ARCTIC LTER

Predicting the Future Ecological Characteristics of the Toolik Lake Region

ABSTRACT

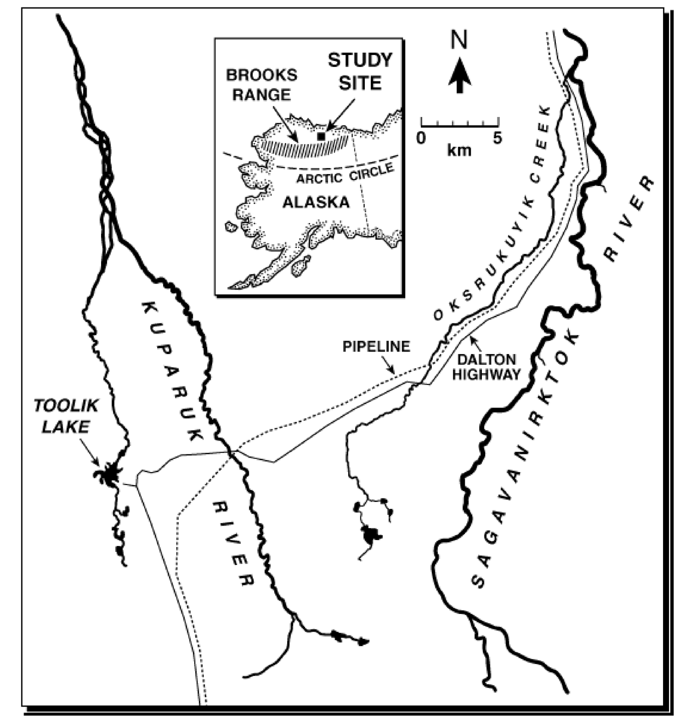
The site lies at 68ºN in the northern foothills of the Brooks Range, Alaska, in tundra vegetation of sedges and grasses mixed with dwarf birch and low willows. The tundra, streams, and lakes at the site have been undisturbed and unchanged for more than 5,000 years; caribou and moose move freely over this region pursued by wolves and grizzly bears. Populations of lake trout, char, and arctic grayling are in a pristine state, often dominated by very large and very old individuals. This allows the analysis of relationships in plants and animal communities in an ecosystem unaffected by an ecological legacy of human use.

The climate of northern Alaska has changed remarkably over the past 30 years; the 0.7ºC per decade increase in temperature could result in much more than the 3-5º total change predicted by GCM models for a doubling of CO_2. Based on several types of observations, there appears to be a biotic response to this regional warming. For example, the NDVI (a satellite-based indicator of plant biomass) has increased in northern Alaska, and vegetation communities at Toolik Lake show a reduction in moss cover and an increase in shrubs.

The goal of this LTER project is to predict the future ecological characteristics of the site based upon our knowledge of the controls of ecosystem structure and function as exerted by physical setting and geologic factors, climatic factors, biotic factors, and the changes in fluxes of water and materials from land to water.

APPROACHES

1. **Long-term monitoring and surveys** of natural variation of ecosystem characteristics in space and time. Includes: climate, plant communities and productivity, thaw depth, stream flow, chemistry of streams and lakes, temperatures of streams and lakes, lake chlorophyll lake productivity, zooplankton abundance.
2. **Experimental manipulation of ecosystems** for years and decades. Includes: tundra warming, shading, and fertilizing, grazer exclusions, fertilization of lakes and streams, addition and subtraction of predators.
3. **Synthesis of results and predictive modeling** at ecosystem and watershed scales. Includes: stream N cycling, lake physics, bioenergetics of fish populations, water movement and transfer of DOC and nutrients from land to water, soil respiration, cycling and storage of C in tundra under different scenarios of future climates.



LOCATION

Toolik Field Station (University of Alaska) is at 68ºN in northern foothills of Brook Range. The site lies in formerly-glaciated rolling hills covered with tussock tundra; the site also contains oligotrophic lakes (20 m d_{max}) and streams.

Air Temp	May	0.6ºC
	June	8.1
	July	11.9
	August	7.4
	Yr Avg	-8.4

Precipitation 200-300 mm

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TERRESTRIAL RESEARCH

Environment and species composition are both changing rapidly in many parts of the world, largely as a direct or indirect result of human activities. To understand how these changes interact to control important ecosystem processes like primary production and organic matter cycling, the Arctic LTER project documents changes as they occur and compares the changes in environment, species composition, and ecosystem processes over time.

In one recent experiment, 15 years of N+P fertilizer addition to Alaskan moist tundra increased biomass and primary production by 2.5-fold. Species composition changed dramatically as well, from a mix of plant forms to strong dominance by a single, deciduous shrub species, *Betula nana*. By the 15th year, however, both new leaf production and total leaf mass were *lower* in fertilized than in control plots, although leaf area in fertilized plots was twice that of controls. This occurred because *Betula* produced thinner leaves than other species, with a high Specific Leaf Area (SLA = leaf area per unit leaf mass). Woody stem mass also increased dramatically in fertilized plots, with secondary growth accounting for over half of aboveground NPP.

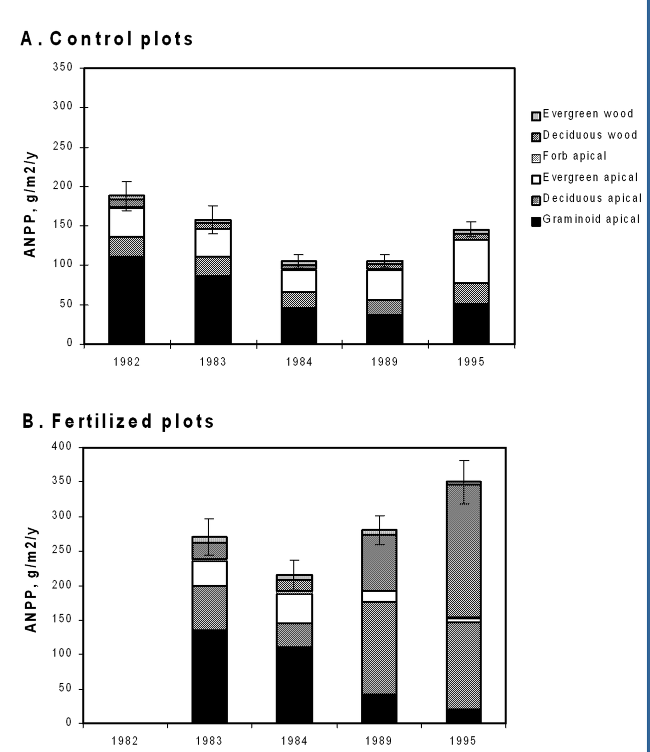

Figure 1. Total Aboveground Net Primary Production (ANPP, mean ± 1 SE, in g m^{-2} y^{-1}) in (A) control and (B) fertilized plots of moist tussock tundra at Toolik Lake, 1982-1995. The lower segments of each bar indicate the apical growth component of ANPP in the four major plant growth forms, with forb biomass included but always too small to be seen at this scale. Upper segments indicate secondary growth (wood production) by deciduous and evergreen shrubs.

The large increase in wood production was made possible in part by the low cost of production of *Betula*'s thin leaves, allowing greater allocation to secondary growth. Wood also had lower N concentrations than leaves, allowing large accumulations of wood at low N cost. Overall, aboveground N concentration in *Betula* did not change in fertilized relative to control plots because its low-N wood mass increased more than its high-N leaf mass (with high SLA). Because *Betula* was so strongly dominant on the fertilized plots and was better able to dilute its greater N supply with new growth, community production and biomass in fertilized plots were higher, and N concentration was lower, than would have been the case if species composition had not changed.

In sum, the experiment shows that both environment and species composition affect primary production and various measures of production efficiency and nutrient use efficiency of the whole ecosystem.

LAND WATER INTERACTIONS

The dissolved ions, nutrients, organic matter, and gases in the streams and lakes of the Arctic LTER mostly come from land. Future changes here, such as precipitation, vegetation, and annual depth of thaw of the upper layers of soil, will result in a variety of changes in the concentration and seasonality of the materials transported from the land into streams and lakes. These changes could result in an increase in the primary productivity of streams and lakes or a change in the chemistry of rivers entering the Arctic Ocean.

Carbon Transport from Land Via Streams The carbon loss from the entire Kuparuk Basin via streams and lakes is around 4 g C m^{-2} y^{-1}. Most of this is as dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) (Figure 2). CO_2 from lakes and streams is released directly into the atmosphere (32% of total).

As shown in Figure 3, The net ecosystem production (NEP) of the terrestrial ecosystem is estimated to vary from +10 to -15 g C m^{-2} y^{-1}. However, these measurements do not take into account a significant loss of around 4 g C m^{-2} y^{-1} carried away from the soil via transport by water. Therefore, the additional loss is a significant fraction of the net ecosystem production that should be added in to the terrestrial calculations of NEP.

Given this importance of the transfer of materials from land to water over the entire river basin, it is necessary to understand what controls this transfer.

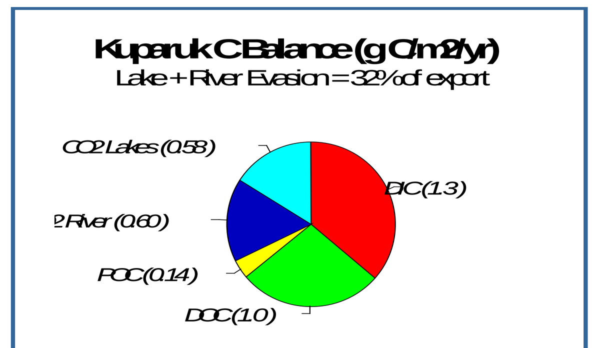

Figure 2. Annual aquatic export of carbon from the 9,000 km^2 Kuparuk Basin.

Kuparuk Basin Carbon Balance

(1) Terrestrial Balance

Long-term Net Ecosystem Production (NEP, modeled since 1920:

~ +10 to -15 (g C m^{-2} y^{-1})

(2) Aquatic Balance

Total loss from basin 1994-1996

~ 4 (g C m^{-2} y^{-1})

Conclusion: Aquatic Loss is 40 - 100% of NEP

Figure 3. Terrestrial and aquatic carbon balance of the Kuparuk Basin.

Flushing Experiment: Differences in Vegetation

In an experiment to test the effect of increased amounts of water on material transport from tundra, we collected soil samples as 28 cm diameter cores from beneath tussocks, from between tussocks, and in a wet sedge area. Every two days, 2 liters of filtered, oxygen-free lake water were passed through each core and the concentrations of dissolved carbon measured. Most of the carbon leaving the cores was as CO_2 in the tussock and wet sedge cores but as dissolved organic carbon (DOC) in the intertussock core (Figure 4). Dissolved inorganic carbon was low in all the waters. We conclude from these data that the type of vegetation is one of the most important controls of the total amount of carbon leaving the tundra via streams. Similar experiments reveal that the frequency of flushing is also an important control. We conclude that in the tundra ecosystems, as in other systems, the amount of water moving through the soils is the primary factor controlling amount of material transported.

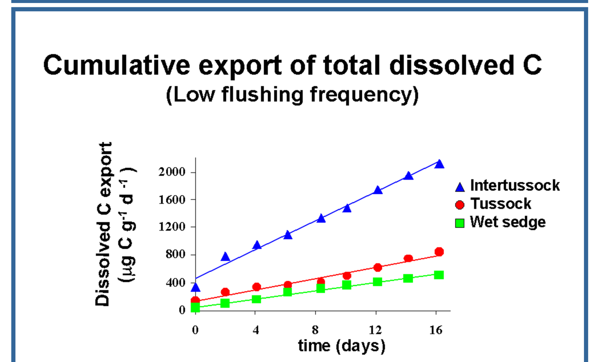

Figure 4. Dissolved carbon export from three types of soils in experimental cores. Every 2 days, 2 liters of water were passed through each core. *Data from K. Judd.*

STREAMS

Human disturbance of the tundra and long-term climate change are causing changes in the input of nutrients to stream Ecosystems. Certain aspects of these changes can be anticipated from the results of our experiments, monitoring and surveys in the Toolik foothills region. For example, a warming climate and human disturbances such as road construction and associated gravel removal can lead to increased seepage of nutrients into tundra streams. Streams research at Toolik has combined long-term monitoring and fertilization of the Kuparuk River with broad-scale surveys of tundra streams throughout the foothills region. Nutrient enrichment of streams that are naturally low in nutrients leads to rapid changes in the benthic diatom communities (Figure 5) and in microbial activity. However, these rapid responses of stream ecosystems are dwarfed by larger changes in the structure of stream ecosystems that occur on the decadel time scale. The riffles of the pristine Kuparuk river were initially covered by bare rocks with an occasional tuft of moss. Ten years later after continuous phosphorus fertilization every summer the riffles were transformed by a dominant cover of the moss *Hygrohypnum* (Figure 6). This moss prefers nutrient rich habitats and occurs naturally where nutrient rich seeps and springs enter rivers. Increased levels of phosphorus have facilitated its spread into the mainstream of the Kuparuk where it is restricted to a few kilometers of phosphorus-rich riffles immediately downstream of the fertilization site.

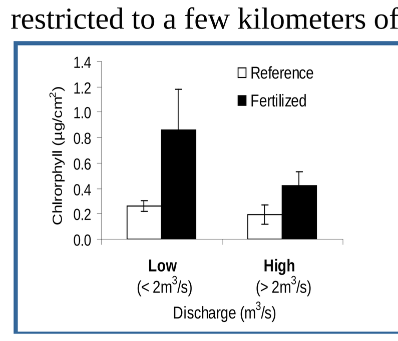

Figure5. Epilithic chlorophyll in July in reference and fertilized reaches of the Kuparuk in low and high discharge periods.

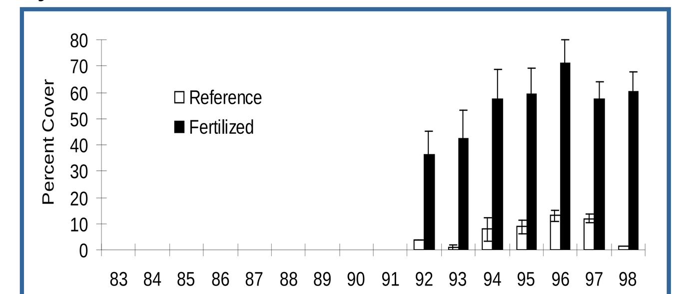

Figure 6. Moss cover (% cover) in the reference and experimental (fertilized) reaches of the Kuparuk River.

The increase in mosses has changed the stream ecosystem in several ways. The mosses now dominate primary production in the fertilized reach and have covered much of the stream bottom area formerly covered by diatoms. Total reach primary production is higher (Figure7) and nitrogen uptake is much greater than in the reference reach. The habitat created by the moss now hosts a very different insect community than was present previously or than that found upstream in the reference reach (Figure 5). The largest changes that appear to be clearly correlated with the moss takeover are the increases in *Ephemerella* and Chironomids. In contrast, the large tube-dwelling *Orthocladius* has been found in very low abundance in moss dominated zones.

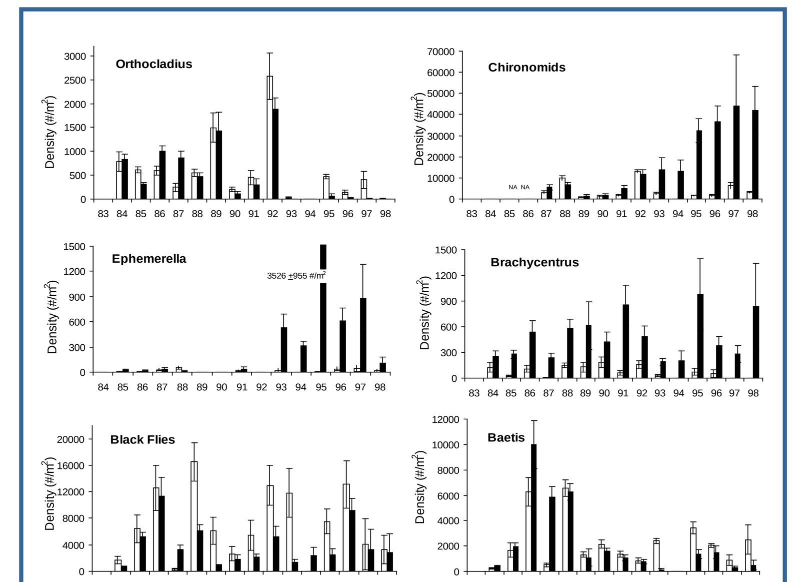

Figure 7. Mean July densities of benthic insect taxa in the reference (clear) and fertilized (black) reaches of the Kuparuk River.

The question of whether or not these experiments and observations will help us predict future changes in tundra streams is an open one. If climate change does indeed result in increased nutrient loading of tundra streams, it is likely that the changes we observe will be repeated in streams throughout the Arctic. On the other hand, if terrestrial systems evolve to be more retentive of nutrients in a changed climate, perhaps nutrient loads will decline. In that case, the streams might remain similar to current stream systems or become even less productive of insects and fishes.

LAKES

The predicted warming of the Arctic may result in increases in the phosphorus entering lakes. How will the added nutrients affect lakes near Toolik Lake? To test this, we divided a small lake (N-2, see photo at right) and added nitrogen and phosphorus to the down-stream side of the lake. The loading rate was 5 times the natural input rate to Toolik Lake. We continued this treatment for 6 years. Nutrient addition increased phytoplankton biomass and productivity (Figure 8). However, each spring the phytoplankton biomass on the fertilized section was similar to the reference section. This lack of carryover of nutrients from one season to the next is due to the strong nutrient sorbing nature of many arctic lake sediments which contain high concentrations of iron and manganese. This effect is so pronounced that there was no phosphorus release from the sediments for the first 4 years of the nutrient addition (bottom graph in Figure 8). Once phosphorus flux from the sediments began to increase, e.g., in 1989 and 1990, there was carryover from one year to the next and primary productivity was greatly stimulated.

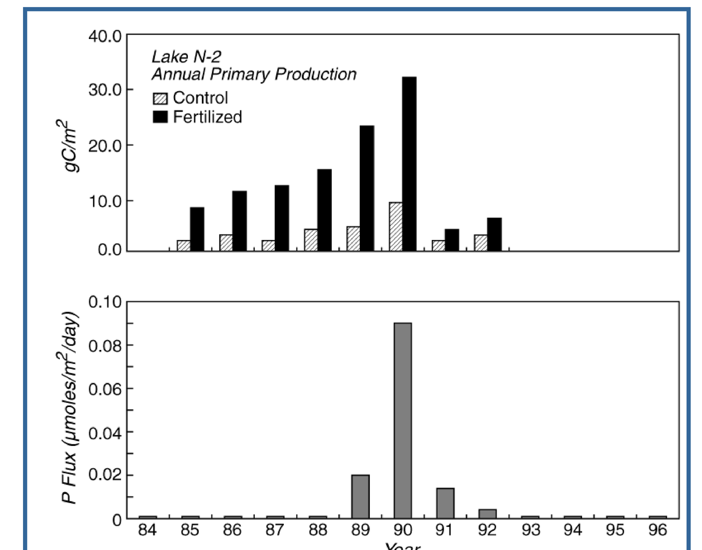

Figure 9. (Top) Primary productivity (annual) in the fertilized and control sides of the divided Lake N-2. Fertilizer was added from 1985-1990. (Bottom) Phosphorus flux (average per day) from the sediments into the water of the fertilized side of Lake N-2.

We also refine our understanding of arctic lakes through modeling. We began by modeling the physical characteristics of arctic lakes. The Arctic Lake Model can accurately simulate the annual temperature cycle in Toolik Lake using daily weather data from the Toolik weather station (Figure 9). This model has been used to predict habitat restriction of lake trout if global warming were to increase arctic summer temperatures. Under a scenario of a 5°C air temperature increase, lake temperatures will increase by 3°C while the ice-free season will increase by seven weeks.

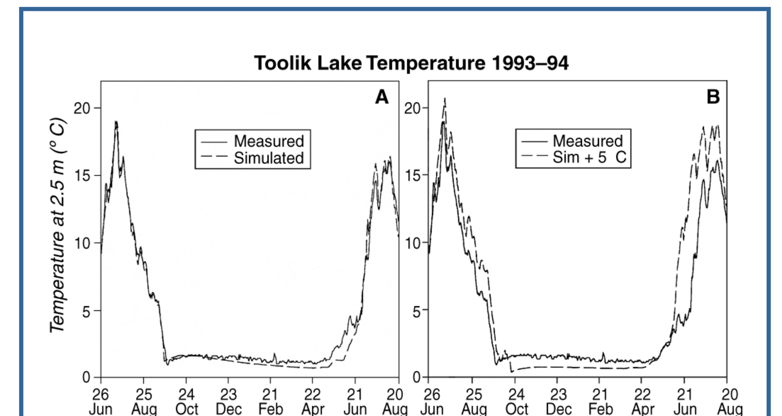

Figure 9. A. The output of the Arctic Lake Model for temperature in Toolik Lake compared with real data (measured) for a full year. **B.** Real data (measured) for a single year in Toolik Lake compared with a simulation using a five degree centigrade increase in air temperature.