Biological Features and Processes of the Circumpolar World

DEVELOPED BY
BRUCE FORBES, SENIOR SCIENTIST, ARCTIC CENTRE, ROVANIEMI, FINLAND
AND
STEVE YOUNG, DIRECTOR, CENTER FOR NORTHERN STUDIES, UNITED STATES

Contents

Key Terms and Concepts

- Adaptation
- Ecosystem
- Energy Cycle
- Fauna
- Flora
- Food Chains
- Hibernation
- Migration
- Polynya
- Trophic Level

Learning Objectives/Outcomes

Upon completion of this module you should:

- Be able to list and describe the four basic concepts that describe our understanding of life in the Circumpolar North and give examples of these concepts in nature;
- Be aware of, and be able to describe in general terms, the unique environmental conditions that govern life in the Circumpolar World;
- Describe and explain the **energy cycle**, and how energy is collected, stored, and distributed for plant and animal use;
- Define and explain the significance of liquid water in the survival of plants and animals; and
- List and describe some of the winter survival strategies used by **homeothermic** and **poikilothermic** animals.

Overview

The flora and fauna the northern regions are unique because their environments are extreme and finely balanced. As an overview statement, it would be safe to say that the major factors involved in the evolution of the biology of circumpolar ecosystems are:

- The climate, including cold temperatures and low precipitation;
- Lack of energy in the form of sunlight through much of the year;
- A rich marine environment along an extended coastline;
- Constant and ongoing changes in the northern environment; and

- The recent emergence of the region from the **last Ice Age**.

The module gives a brief introduction to the physical features and processes of the Arctic region and highlights the significant factors that influence those features and processes.

Lecture

Basic Concepts

To begin to understand the living Arctic and Subarctic, we need to consider a few basic concepts:

1. All living things are part of a system and cannot exist except as part of this system;
2. All living systems depend on energy that originates in the sun;
3. Living things can thrive only in the presence of liquid water; and
4. The Arctic and Subarctic environments are comparatively new.

Since living things are part of the **ecosystem**, we cannot study them without being aware of their relations with other organisms and with the non-living parts of the system such as solar energy. If we want to study wolves, we cannot go very far unless we also study their prey—their energy source. Similarly, we cannot study the prey—caribou, hare, and lemmings, for example—without studying the plants they eat.

At the same time, individual animals, or kinds (species) of animals and plants have certain characteristics and requirements that are unique to them. Spruce trees, for example, can withstand much colder temperatures than oak trees, and this is probably the main reason that spruce trees, and not oaks, are found in the Subarctic. What they all have in common is a need for liquid water.

Figure 1: "Do not cut this tree." *Tree survival at the northern limit of trees is an object of intensive research in all of the circumpolar countries for both basic and applied reasons. Outlying individuals and populations can provide information on past and present climate and tree growth. The treeline is not a solid barrier, but rather a band of trees dispersed unevenly. Local microclimates and landscapes can create places that can support trees in isolation, like the tree in this picture.*

Energy

To be alive requires energy, and all of this energy is ultimately derived from the sun. Green plants are capable of **photosynthesis**, that is, they are able to change solar energy and other non-organic compounds directly into chemical energy (organic compounds), which they then store in their tissues (roots, stems, leaves, or flowers). This makes them primary producers for the whole system. These green plants can live on land or in water.

All animals depend on solar energy that has been stored by plants for their energy, either directly or indirectly. When a caribou, or other herbivorous prey animal, eats plants or lichens, it is directly consuming plant-stored energy so it can

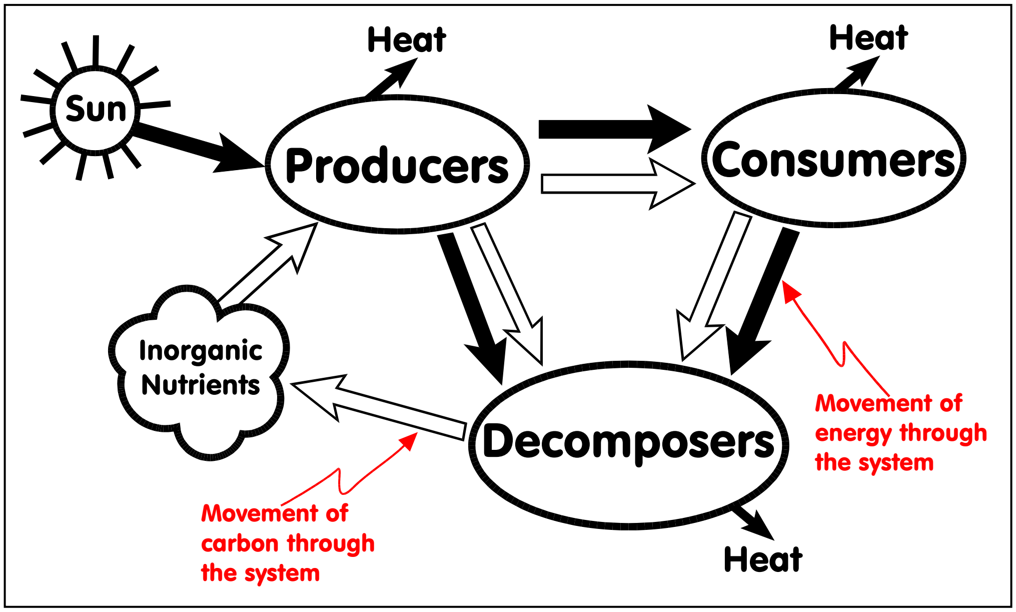

Figure 2. Diagram showing the movement of energy and carbon through an ecosystem.

live and grow. When a bear, or some other predator, eats a caribou that grew by eating plants, it is indirectly consuming the plant-stored energy. Plant energy has been converted to flesh by the prey species. Omnivores can derive energy from both plants and animals, because they are physically capable of digesting and benefitting from both.

Each time there is a transfer of energy to a "higher" level in the system, much of the energy is lost through inefficiency because not everything in the lower levels gets eaten, not everything that is eaten is digested and energy is always being lost as heat. About 10 per cent of the energy available in one **trophic level** will be passed on to the next. Wolves are at a higher trophic level than caribou, since they eat caribou. In the system, there must always be many fewer wolves than caribou. Indeed, the food chain is more like a pyramid in its simplest form. In terrestrial (land) ecosystems, the food chain—the number of trophic levels—is usually short: plants, caribou, wolves, for example.

The movement of processed energy up through the food chain, or across a food web, is of particular interest to scientists studying organic pollutants in plants and animals of the North. The optional Arctic Monitoring and Assessment Program (AMAP) reading "Polar Ecology" includes a discussion of the way that pollutants are transported to the North from more heavily industrialized areas. It also explains how these pollutants are concentrated in the bodies of animals that feed on contaminated plants and other contaminated animals.

In aquatic ecosystems—seas, rivers, and lakes or marine, riverine and lacustrine ecosystems—the plants are mostly very small and are eaten by tiny animals that, in turn, are eaten by slightly larger animals; the food chain can have many stages or links. The problem of concentrated pollutants occurs in aquatic ecosystems in the same way as it occurs in terrestrial ecosystems.

Much of the transfer of energy through the systems occurs when organisms, or parts of organisms, such as the above-ground leaves of **perennial plants**, die naturally. Their bodies are broken down by other living things such as fungi and bacteria. These organisms, called decomposers, use much of the energy to maintain their own lives, but they return important chemical compounds to the soil and water, and these chemicals often make it possible for other plants to grow in abundance (see the diagram in Figure 2).

Activity

You have a ham, tomato, and lettuce sandwich for lunch. Trace the energy in the various components of your lunch (bread, butter, ham, lettuce, and tomato) back to the sun. Which part went through the greatest number of trophic levels? Just to make it interesting, imagine that the tomato was grown hydroponically, using artificial light rather that direct sunlight.

In the polar regions, the energy supply is seasonal. North of the Arctic Circle, there is a period each year when there is no direct solar energy available. Even when the sun does shine, temperatures are often so low that plants are not able to process solar energy. Living things need to be able to use energy that was stored by plants during the warmer season. To survive the periods when resources are hard to find and energy is low, they may reduce their energy requirements by becoming dormant, or hibernating. Some animals, like caribou, and especially birds and marine mammals and fish, may deal with the shortage of energy by migrating to areas where the climate is warmer and plants are actively producing food. Some animals and plants have physical adaptations to help them through the long winters. These include insulating fur, hair or fat, or small extremities.

Water

It is not only lack of energy that limits life in the northern winter. Living cells can only function if temperatures are warm enough for liquid water to exist.

Many Arctic plants and some animals have the ability to survive freezing. Some have cells that are able to go into a suspended state, in which most activities are nearly or totally shut down, if they are able to cool down slowly. Other cells are destroyed by the formation of ice crystals inside them. Whether they can survive freezing or not, cells cannot grow, reproduce, or fulfil most of the functions of a truly living thing until temperatures return to those that allow their contents to be liquid.

Survival Strategies

Poikilothermic (cold-blooded) animals (like frogs and insects) and plants can be prevented from completing their life cycles or storing enough energy to survive by lack of available energy during the growing season. Amphibians may burrow into the mud at lake bottoms to escape freezing. Should the lake freeze entirely they can be killed.

Homeothermic (warm-blooded) animals deal with the problem of winter cold in a different way; they keep their bodies always at a temperature well above freezing. In the North, this is a very demanding strategy, since it requires the animal to spend the most energy to keep warm during the time of year when the least energy is available. There is little margin for error; freezing is lethal. Warm-blooded animals have three main ways of dealing with cold:

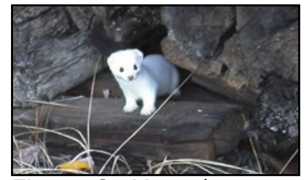

Figure 3. *Mustela erminea richardsonii*, or ermine, in winter coat. Photograph by Murray Lundberg. Used with permission.

1. Adaptation;
2. Hibernation; and
3. Migration.

We'll look at these in a bit more detail next.

Adaptation

Adaptation involves slow genetic changes to floral or faunal physiology that improve the species' and the individual's chances of surviving particularly harsh conditions. In Arctic plants, small stature, hairiness, and strong roots, ensure their survival in dry, windy places where temperatures can drop unexpectedly. Some Arctic animals, such as Peary caribou and musk ox have short legs and tails to minimize heat loss. In most northern species, ears are small, too. Many species develop thick layers of fat. Others have specially adapted hair: caribou hair is hollow, to trap air, and polar bear fur is transparent with a hollow core. A polar bear's hairs trap heat, sending it to the skin (which is black). Subarctic lynx, ptarmigan, and moose have adaptations that allow them to move in snow. Lynx and ptarmigan feet are furred and feathered to act as snowshoes and spread the animal's weight over a wider area. Moose legs are jointed in a way that allows the animal to lift its feet very high and thus walk through deep snow.

Figure 4. *Ovibos moschatus*, musk ox. Photograph by US Fish & Wildlife Service.

Hibernation

Hibernation is a survival strategy of some smaller Arctic and Subarctic homeothermic animals. As noted above, animals need energy to maintain their biological systems. They acquire that energy from the environment from plants or other small animals. In winter, there are few plants to eat and the cold means that the animals need a great deal of energy to produce body heat. Hibernating animals are able to reduce their body temperatures by as much as 30°C, or lower their metabolisms by 95 per cent. Their heat and breathing rates can be reduced. Hibernating Arctic ground squirrels have body temperatures of -3°C, though most other hibernators maintain their body temperatures around 5°C. Arctic ground squirrels wake every two weeks or so for a short while, shivering to raise their body temperatures back up to normal. This prevents brain damage. Another animal that we think of as hibernators are bears. Bears become dormant in winter, which is not quite the same as the hibernation of Arctic ground squirrels. Bear body temperatures only decrease a bit, by about 3 to 5°C. They are able to move around and even nurse their young, which deep hibernators cannot do.

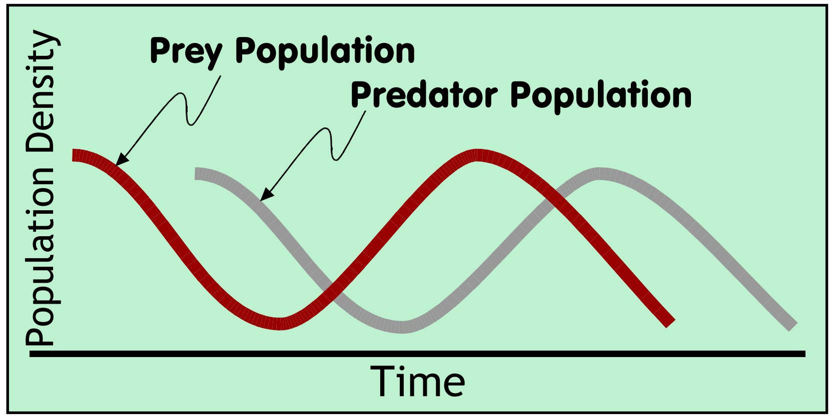

Figure 5. Schematic diagram showing the relationship between prey abundance and predator abundance, the "predator-prey cycle". *Many Arctic and Subarctic species exhibit these population cycles. Can you think of some in your region?*

Migration

Migration is a survival strategy employed by a large variety of animals, from oceanic zooplankton, to fish, seals and whales, birds, and terrestrial mammals such as caribou. Moving around allows the migrants to use the best environments for breeding and survival. Migration is an energy-expensive option, especially for animals that need to walk (flying takes the least effort, and swimming takes a bit more but less than walking).

Short growing seasons with low temperatures keep many species of plants and animals from being able to colonize the Arctic at all. Most Arctic and Subarctic ecosystems contain relatively few species—though most with very large numbers of individuals, as compared to temperate or tropical forests. In theory, this makes the ecosystem less complex, and scientists used to point to the Arctic as a place or laboratory to learn about ecosystems, then apply the lessons learned there to other areas with more species.

We now know that the Arctic makes up for its comparatively few species by all the complexities associated with changing seasons and other phenomena, such as large variations in populations of various interrelated organisms from year to year, as in the famous lynx-hare cycles (see Figure 5). Abundant prey produces well-fed predators who have the resources to produce offspring, often many more than in leaner years. The predator population expands and places greater pressure on the prey species. Prey numbers decline and predators pay the consequences by starving or succumbing to diseases in their weakened states. The weaker predators produce fewer offspring and the prey species is able to expand once again and the cycle continues.

Marine Environments

Plants and animals in marine and aquatic environments do not need to deal with great changes in temperature. Many marine ecosystems maintain a nearly constant temperature summer and winter, with the water always just above the freezing point. But marine organisms need to deal with long periods of low light conditions, especially if there is a thick covering of ice. Air-breathing marine mammals, such as whales, seals, and walruses, must make some provision for getting to the surface of the ice to breathe. Other organisms must deal with the often low levels of oxygen in the winter aquatic ecosystem where plants cannot photosynthesize in the darkness, and so produce little or no oxygen.


Figure 6. Arctic polynya. SCIEX 1998 photograph.

Some animals migrate to more productive areas. Others remain in the North and concentrate in ice-free areas where the water remains open year-round because of tides, currents or other local factors. These areas are called **polynyas**.

Activity

Investigate and describe the Arctic Ocean marine ecosystem directly north of your community. What marine mammals, fish, and crustaceans live there, and what main strategies do they use to survive the low-energy period of winter?

Changing Environments

We also need to be aware that the present Arctic and Subarctic ecosystems have not been around very long, in geological terms. Fifty-five million years ago, the Arctic was tropical (see Figure 7). Only a few million years ago, temperate forests were growing on the shores of the Arctic Ocean. Animals, such as caribou, probably first developed in high mountain systems in temperate regions, then moved into the Arctic following the retreating ice sheets. We also need to be aware that the Ice Ages of the past million years (see Table 1) or so have repeatedly driven animals and plants out of vast areas of the Arctic and Subarctic, then allowed them to return as the glaciers temporarily melted away.

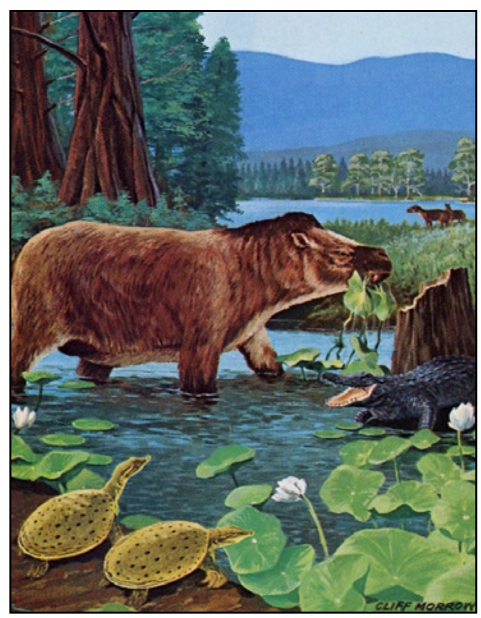

Figure 7. Illustration by Cliff Morrow of the Arctic 55 million years ago showing tropical conditions (Thurston, 1986).

So, the Arctic ecosystem has been in constant change and has been a "melting pot" for all the few millions of years that it has been in existence. One result of this has been that many earlier members of the Arctic ecosystem have died out—become extinct. Only a few thousand years ago, the tundra was a home to woolly mammoths, bison, horses, and even rhinos. We might say that the Arctic ecosystem is still recovering from the loss of many of its species, and new colonists may, even now, be coming in from the temperate regions.

Table 1. Glacial Epochs

EPOCHS	AGES AND STAGES				APPROXIMATE TIME
Recent	North America		Europe		
	Postglacial				
	Wisconsin	*Mankato	Würm	*Würm IV	15,000-5,000 B.C.
		*Cary		*Würm III	
		*Tazewell		*Würm II	
		*Iowan		*Würm I	
Pleistocene	Sangamon	III Interglacial	Riss-Würm		125,000 B.C.
	Illinoian		Riss		375,000 B.C.
	Yarmouth	II Interglacial	Mindel-Riss		675,000 B.C
	Kansan		Mindel		750,000 B.C
	Aftonian	I Interglacial	Günz-Mindel		900,000 B.C
	Nebraskan		Günz		1,000,000 B.C
Pliocene		Periglacial			

* Substage

Activity

Investigate what large mammal species have become extinct in your area over the last 10,000 years. Are there any "new" species in your area (fish, birds, mammals, or insects that have adapted in the last 20 years or so)? If so, why?

The Present Distribution of the Tundra and Taiga Biomes

The current distribution of the tundra and taiga biomes is circumpolar. This is because major floristic elements of the Arctic and Subarctic flora are circumpolar. The total Arctic flora is around 900 species. Many occur only in certain regions and are not circumpolar, and many range far south of the Arctic into alpine regions. In biogeographic terms, the Arctic is treated as a single floristic region and its entire vascular flora considered as a single unit, even though the distributions of some species are uneven.

Many botanists, particularly in Russia, have broken the circumpolar North into distinct phytogeographic provinces based on regional floristic similarities (see Figure 8. Note that this map is oriented differently than your Canadian course map. This one has Russia at the bottom.).

We saw in Module 2 that the terrestrial North is divided into two main bioregions, the treeless tundra and the boreal forest, or taiga. Many Arctic ecologists prefer to think of the northern regions as composed of a series of zones, starting with the thick forest of the southern taiga and extending to the extreme High Arctic, or Polar Desert in the northernmost lands around and in the Arctic Ocean.

Activity

Describe the floral biome in your area. List the major plant species.

Polar Bears as Indicators of Ecosystem Health

For many people interested in the Circumpolar World, polar bear populations have become an indicator of the overall health of the northern environment. Because polar bears are at the top of a complex food chain, environmental pollutants tend to **bioaccumulate** in their systems, making them particularly susceptible to fairly low levels of background chemical toxins.

Because they are intimately connected to the seasons and population cycles of prey species, shifts in bear populations, or aberrant behaviour within a given population, are sometimes taken as signs of changes further down the food chain (See Figure 9). While polar bear population size may be a good measure of environmental health, it is dangerous to rely too heavily on just one indicator. Polar bears are extremely adaptable to changing conditions, and that ability may mask problems within the overall system.

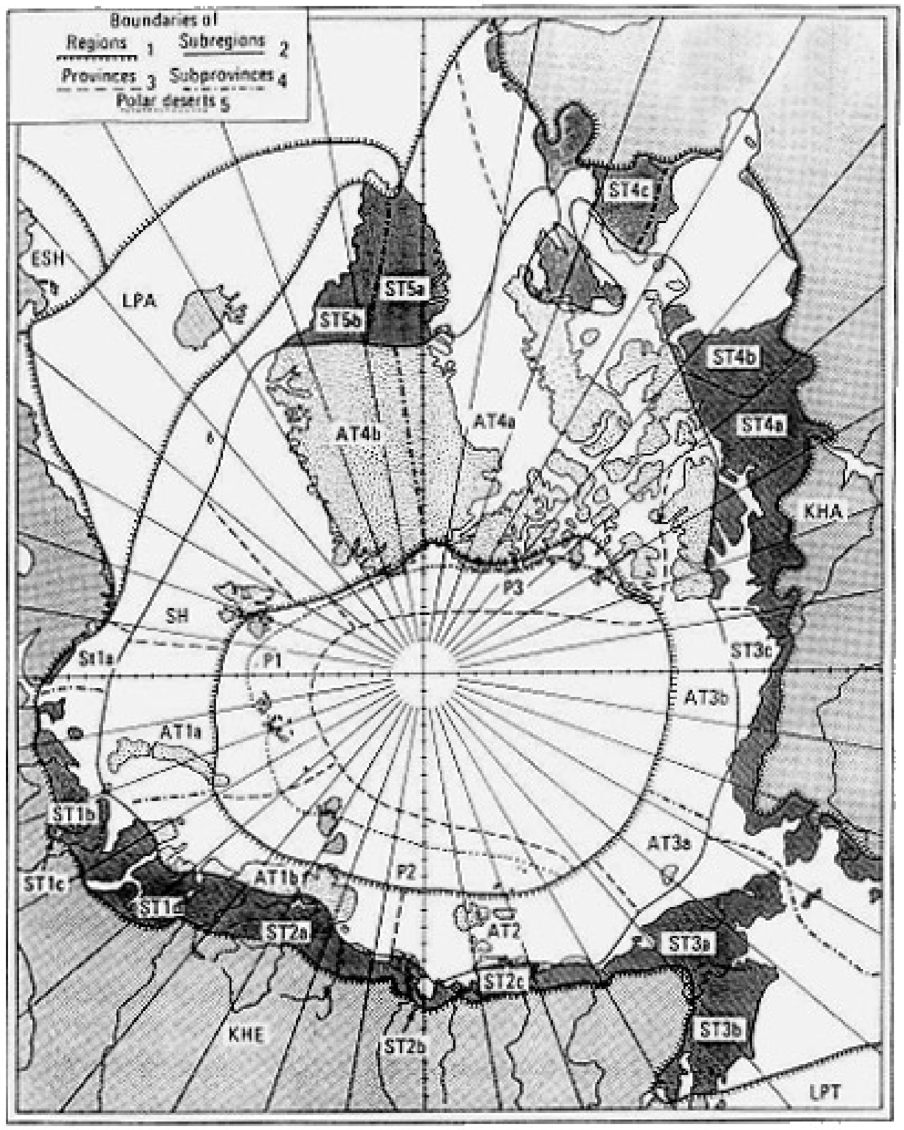

Figure 8: The limits of Arctic geobotanical areas from Aleksandrova 1988. *The key indicates the borders and boundaries between: 1, geobotanical regions; 2 subregions; 3, provinces; 4, subprovinces; 5, the northern and southern belts of the polar deserts. Regions: LPA, the North Atlantic grass- and heath-land; EHS, the European broadleaved forests; KHE, the Eurasiatic coniferous forests (taiga); LPT, the North Pacific grass- and heath-land; KHA, the North American coniferous forests (taiga). Subregions of the tundra area: ST, subarctic tundra; AT, Arctic tundra. Provinces of the subarctic tundra area: ST1, East European—West Siberian subarctic tundra (subprovinces: ST1a, Kola; ST1b, East European; ST1c, Urals-Pai-Khoy; ST1d,* Yamal-Gyda-Zapadnyy Taymyr); ST2, the Western Siberian subarctic tundra (subprovinces: ST2a, Khatanga-Olenek; ST2b; Kharaulakh; ST2c; Yana-Indigurka); ST3, the Chukotka-Alaska subarctic tundras.

This module presents only the briefest look at the exciting and complex biological world that surrounds us in the Circumpolar World.

You can find further information on the topics we've introduced here in your local school or public library and in the supplementary readings and in resources suggested to you by your instructor. Further courses in the biology and biological processes of the Circumpolar North are available at many University of the Arctic member institutions.

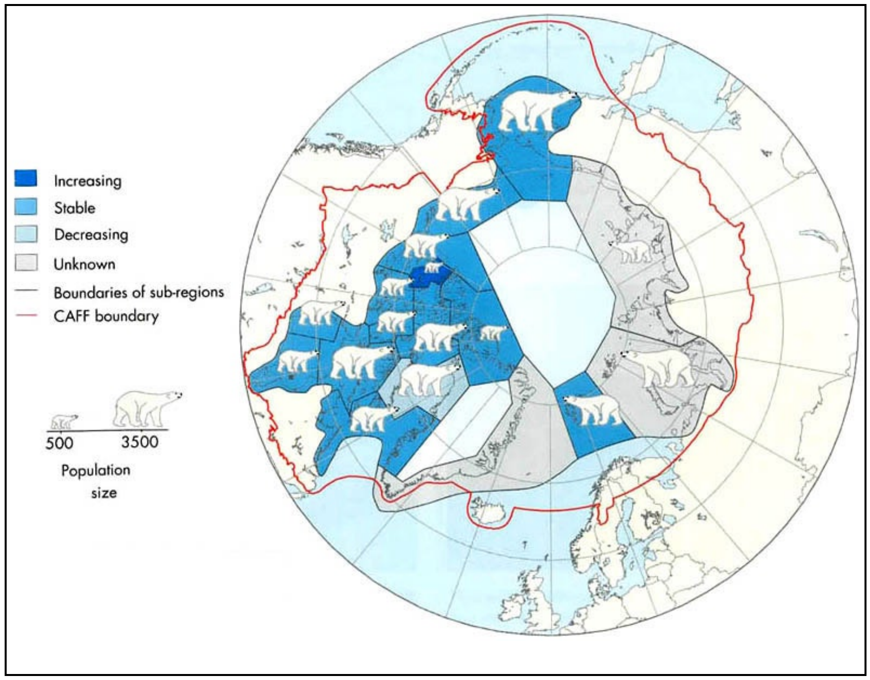

Figure 9. Distribution and population status of polar bear, *Ursus maritimus*, in the Arctic. Source: GRID/Arundel, IUCN Polar Bear Specialist Group, 1998.

Supplementary Readings/Materials

Aleksandrova, Vera Danilovna. 1988. *Vegetation of the Soviet Polar Deserts*. Doris Löve, trans. Cambridge: Cambridge University Press.

Bliss, L.C., O.W. Heal and J.J. Moore (eds.). 1980. *Tundra Ecosystems: A Comparative Analysis*. Cambridge: Cambridge University Press.

Carey, C., G.L. Florant, B.A. Under, and B. Horowitz (eds.). 1993. *Life in the Cold: Ecological, Physiological and Molecular Mechanisms*. Boulder, CO: Westview Press.

Chapin, F.S. III and C. Körner (eds.) 1995. *Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences*. New York: Springer-Verlag.

Chernov, Yu.I. 1985. *The Living Tundra*. D. Löve, trans. Cambridge: Cambridge University Press.

Gedney, Larry. 1986. "Open Water in the Ice Pack." Article #767. Alaska Science Forum. May 5. Available at http://www.gi.alaska.edu/ScienceForum/ASF7/767.html

Sage, B. (ed.) 1986. *The Arctic and its Wildlife*. New York: Facts on File. pp. 118–154.

Thurston, Harry. 1986. "Icebound Eden." *Equinox: The Magazine of Canadian Discovery*. May/June.

Young, S.B. 1989. *To the Arctic: An Introduction to the Far Northern World*. New York:

Wiley Science.

Study Questions

1. List and describe the four basic concepts that underlie our understanding of life in the Arctic and Subarctic and give examples of these concepts in nature.
2. Describe, in general terms, the unique environmental conditions that govern life in the Circumpolar World.
3. Describe the energy cycle, and explain how energy is collected, stored, and distributed for plant and animal use.
4. Define and explain the significance of liquid water in the survival of plants and animals.
5. List and describe some of the survival strategies used by homeothermic and poikilothermic animals in the circumpolar world.
6. Give some examples of homeothermic animals. Of poikilothermic animals.

Glossary

Bioaccumulation: The build up of organic compounds in the fatty tissues of organisms. Bioaccumulation of toxins and other organic pollutants in food animals dramatically increases in concentration as one moves up the food chain.

Carrying Capacity: The maximum number of individuals that the resources in a given environment can maintain indefinitely. Any essential resource that is in short supply can limit the growth or sustainability of a population. Food, shelter, non-toxic environment are examples of limiting factors.

Ecosystem: An association of organisms and their physical environment, interconnected by an ongoing flow of energy and a cycling of materials through it. The balance between all elements of an ecosystem is known as the carrying capacity.

Fauna: English word from the Latin. All animal life. This word can be modified by various prefixes, such as megafauna (very large animals), microfauna (very small animals), etc.

Flora: English word from the Latin name for the Roman goddess of flowers. General term meaning plant or bacterial life. This word can be modified to mean the plant and bacterial life of particular environments, e.g., fossil flora.

Food Chain: A straight-line sequence of steps by which energy passes to the next highest trophic level, that is, a hierarchy of organisms in which each feeds on those below and is the source of food for those above. Species, especially those on a low trophic level, often belong to more than one chain, so the chains tend to be connected together, creating food webs.

Hibernation: A survival strategy used by animals, including many insects. When hibernating, an animal spends an extended period of time in a protected place, usually through the winter, in a dormant state. It lives on fat or energy reserves built up during the active time of the year.

Homeothermic: Animals that depend on the internal generation of heat are homeothermic, or warm blooded. Mammals and birds are homeothermic.

Migration: A faunal survival strategy involving moving from one area to another for a time and then back. Migration is used by sea and land animals, birds, fish, and some insects. Migrations are usually seasonal and involve moving to an area where more food is available or where the climate is warmer. Human migration involves the more-or-less permanent movement of groups of people from one area to another.

Perennial Plants: Plants that live for more than one year, such as trees and shrubs.

Photosynthesis: The process in which the energy of sunlight is used by green plants to synthesize energy in the form of carbohydrates from carbon dioxide and water. A by-product of photosynthesis is oxygen.

Poikilothermic: Animals that do not depend on the internal generation of heat, but on external sources, are poikilothermic, or cold-blooded. Fish, insects and reptiles are poikilothermic.

Polynya: Year-round ice-free areas in polar ice pack.

Trophic: Of or concerned with nutrition.

Trophic Level: An organism's trophic level refers to its position in the food chain. Organisms that convert sun energy and inorganic compounds into organic compounds are autotrophs and are located at the base of the chain. Organisms that eat autotrophs are called herbivores or primary consumers. Organisms that eat herbivores are carnivores, is a secondary consumer and is at a higher trophic level. A carnivore that eats a carnivore that eats a herbivore is a tertiary consumer, and so on. Many animals do not specialize in their diets. Omnivores (such as humans) eat both animals and plants. Further, except for some specialists, most carnivores don't limit their diet to organisms of only one trophic level.

Useful Web Sites

Environmental Biology - Ecosystems
http://www.marietta.edu/~biol/102/ecosystem.html

Biomes of the World (scroll down to "Taiga" and "Tundra")
http://www.ups.edu/biology/museum/worldbiomes.html

World Boreal Forests – Introduction
http://www.borealforest.org/world.htm

Boreal Forest Plants and Animals
http://www.borealforest.org/world/world_species.htm

Animal Adaptations to Cold
http://www.biology.ualberta.ca/courses.hp/bio366/birds.htm

NWT Species at Risk Fact Sheets
http://www.nwtwildlife.rwed.gov.nt.ca/Publications/speciesatriskweb/default.htm

NWT Wildlife Species
http://www.nwtwildlife.rwed.gov.nt.ca/NWTwildlife/default.htm

These web links were last verified 21 June 2004.