Algal blooms in the alpine – coupled effects of chronic nitrogen deposition and climate change on alpine lakes

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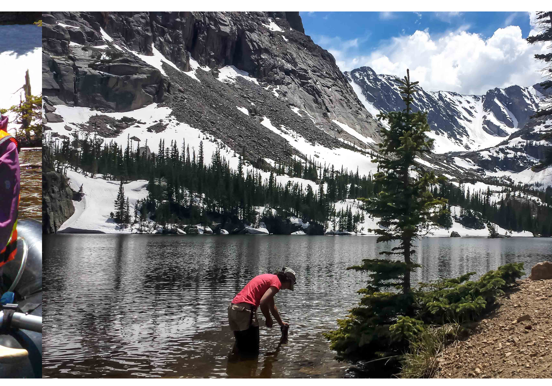
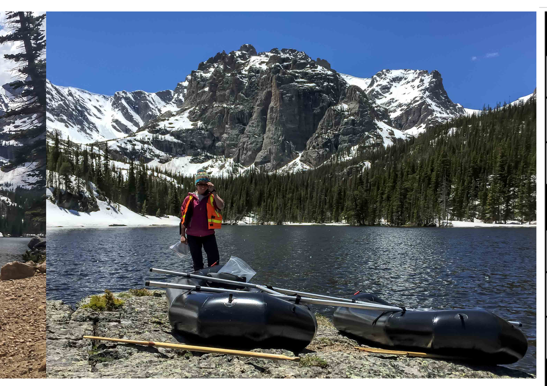
Abstract: Visible green algal and cyanobacteria growth is beginning to be reported from oligotrophic lakes in the United States without a history of algal blooms. Locally, mats of the green alga Zygnema spp. have been observed in The Loch and Sky Pond, sub-alpine and alpine lakes, respectively, in the Loch Vale Watershed (LVWS), Rocky Mountain National Park. These algal mats have not been observed prior to 2010 in this long-term monitoring and research site. *Zygnema spp.* are common green algae in waters rich in nutrients, and Loch Vale watershed has received chronic nitrogen (N) deposition since the mid-20th century. The fact that the algal mats are only recently observed suggests some other forcing factor is facilitating attached algal growth. In addition to continued high N deposition lake water temperatures have increased steadily in response to summer warming since the 1980s. For Loch Vale watershed, we hypothesize that chronic N deposition in conjunction with warming may be causing algal productivity to increase. A more global hypothesis is that lakes that were heretofore oligotrophic and characterized by very low nutrient waters may be transitioning to a different trophic state induced by changing climatic drivers and a legacy of nitrogen deposition. We present the results of our first season of data collection as well as outline future directions for the research project.

Summer 2015 Questions

1: Is there a pattern in spatial distribution of benthic algal growth in the Loch and Sky Pond?

2: What abiotic factors influence benthic algal growth in these lakes?

3: Did water chemistry influence phytoplankton growth in these lakes?

	NO_3^- (mg/L)	NH_4^+ (mg/L)	Total N (mg/L)	DOC (mg/L)	Total P (µg/L)
June					
The Loch	0.292 ± 0.065	0.063 ± 0.012	0.333 ± 0.107	1.589 ± 0.881	6.5 ± 1.633
Sky Pond	0.333 ± 0.084	0.053 ± 0.015	0.376 ± 0.082	0.529 ± 0.107	9.0 ± 1.095
July					
	NO_3^- (mg/L)	NH_4^+ (mg/L)	Total N (mg/L)	DOC (mg/L)	Total P (µg/L)
The Loch	0.151 ± 0.030	0.041 ± 0.004	0.219 ± 0.031	0.741 ± 0.139	5.929 ± 1.439
Sky Pond	0.199 ± 0.068	0.042 ± 0.004	0.257 ± 0.069	0.369 ± 0.072	8.588 ± 1.734
August					
	NO_3^- (mg/L)	NH_4^+ (mg/L)	Total N (mg/L)	DOC (mg/L)	Total P (µg/L)
The Loch	0.110 ± 0.024	0.044 ± 0.000	0.168 ± 0.035	0.596 ± 0.076	6.800 ± 1.135
Sky Pond	0.152 ± 0.097	0.044 ± 0.000	0.201 ± 0.111	0.446 ± 0.126	8.688 ± 1.831

Table 1. Water chemistry summary table. Values displayed are monthly mean values (±σ) at each site (lake outlet, inlet, surface, and hypolimnion) during each month of sampling. Sky Pond is enriched in NO_3^-, Total N and Total P compared to The Loch, but is depleted in DOC. This illustrates that nutrient chemistry alone may not be driving productivity.

Background

- Cultural eutrophication afflicts many low elevation lakes (e.g., Hudon *et al.* 2014, Tapolczai *et al.* 2014, Kravtsova 2014), but is extremely rare in high elevation lakes
- Globally, lakes are already warming (O'Reilly et. al. 2015)
- LVWS long term record (30+ years) indicates increasing summer lake temperatures (*https://www.nrel.colostate.edu/projects/lvws/data.html*)
- Loch Vale watershed lakes appear to be undergoing a trophic shift from historically oligotrophic to mesotrophic conditions
- In spite of the abundant nitrate (NO_3^-), past experiments demonstrate N-limitation in these lakes

We hypothesize that a temperature threshold has been crossed, allowing the utilization of the previously inaccessible nitrate pool and proliferation of algae in a historically ultra-oligotrophic alpine lakes.

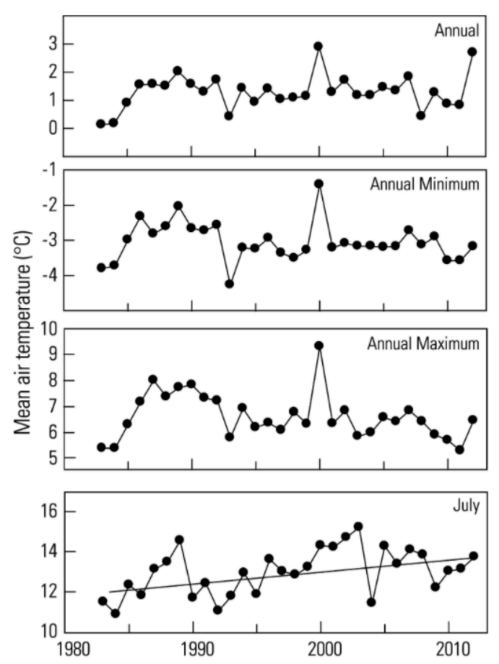


Figure 1. Our long term record indicates no trend in annual mean temperature. However, there is a significant increase in mean July air & Loch Lake outlet temperature (Mast et. al. 2014)

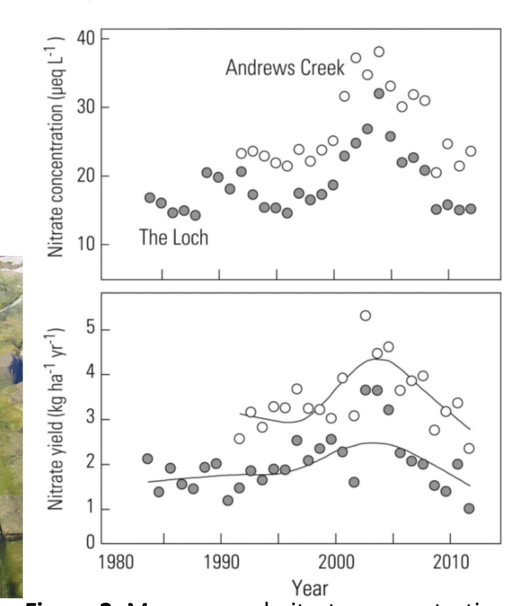


Figure 2. Mean annual nitrate concentrations and annual nitrate yields at Andrews Creek and The Loch outlet. Symbols are annual concentrations and yields, and lines are flow-normalized yields.

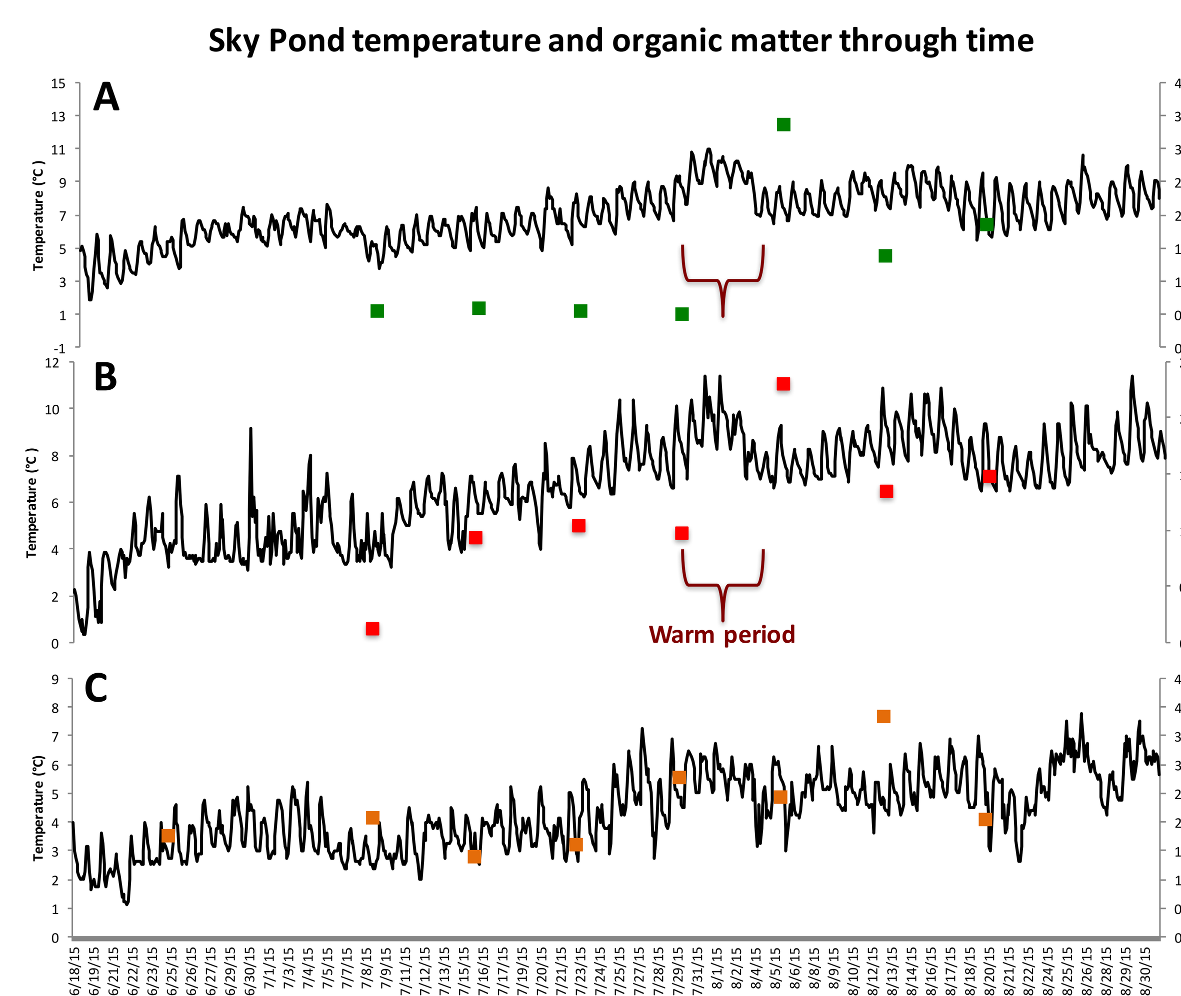


Figure 3. Continuous temperature and ash-free dry mass content of benthic algal mats at 3 different benthic sampling stations (A = SB2, B= SB3, C= SB5) in Sky Pond. We observed our first algal "bloom" of *Zygnema* spp. at sites SB2 and SB3 after a marked increase in lake temperature in late July.

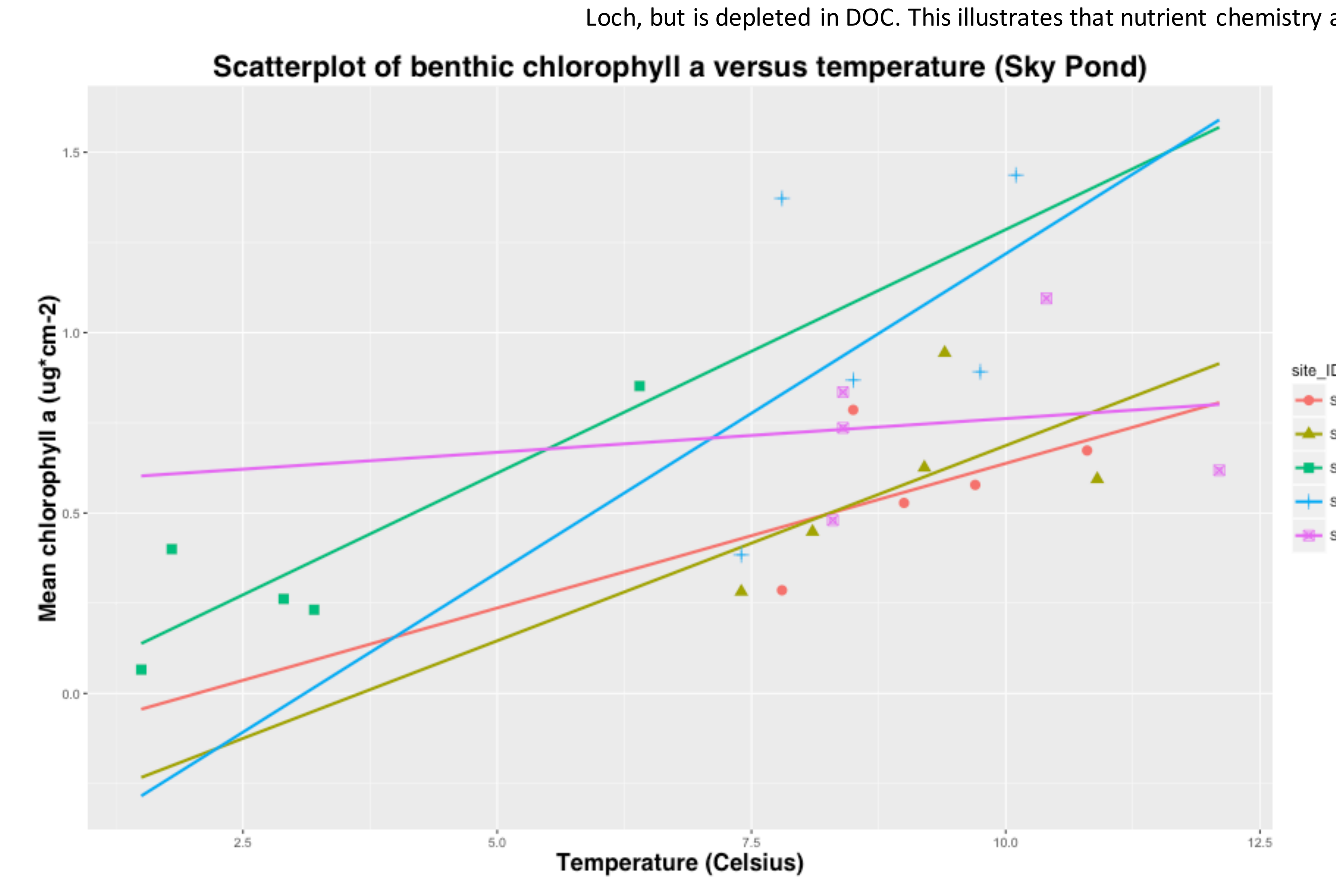
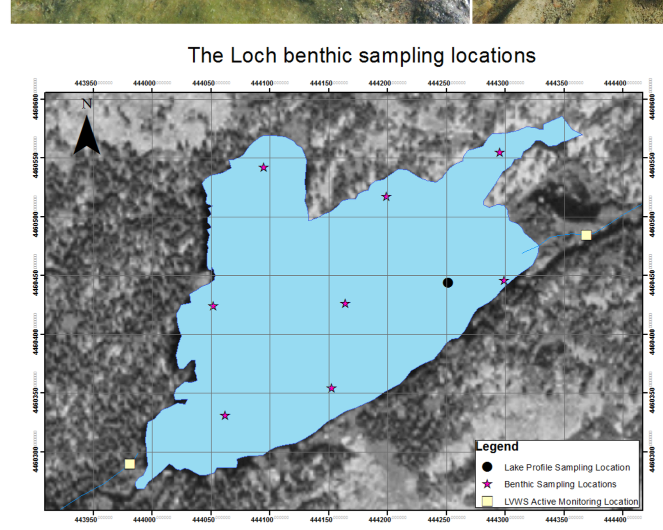


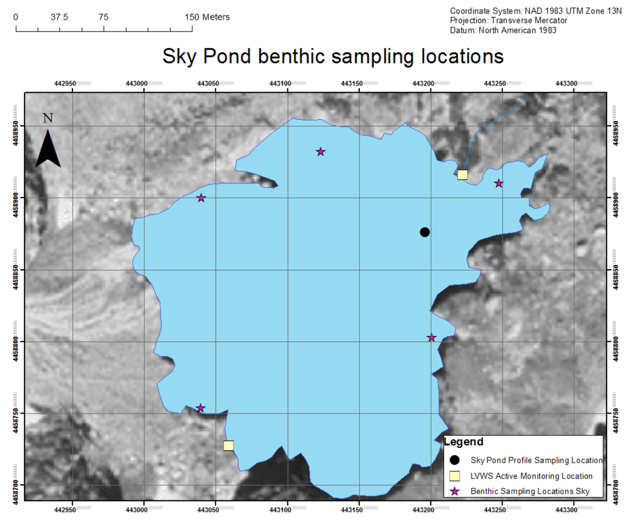
Figure 5. Plot of benthic chlorophyll vs. temperature at Sky Pond. Interestingly, SB5 (where, visually, we saw the least amount of benthic growth and did not see *Zygnema spp.* mats) does not show a positive correlation with temperature.

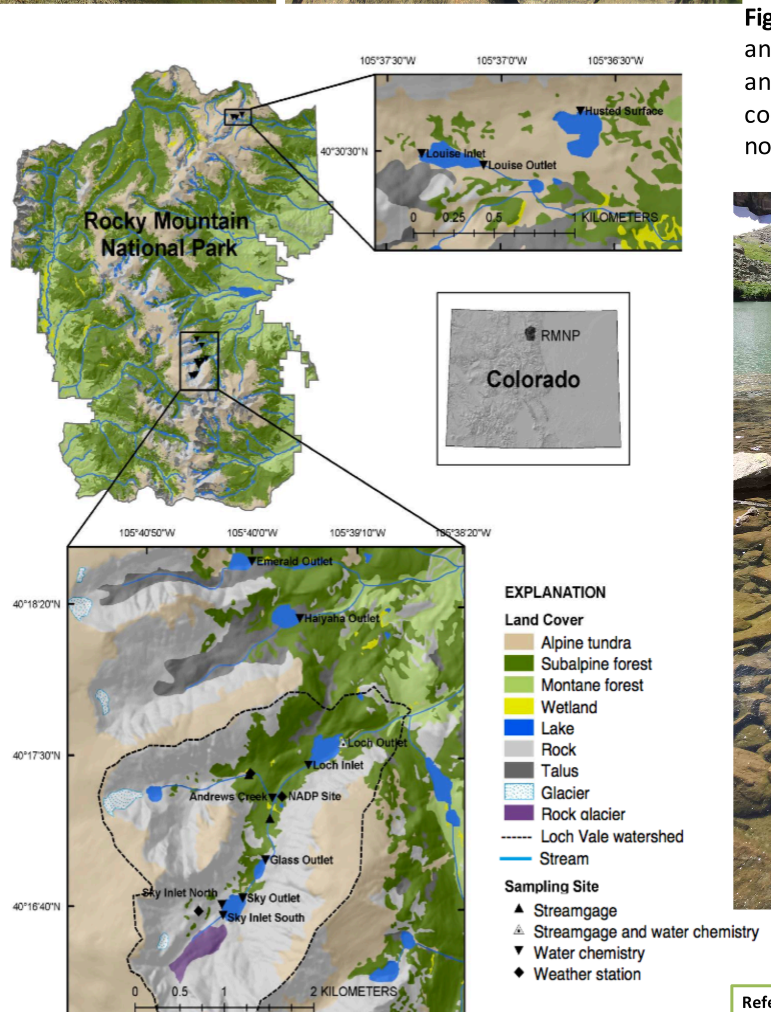
Across all sites, multiple R^2 = 0.3026 and **p-value: 0.004386.**

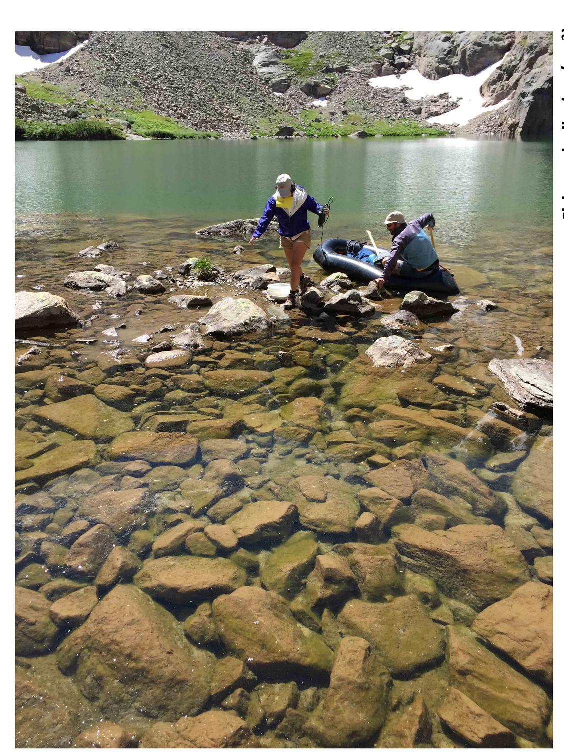
There was no relationship between either benthic chlorophyll vs. temperature or AFDM vs. temperature at the Loch.











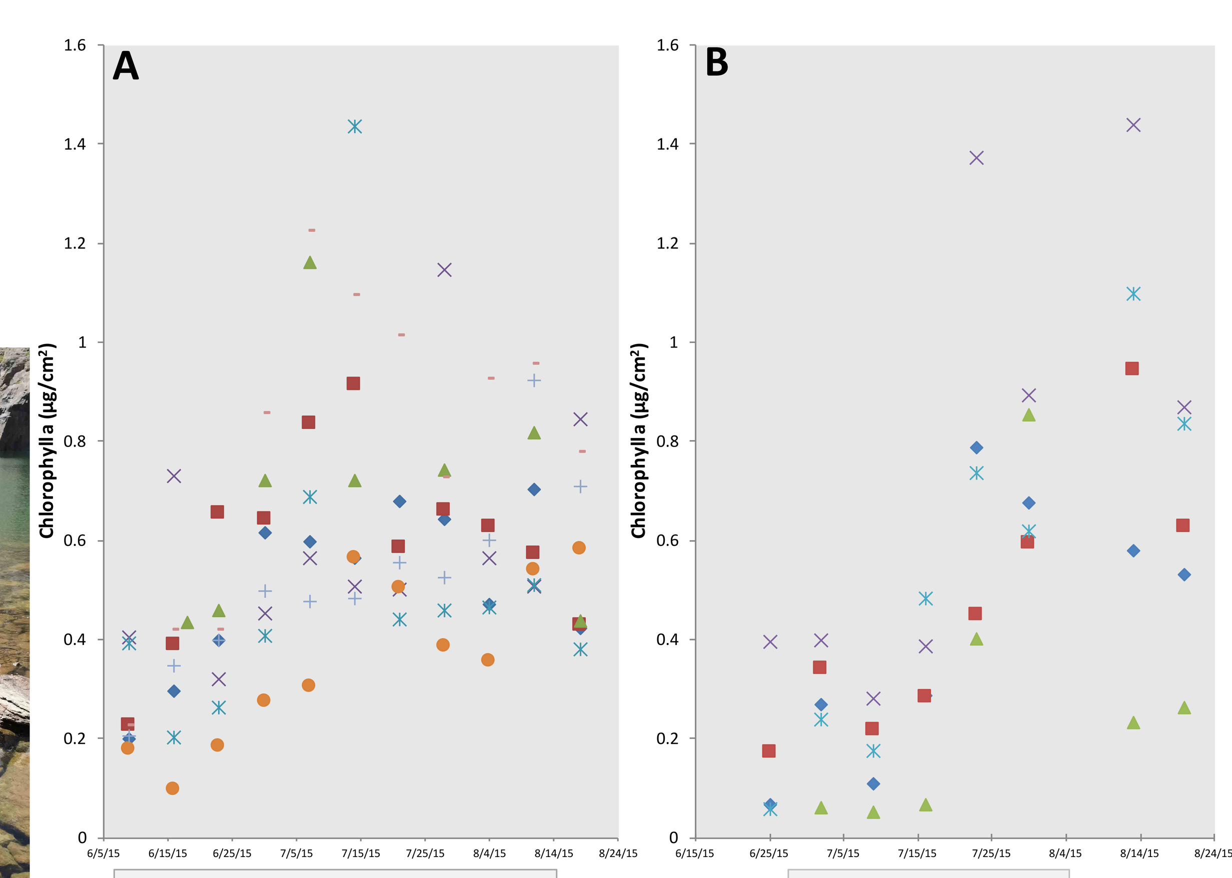


Figure 4 . Panels A & B show changes in benthic chlorophyll *a* (A) and benthic organic matter content (B) at each site in The Loch through time. The timing and peaks of benthic algal growth differed between lakes as well as between sites within each lake.

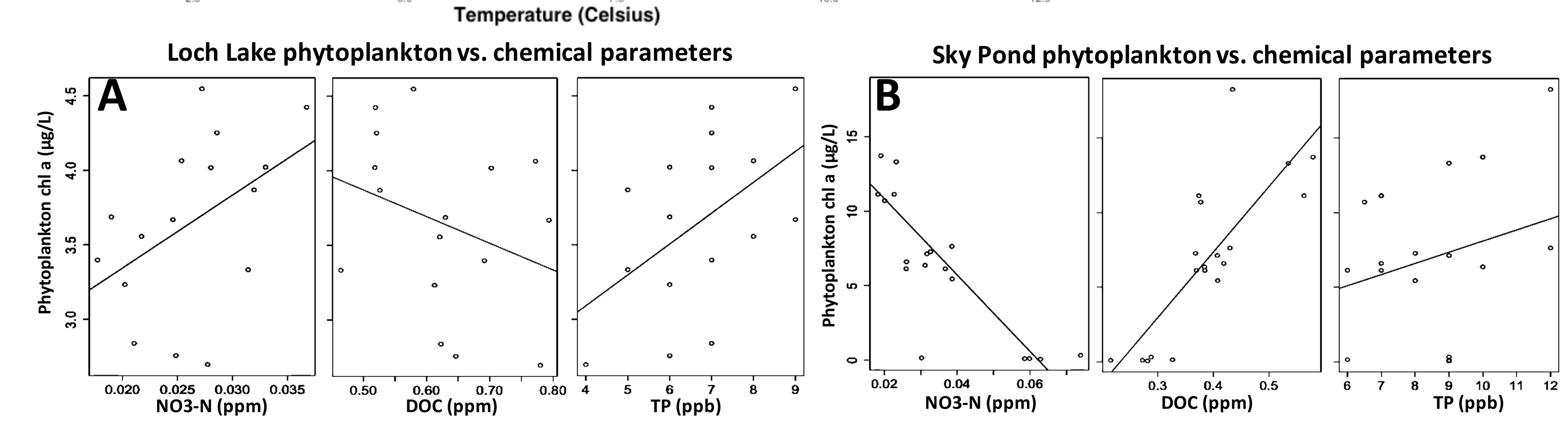


Figure 6. We used backward elimination to arrive at a final multiple linear regression model: if the interaction term was significant at p < 0.05, the lower order terms remained in the equation. In both Loch (panel 6A) and Sky Pond (panel 6B), NO3-N and total phosphorus were significant predictors of phytoplankton chlorophyll *a* (p-values < 0.01). The overall model fits were R^2 = 0.64 and R^2 = 0.82 in the Loch and Sky Pond, respectively.

Future Directions

After one season of intensive field sampling, it is abundantly clear that these lakes are dynamic and show marked differences between lakes (Sky vs. Loch) and a high degree of spatial heterogeneity within lakes. In the next year we will continue summer sampling, analyze sediment cores, and perform incubation experiments to answer the following scientific questions:

1: Are *Zygnema spp.* blooms a new occurrence in this basin or simply a new observation? Has primary production increased in the Loch in recent years?

2: What are the effects of FGA on alpine food webs and the transfer of N and P through the food chain?

3: How similar is benthic and phytoplankton productivity to other alpine lakes?

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