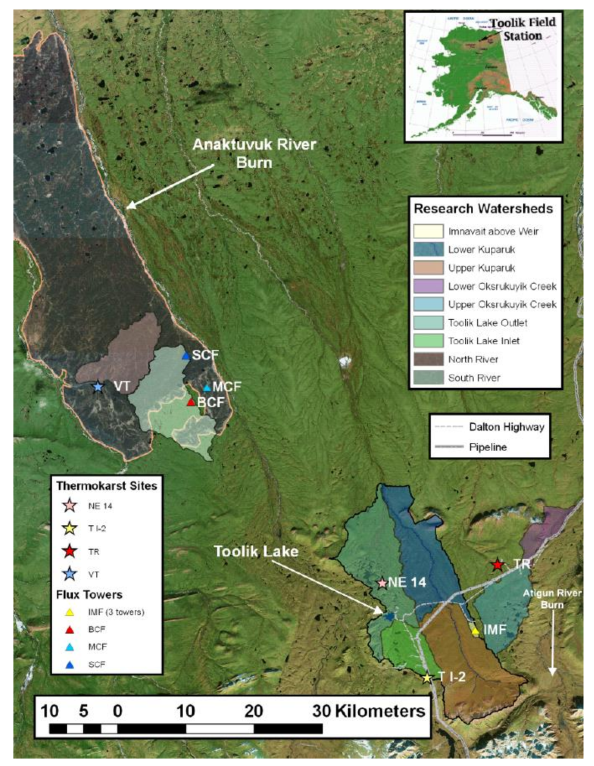
ARCTIC LTER: CLIMATE CHANGE AND CHANGING DISTURBANCE REGIMES IN AN ARCTIC LANDSCAPE

ABSTRACT

The Arctic region has warmed significantly over the past 30 years and arctic lands and freshwaters are already changing in response. The changes include a general "greening" of the arctic landscape, changes in species distributions and abundance, changes in food webs, and changes in geophysical and biogeochemical processes and cycles at local and regional scales. Many of these responses to warming are limited or regulated by low inputs, turnover, and availability of essential elements like N and P, and thus one of the main research needs is to predict the effects of arctic warming on N and P cycles and their interactions with species composition and with the C cycle. This need has been met in recent decades by experimental manipulations of whole terrestrial, lake, and stream ecosystems, by long-term monitoring in relation to climate, and by comparisons among climatically different arctic sites. Increasingly, however, it is apparent that climatic warming in the Arctic is accompanied by dramatic changes in large-area disturbances, especially disturbances related to thawing of permafrost and a surprising increase in wildfire. These large-area disturbances also interact with N and P cycles, producing much more dramatic and rapid changes in ecosystems and element cycles than in response to warming alone. In the long term, warming-related changes in disturbance regime may be more important than the direct effects of warming alone on terrestrial and freshwater communities, ecosystems, and the entire Arctic.



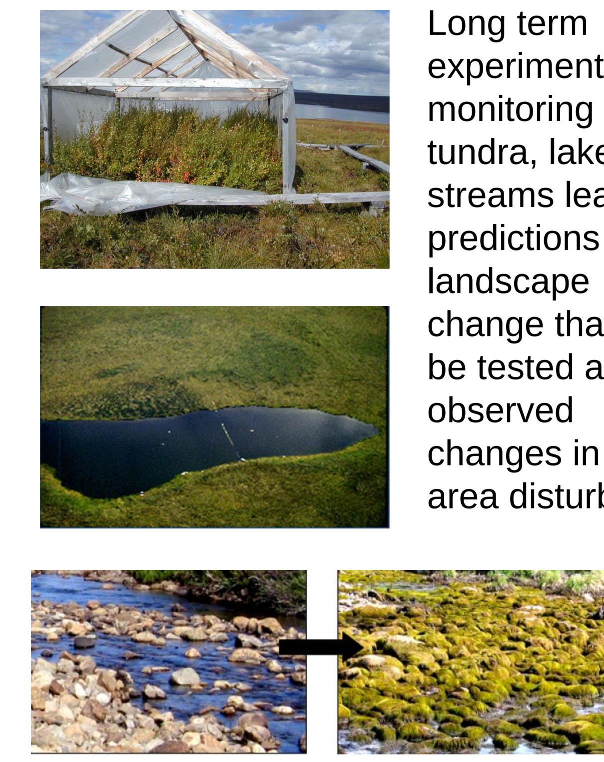
LOCATION

Toolik Field Station is at 68ºN, in northern foothills of the Brooks Range, Alaska. The site lies in formerly-glaciated rolling hills and includes an array of tundra ecosystems, streams, and oligotrophic lakes up to 20 m depth

CLIMATE

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

Precipitation 200-300 mm



Long term experiments and monitoring in tundra, lakes and streams lead to predictions of landscape change that can be tested against observed changes in large-area disturbances

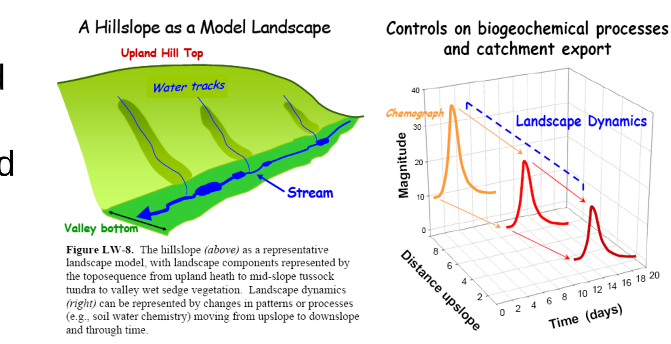


Figure LW-8. The hillslope *(above)* as a representative landscape model, with landscape components represented by the toposequence from upland heath to mid-slope tussock tundra to valley wet sedge vegetation. Landscape dynamics *(right)* can be represented by changes in patterns or processes (e.g., soil water chemistry) moving from upslope to downslope and through time.

Fig 2-4. Disturbances create patches of dramatically different biogeochemistry and environmental conditions that can dominate the C or energy balance and community dynamics of much larger areas. LEFT: 1000 km^2 Anaktuvuk River Burn (arrow) adjacent to the 9200 km^2 Kuparuk River watershed. CENTER: <1 ha thermokarst (arrow) on the shore of 25 ha Lake NE-14. RIGHT: Extreme low water in the Kuparuk River caused by occasional drought blocks fish migration to headwater lakes 10 km away.

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TERRESTRIAL RESEARCH

Mammalian herbivores have many impacts on tundra in addition to the direct effects of herbivory, with small mammals, particularly voles, creating haypiles, trails, and latrines that alter the distribution of plant matter and nutrients. These effects differ across plant communities. In moist acidic tundra (MAT), the presence of herbivores increased productivity and decreased species richness under both ambient and fertilized conditions, while in dry heath (DH) herbivores negatively affected productivity when nutrients were added (Figs. 1, 2).

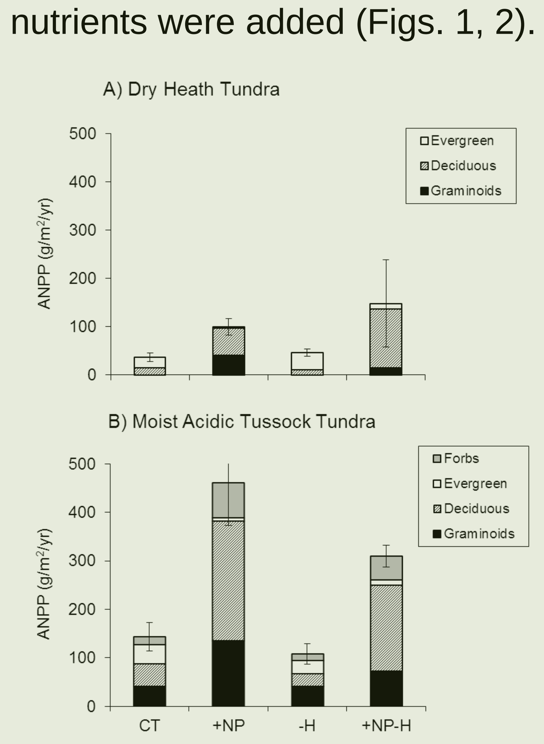


Figure 1. Aboveground net primary productivity (ANPP) after 10 years of manipulation: CT=control, +NP=annual N&P fertilization, -H=mammals excluded. (Gough et al. 2012).

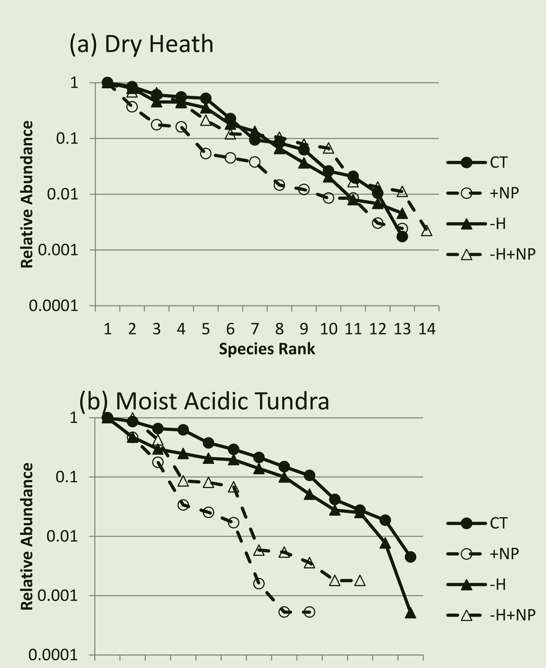
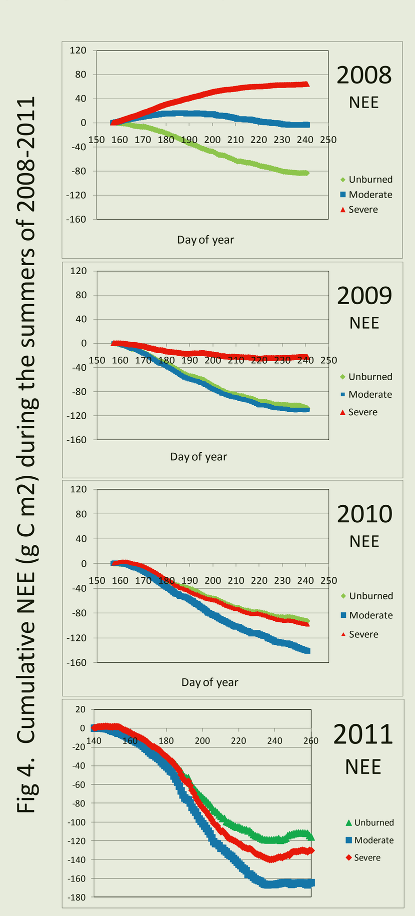
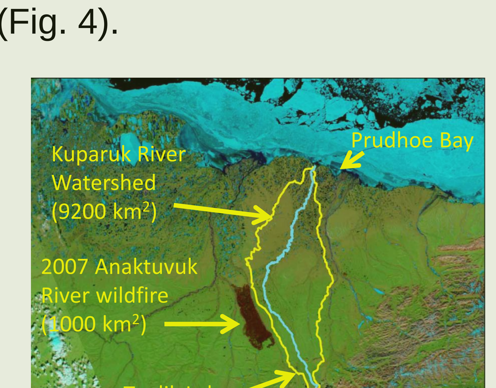


Figure 2. Vascular plant rank-abundance curves after 10 years of manipulation: CT=control, +NP=annual N&P fertilization, -H=mammals excluded. (Johnson and Gough, in revision).



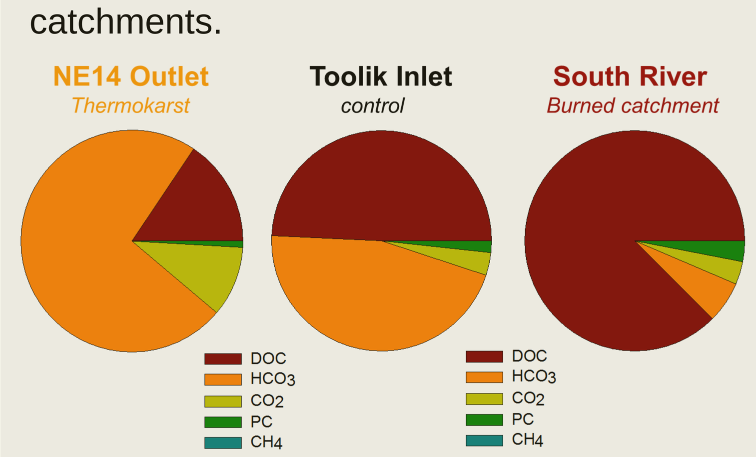
Wildfire is a novel disturbance in Northern Alaska, increasing in importance. In 2007, the Anaktuvuk River wildfire burned over 1000 km^2 about 40 km N of Toolik Lake (Fig 3), releasing >2 Tg of C to the atmosphere. In succeeding years the slow regrowth of the vegetation has caused the burned area to be first a major net source of C to the atmosphere (in 2008) but by 2011 the burned areas were sequestering more C than the unburned tundra (Fig. 4).

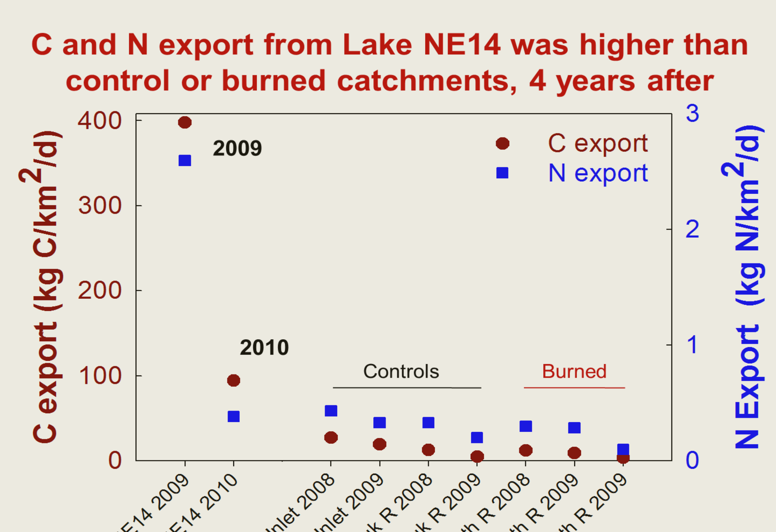


LAND-WATER INTERACTIONS RESEARCH

Rapid disturbances (e.g., fires and thermokarst failures) are increasingly affecting the character and amounts of materials generated on land and exported to surface waters.

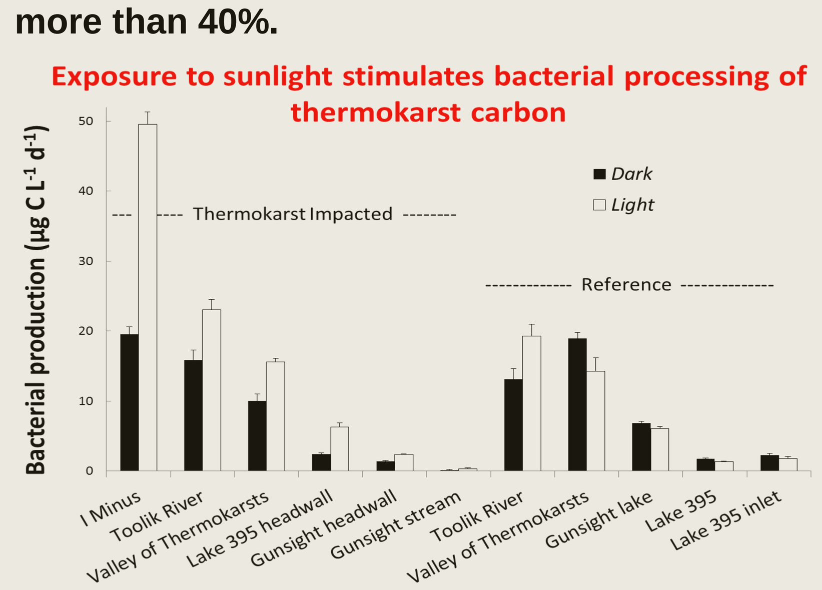
1. Disturbance type alters the carbon species and export from aquatic ecosystems. Thermokarst failures export predominately mineral forms of carbon (DIC), burned catchments are dominated by organic forms (DOC), and undisturbed catchments export equal amounts of DIC and DOC. Downstream processing will be dependent on the forms of carbon moved from land to water. Carbon and nitrogen export is much higher from thermokarst-affected systems than from either control or burned catchments.





Above – Lake NE-14 changed color due to the mineral inputs from a thermokarst failure. Inputs from the failure to the lake also affected the C species and the C and N export from the lake.

2. Previously frozen soil C released from thermokarst failures is labile to bacteria, and exposure to light amplifies this lability by more than 40%.

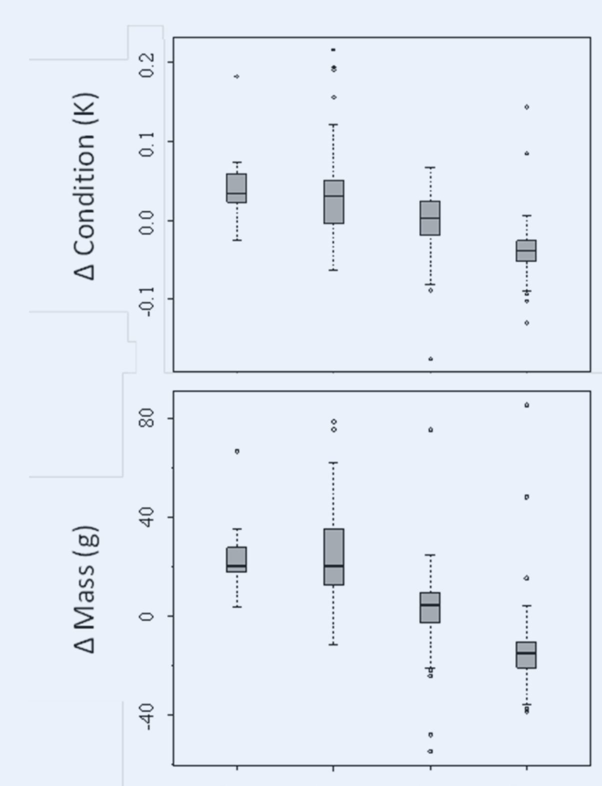


Left -- In thermokarst impacted sites, water exposed to natural sunlight (UV) stimulated bacterial activity and DOM processing by 47%, while in the reference lakes and streams sunlight decreased bacterial activity by 14%.

DATA FROM ROSE CORY AND BYRON CRUMP.

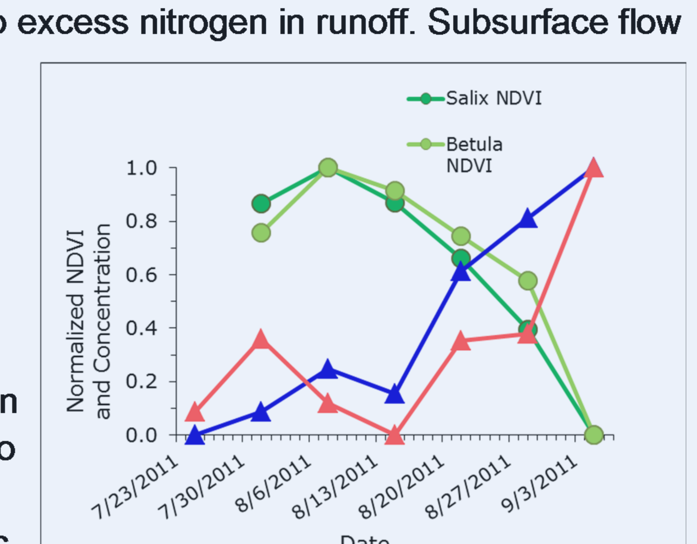
STREAMS RESEARCH

Warming of the arctic is increasing the duration of the "flowing water" season, but the duration and periodicity of sunlight is not changing. This asynchronous change in key physical drivers is having unexpected influences on the chemistry and biology of stream ecosystems:



1.) The warming climate has caused unusual, late-season droughts that may significantly reduce the health of migrating Arctic grayling. The condition (upper) and mass (lower) of Arctic grayling in the upper Kuparuk River during a drought in 2011 that caused an important reach of the river to go dry (hyporheic). This dry reach isolated fish in the river and limited their ability to feed effectively. An increase in frequency or duration of late-season droughts could threaten the viability of this important fish population.

2.) There is an apparent "seasonal asynchrony" in nitrogen production and uptake that causes dissolved inorganic nitrogen concentrations and fluxes to increase during the early fall. Ammonium and nitrate concentrations (normalized to the maximum observed) increase after plants become dormant (indicated by a decrease in NDVI, also normalized to the maximum value in the summer). The flush of nutrients in the fall may occur for several reasons. Microbial production of nitrogen may continue long after plant demand ceases, leading to excess nitrogen in runoff. Subsurface flow may leach deeper soil horizons later in the field season. Or organic matter from terrestrial sources might be processed within the stream channel. The likelihood of these alternatives is poorly known and must be understood to predict the influences of future warming in the arctic.



LAKES RESEARCH

The Arctic landscape is littered with thousands of lakes that arose after a series of Pleistocene glaciations and show surprising variation in water chemistry, lake type and physical processes. Biogeochemical processes are driven by a 9 month period of ice cover, with 24 hours of sunlight during the short ice- free period. These lakes are nutrient-poor, with low biological productivity and low species diversity. Consequently the lake ecosystems are particularly sensitive to environmental change, either directly from the effects of a warmer climate or indirectly from disturbances linked to climate change.

In addition to long-term monitoring of sentinel lakes, we study the effects of whole-lake nutrient enrichment experiments to evaluate different pathways of energetic transfer and to determine whether whole lake responses to nutrient additions differ between deep, stratified lakes and shallow, unstratified lakes (Fig 3.). Here, we show results only for the deep lake component of the experiment.

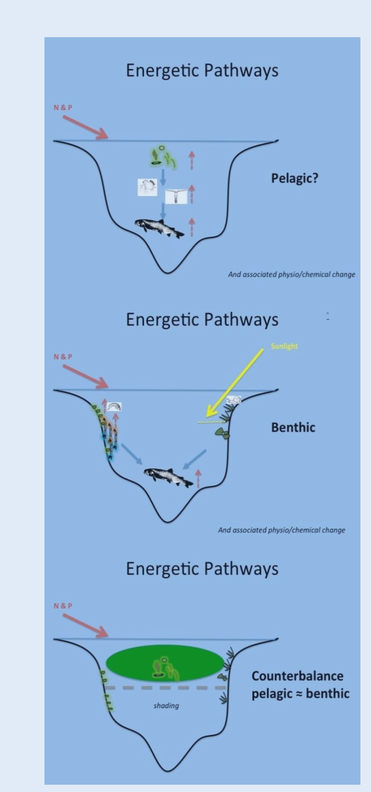
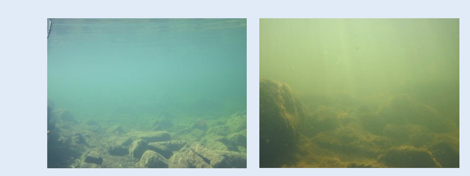


Figure 3. Energetic pathways whereby enrichment can enter and stimulate the food web and lake ecosystem productivity.



During the experiment, we observed significant increases in primary, secondary, and tertiary productivity in the enriched deep lake relative, to the control deep lake (Fig 4). Enrichment first stimulated primary production but did not appear to have a measurable effect on higher trophic levels until the 8-9[th] year of the study, after which secondary productivity increased dramatically. Increases in primary productivity resulted in concordant decreases in hypolimnetic oxygen and reduced water transparency.

Continued stimulation of epilimnetic phytoplankton now appears to be shading the benthos; however, based on stable isotope analyses of the food web, there is considerable inter-annual recycling of ^{15}N in the deep pelagia.

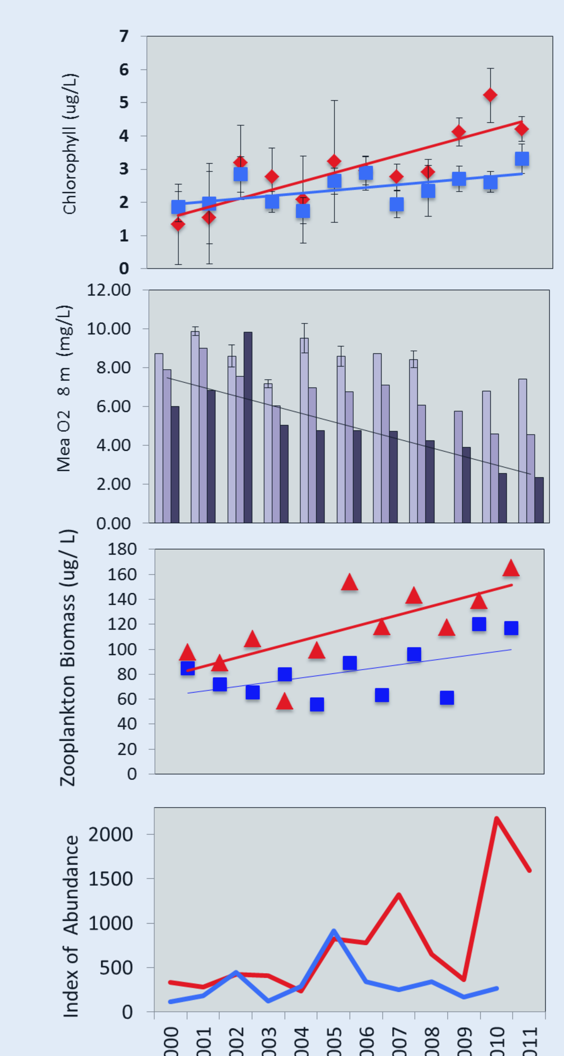


Figure 4. Results of enrichment at several trophic levels; from top to bottom: epilimnetic chlorophyll a, hypolimnetic oxygen, zooplankton biomass, and fish abundance. In all line graphs, the enriched lake is shown in red relative to the control lake in blue. Bar graph shows h. oxygen in June (lightest shade), July, (medium shade), and August (darkest shade).