Arctic Long-Term Ecological Research (ARC)

The Arctic Long-Term Ecological Research (ARC LTER) site is located in the northern foothills of the Brooks Range, Alaska. It is a region of diverse vegetation and animals that have adapted to the frigid, dry and windy climate. Mean temperature is -10^{o}C; annual precipitation 20-40 cm. In the winter, there is complete snow cover for seven to nine months as well as an ice cover on lakes and streams with no stream flow.

Summers are relatively warm, with an average temperature of 7 to 12^{o}C, permitting continuous vegetation cover, flowing streams and lakes that are open for more than three months. From the end of May to mid-July, there is sunlight for 24 hours.

Plants are low-growing and carry out photosynthesis in a very short growing season. There are no trees. Tussock tundra is the dominant vegetation but there are extensive areas of wet sedge tundra, drier heath tundra on ridge tops and river-bottom willow communities. Permafrost is continuous. The streams in the area make up the headwaters of the Kuparuk River, and oligotrophic (low nutrient) lakes of various ages are abundant.

ARC LTER focuses its research on predicting the effects of environmental change on the ecology of tundra, streams and lakes. One reason to study this low Arctic region is that global change is predicted to warm the Arctic sooner and more extensively than the rest of the Earth. In fact, a strong warming has been taking place in northern Alaska for more than three decades. This change allows scientists to test predictions such as whether there is a trend toward more shrubs and more permafrost thawing.

A second reason is that Arctic soils contain large amounts of organic carbon, enough to double the atmospheric concentration if the soil carbon were to be oxidized to carbon dioxide when permafrost thaws.

The ARC LTER is headquartered at the Marine Biological Laboratory, Woods Hole, Massachusetts. Scientists from 11 institutions are principal investigators on the project (Universities of Michigan, Northern Colorado, California at Santa Barbara, Alabama, Vermont, Texas at Arlington, Maryland at Horn Point, Alaska at Fairbanks, Utah State, the Georgia Institute of Technology and the Marine Biological Laboratory).

The Arctic LTER Site at the Toolik Field Station

The University of Alaska Fairbanks (http://www.uaf.edu/toolik/) operates the Toolik Field Station (TFS), located along the Dalton Highway at 68^{o} N, 149^{o} W, with support from the National Science Foundation. The TFS supports up to 100 scientists and includes modern laboratories and living quarters. It is open year-round.

Populations and Processes

A great deal is known about the populations of plants and animals in the streams and lakes and on the tundra. Our present work focuses on predicting the impact of climate change on these populations. On the tundra, we examine long-term and slow changes in the abundance of plant species. In the streams and lakes, we focus on the annual growth and survival of sport fish such as arctic grayling, lake trout and arctic char. In the soil, we focus on enumerating the types, abundance, and function of microbes, bacteria and mycorrhizal fungi, as well as on their animal grazers.

Changing Biogeochemistry

Permafrost, lying 30 to 50 centimeters below the surface, prevents deep drainage of water so the tundra is moist despite the low precipitation. The moist conditions, combined with low temperatures, inhibit decomposition, causing the soils to accumulate organic matter. Nutrients, primarily nitrogen and phosphorus, are tied up in the organic matter and the resulting lack of available nutrients limits plant productivity. One effect of climate warming is an increase in mineralization (conversion of organic matter to nutrients such as nitrogen and phosphorus), making more nutrients available to tundra plants. Arctic lakes and streams are also nutrient-poor leading to an oligotrophic food web.

Much of our present research focuses on the impact of changes in temperature and nutrients on the biota. Several decade-long experiments in heating and nutrient addition are underway in four types of tundra plant communities. In the Kuparuk River, low amounts of phosphate have been continuously added each summer since 1983. Another biogeochemical experiment looks at whether phosphate released from parent material to streams will drastically change the biota when permafrost thaws.

The Legacy of Past Glaciations

Different vegetation communities near the Toolik Field Station (TFS) are the result of the age of the surface soils laid down by glaciers. Northern Alaska was not covered by the continental glaciations but mountain glaciers from the Brooks Range expanded over the foothills a number of times. Surface soils near the TFS have ages of ~10,000, ~60,000 and >300,000 years. We have found that the pH of the soils decreases from near neutrality in the youngest soils to a pH of 3.5 in older soils. The water in lakes and streams on these glacial surfaces has strong differences in conductivity (one measurement of weathering). These differences in age allow scientists to sort out the effects of climate warming from the effects of primary succession in the soils, streams and lakes.

Water Dynamics

The rainfall at TFS is desert-like, yet the soil is moist underfoot, and grasses and shrubs cover the hills. This is caused by permafrost that is 30 to 50 centimeters below the soil surface and stops any downward drainage of water. Climate warming and human activities in the future will change the water cycle: too much water will slow down the decomposition of organic matter, too little water will drastically reduce plant growth. Water movement downslope supplies all-important nutrients and organic matter to streams and lakes. To test our understanding of water movement and of the soil processes that produce the nutrients and organic matter in the soil water, we are developing both soil chemistry and hydrology models. Eventually the linked models will permit us to predict the effects on terrestrial and aquatic ecology of changes in precipitation caused by an array of possible future changes.

Putting it all together

Mathematical modeling allows scientists to assemble or synthesize information about the many ecological processes that interact to make up an entire ecosystem. Once models are constructed, knowledge about these systems can be tested for completeness and modeling results extended to large regions and to centuries. One terrestrial model, the General Ecosystem Model (GEM), has been calibrated for the tussock tundra using data from experiments in which light, temperature and nutrients were changed. The GEM has been used to simulate primary productivity of an entire 9,500-km^2 watershed and to predict carbon storage above and below ground for the next 200 years. Our focus now is on modeling the movement of water and nutrients down a hill slope and on the incorporation of soil processes into the larger-scale models. Additional modeling of the physical processes in lakes and on the food webs in streams allows us to estimate the impact of such changes as warmer summer temperatures on the aquatic plants and animals that feed the sport fish at the top of the food web.