

Controls on Biomass:Nutrient Ratios in Streams and Rivers

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Introduction

Nutrients (N or P) create environmental degradation in surface waters by fueling increases in algal biomass. Algae respond to multiple factors associated with their resource base. Both nutrients and light intensity can influence algal growth rates, photosynthetic rates, species composition and diversity. These algal responses are related to one another, but they may not be tightly coupled. The stoichiometry of biomass:nutrients in algae is variable, and the carbon:phosphorus ratios in algae are known to range over approximately one order of magnitude. Controls on this ratio are especially poorly understood in running waters. Predictive models of nutrient releases such as from treatment plants, agricultural activities such as feedlots, or from generally increased atmospheric deposition of nitrogen will depend on improved understanding of the C:P stoichiometry in streams and rivers. This information can be used to predict how much increased stream algal biomass we can expect from any increase in nutrient input.

In lakes, the balance of light and nutrients is thought to play a large role in biomass:nutrient ratios. Patterns in streams may differ from lakes, however, for a number of reasons. The velocity of moving water may impose different constraints on biogeochemistry. Algae in streams may exist in a predominantly two-dimensional habitat (periphyton) or in a well-mixed three-dimensional habitat (suspended), whereas in water columns in lakes, they are all in a three-dimensional habitat. Other factors such as differences in food webs, proximity to substrate and others may generate different patterns in streams than lakes.

In this project, experiments and measurements were performed to assess how the balance of light and nutrients influences the ratio of biomass:nutrients in streams from several regions in Minnesota. Experiments manipulated the levels of light and nutrients, and periphyton responses were recorded. In addition, light, nutrients and periphyton stoichiometry were surveyed in several regions in the state, and statistical models were used to explore these couplings.

Data from this project allowed us further to see how algal nutrient content (C:N:P ratio) related to nutrient limitation in the stream. If there is a good correspondence in these two things, algal C:N:P ratio would have a potential as an indicator of nutrient limitation.

Methods and Procedures

Phase One, 1999

This work concentrated on mid-summer (July) characteristics of four sites in and near Itasca State Park in north central Minnesota. Streams all were first or second order, surrounded by either mixed coniferous-deciduous forest or grasses and sedges. Nutrient and light limitation *in situ* were assessed by experiments with nutrient-diffusing substrates and shading. Half-liter polycarbonate bottles were filled with nutrient-amended water and were autoclaved to sterilize. A nylon membrane was then placed over the mouth of the bottle, and a glass fiber filter was placed over the membrane. Caps with holes held the filters on the bottles, and bottles were incubated in the streams using PVC racks. Some bottles had neutral-density screening over them to lower the light levels. Incubations were approximately 2.5 weeks. At the end of the experiment, filters were analyzed for particulate carbon and nitrogen and for chlorophyll (the latter using HPLC). For technical reasons, we were unable to measure particulate phosphorus in some treatments. Water chemistry also was measured.

Phase Two, 2000

In this phase of the work, 26 Minnesota streams located in four regions throughout the State (Figure 1) were sampled. These regions differ from one another geologically in that the north-east streams flow over Superior Lobe glacial till that is low in carbonates; the north-central and southern sites flow over calcareous glacial till; and the metro streams are a mixture of the two types of glacial till. Nutrient limitation experiments similar to those described above were performed in a subset of these. These streams were first through third order. In seven of these streams, two stream reaches, one with an open canopy and one shaded, were sampled. Locations were

sampled once. Periphyton was collected by scraping a standard area of flat-topped rocks and filtering the material thus obtained onto filters.

Results and Discussion

Our primary hypothesis was that, like lakes, stream algae would have carbon:nutrient ratios determined by the balance of available light and nutrients. In general, this hypothesis found little support in the data.

In 1999, the four Itasca sites responded differently to the manipulations of light and nutrients (Table 1). Considering all possible response variables (chlorophyll and particulate C, N, P and ratios), Bear Creek and Nicollet Creek both responded to decreased light, but not to increased nutrients. Sucker Brook responded to light and phosphorus. La Salle Creek responded both to nitrogen and to phosphorus, as well as to light. La Salle was the most intensively nutrient limited site considering the magnitude of algal increases to nutrients. This site also had the most pronounced shift in algal community composition as measured by HPLC of pigments; P addition increased significantly the proportion of cyanobacteria and decreased the proportion of green algae.

In general, predicted shifts in algal nutrient ratios as a consequence of changed light and nutrients did not follow our predictions. For example, in Sucker Brook, C:N was higher in shaded than open treatments. La Salle, the most nutrient limited site, was the only one of the four where predictions were generally supported.

In 2000, we found that stream algal C:N:P ratios were significantly related to several predictor variables. Among these, the most important probably was soluble reactive phosphorus, SRP in predicting the C:P of suspended stream algae (Figure 2). We found a wide range in SRP among the regions and reaches, with particularly high values in the south. The trend in suspended matter C:P ranged from approximately 250 (considered indicative of moderate P limitation) to approximately 100, or near the Redfield Ratio of 106.

Conclusions

This project did not support the basic hypothesis that conversion of nutrients to biomass in streams is governed principally by the ratio of light:nutrients. Though certain individual sites were consistent with this hypothesis, the majority of sites had weak or absent nutrient and also possibly light limitation.

This study found, perhaps for the first time, that there are systematic differences in the stoichiometry of stream suspended matter and periphyton. This finding has implications for our understanding of stream functioning, and it argues that the exchange of attached and suspended biomass is not as rapid as has previously been thought to be the case.

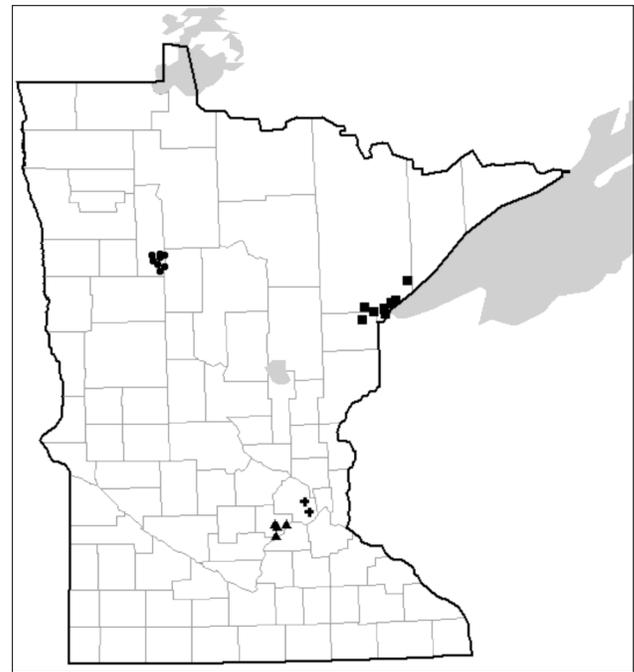


Figure 1. Location of sites by region: north-east (square); north-central (circle); south (triangle); metro (plus).

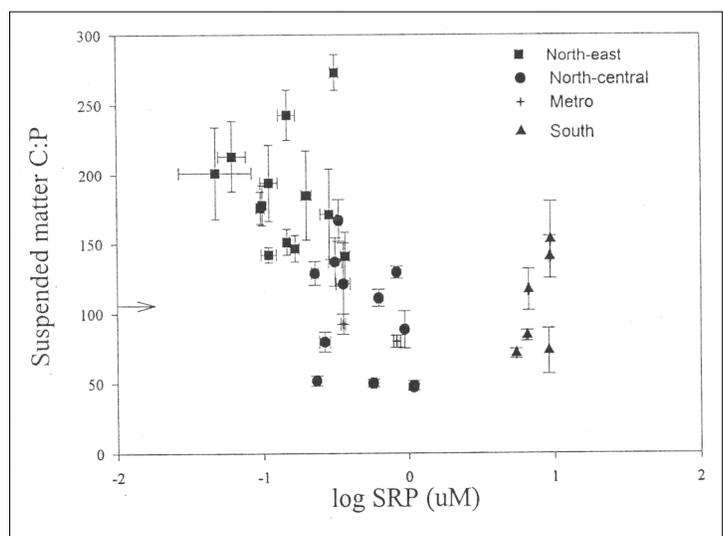


Figure 2. Log SRP vs. suspended matter C:P. All values are mean \pm SD. Ratio SDs calculated through error propagation (Bevington 1969). Arrow indicates C:N:P Redfield ratio of 106:16:1. Means grouped by region.

Table 1. F statistic, P-value, and direction (+/-) of change from ANOVAs at each site, with chlorophyll *a* (Chl *a*), carbon (C), C:N, C:P, N:P, and C:chlorophyll *a* as the dependent variables. L = light, N = nitrogen, P = phosphorus. Numbers in the df (degrees of freedom) row are the df_{effects} , df_{error} for each ANOVA. P-values < 0.05 are marked with an *. All effects for the C:P and N:P models were not able to be tested due to missing periphyton phosphorus data (see text). Continued on next page.

Treatment	Chl <i>a</i>		C		C:N		C:P		N:P		C:Chl	
	F	P	F	P	F	P	F	P	F	P	F	P
Bear, df	1,20		1,16		1,16		1,8		1,8		1,4	
L	9.99	0.00 +*	0.36	0.56	11.85	0.00 -*	0.01	0.93	1.61	0.24	40.98	0.00 -*
N	0.04	0.84	1.44	0.25	0.04	0.85	0.45	0.52	1.06	0.33	4.08	0.11
P	0.40	0.53	0.22	0.64	1.80	0.20					2.06	0.22
L x N	0.01	0.91	0.05	0.82	0.02	0.90	0.03	0.87	0.02	0.90		
L x P	0.00	0.98	0.30	0.59	0.02	0.88						
N x P	0.95	0.34	0.12	0.74	0.07	0.80						
L x N x P	0.05	0.83	0.00	1.00	0.67	0.43						
Sucker, df	1,19		1,16		1,16		1,8		1,8		1,4	
L	1.20	0.29	9.38	0.01 +*	3.34	0.09	0.54	0.48	0.23	0.65	0.22	0.66
N	4.12	0.06	0.00	0.99	0.00	0.98	1.17	0.31	2.42	0.16	12.95	0.02 -*
P	0.11	0.74	0.71	0.41	4.95	0.04 -*					0.03	0.87
L x N	0.00	0.97	0.06	0.81	3.09	0.10	0.55	0.48	1.32	0.28		
L x P	0.46	0.51	0.32	0.58	5.29	0.04 *						
N x P	1.98	0.18	2.41	0.14	3.12	0.10						
L x N x P	0.92	0.35	0.80	0.38	1.88	0.19						

Table 1. Continued from previous page.

Treatment	Chl a		C		C:N		C:P		N:P		C:Chl	
	F	P	F	P	F	P	F	P	F	P	F	P
Nicollet, df	1,23		1,16		1,16		1,8		1,8		1,4	
L	6.13	0.02+*	0.34	0.57	0.07	0.80	0.63	0.45	0.95	0.36	1.54	0.28
N	0.45	0.51	0.87	0.36	0.11	0.75	0.05	0.82	0.01	0.94	0.00	0.97
P	0.01	0.93	0.19	0.67	0.32	0.58					0.12	0.74
LxN	0.37	0.55	2.46	0.14	0.13	0.72	1.35	0.28	0.99	0.35		
LxP	0.00	0.98	0.57	0.46	0.23	0.64						
NxP	0.76	0.39	3.47	0.08	0.00	0.98						
LxNxP	0.54	0.47	0.05	0.83	0.01	0.92						
La Salle, df	1,23		1,16		1,16		1,8		1,8		1,4	
L	0.75	0.39	1.80	0.20	40.03	0.00+*	0.52	0.49	2.90	0.13	0.02	0.89
N	27.45	0.00+*	2.66	0.12	0.44	0.52	1.30	0.29	3.10	0.12	4.73	0.10
P	114.63	0.00+*	36.26	0.00+*	11.26	0.00-*					14.98	0.02-*
LxN	0.89	0.35	2.25	0.15	5.44	0.03*	0.01	0.93	0.07	0.79		
LxP	0.04	0.85	0.84	0.37	4.59	0.05*						
NxP	31.38	0.00*	16.81	0.00*	7.63	0.01*						
LxNxP	0.03	0.87	0.54	0.47	6.12	0.02*						