ARCTIC LTER

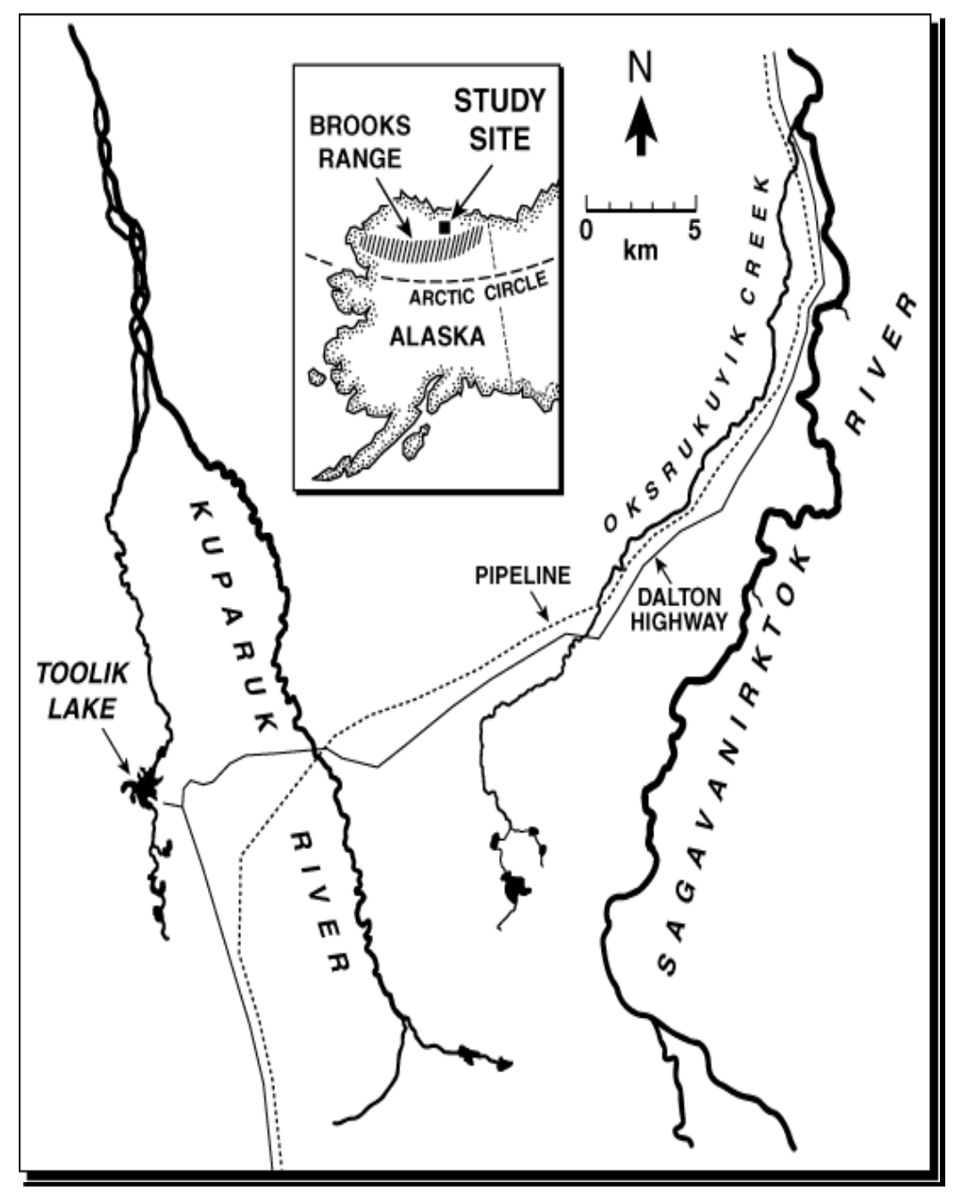
Predicting the Future Ecological Characteristics of the Toolik Lake Region

ABSTRACT

The prediction of the future ecological characteristics of Arctic Alaska depends upon 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. The site lies at 68ºN in the foothills of the Brooks Range 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 for more than 5,000 years; caribou and moose graze over this site with wolves and grizzly bears as predators. Populations of lake trout, char, and Arctic grayling are in a pristine state. Relationships may be analyzed in plant and animal communities unaffected by a legacy of human use.

The climate of northern Alaska has changed remarkably over the past 34 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. The nature of this response, its controls, and its long-term implications are under investigation through:

1. **Long-term monitoring and surveys** of natural variation of terrestrial and aquatic ecosystems in space and time show definite, but very slow, changes. Plant communities are becoming more shrubby, the active layer (annual thaw layer) above the permafrost is becoming thicker as evidenced by stream and lake chemistry, stream nitrate concentration is increasing, an increase in drought conditions has caused disruption in the stream fish habitat with resulting major decrease in the top predators, and the snow-free period is lengthening.
2. **Long-term experimental manipulations of terrestrial and aquatic ecosystems** show very slow recovery of lakes from nutrient fertilization. They also show a rapid response to heating and fertilization of tundra that is similar to the changes happening very slowly in the natural systems.
3. **Synthesis of results and predictive modeling** at ecosystem and watershed scales. A model of terrestrial primary productivity can be applied across a wider range of PanArctic tundra than exist at the LTER site. An Ensemble Kalman Filter was used to assimilate eddy covariance data into a simple model of Net Ecosystem Production. Stable isotopes of mycorrhizal fungi and plants indicate the strong importance of these fungi in moving N from the abundant organic pools to the plants. Synthesis of lake data show that annual summer temperatures correlate with both average air temperature and the number of wind or cooling events.



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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http://ecosystems.mbl.edu/arc

TERRESTRIAL RESEARCH

Tundras and boreal forests are strongly N limited with shrubs and trees symbiotic with ectomycorrhizal and ericoid mycorrhizal fungi. Fungal hyphae break down organic nitrogen, transport amino acids back to plant roots, and receive plant sugars. Therefore, decomposition is independent of the C:N ratio of the organic matter. In this process, N isotopes fractionate: amino acids depleted in ^{15}N are moved into plants and amino acids enriched in ^{15}N are moved into the fruiting bodies. The ^{15}N of the plant foliage and of the fruiting bodies is a marker of this process; patterns of isotope distribution show that the process is similar across a latitudinal transect through boreal forest and tundra (Fig. 1).
From the isotope data, we calculate that 70-90% of the N in the dominant trees and shrubs (birch, willow, ericoid shrubs) at the LTER site at Toolik Lake entered through the mycorrhizal pathway. Fungi, with up to 100 times more biomass than bacteria in the soil, are an important part of the decomposer food web in the tundra and boreal forest.

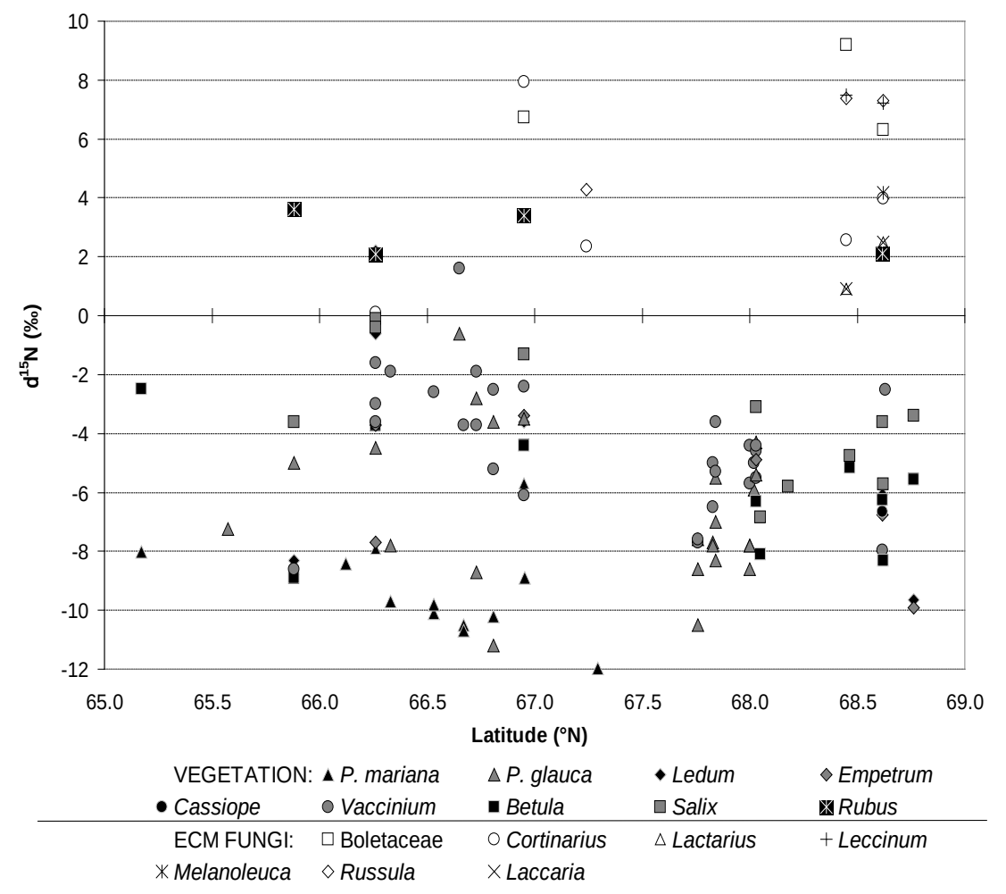
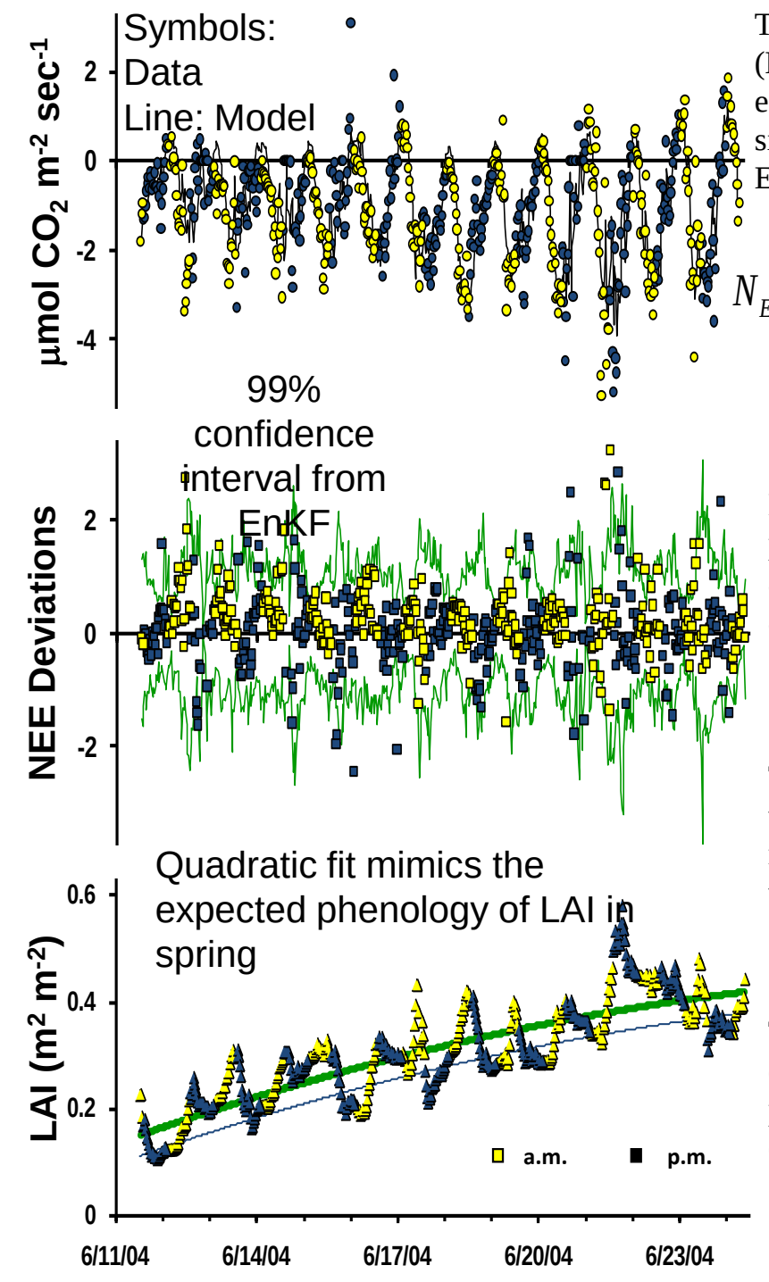


Figure 1. The δ^{15}N of foliage (bottom) and fruiting bodies (top) of mycorrhizal vegetation and fungi collected along a northern Alaska transect from south of the Yukon River (65.9ºN) to beyond Toolik Lake (68.4ºN). The extremes are bolete mushrooms (*Leccinum*) and black spruce (*Picea mariana*). Figure from Hobbie et al. (2009) in CJM.

Figure 2. An eddy flux tower in a field of flowering *Eriophorum* tussocks, North Slope, Alaska.



The Ensemble Kalman Filter (EnKF) was used to assimilate eddy covariance data into a simple model of ecosystem Net Ecosystem Production:

$$N_{EP}=\frac{P_{max}}{k}\ln\left(\frac{P_{max}+E_oI}{P_{max}+E_oI\,e^{-kL}}\right)-\left(R_0+R_XLQ_{10}^{T/10}\right)$$

Model tends to under predict photosynthesis in the morning and over predict it in the afternoon

To compensate, the EnKF tends to increase LAI estimates in the morning and decreases them in the afternoon

This dynamic is indicative of a deficiency in the model, perhaps afternoon stomatal closure or carbohydrate buildup

Figure 3. Results and interpretations of modeling NEE (net ecosystem exchange) data from Toolik, Alaska.

Eddy flux towers (Fig. 2) give continuous data on the exchange of CO_2 and water vapor between the land surface (vegetation and soils) and the atmosphere. Signal processing software can be used to remove random noise from the data and to estimate confidence limits. In this case (Fig. 3), a simple model of arctic net ecosystem production (NEP) was embedded in the Ensemble Kalman filter (EnKF) and used to filter data from an eddy flux tower at the Arctic LTER. The EnKF was also used to estimate the leaf area index (LAI) in the tower footprint. The diel pattern in the LAI estimates is an indication of a deficiency in the model, probably associated with unrepresented processes in the model like stomatal closure or carbohydrate buildup in the afternoon.

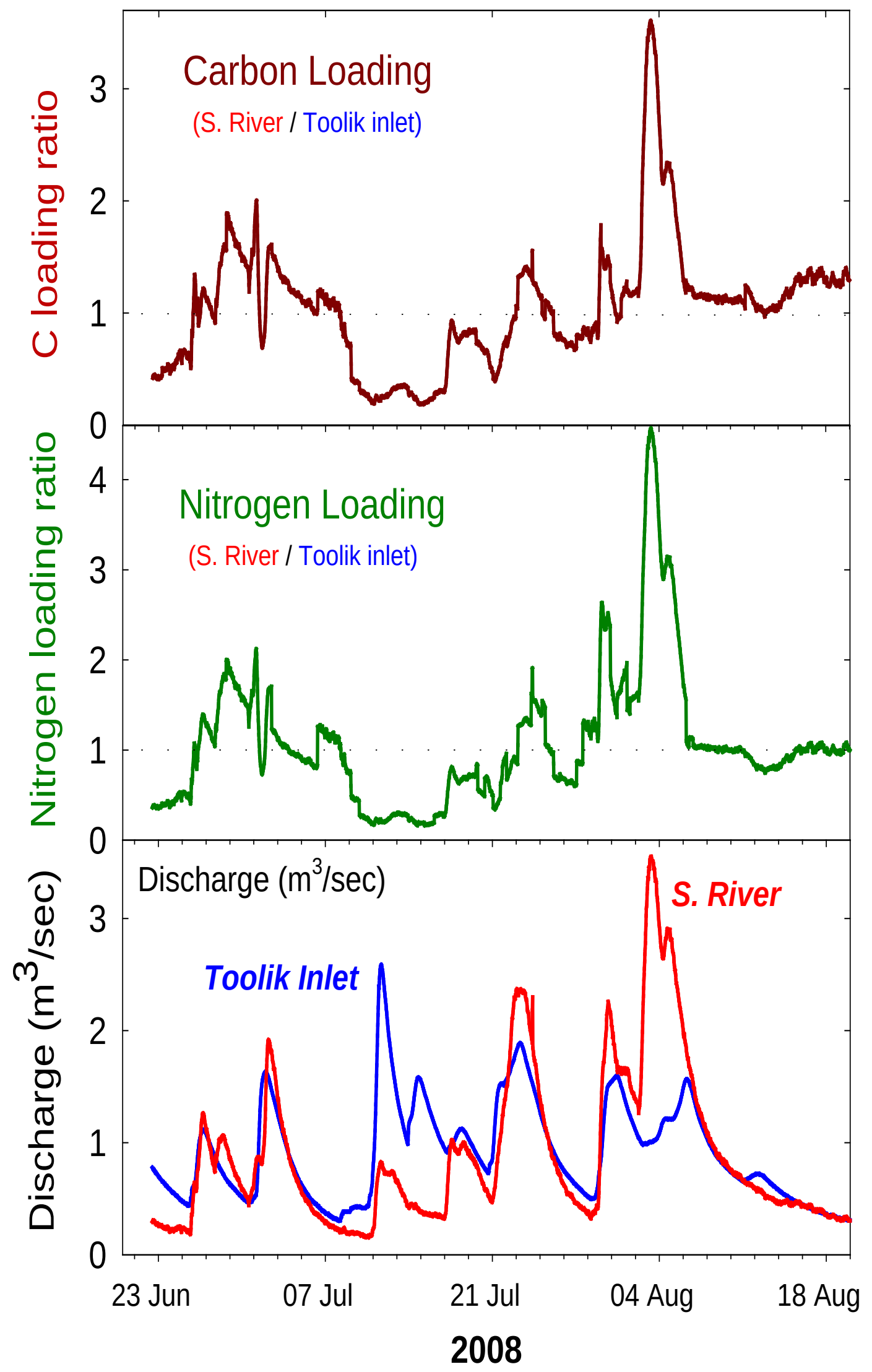
LAND-WATER INTERACTIONS

Slow, steady changes (e.g., climate) and rapid disturbances (e.g., fires and thermokarst failures) have the potential to alter amounts of materials generated on land and exported to surface waters;

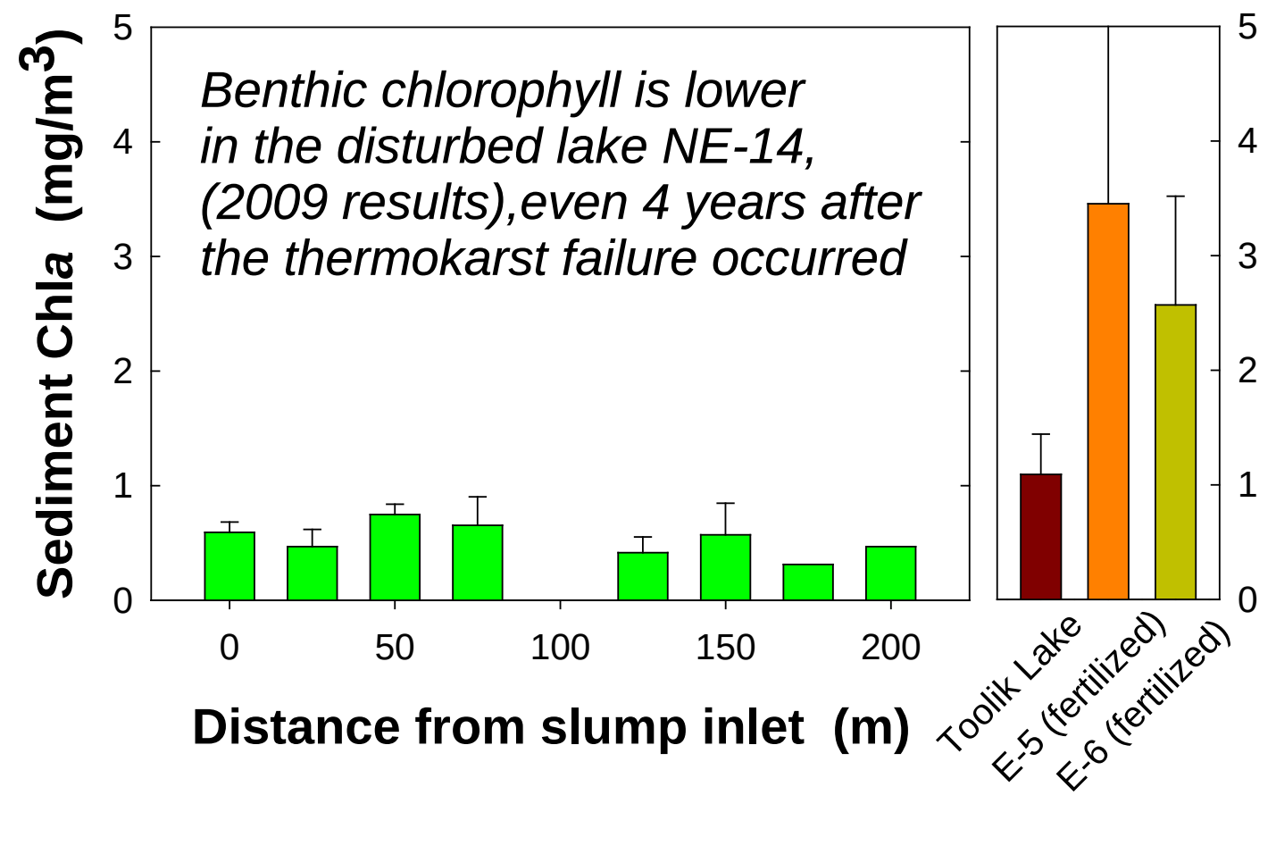
Main Results:

1. Steady, long-term (0 year) doubling of alkalinity has occurred in Toolik Lake. Upland thaw depth has not changed, but deeper thaw and weathering of carbonate materials under streams and lakes has increased *(see associated poster).*

2. A huge fire burned 1000 km² of tundra in late 2007. The following summer, streams in burned catchments exported more C and N than control streams when discharge was equal (*ratios of burned to unburned export >1).*



3. Clay-rich sediment input from a thermokarst slump covered the bottom of Lake NE-14 and reduced benthic chl*a* concentrations compared to nearby lakes.



Chlorophyll data from Tracy Coolidge, Jason Dobkowski, Jen Kostrzewski, and Cody Johnson

STREAMS

The long-term database for the streams monitoring initiative within the Arctic LTER program began in 1983 giving us a 25+ year perspective on the behavior of streams in the vicinity of the Toolik Field Station, especially the Kuparuk River. The Kuparuk River is also the subject of the longest intentional stream fertilization experiment in the Arctic. The monitoring and manipulative experimental data provide a unique perspective on the long-term dynamics of nutrient loading in these oligotrophic ecosystems that are now undergoing rapid changes due to climate warming. Several trends we have observed in these data would not have been evident without long-term monitoring.

Nitrate is the major form of inorganic N and is utilizable by the biota. The concentration of dissolved organic N (DON) is larger, but this fraction is more recalcitrant. Dissolved inorganic P is nearly undetectable; but we can measure total dissolved P (TDP) more reliably. Over the years in which we have monitored, the ratio of nitrate to TDP has increased significantly, largely due to an increase in nitrate rather than a decrease in TDP. We do not yet know why this change has occurred, but the potential influences of this change in nutrient stoichiometry may be important to the stream biota.

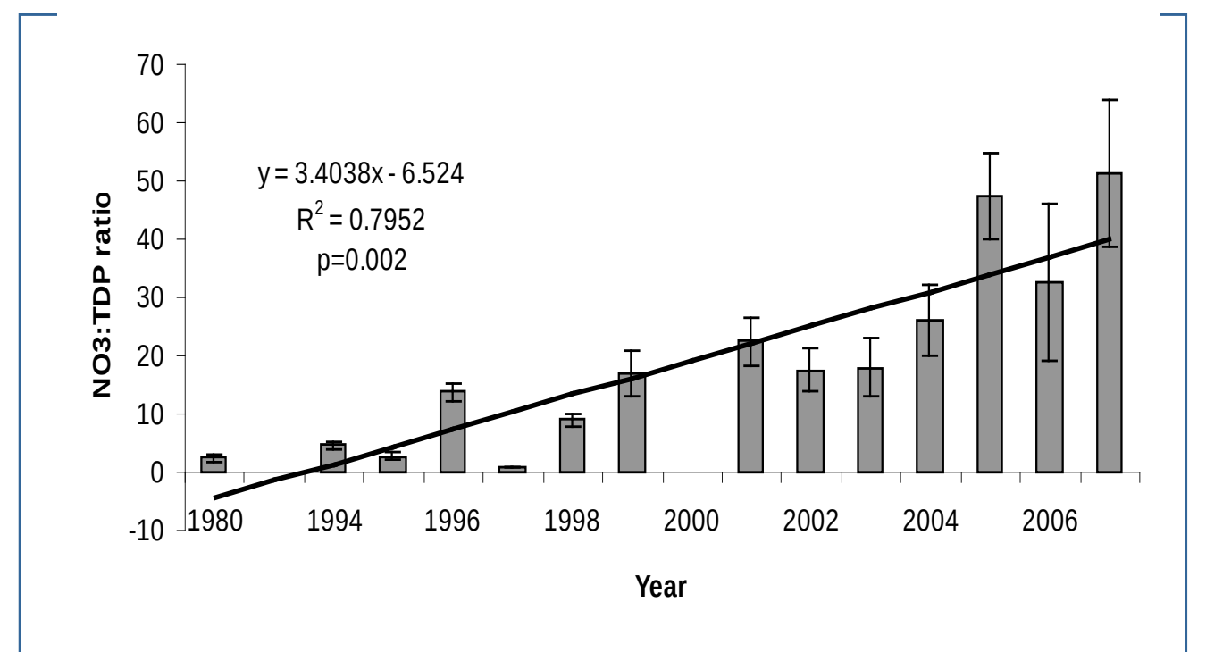


Figure 1. The ratio of mean annual nitrate to total dissolved phosphorus in the Kuparuk River from 1980 to 2007.

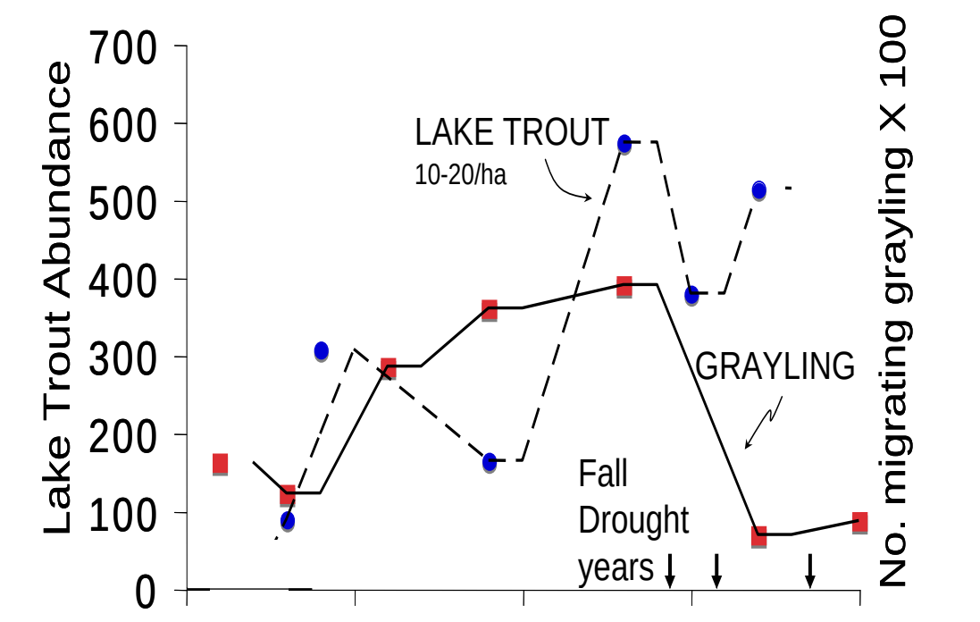


Figure 2. Arctic Grayling and Lake Trout abundances in the Kuparuk River and an overwintering headwater lake.

Grayling spend the brief Arctic summer eating insects in rivers and then migrate to deep lakes to overwinter before the rivers freeze solid. These lakes also support lake trout that can eat the grayling. In the Kuparuk River, grayling were very abundant thoughout the 1980's and 1990's. However, recent droughts during the crucial fall migration have reduced the number of fish reaching the overwintering lake, resulting in a population decline to historic lows
(Fig. 2). After 1999, lake trout became less abundant (and were less healthy), suggesting that the Arctic grayling migration provides an important trophic subsidy to the lake trout, a subsidy that might be affected by climate change.

Historic data confirm that that the Arctic warmed significantly in the later half of the 1900's. Model predictions suggest that by 2100 annual average temperatures in the Alaskan Arctic may warm further by 7ºC or more. Currently most of the Alaskan North Slope lies in a region of continuous permafrost (permanently frozen soil). Existing data document that this permafrost is getting warmer and if annual temperatures warm as much as projected, the upper layers may thaw. The effects of such a thaw are unknown. We have documented that thermokarst features (physical subsidence and mass failure of hillslopes due to thawed permafrost) have increased significantly in two areas that we have documented carefully: the Toolik Lake Region and the western Noatak Basin. Research is underway now to quantify how thermokarst features affect ecosystem and landscape processes in the Arctic. We plan to incorporate this important dynamic into the future research plans for the Arctic LTER program.

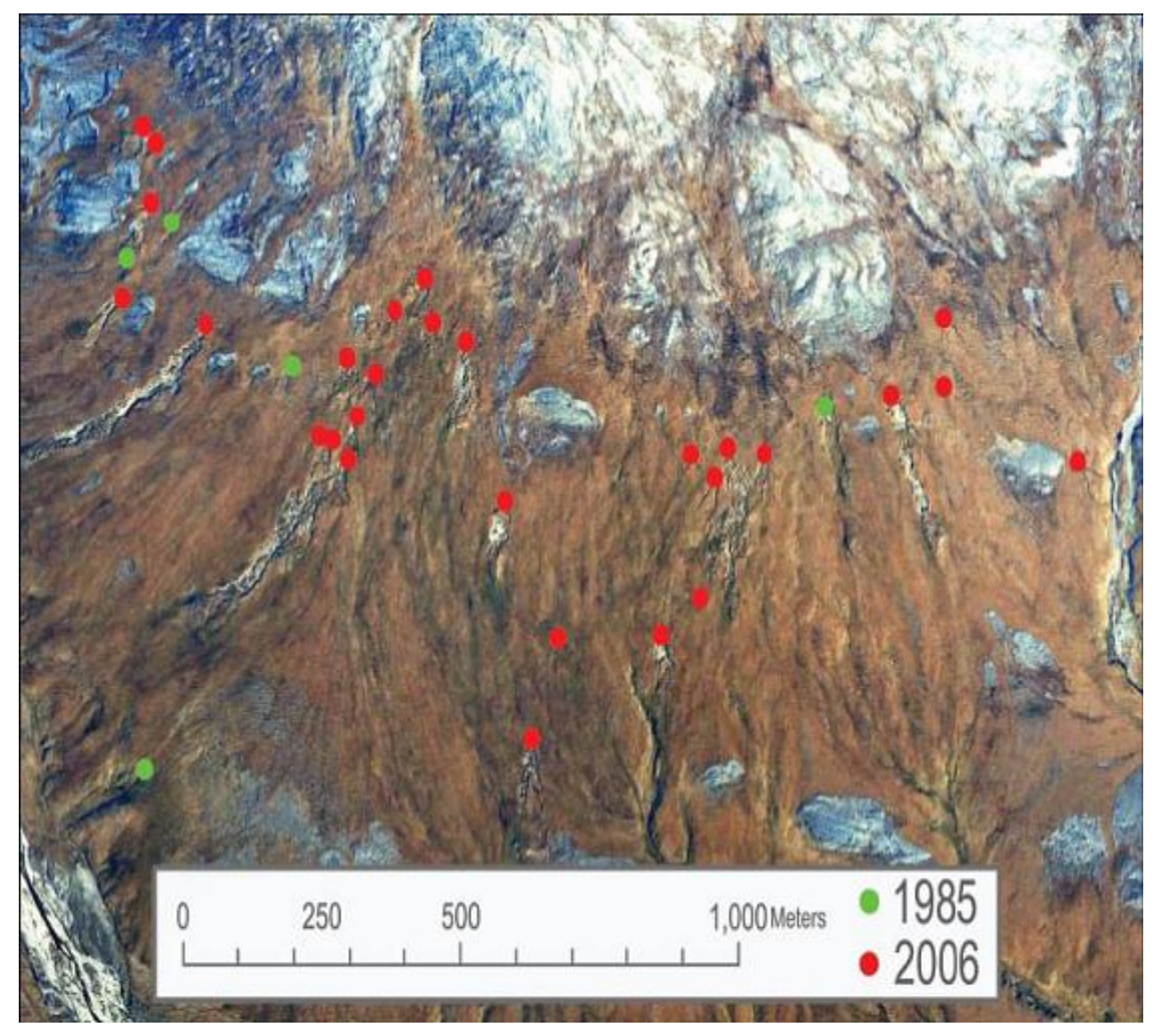
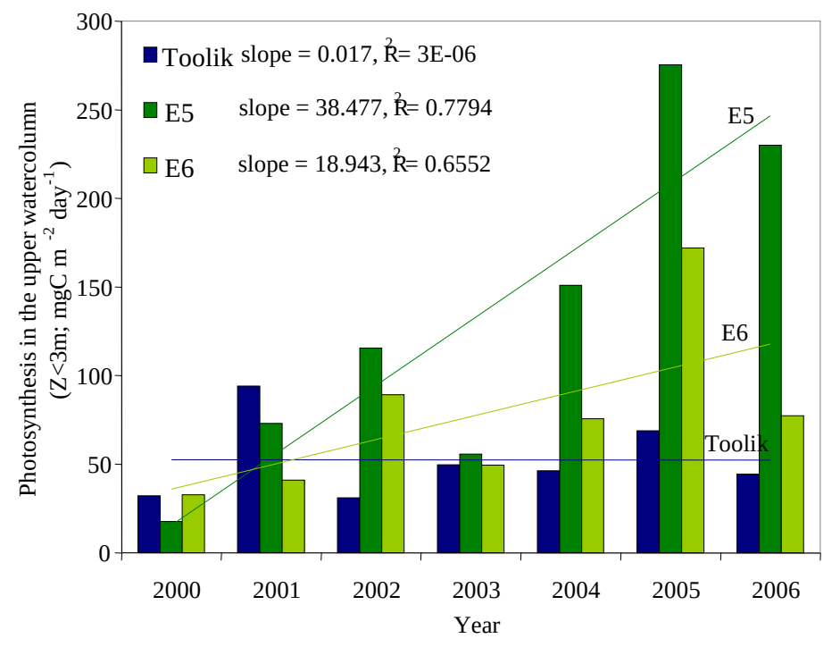


Figure 3. Aerial photo of a site near Feniak Lake in the Noatak National Park (about 360 km west of the Toolik Lake region), taken in September 2006, showing 28 new thermokarst failures since 1985 (red dots) when only 5 such features were identified (green dots). Taken from Gooseff et al. (2009) EOS 90(4):29-30 (27 January).

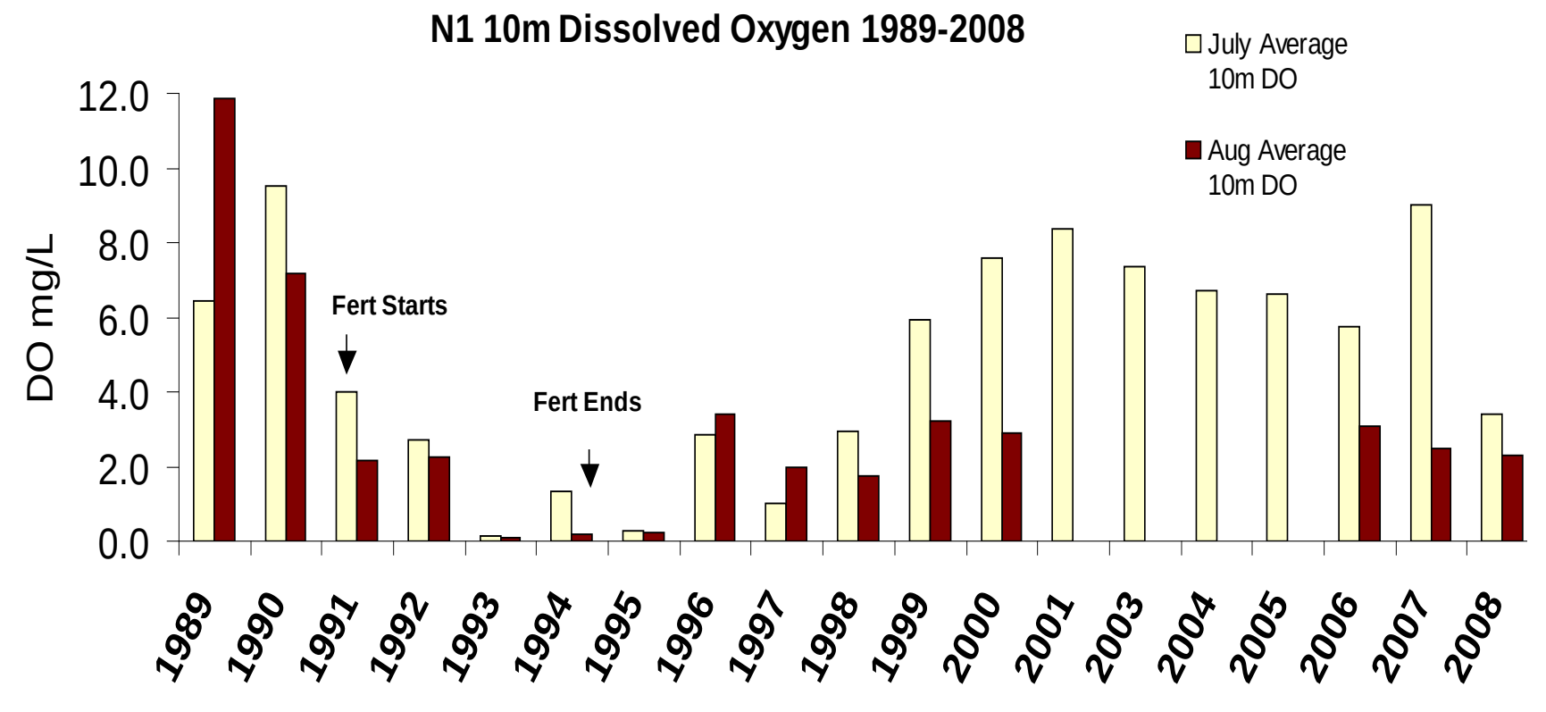
LAKES

Research on Lakes near the Toolik Field Station focuses on physical dynamics of lake mixing, the effect of nutrient additions on lake food webs, the recovery of lakes from eutrophication, and the impact of organisms on lake biogeochemistry through their feeding and movement patterns. We present results from recent studies on nutrient additions, recovery from fertilization, and fish migration.

Addition of 2X ambient loadings of N and P to a shallow (E6) and a deep lake (E5) greatly increased primary productivity. No subsequent increase in secondary production has been observed. Inter-annual differences in water temperatures reduce the ability of zooplankton to respond to increases in food availability.



Lake N1 was fertilized for 4 years beginning in 1991. In response to the fertilization the lake showed a large increase in pelagic primary production, pelagic chlorophyll concentrations, and a large decrease in hypolimnetic oxygen concentrations. Within two years after fertilization had ceased primary production and pelagic chlorophyll values had returned to pre-fertilization levels. Hypolimnetic oxygen values did not rebound as quickly and oxygen levels in late summer are still depressed 14 years after fertilization has ceased.



We take advantage of an ^{15}N addition to a deep lake (NE12) to follow ^{15}N labeled grayling as they move across the landscape. Grayling over-winter in deep lakes but frequently migrate to shallow lakes (GTH 156) in summer to feed on abundant zooplankton populations. Grayling that migrate to shallow lakes in summer exhibit higher growth rates. We are currently investigating how migration patterns impact fitness of grayling across the landscape of lakes, ponds, and streams.