Climate Change and the Arctic Ecosystem

Key Concepts:

- Biome
- Carbon sink
- Global warming
- Greenhouse
- Permafrost

WHAT YOU WILL LEARN

1. You will analyze the impact of global warming on the Arctic region.
2. You will analyze the effect of Arctic climates on plant and animals populations.

Engage Your Thinking

The northern polar region, the Arctic, consists of the Arctic Ocean surrounded by land while the southern polar region, the Antarctic, is an ice-covered continent surrounded by ocean. The Arctic ecosystem is a fragile ecosystem. The short growing season and the low diversity of living organisms make the Arctic ecosystem vulnerable to global warming and climate change.

In this case study you will learn about the ways in which global warming and climate change may be affecting the Arctic ecosystem. Part I consists of a series of questions that will help you to clarify your current knowledge and to think about the impact of global warming and climate change on the arctic ecosystem. Part II involves a case study of the impact of global warming and climate change on the Arctic ecosystem. Reading this case study will provide you with the actual scientific data and information often used as evidence of the impact of global warming on the Arctic ecosystem. The case study will add to what you already know about the problem of global warming; the questions in this section will help you to think about and analyze the data and evidence. Part III will promote your reflection on these initial ideas and your thinking about the impact of global warming and climate change on the Arctic ecosystem. As a result, you will be able to develop answers to problems and questions concerning the Arctic ecosystem.

1. What are some human activities that might be influencing climate change?

2. How does climate change seem to impact the Arctic ecosystem?

Case Study

Do greenhouse gases and human activities affect climate change?

Carbon dioxide, water vapor, nitrous oxide, and methane are naturally occurring gases in the Earth's atmosphere. These gases let the sun's energy (visible light) pass through the atmosphere and reach the Earth's surface, where some of the sun's energy is absorbed and changed into heat (infrared radiation). This heat is then radiated back toward the atmosphere. The carbon dioxide, water vapor, nitrous oxide, and methane in the atmosphere trap some of the sun's heat and re-radiate it back towards the Earth's surface, warming it as shown in Figure 1. This natural process is similar to what happens in a greenhouse where the glass roof and walls trap the warmth of the sun and warm the air. Carbon dioxide, water vapor, nitrous oxide, and methane are known as greenhouse gases and this natural process is called the **greenhouse effect**. Naturally occurring levels of these greenhouse gases are essential to life on earth. With a decrease or absence of these greenhouse gases, the Earth's atmospheric temperature would be 60^{o}F cooler. With an increase in the atmospheric concentration of these greenhouse gases, the Earth's atmospheric temperature would increase and the Earth would become much warmer.

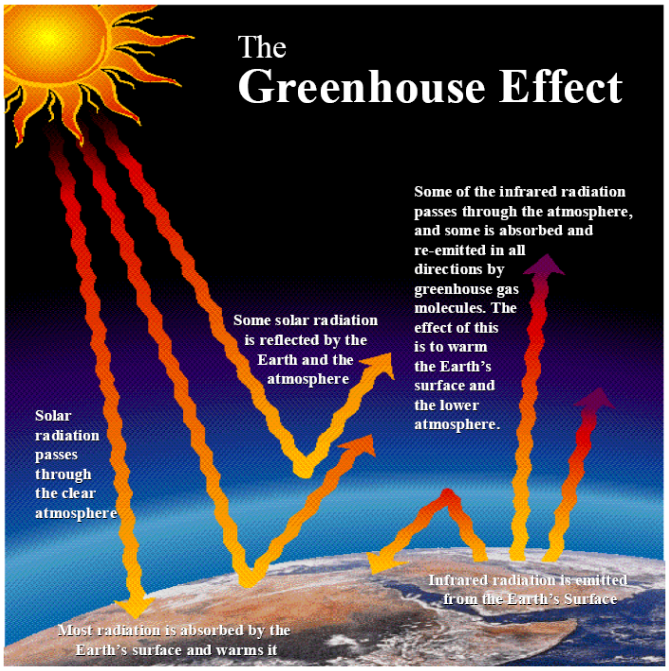

Figure 1. The greenhouse effect (Source: EPA)

Since the time of the Industrial Revolution, human activities have continued to add/ have added more and more greenhouse gases—especially carbon dioxide—to the atmosphere. Carbon dioxide (CO_2) enters the atmosphere through the burning of fossil fuels, solid waste, trees, and wood products. Atmospheric concentrations have increased from about 280 ppm. prior to the Industrial Revolution to about 380 ppm today. Methane (CH_4) is emitted during the production and transport of coal, natural gas, and oil. Methane emissions are also caused by raising livestock and by other agricultural practices as well as from the decay of organic waste (garbage) in municipal solid waste landfills.

Nitrous oxides (NO_x) are emitted during agricultural and industrial activities and during the combustion of fossil fuels and solid waste. The increase in the concentration of greenhouse gases has, in turn, resulted in an increase in the Earth's atmospheric temperature. This temperature increase is known as **global warming** (Figure 2).

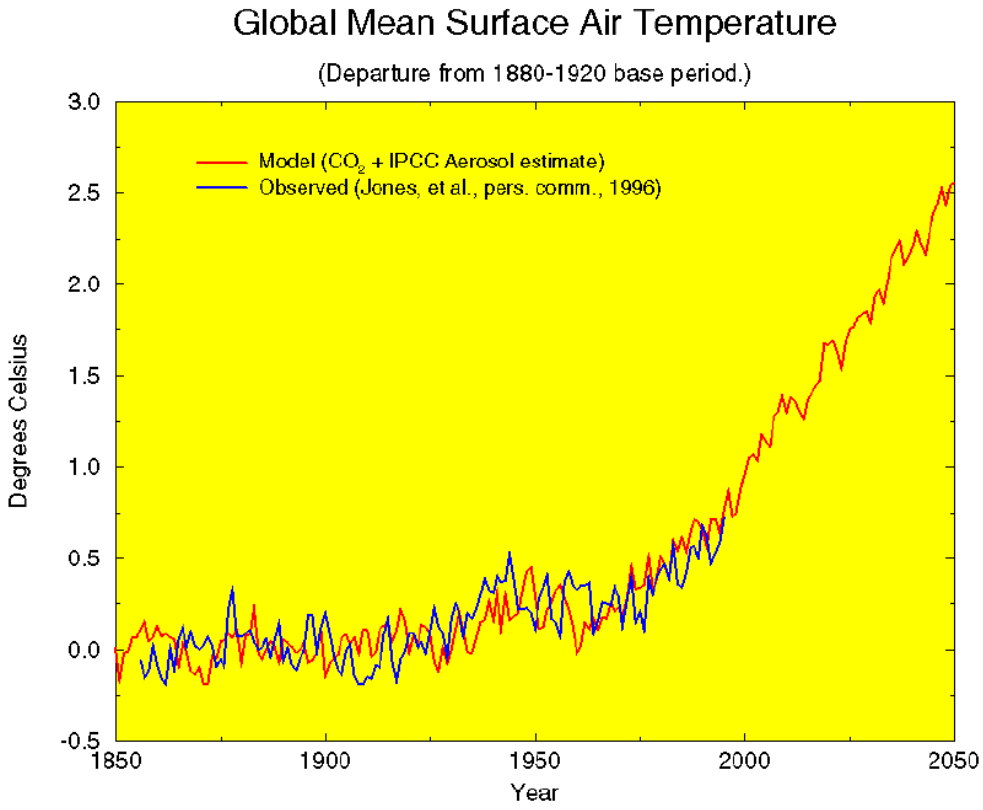

Figure 2. Changes in the Earth's temperature
(Source: Geophysical Fluid Dynamics Laboratory)

How does global warming currently impact the Arctic region?

The Earth's global temperature has increased approximately 1^oC in the past 100 years (as shown in Figure 2), with the years 1995-2006 among the 12 warmest years since records have been kept. The greatest warming has occurred in the Arctic region: the Northern latitudes between 40^oN and 70^oN (Figure 3). This is due, in part, to the loss (or melting) of snow and ice. Also, both land and water absorb and transfer more heat to the atmosphere than snow and ice, so the more open land and water, the warmer the atmosphere. This further adds to the rate at which snow and ice melt.

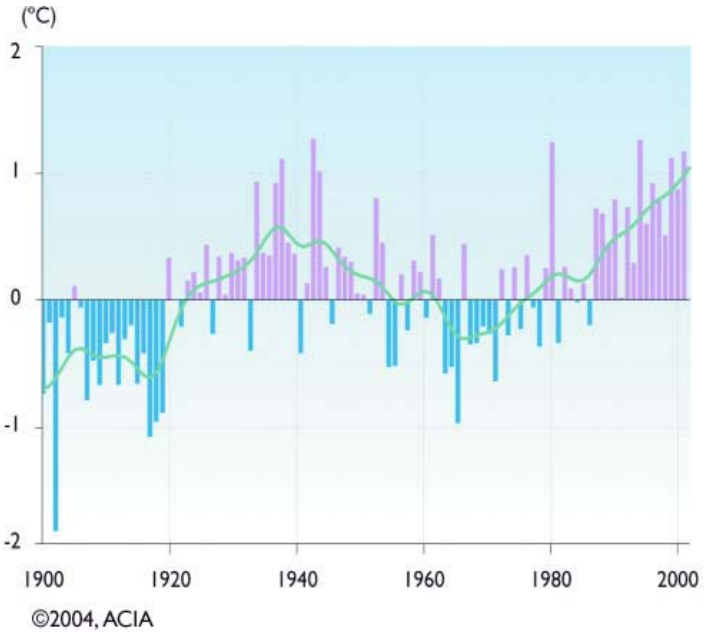

Figure 3. Change in Arctic temperature (Source ACIA)

3. How might warming Arctic temperatures impact snow cover, sea ice, and permafrost?

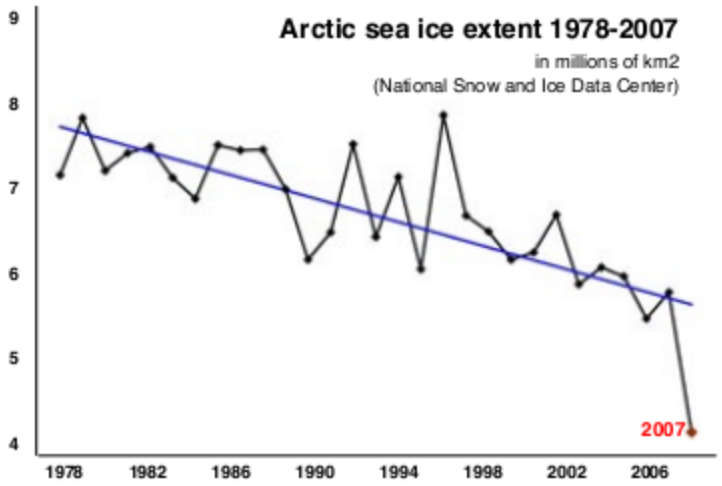

Figure 4. Change in sea ice extent (Source: Takver)

4. Based on the data in Figure 4, describe and explain the change in the Arctic sea ice.

The 2006 snow cover over the Northern Hemisphere averaged 24,900,000 $km^{2,}$ which was 600,000 km^2 less than the 37-year average. Figure 5 shows the snow cover projection for the time period from May, 2070 through May, 2090. The white area indicates the projected snow coverage. The gray area indicates the current May snow coverage, or the area that will be free of snow by 2070-2090.

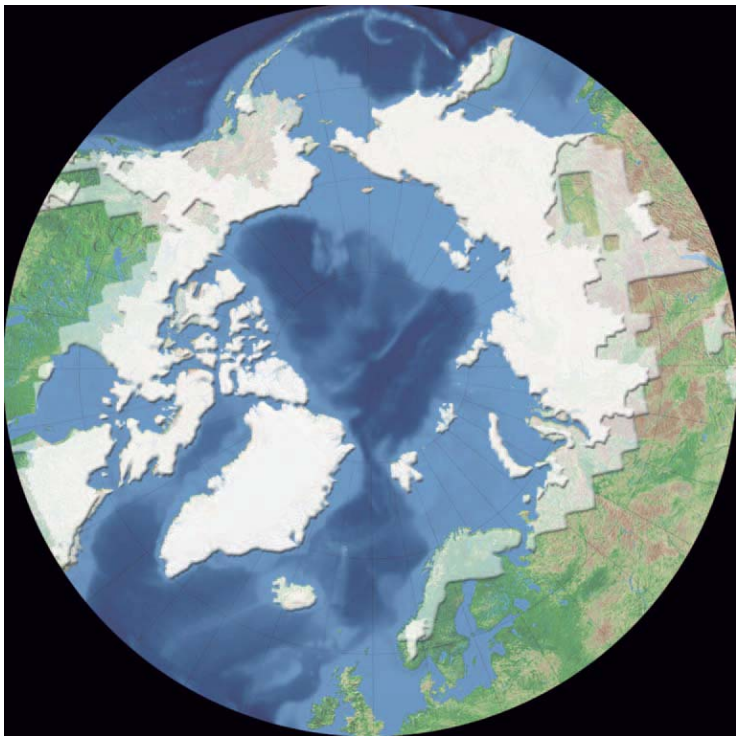

Figure 5. Projected change in Arctic snow cover (Source: ACIA)

5. Based on Figure 5, how does global warming impact May snow cover in the Arctic?

Permafrost is ground that is frozen all year. The farther north one goes, the thicker and colder the permafrost becomes. Permafrost depth varies, but has a maximum depth of 150 meters or more. The upper layer of the permafrost melts and refreezes. This layer is called the *active layer*. As temperatures increase, more permafrost melts and the active layer becomes thicker. The melting of the permafrost affects ground water, drainage, runoff, ecological systems, and structures that humans build on top of the permafrost. Temperatures in the permafrost have warmed since the 1960's. The trend in permafrost temperatures in Northern Alaska at a depth of 20 meters is shown in Figure 6.

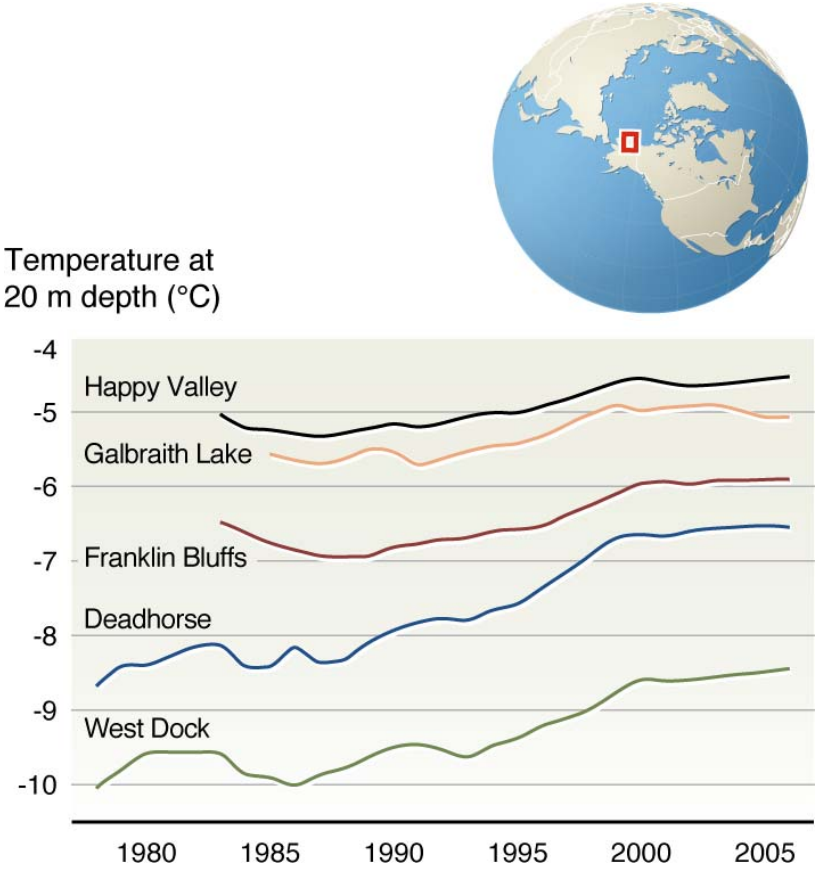

Figure 6. Trends in permafrost temperatures in Northern Alaska (Source: United Nations Environmental Program Maps)

6. Based on Figure 3 and Figure 6, describe the relationship between air temperature and permafrost temperature.

How might a change in arctic climate affect the plants and animals of the arctic ecosystem?

The Arctic region consists of three major **biomes** or vegetation zones: the polar deserts (or polar ice cap), the tundra, and the boreal forest (Figure 7). The polar desert is characterized by patches of open ground and the absence of woody shrubs. The tundra has low-growing shrubs, grasses, mosses, and lichens. The boreal forest (or taiga) is characterized by coniferous trees such as fir and spruce. For most of the year the boreal forest experiences cold harsh temperatures and little sunshine, so the growing season is short.

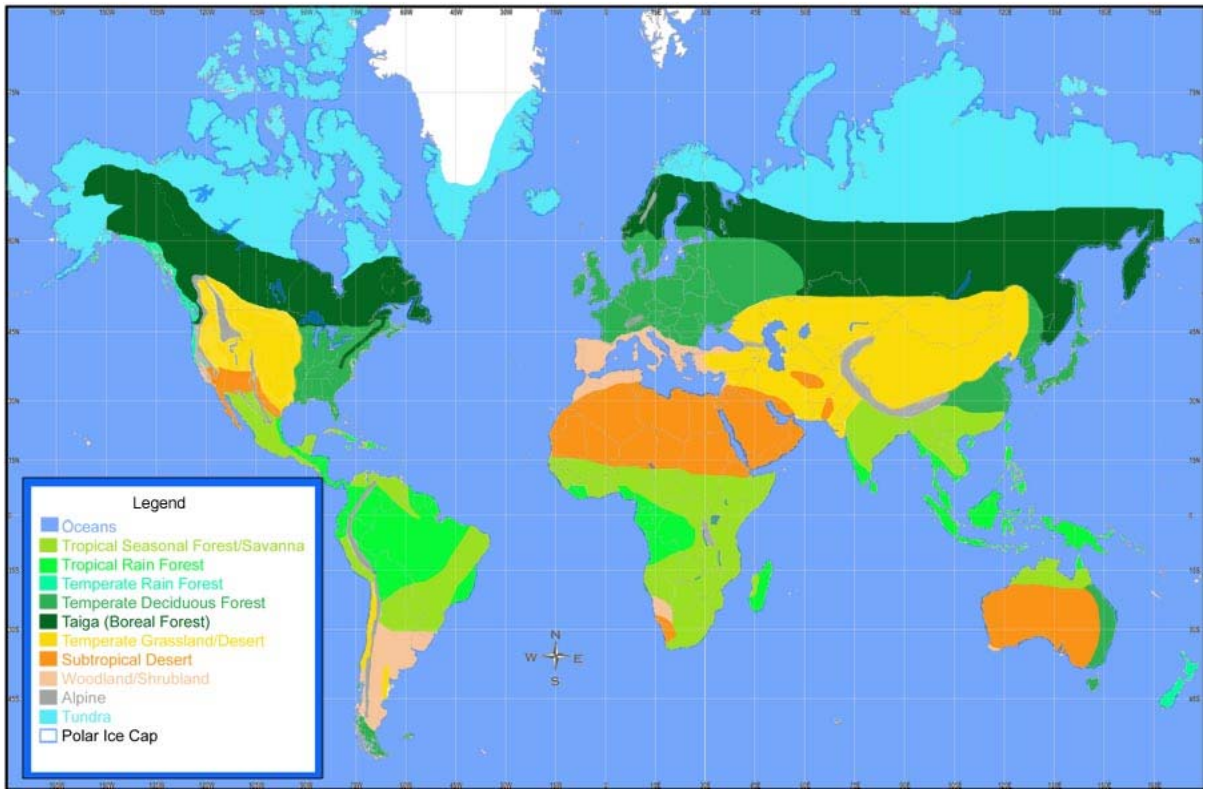

Figure 7. Biome map of the world (Source: Marietta Education)

7. Based on Figure 7, how might climate change cause a shift in the biomes of the Arctic region?

Climate change is expected to cause these biomes, or vegetative zones, to shift northward. The tundra is expected to creep into the arctic desert, and the boreal forest will shift north into the tundra. As a result of the shift in the boreal forest, scientists project that the tundra will shrink in size (area). With the loss of tundra, there will be fewer grasses, mosses and lichens. The boreal forest is sensitive to changes in temperature and precipitation; if temperatures continue to warm and soils become drier, the boreal forest will become more susceptible to forest fires and insects. Consequently, increasing arctic temperatures have caused an increase in forest fires. Canadian scientists expect a 40% to 50% increase in the annual forest area that will be burned if greenhouse gases double as expected in the next 30-50 years.

The warming climate will also result in an increase in insect infestations (Figure 8). Spruce bark beetles, cone worms, larch sawflies, and spruce budworm have all had increased outbreaks in the boreal forests in the last decade. For example, warmer winter temperatures allow more spruce bark beetles to survive the winter, and warmer summer temperatures enable the spruce bark beetle to complete its life cycle in one year instead of two. The increase in winter survival rates and the shorter life cycle result in an increase in spruce bark beetle populations. The resulting increase in the number of spruce bark beetles, combined with the tree stress caused by warmer temperatures, makes the boreal forest ripe for large-scale tree damage caused by spruce bark beetles.

Figure 8. A spruce tree killed by spruce bark beetles

8. Explain why an increase in spruce bark beetles might cause an increase in the area burned by forest fires.

The boreal forest serves as a carbon sink. A **carbon sink** removes more carbon dioxide (CO_2) out of the atmosphere than it releases. As trees grow, they remove carbon dioxide from the atmosphere and store it in their wood and leaves. When the boreal forest is destroyed by insect infestation and fire, the natural carbon sink is disrupted, and less carbon dioxide is removed from the atmosphere. Forest fires also release carbon dioxide into the atmosphere.

How will Arctic animals be affected by climate change? The ocean (aquatic zone) accounts for more than half of the Arctic region; ocean productivity affects many arctic life forms. Thus the ocean must be considered when looking at the impacts of climate change. A marine food web for the arctic region is shown in Figure 9.

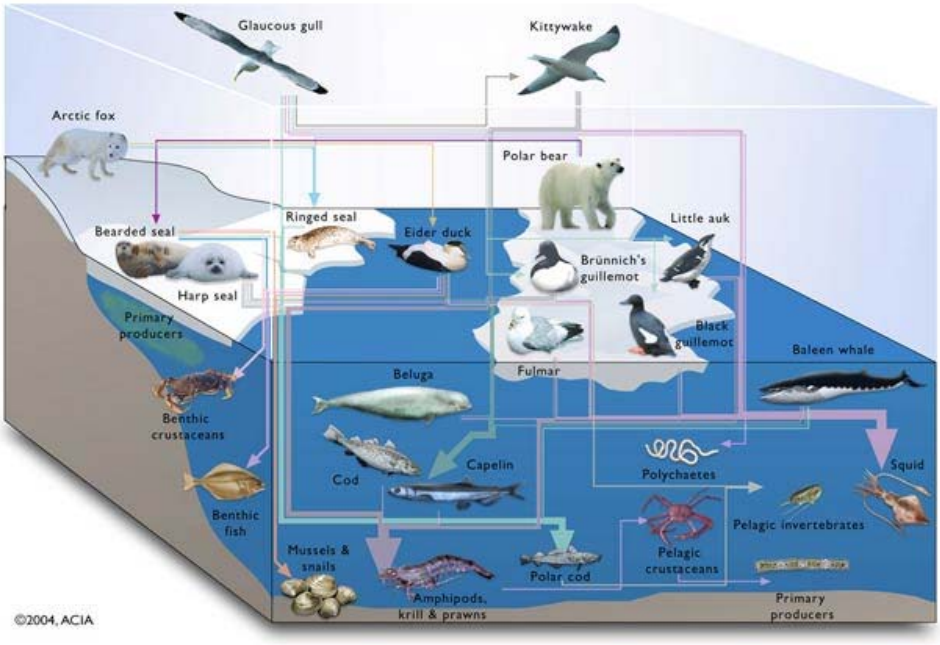

Figure 9. Arctic marine food web (Source: ACIA)

9. What roles do the primary producers play in the food chain?

Marine species that may be affected are ice-dependent seals, polar bears, seabirds, walruses, and ice algae. Ice-dependent seals give birth, nurse their pups, and rest on the sea ice. Polar bears use the sea ice for hunting seals, migration corridors, den sites, and resting platforms. The polar bear's primary diet consists of ice-dependent seals. Seabirds use the sea ice for nesting and breeding to avoid predators. One species of seabird, the ivory gull, has seen a 90% decline in Canada over the last 20 years because of the loss of sea ice. Walruses use the ice for resting and feeding and eat clams and shellfish on the continental shelf. As the ice melts, the edges move farther away from the continental shelf, making it more difficult for walruses to find food.

Marine ice algae, which grows on the porous bottom of the sea ice, has declined in recent years as well. Ice algae serve as the basis of the marine food web. Scientists have found areas where marine ice algae have been replaced by less productive freshwater ice algae. Researchers have found a 30- meter layer of fresh water deeper under the ice than any that existed 20 years ago.

10. What would cause the freshwater layer under the sea ice to become thicker?

11. How would the change in the fresh water layer interrupt the marine food web?

Because Arctic plant species are limited, any changes in arctic plant life would also significantly impact animal species. Tundra mosses and lichens are also very sensitive to warming. This means that, as temperatures increase, mosses and lichens might migrate farther north and become susceptible to freeze-thaw events, which are now occurring more often. The freeze-thaw event then creates ice crusting. Ice crusting may kill the plants and make it harder for herbivores (plant eaters) to obtain their food. Plant eaters such as voles, ground squirrels, lemmings, musk ox, caribou, and hares may all suffer as their food sources diminish.

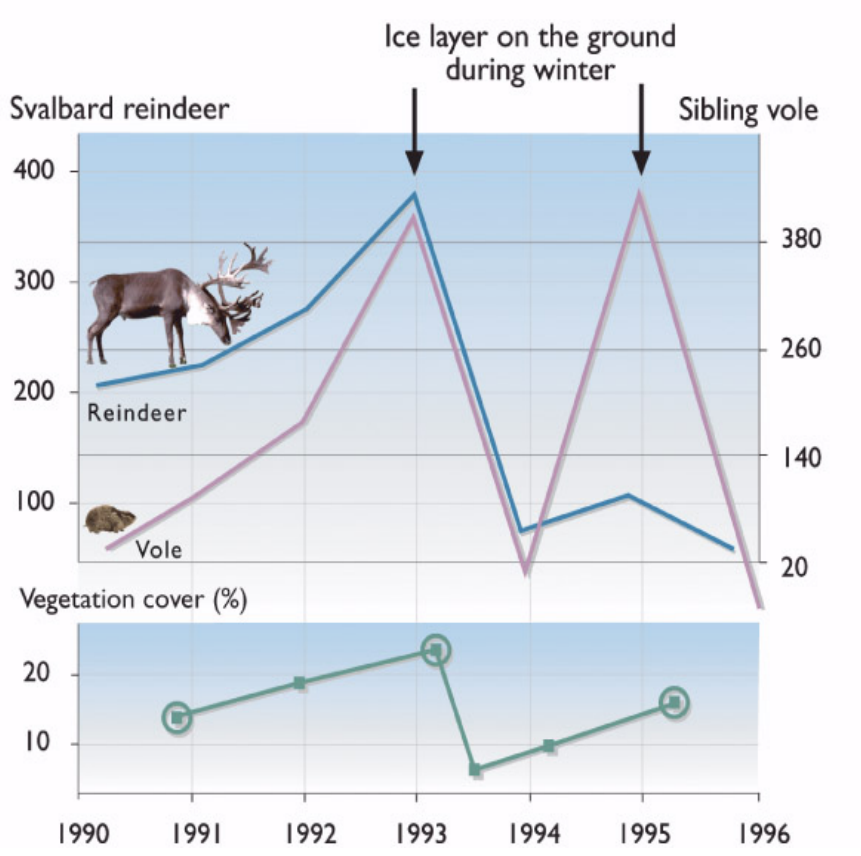

Figure 10 Relationship between vegetation and animal survival (Source: ACIA)

Predators such as wolves, foxes, and snow owls, may also be affected by the decline in the number of prey. Thus, a *cascading* effect might occur throughout the arctic ecosystem. For example, as fewer tundra mosses and lichens survive, less food will be available for caribou and reindeer. This will result in a decline in the caribou and reindeer that feed primarily on mosses and lichens (Figure 10). Declines in the caribou and reindeer populations result in a decline in the predators (carnivores), such as wolves, that prey on caribou and reindeer.

12. Based on Figure 10, describe the relationship between vegetation cover and reindeer and vole population.

The loss of snow cover will impact lemmings and voles. Lemmings and voles use the air pockets between the snow and the ground for feeding and living areas. The snow also provides insulation. Less snow would mean less insulation which would affect the survival rate of lemmings and voles.

13. How would the survival rate of lemmings and voles impact the Arctic food web?

Arctic freshwater ecosystems include rivers, lakes, ponds, and wetlands. Climate change would increase water temperatures, lower dissolved oxygen levels, and change freezing and thawing periods and ice cover. These changes would modify the timing of the spring melt and the timing of nutrient, sediment, and water influx. In turn, these changes would impact species composition and diversity, as well as food web structures. For example, warmer lake water would impact lake trout survival and, as a result, would affect the stability of the lake food web.

Thawing the permafrost would increase water runoff into streams and lakes. It would also increase water temperatures the density of nutrients and sediments carried into the streams and lakes. Thawing permafrost would also cause the surface ground to collapse, the resulting depressions would fill with water to form new wetlands and ponds.

Climate change could impact the Arctic ecosystem in other ways: increased precipitation could transport more pollution from the south to the Arctic region. Other plant and animal species may expand their range into the Arctic

ecosystem, competing with native Arctic species for food, shelter, and water. Warmer temperatures could bring an increase of human activities.

Conclusion

Scientists believe that global warming is due to the increase of greenhouse gases in the atmosphere. This causes an increase in temperature, which results in climate changes that affect the arctic ecosystem by decreasing the amount of sea-ice, snow cover, and permafrost. These decreases could, in turn, cause Arctic vegetation zones to shift northward, affecting many plant species. Fires, insect infestations, and an increase of freeze-thaw cycles could negatively impact arctic plant species. The many animal species populations that depend upon arctic plants would then be affected, and this would next affect the number of arctic predators that are dependent upon herbivores. Thus, climate change could have a *cascading* effect on the arctic ecosystem.

14. Create a concept map or flow chart that illustrates how climate change could impact the Arctic ecosystem.

Reflect on What You Have Learned

15. What kinds of human activities currently influence climate change?

16. How is climate change now impacting the Arctic ecosystem?

17. Please explain how your ideas about climate change and Arctic ecosystems have changed.