritage Site, N 67.
– Svalbard Archipelago – Mixed World Heritage Site, N 77–80.

The overwhelming majority of the properties listed above cannot be regarded even as remote analogues of LIA: all of them have their own unique features that make them differ from the property in northeastern North America. Svalbard, the large Arctic archipelago located at approximately the same latitude as LIA but in Northern Europe, seems to be the only exception. Svalbard is also characterized by rich biota and abundance of marine animals; it also has the heavy contemporary glaciation (from corrie and mountain-valley glaciers to transection or semi-continental glaciation, calving glaciers, up to 60% of the archipelago is covered with ice) and well-developed various glacial processes and glacial forms of relief (fjord type coasts, trough valleys, corries, nunataks, etc.). It is true both for the islands and for the water area. However, as the sites are located in different sectors of the Arctic, they have a different history of development, different duration of glaciation periods (the LIA area has a much more ancient ice sheet, which is older than a hundred thousand years at some places as compared to the much younger glaciers of Spitsbergen), differentiation in current dynamics and distribution of glaciers. Meanwhile, it is obvious that the degree of reclamation of Svalbard areas is much greater and the history of people settling there is much older. These facts reduce the degree of similarity between these two Arctic regions.

One should also take into account that one of the aforementioned promising candidates (the Canada's Tentative List of World Heritage Sites), namely, Quttinirpaaq National Park, is a component of the area under study (LIA) according to the new scheme. The criteria for inscribing this national park, which was added to the Canada's Tentative List in 2004, are as follows: (iii)(vii)(viii)(x); i.e., it is the Mixed World Heritage Site.

SUMMARY. No obvious analogues of LIA have been identified among the few UNESCO sites that are also located in the Arctic and Subarctic, as well as in the northern portion of the temperate zone. No analogues have been detected among the tentative UNESCO sites. Hence, there are all reasons for claiming that this region is globally unique as it demonstrates various glacial processes (fast moving outlet glaciers, their calving glaciers, formation of large icebergs, recent destruction ice shelves, etc.) and relief forms (trough valleys, corries, cirque landforms, fjords, alpine type ranges, nunataks, etc.), is a good combination of insular, coastal, and marine landscapes, and has a rather abundant (for such high latitudes) biological diversity mostly due to marine dwellers, such as marine mammals, fish, aquatic invertebrates, and ornithofauna (colonial birds). A significant number of globally endangered species inscribed in the IUCN Red List are found here. Most importantly, the relatively unchanged nature of the Last Ice Area in what is literally projected to be an ocean of change distinguishes it from any other current or potential future World Heritage Site in the Arctic. Hence, the property deserves to be inscribed on the UNESCO World Heritage List in accordance with three natural criteria (viii, ix and x).

Excerpts from the Operational Guidelines for the Implementation of the *World Heritage Convention*

Figure 62. The Arctic Tern, Devon Island.

I. **INTRODUCTION**

I.B ***The World Heritage Convention***

4. The cultural and natural heritage is among the priceless and irreplaceable assets, not only of each nation, but of humanity as a whole. The loss, through deterioration or disappearance, of any of these most prized assets constitutes an impoverishment of the heritage of all the peoples of the world. Parts of that heritage, because of their exceptional qualities, can be considered to be of "Outstanding Universal Value" and as such worthy of special protection against the dangers which increasingly threaten them.

5. To ensure, as far as possible, the proper identification, protection, conservation and presentation of the world's heritage, the Member States of UNESCO adopted the *World Heritage Convention* in 1972. The *Convention* foresees the establishment of a «World Heritage Committee» and a «World Heritage Fund». Both the Committee and the Fund have been in operation since 1976.

6. Since the adoption of the *Convention* in 1972, the international community has embraced the concept of «sustainable development». The protection and conservation of the natural and cultural heritage are a significant contribution to sustainable development.

7. The *Convention* aims at the identification, protection, conservation, presentation and transmission to future generations of cultural and natural heritage of Outstanding Universal Value.

8. The criteria and conditions for the inscription of properties on the World Heritage List have been developed to evaluate the Outstanding Universal Value of properties and to guide States Parties in the protection and management of World Heritage properties.

9. When a property inscribed on the World Heritage List is threatened by serious and specific dangers, the Committee considers placing it on the List of World Heritage in Danger. When the Outstanding Universal Value of the property which justified its inscription on the World Heritage List is destroyed, the Committee considers deleting the property from the World Heritage List.

I.C **The States Parties to the *World Heritage Convention***

12. States Parties to the *Convention* are encouraged to ensure the participation of a wide variety of stakeholders, including site managers, local and regional governments, local communities, non-governmental organizations (NGOs) and other interested parties and partners in the identification, nomination and protection of World Heritage properties.

13. States Parties to the *Convention* should provide the Secretariat with the names and addresses of the governmental organization(s) primarily responsible as national focal point(s) for the implementation of the *Convention*, so that copies of all official correspondence and documents can be sent by the Secretariat to these national focal points as appropriate. A list of these addresses is available at the following Web address:
http://whc.unesco.org/en/statespartiesfocalpoints
States Parties are encouraged to publicize this information nationally and ensure that it is up to date.

14. States Parties are encouraged to bring together their cultural and natural heritage experts at regular intervals to discuss the implementation of the *Convention*. States Parties may wish to involve representatives of the Advisory Bodies and other experts as appropriate.

15. While fully respecting the sovereignty of the States on whose territory the cultural and natural heritage is situated, States Parties to the *Convention* recognize the collective interest of the international community to cooperate in the protection of this heritage. States Parties to the *World Heritage Convention*, have the responsibility to:

- a) ensure the identification, nomination, protection, conservation, presentation, and transmission to future generations of the cultural and natural heritage found within their territory, and give help in these tasks to other States Parties that request it;
- b) adopt general policies to give the heritage a function in the life of the community;
- c) integrate heritage protection into comprehensive planning programmes;
- d) establish services for the protection, conservation and presentation of the heritage;
- e) develop scientific and technical studies to identify actions that would counteract the dangers that threaten the heritage;
- f) take appropriate legal, scientific, technical, administrative and financial measures to protect the heritage;
- g) foster the establishment or development of national or regional centres for training in the protection, conservation and presentation of the heritage and encourage scientific research in these fields;
- h) not take any deliberate measures that directly or indirectly damage their heritage or that of another State Party to the *Convention*;
- i) submit to the World Heritage Committee an inventory of properties suitable for inscription on the World Heritage List (referred to as a Tentative List);
- j) make regular contributions to the World Heritage Fund, the amount of which is determined by the General Assembly of States Parties to the *Convention*;
- k) consider and encourage the establishment of national, public and private foundations or associations to facilitate donations for the protection of World Heritage;
- l) give assistance to international fund-raising campaigns organized for the World Heritage Fund;
- m) use educational and information programmes to strengthen appreciation and respect by their peoples of the cultural and natural heritage defined in Articles 1 and 2 of the *Convention*, and to keep the public informed of the dangers threatening this heritage;
- n) provide information to the World Heritage Committee on the implementation of the *World Heritage Convention* and state of conservation of properties; and

16. States Parties are encouraged to attend sessions of the World Heritage Committee and its subsidiary bodies.

I.I Partners in the protection of World Heritage

39. A partnership approach to nomination, management and monitoring provides a significant contribution to the protection of World Heritage properties and the implementation of the *Convention*.

40. Partners in the protection and conservation of World Heritage can be those individuals and other stakeholders, especially local communities, governmental, non-governmental and private organizations and owners who have an interest and involvement in the conservation and management of a World Heritage property.

II. THE WORLD HERITAGE LIST

II.A Definition of World Heritage

Outstanding Universal Value

49. Outstanding Universal Value means cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole. The Committee defines the criteria for the inscription of properties on the World Heritage List.

50. States Parties are invited to submit nominations of properties of cultural and/or natural value considered to be of "Outstanding Universal Value" for inscription on the World Heritage List.

51. At the time of inscription of a property on the World Heritage List, the Committee adopts a Statement of Outstanding Universal Value (see paragraph 154) which will be the key reference for the future effective protection and management of the property.

52. The Convention is not intended to ensure the protection of all properties of great interest, importance or value, but only for a select list of the most outstanding of these from an international viewpoint. It is not to be assumed that a property of national and/or regional importance will automatically be inscribed on the World Heritage List.

53. Nominations presented to the Committee shall demonstrate the full commitment of the State Party to preserve the heritage concerned, within its means. Such commitment shall take the form of appropriate policy, legal, scientific, technical, administrative and financial measures adopted and proposed to protect the property and its Outstanding Universal Value.

II.D Criteria for the assessment of Outstanding Universal Value

77. The Committee considers a property as having Outstanding Universal Value (see paragraphs 49-53) if the property meets one or more of the following criteria. Nominated properties shall therefore :

- (i) represent a masterpiece of human creative genius;
- (ii) exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;
- (iii) bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;
- (iv) be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;
- (v) be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;
- (vi) be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria) ;
- (vii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
- (viii) be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;
- (ix) be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;
- (x) contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation.

78. To be deemed of Outstanding Universal Value, a property must also meet the conditions of integrity and/or authenticity and must have an adequate protection and management system to ensure its safeguarding.

II.F Protection and management

96. Protection and management of World Heritage properties should ensure that their Outstanding Universal Value, including the conditions of integrity and/or authenticity at the time of inscription, are sustained or enhanced over time. A regular review of the general state of conservation of properties, and thus also their Outstanding Universal Value, shall be done within a framework of monitoring processes for World Heritage properties, as specified within the Operational Guidelines.

97. All properties inscribed on the World Heritage List must have adequate long-term legislative, regulatory, institutional and/or traditional protection and management to ensure their safeguarding. This protection should include adequately delineated boundaries. Similarly States Parties should demonstrate adequate protection at the national, regional, municipal, and/or traditional level for the nominated property. They should append appropriate texts to the nomination with a clear explanation of the way this protection operates to protect the property.

Legislative, regulatory and contractual measures for protection

98. Legislative and regulatory measures at national and local levels should assure the survival of the property and its protection against development and change that might negatively impact the Outstanding Universal Value, or the integrity and/or authenticity of the property. States Parties should also assure the full and effective implementation of such measures.

Boundaries for effective protection

99. The delineation of boundaries is an essential requirement in the establishment of effective protection of nominated properties. Boundaries should be drawn to ensure the full expression of the Outstanding Universal Value and the integrity and/or authenticity of the property.

100. For properties nominated under criteria (i) – (vi), boundaries should be drawn to include all those areas and attributes which are a direct tangible expression of the Outstanding Universal Value of the property, as well as those areas which in the light of future research possibilities offer potential to contribute to and enhance such understanding.

101. For properties nominated under criteria (vii) – (x), boundaries should reflect the spatial requirements of habitats, species, processes or phenomena that provide the basis for their inscription on the World Heritage List. The boundaries should include sufficient areas immediately adjacent to the area of Outstanding Universal Value in order to protect the property's heritage values from direct effect of human encroachments and impacts of resource use outside of the nominated area.

102. The boundaries of the nominated property may coincide with one or more existing or proposed protected areas, such as national parks or nature reserves, biosphere reserves or protected historic districts. While such established areas for protection may contain several management zones, only some of those zones may satisfy criteria for inscription.

Management systems

108. Each nominated property should have an appropriate management plan or other documented management system which must specify how the Outstanding Universal Value of a property should be preserved, preferably through participatory means.

109. The purpose of a management system is to ensure the effective protection of the nominated property for present and future generations.

110. An effective management system depends on the type, characteristics and needs of the nominated property and its cultural and natural context. Management systems may vary according to different cultural perspectives, the resources available and other factors. They may incorporate traditional practices, existing urban or regional planning instruments, and other planning control mechanisms, both formal and informal. Impact assessments for proposed interventions are essential for all World Heritage properties.

111. In recognizing the diversity mentioned above, common elements of an effective management system could include:

- **a)** a thorough shared understanding of the property by all stakeholders;
- **b)** a cycle of planning, implementation, monitoring, evaluation and feedback;
- **c)** the monitoring and assessment of the impacts of trends, changes, and of proposed interventions;
- **d)** the involvement of partners and stakeholders;
- **e)** the allocation of necessary resources;
- **f)** capacity-building; and
- **g)** an accountable, transparent description of how the management system functions.

112. Effective management involves a cycle of short, medium and long-term actions to protect, conserve and present the nominated property. An integrated approach to planning and management is essential to guide the evolution of properties over time and to ensure maintenance of all aspects of their Outstanding Universal Value. This approach goes beyond the property to include any buffer zone(s), as well as the broader setting.

113. Moreover, in the context of the implementation of the Convention, the World Heritage Committee has established a process of Reactive Monitoring (see Chapter IV) and a process of Periodic Reporting (see Chapter V).

114. In the case of serial properties, a management system or mechanisms for ensuring the co-ordinated management of the separate components are essential and should be documented in the nomination (see paragraphs 137 -139).

115. In some circumstances, a management plan or other management system may not be fully in place at the time when a property is nominated for the consideration of the World Heritage Committee. The State Party concerned should then indicate when the management plan or system will be fully in place, and how it proposes to mobilize the resources required to achieve this. The State Party should also provide documentation which will guide the management of the site until the management plan or system is finalized fully in place.

116. Where the intrinsic qualities of a property nominated are threatened by action of man and yet meet the criteria and the conditions of authenticity or integrity set out in paragraphs 78-95, an action plan outlining the corrective measures required should be submitted with the nomination file. Should the corrective measures submitted by the nominating State Party not be taken within the time proposed by the State Party, the property will be considered by the Committee for delisting in accordance with the procedure adopted by the Committee (see Chapter IV.C).

117. States Parties are responsible for implementing effective management activities for a World Heritage property. State Parties should do so in close collaboration with property managers, the agency with management authority and other partners, and stakeholders in property management.

118. The Committee recommends that States Parties include risk preparedness as an element in their World Heritage site management plans and training strategies.

Sustainable use

119. World Heritage properties may support a variety of ongoing and proposed uses that are ecologically and culturally sustainable. and which may contribute to the quality of life of communities concerned. The State Party and its partners must ensure that such sustainable use or any other change does not impact adversely on the Outstanding Universal Value of the property. For some properties, human use would not be appropriate. Legislations, policies and strategies affecting World Heritage properties should ensure the protection of the Outstanding Universal Value, support the wider conservation of natural and cultural heritage, and promote and encourage the active participation of the communities and stakeholders concerned with the property as necessary conditions to its sustainable

IV. PROCESS FOR MONITORING THE STATE OF CONSERVATION OF WORLD HERITAGE PROPERTIES

IV.A Reactive Monitoring

Definition of Reactive Monitoring

169. Reactive Monitoring is the reporting by the Secretariat, other sectors of UNESCO and the Advisory Bodies to the Committee on the state of conservation of specific World Heritage properties that are under threat. To this end, the States Parties shall submit by 1 February to the Committee through the Secretariat, specific reports and impact studies each time exceptional circumstances occur or work is undertaken which may have an effect on the state of conservation of the property. Reactive Monitoring is also foreseen in reference to properties inscribed, or to be inscribed, on the List of World Heritage in Danger as set out in paragraphs 177-191.Reactive Monitoring is foreseen in the procedures for the eventual deletion of properties from the World Heritage List as set out in paragraphs 192-198.

Objective of Reactive Monitoring

170. When adopting the process of Reactive Monitoring, the Committee was particularly concerned that all possible measures should be taken to prevent the deletion of any property from the List and was ready to offer technical co-operation as far as possible to States Parties in this connection.

171. The Committee recommends that States Parties co-operate with the Advisory Bodies which have been asked by the Committee to carry out monitoring and reporting on its behalf on the progress of work undertaken for the preservation of properties inscribed on the World Heritage List.

Information received from States Parties and/ or other sources

172. The World Heritage Committee invites the States Parties to the Convention to inform the Committee, through the Secretariat, of their intention to undertake or to authorize in an area protected under the Convention major restorations or new constructions which may affect the Outstanding Universal Value of the property. Notice should be given as soon as possible (for instance, before drafting basic documents for specific projects) and before making any decisions that would be difficult to reverse, so that the Committee may assist in seeking appropriate solutions to ensure that the Outstanding Universal Value of the property is fully preserved.

173. The World Heritage Committee requests that reports of missions to review the state of conservation of the World Heritage properties include:

- **a)** an indication of threats or significant improvement in the conservation of the property since the last report to the World Heritage Committee;
- **b)** any follow-up to previous decisions of the World Heritage Committee on the state of conservation of the property;
- **c)** information on any threat or damage to or loss of Outstanding Universal Value, integrity and/or authenticity for which the property was inscribed on the World Heritage List.

174. When the Secretariat receives information that a property inscribed has seriously deteriorated, or that the necessary corrective measures have not been taken within the time proposed, from a source other than the State Party concerned, it will, as far as possible, verify the source and the contents of the information in consultation with the State Party concerned and request its comments.

Decision by the World Heritage Committee

175. The Secretariat will request the relevant Advisory Bodies to forward comments on the information received.

176. The information received, together with the comments of the State Party and the Advisory Bodies, will be brought to the attention of the Committee in the form of a state of conservation report for each property, which may take one or more of the following steps:

- **a)** it may decide that the property has not seriously deteriorated and that no further action should be taken;
- **b)** when the Committee considers that the property has seriously deteriorated, but not to the extent that its restoration is impossible, it may decide that the property be maintained on the List, provided that the State Party takes the necessary measures to restore the proper-

ty within a reasonable period of time. The Committee may also decide that technical co-operation be provided under the World Heritage Fund for work connected with the restoration of the property, proposing to the State Party to request such assistance, if it has not already been done;

c) when the requirements and criteria set out in paragraphs 177-182 are met, the Committee may decide to inscribe the property on the List of World Heritage in Danger according to the procedures set out in paragraphs 183-189;

d) when there is evidence that the property has deteriorated to the point where it has irretrievably lost those characteristics which determined its inscription on the List, the Committee may decide to delete the property from the List. Before any such action is taken, the Secretariat will inform the State Party concerned. Any comments which the State Party may make will be brought to the attention of the Committee;

e) when the information available is not sufficient to enable the Committee to take one of the measures described in a), b), c) or d) above, the Committee may decide that the Secretariat be authorized to take the necessary action to ascertain, in consultation with the State Party concerned, the present condition of the property, the dangers to the property and the feasibility of adequately restoring the property, and to report to the Committee on the results of its action; such measures may include the sending of a fact-finding or the consultation of specialists. In case an emergency action is required, the Committee may authorize its financing from the World Heritage Fund through an emergency assistance request.

VI. ENCOURAGING SUPPORT FOR THE *WORLD HERITAGE CONVENTION*

VI.A Objectives

211. The objectives are:

a) to enhance capacity-building and research;

b) to raise the general public's awareness, understanding and appreciation of the need to preserve cultural and natural heritage;

c) to enhance the function of World Heritage in the life of the community; and

d) to increase the participation of local and national populations in the protection and presentation of heritage.

VI.B Capacity-building and research

212. The Committee seeks to develop capacity-building within the States Parties in conformity with its Strategic Objectives.

The Global Training Strategy

213. Recognizing the high level of skills and multidisciplinary approach necessary for the protection, conservation, and presentation of the World Heritage, the Committee has adopted a Global Training Strategy for World Cultural and Natural Heritage. The primary goal of the Global Training Strategy is to ensure that necessary skills are developed by a wide range of actors for better implementation of the Convention. In order to avoid overlap and effectively implement the Strategy, the Committee will ensure links to other initiatives such as the Global Strategy for a Representative, Balanced and Credible World Heritage List and Periodic Reporting. The Committee will annually review relevant training issues, assess training needs, review annual reports on training initiatives, and make recommendations for future training initiatives.

National training strategies and regional cooperation

214. States Parties are encouraged to ensure that their professionals and specialists at all levels are adequately trained. To this end, States Parties are encouraged to develop national training strategies and include regional co-operation for training as part of their strategies.

Research

215. The Committee develops and coordinates international co-operation in the area of research needed for the effective implementation of the Convention. States Parties are also encouraged to make resources available to undertake research, since knowledge and understanding are fundamental to the identification, management, and monitoring of World Heritage properties.

International Assistance

216. Training and Research Assistance may be requested by States Parties from the World Heritage Fund (see Chapter VII).

VI.C Awareness-raising and education

Awareness-raising

217. States Parties are encouraged to raise awareness of the need to preserve World Heritage. In particular, they should ensure that World Heritage status is adequately marked and promoted on-site.

218. The Secretariat provides assistance to States Parties in developing activities aimed at raising public awareness of the Convention and informing the public of the dangers threatening World Heritage. The Secretariat advises States Parties regarding the preparation and implementation of on-site promotional and educational projects to be funded through International Assistance. The Advisory Bodies and appropriate State agencies may also be solicited to provide advice on such projects.

Education

219. The World Heritage Committee encourages and supports the development of educational materials, activities and programmes.

International Assistance

220. States Parties are encouraged to develop educational activities related to World Heritage with, wherever possible, the participation of schools, universities, museums and other local and national educational authorities.

221. The Secretariat, in co-operation with the UNESCO Education Sector and other partners, produces and publishes a World Heritage Educational Resource Kit, "World Heritage in Young Hands", for use in secondary schools around the world. The Kit is adaptable for use at other educational levels.

222. International Assistance may be requested by States Parties from the World Heritage Fund for the purpose of developing and implementing awareness-raising and educational activities or programmes (see Chapter VII).

VII. THE WORLD HERITAGE FUND AND INTERNATIONAL ASSISTANCE

VII.A The World Heritage Fund

223. The World Heritage Fund is a trust fund, established by the Convention in conformity with the provisions of the Financial Regulations of UNESCO. The resources of the Fund consist of compulsory and voluntary contributions made by States Parties to the Convention, and any other resources authorized by the Fund's regulations.

224. The financial regulations for the Fund are set out in document WHC/7 available at the following Web address: http://whc.unesco.org/en/financialregulations.

VII.B Mobilization of other technical and financial resources and partnerships in support of the *World Heritage Convention*

225. To the extent possible, the World Heritage Fund should be used to mobilize additional funds for International Assistance from other sources.

226. The Committee decided that contributions offered to the World Heritage Fund for international assistance campaigns and other UNESCO projects for any property inscribed on the World Heritage List shall be accepted and used as international assistance pursuant to Section V of the Convention, and in conformity with the modalities established for carrying out the campaign or project.

227. States Parties are invited to provide support to the Convention in addition to obligatory contributions paid to the World Heritage Fund. This voluntary support can be provided through additional contributions to the World Heritage Fund or direct financial and technical contributions to properties.

228. States Parties are encouraged to participate in international fund-raising campaigns launched by UNESCO and aimed at protecting World Heritage.

229. States Parties and others who anticipate making contributions towards these campaigns or other UNESCO projects for World Heritage properties are encouraged to make their contributions through the World Heritage Fund.

230. States Parties are encouraged to promote the establishment of national, public and private foundations or associations aimed at raising funds to support World Heritage conservation efforts.

231. The Secretariat provides support in mobilizing financial and technical resources for World Heritage conservation. To this end, the Secretariat develops partnerships with public and private institutions in conformity with the Decisions and the Guidelines issued by the World Heritage Committee and UNESCO regulations.

232. The Secretariat should refer to the "Directives concerning UNESCO's co-operation with private extra-budgetary funding sources" and "Guidelines for mobilizing private funds and criteria for selecting potential partners" to govern external fund-raising in favour of the World Heritage Fund. These documents are available at the following Web address: http://whc.unesco.org/en/privatefunds

Excerpts from the World Heritage Information Kit

Figure 63. Bylot Island.

Success Stories

THE *WORLD HERITAGE CONVENTION* IS NOT ONLY 'WORDS ON PAPER' BUT IS above all a useful instrument for concrete action in preserving threatened sites and endangered species. By recognizing the outstanding universal value of a site, States Parties commit to its preservation and strive to find solutions for its protection. If a site is inscribed on the List of World Heritage in Danger, the World Heritage Committee can take immediate action to address the situation and this has led to many successful restorations. The *World Heritage Convention* is also a very powerful tool to rally international attention and actions through international safeguarding campaigns.

FINDING SOLUTIONS

Often, the World Heritage Committee and the States Parties, with the assistance of UNESCO experts and other partners, find solutions before a given situation deteriorates to an extent that would damage the site.

Giza Pyramids in Egypt These pyramids were threatened in 1995 by a highway project near Cairo which would have seriously damaged the values of this archaeological site. Negotiations with the Egyptian Government resulted in a number of alternative solutions which replaced the disputed project.

Royal Chitwan National Park in Nepal This Park provides refuge for about 400 greater one-horned rhinoceros characteristic of South Asia. The World Heritage Committee, in the early 1990s, questioned the findings of the environmental impact assessment of the proposed Rapti River Diversion Project. The Asian Development Bank and the Government of Nepal revised the assessment and found that the River Diversion project would threaten riparian habitats critical to the rhino inside Royal Chitwan. The project was thus abandoned and this World Heritage site was saved for the benefit of future generations.

Archaeological Site of Delphi in Greece At the time of its nomination in 1987, plans were underway to build an aluminium plant nearby the site. The Greek Government was invited to find another location for the plant, which it did, and Delphi took its rightful place on the World Heritage List.

Whale Sanctuary of El Vizcaino in Mexico In 1999, the World Heritage community campaigned against a plan for enlarging an existing salt factory to commercial scale in Laguna San Ignacio in El Vizcaino Bay, the last pristine reproduction lagoon for the Pacific grey whale. The World Heritage Committee forewarned the Mexican Government of the threats posed to the marine and terrestrial ecosystems, the grey whales as key species as well as the overall integrity of this World Heritage site by locating saltworks inside the Sanctuary. As a result, the Mexican Government refused permission for the saltworks in March 2000.

Mount Kenya National Park/Natural Forest in Kenya The nomination of this site was first referred back to the State Party on the basis of findings during the evaluation that suggested there were serious threats to the site, primarily illegal logging and marijuana cultivation inside the Park. The State Party responded with an action plan which included provision of additional vehicles, increased patrols, community awareness projects, training of forest guards and a review of the policy affecting the adjacent forest reserve. Based on these assurances, the Committee inscribed the site in 1997. Today, some threats still remain but there has been significant progress in the management of the site.

INTERNATIONAL SAFEGUARDING CAMPAIGNS

Sites for which international campaigns were launched in the 1960s', often became World Heritage sites, and the World Heritage concept itself developed from these first international campaigns launched by UNESCO.

Typically, however, international campaigns are much broader in their scope, more complex in their technology, and involve millions of US dollars. The Abu Simbel project in Egypt, for example, cost in excess of US$80 million.

Over the years, 26 international safeguarding campaigns were organized, costing altogether close to US$1 billion.

Venice in Italy This longest running international safeguarding campaign started in 1966 when UNESCO decided to launch a campaign to save the city after the disastrous floods of 1965, a task requiring time, a high degree of technical skill and, above all, money. The international synergy that arose from this project was an important source of inspiration to the founding efforts of the Convention.

Temple of Borobudur in Indonesia An international safeguarding campaign was launched by UNESCO in 1972 to restore this famous Buddhist temple, dating from the 8th and 9th centuries. Abandoned in the year 1000, the temple was gradually overgrown with vegetation and was not rediscovered until the 19th century. With the active participation of the Japan Trust Fund for the Preservation of World Cultural Heritage and other partners, the restoration of Borobudur was completed in 1983.

Partnerships for Conservation

Over the past forty years of inscribing natural and cultural properties on the prestigious World Heritage List and promoting their conservation and preservation for future generations, the *World Heritage Convention* has become an international success. With over 1000 properties inscribed on the UNESCO World Heritage List, neither UNESCO nor governments can protect World Heritage alone. The World Heritage Fund is by no means sufficient to ensure the preservation and promotion of our world's natural and cultural treasures.

As World Heritage is our shared heritage, the responsibility to protect it also needs to be shared between the States Parties, the international community and the civil society. With the number of World Heritage sites growing every year along with the number of threats facing them, the success of the *Convention* depends on this international solidarity but also on strengthened cooperation through partnerships.

The World Heritage PACT (Partnerships for Conservation) Initiative, launched in 2002, is a solutions-oriented approach to sustainable World Heritage conservation which aims to raise awareness and to mobilize sustainable resources for the long-term conservation of World Heritage. It involves a network of foundations, conservation and research institutions, companies and media organizations interested in assisting in the implementation of the *World Heritage Convention*.

In parallel to these partnerships, PACT is also expanding the existing network of bilateral and multilateral partnerships with governments and intergovernmental institutions to build and maintain a system of international cooperation. One of the major partners of the World Heritage Centre is the United Nations Foundation which has supported numerous biodiversity projects relative to World Heritage sites recognized for their outstanding natural values. Their important financial contribution has tripled the World Heritage Centre's resources for the effective management and protection of natural World Heritage sites.

Other agreements involving the provision of staff and the mainstreaming of World Heritage into development programmes have also been made with the World Bank, the Inter-American Development Bank, the United Nations Development Programme/Global Environment Facility (UNDP-GEF) Small Grants Programme, the Agence Fran aise de D veloppement, the European Union and the Japan Bank for International Cooperation to ensure the conservation of World Heritage properties at local and national levels.

Recognizing that partnerships should be joint undertakings between partners in pursuit of common goals, the World Heritage PACT operates around key principles such as common purpose, transparency, bestowing no unfair advantages upon any partner, mutual benefit, respect and accountability. UNESCO's policy framework for partnerships derives from the Global Compact guidelines adopted by the United Nations in 2000, whose ten universal principles provide a framework for businesses to integrate social values into the production of commercial goods and services.

By working with the World Heritage Centre, partners can share their expertise and management skills and gain a competitive advantage by integrating heritage protection into strategic planning. In turn, partners will receive public recognition for sharing UNESCO's values and high standards for business in areas of human rights, work conditions and the environment. Furthermore, partners will have the opportunity to identify their business with an outstanding cause – working towards the sustainable preservation of our Planet's diversity and the sustainable development of communities.

EXAMPLES OF PARTNERSHIPS FOR CONSERVATION:
In 2004, the World Heritage Centre entered into an ambitious ten-year capacity-building project to protect the biodiversity of India's natural World Heritage sites, Manas Wildlife Sanctuary and Kaziranga, Keoladeo and Nanda Devi National Parks, including their endangered species: the one-horned rhinoceros, tiger, pygmy hog, Indian rhinoceros and elephant. The United Nations Foundation, United Nations Fund for


Figure 64. Lead in ice. Bylot Island.
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International Partnerships (UNFIP), American India Foundation, Ford and Suri Sehgal Foundation, Ashoka Trust for Research in Ecology and the Environment, and the Wildlife Institute of India are active partners in this initiative.

The Centre has also been working with the Congolese Institute for Nature Conservation, the Government of Belgium and the United Nations Foundation to safeguard the five World Heritage sites in the war-torn Democratic Republic of the Congo – Virunga, Garamba, Kahuzi-Biega and Salonga National Parks and Okapi Wildlife Reserve – to prevent the biological wealth of this rich region from disappearing. A monitoring programme using satellites to observe forest degradation has also been developed with the European Space Agency and the Belgian Ministry of Science.

UNESCO and its long standing media partner EVERGREEN Digital Contents, Japan, have launched a new partnership through a project aiming to promote World Heritage Education in Japan. The project focuses on raising the awareness of elementary school students about natural World Heritage sites and issues concerning them. As part of this partnership, a new i-mode site was developed for NTT DoCoMo called UNESCO kids. This entertaining and educational i-mode site, accessible by using all web compatible mobile phones, was designed to stimulate children into learning and caring for the environment in which they live. The project also aims to encourage them to visit World Heritage sites responsibly and share their experience by photographing their visits to contribute them to the i-mode site. This is the first i-mode site to provide information regarding World Heritage via a mobile phone service and it is anticipated that similar activities will spread throughout the world.

Training World Heritage site managers is one of the most valuable environments in heritage conservation, particularly as these sites confront the challenges of increasing flows of tourism and diminishing flows of international assistance for conservation and management. In January 2006, the World Heritage Centre joined forces – with the French NGO Association Vocations Patrimoine and its partners, the multinational groups AXA and MAZARS, to launch a programme of Fellowships for World Heritage site managers as well as people intending to pursue a career in World Heritage site management. A special focus of the programme is on training emerging leaders from developing countries or those working at sites with critical conservation needs. The fellowships provide tuition and living stipends for study at advanced level interdisciplinary training in World Heritage studies.

World Wildlife Fund (WWF) Canada.

World Wildlife Fund (WWF) Global Arctic Programme.

The Natural Heritage Protection Fund was established in 2000 in compliance with article 17 of the UNESCO Convention concerning the Protection of the World Cultural and Natural Heritage. The Fund's priority is the overall support of World Heritage properties, as well as obtaining this status for new natural sites both in Russia and the CIS. http://www.nhpfund.org

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