The Effect of Soluble Phosphorus on the Standing crops of Phytoplankton and Zooplankton in Ten Lakes

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Abstract

In our study we looked at the complex interactions between biotic and abiotic factors in lake ecosystems . Specifically we examined the effect of soluble phosphorus on phytoplankton and zooplankton biomasses. Since soluble phosphorus is commonly the limiting nutrient for phytoplankton in fresh water lakes and phytoplankton are the main food source for zooplankton we expected positive correlation between soluble phosphorus and these two variables. We sampled ten lakes in Cheboygan County in order to measure the soluble phosphorus concentrations, chlorophyll- a concentrations and zooplankton biovolume. A regression analyses showed no significant correlations between any of our variables. We found several explanations consistent with these results, including the fluctuations in phosphorus availability and predation on both phytoplankton and zooplankton.

Key words: primary producers, secondary consumers, lake ecosystem, trophic levels, algal phosphorus, soluble phosphorus, zooplankton biomass, phytoplankton biovolume, turnover rates

Introduction

Community structure within lake ecosystems is often characterized by complex interactions between organisms and abiotic factors. Among the abiotic factors influencing freshwater communities, nutrients play a particularly important role. They often control the distribution and abundance of algal populations which are the base of the food web. According to Liebig's law of the minimum, a single nutrient should limit algal growth at any given time. Several major nutrients are essential to algal growth: carbon, phosphorus, nitrogen, hydrogen, oxygen and sulfur. Of these nutrients only carbon, nitrogen and phosphorus are known to be limiting in freshwater ecosystems. For phytoplankton phosphorus is considered to be the most commonly limiting nutrient. Within this study we have focused on the effect of phosphorus on primary producers and secondary consumers in the trophic structure of a lake ecosystem.

Phytoplankton is a group of primary producers consisting of planktonic organisms which contain chlorophyll-a. Phosphorus plays a crucial role in energy transformation during algal photosynthesis. It is vital to algal metabolic processes including the synthesis of nucleotides, phospholipids and sugar phosphates (Wetzel, 1983). Whereas carbon and nitrogen can enter lakes through atmospheric cycles, the major mechanism through which phosphorus enters lakes involves a slower process of phosphatic mineral weathering. The most important form of phosphate available in the lake is dissolved inorganic phosphate, which is most readily utilized by phytoplankton. Under most conditions it is taken up rapidly by both bacteria and phytoplankton until low concentrations remain in the water.

Zooplankton are the main predator of phytoplankton. Whereas phytoplankton are found predominantly in the upper strata of the lake, zooplankton follow a diel vertical migration pattern. Zooplankton migrate to the upper strata during the night to feed on the abundant phytoplankton and return to the lower strata during the day to avoid predation (Gliwicz, 1986). Zooplankton play an important role in nutrient recycling through excretion which increases nutrient supply to phytoplankton. Increased phytoplankton growth has been attributed to phosphorus excreted by zooplankton (Sterner, 1990). Phytoplankton growth indicates an increase in the rate of production of biomass but does not imply an increase in the biomass within a unit area. For example, predation on the phytoplankton by zooplankton can maintain the algal biomass at a low level even though the growth rate is high. The distinction between growth rate and standing crop is important when considering the relationship between phytoplankton and zooplankton. The turnover rate of phytoplankton is an important indicator of phytoplankton growth and is defined as the rate at which individuals within a population reproduce and die.

To study the effect of phosphorus on the primary producers and secondary consumers in lake ecosystems, we have examined the effect of phosphorus on algal and zooplankton biomasses. If phosphorus limits algal growth, we expect phytoplankton biomass to increase with increased phosphorus availability. If phytoplankton biomass limits zooplankton biomass, we should see an increase in the zooplankton biomass with increasing phytoplankton biomass. It follows that if phytoplankton biomass depends on phosphorus and zooplankton biomass depends on phytoplankton biomass then zooplankton biomass depends on phosphorus.

When a relationship between phosphorus and algal biomass exists, measuring this can be difficult because predation can mask the real effect of phosphorus on algal growth. Even if we don't see the correlation between soluble phosphorus and algal biomass, we may see a correlation between soluble phosphorus and turnover rate. If soluble phosphorus limits phytoplankton growth rate and phytoplankton biomass limits zooplankton biomass we expect an increase in the turnover rate of phytoplankton with increasing phosphorus availability.

To explore these relationships we investigated the soluble phosphorus, algal phosphorus, and algal biomass and zooplankton biomass in ten lakes.

Materials and Methods

Collection of Samples

Samples were collected for analyses from ten lakes; Cochran, Burt, Vincent, Lancaster, Douglas, Roberts, Crooked, Mullet, Arnott and Monro. We chose the lakes with the largest range in total phosphorus readings, based on a previous survey (Rann 1974). In three days, June 4 , June 6, and June 7, we sampled ten lakes over a 6 hour period from 10 pm to 4 am. A single site at each of the lakes was sampled. All samples were collected at surface level where the water was approximately 15 feet deep. Four measurements were taken for each lake: soluble phosphorus, algal phosphorus, chlorophyll-a concentrations, and zooplankton biovolume.

We defined soluble phosphorus as all phosphorus that can pass through a .45μm membrane filter. This form, PO_4^{3-}, is available for uptake by phytoplankton. We defined algal phosphorus as the phosphorus that cannot pass through a .45μm membrane filter. We assume that this consists primarily of phosphorus in algal cells and does not include detritus, zooplankton, or bacteria. To measure the phytoplankton biomass we used chlorophyll-a concentrations which on the average constitute 1.5% of the dry weight organic matter of phytoplankton (Clescern, 1989). Lastly, zooplankton biovolume was used to evaluate relative zooplankton biomasses.

For the soluble phosphorus, algal phosphorus and algal biomass tests 4 l or 2 l of water, depending on ease of filtration, were collected and concentrated to 120 ml using 10 and 25 mesh plankton tows successively. Only the sample from the 25 mesh plankton tow was used which contained primarily phytoplankton. The concentrated sample was then filtered through a .45μm membrane filter in order to collect the phytoplankton. The filtrate was placed in an acid washed polyethylene jar with 2 ml of concentrated H_2SO_4 and frozen until analyzed. The filter paper was used for the algal phosphorus and algal biomass tests.

Samples for zooplankton biovolume analysis were collected by filtering approximately 100 l of water through plankton tows of mesh size 10 and 25 successively. We filtered with plankton tows to concentrate the sample. This facilitated the biovolume analysis. The samples from each plankton tow were combined and preserved with formalin until analyzed.

Chemical Analysis of Samples

Each membrane filter was placed in a centrifuge tube with 10 ml of buffered acetone then placed in a refrigerator at 4°C for at least 48 hours. An extraction was made to test for algal biomass by using the flourometric method of chlorophyll-a concentration determination (Adams, 1990). In order to determine algal biomass the chlorophyll-a reading was multiplied by a factor of 67. Algal phosphorus was determined by using a colorimeter and the molybdenum blue method.(Clescern et al., 1989).

Biovolume Analysis of Samples

Each sample was concentrated to 25 ml, 1 ml of which was counted drop by drop under a dissecting microscope. Zooplankton were categorized into six size classes: 0-.25 mm, .25-.50 mm, .50-.75 mm, .75-1 mm, 1.-1.5 mm, and 1.5-2.0 mm. In order to estimate the biovolume of the zooplankton for each lake's sample, the length, width, and breadth for five individuals in each size class were averaged. Using a cylinder to approximate the shape of a zooplankton, we calculated the volume of the average individual in each size class.

Statistical Analysis

To determine the statistical significance of the data a regression analysis was done on the four measured variables. As an indicator of turnover rate we used the ratio of zooplankton biovolume to chlorophyll-a concentration.

Results

A regression analysis revealed no significant correlation between soluble phosphorus and phytoplankton biomass (r2=.063, p=.4826; Fig. 1).

There was no significant correlation between phytoplankton biomass and zooplankton biovolume (r2=.01, p=.78; Fig. 2).

There was no significant correlation between the amount of soluble phosphorus in the lake and zooplankton biovolume (r2=.107, p=.3557; Fig. 3).

Lastly, there was no significant correlation between soluble phosphorus concentration and the "turnover rate" of phytoplankton (r2=.147, p=.2741; Fig. 4).

Discussion

Our study investigated the complex interactions between primary producers and secondary consumers in lake ecosystems. The four interactions studied between phosphorus levels, phytoplankton, and zooplankton levels include: 1) the effect of soluble phosphorus concentration on algal standing crop, 2) the effect of zooplankton standing crop on algal standing crop, 3) the effect of soluble phosphorus concentration on zooplankton standing crop, 4) the effect of soluble phosphorus concentration on turnover rate. It is surprising we found no correlation between these variables (Fig. 1-4). It is easy to conclude that phosphorus is not the limiting nutrient in the lakes we studied. However, there are other equally plausible explanations for the lack of correlation between the variables.

There are many ways to explain why soluble phosphorus did not effect algal growth. We will address two explanations for this observation; seasonal effect and predation. Phytoplankton grow at a fast rate in the spring because they are not being limited by phosphorus. In Nova Scotia, phosphorus was not found to limit phytoplankton growth as late as the end of June (Fogg, 1965). Given that we sampled in June, phytoplankton populations could have been in a period when soluble phosphorus is not yet limiting algal growth.

Predation could also explain why soluble phosphorus did not limit algal growth. Zooplankton predation can keep the phytoplankton population below the level at which phosphorus becomes limiting. When zooplankton predate upon phytoplankton the nutrients are excreted back into the system in the form most readily used by phytoplankton, soluble phosphorus (Sterner, 1990). In this case we would expect a high algal growth rate since nutrients are abundant relative to the standing crop of phytoplankton.

We also looked at turnover rates to evaluate the explanations for the lack of correlation between soluble phosphorus and phytoplankton standing crop. Specifically we considered the explanation that grazing by zooplankton kept the phytoplankton at a low density such that phosphorus was not limiting. Surprisingly enough, soluble phosphorus concentrations had no effect on the ratio of zooplankton biomass to algal biomass (Fig. 4). This suggests that the seasonal effect is more important than predation.

There are several reasons why zooplankton are not correlated to algal biomass nor soluble phosphorus. On the one hand, phytoplankton vary in their nutritional value which results in selective predation by zooplankton. There are three different forms of algae, filamentous, spinous, and cellular. Of these three forms zooplankton preferentially feed upon cellular forms due to their ease of ingestion and digestion, as well as their greater nutritional value (Wetzel, 1983). On the other hand, zooplankton could be predated upon by planktivorous fish or other predators to a level where phytoplankton is not a limiting resource. Vanni (1986) found increased phytoplankton density in the presence of fish relative to the densities found in the absence of fish. This suggests that in the presence of fish, phytoplankton do not limit the standing crop of zooplankton.

Within the trophic levels of a lake ecosystem there are many complex interactions. In our study we found no significant effect of 1) soluble phosphorus on phytoplankton biomass, 2) phytoplankton biomass on zooplankton biomass, 3) soluble phosphorus on zooplankton biomass, nor 4) soluble phosphorus on the ratio of zooplankton biomass to phytoplankton biomass. We described several plausible explanations for our results. The lack of effect of phytoplankton biomass on zooplankton biomass can be explained by differing nutritional values of phytoplankton for zooplankton, and predation on zooplankton by planktivorous fish. The lack of effect of soluble phosphorus on phytoplankton biomass can be explained by predation on phytoplankton by zooplankton and the effect of seasonal phosphorus availability.

Since there are many ways to explain the apparent lack of effect of phosphorus on phytoplankton biomass, we cannot conclude that phosphorus is not the limiting nutrient in the lakes we sampled. It may have major effects on the trophic structure of the lakes studied that we were not able to detect . Further experimentation is necessary in order to isolate the most reasonable explanation for our results.

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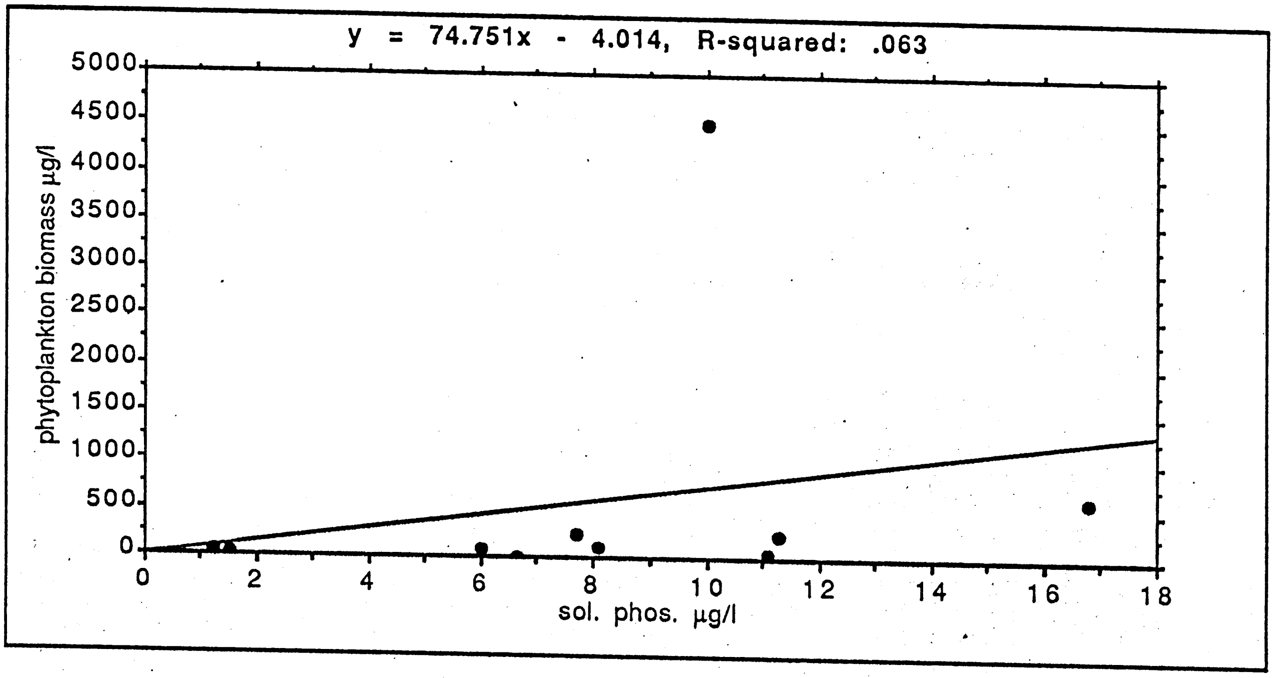


Fig. 1 The Effect of Soluble Phosphorus on Phytoplankton Biomass

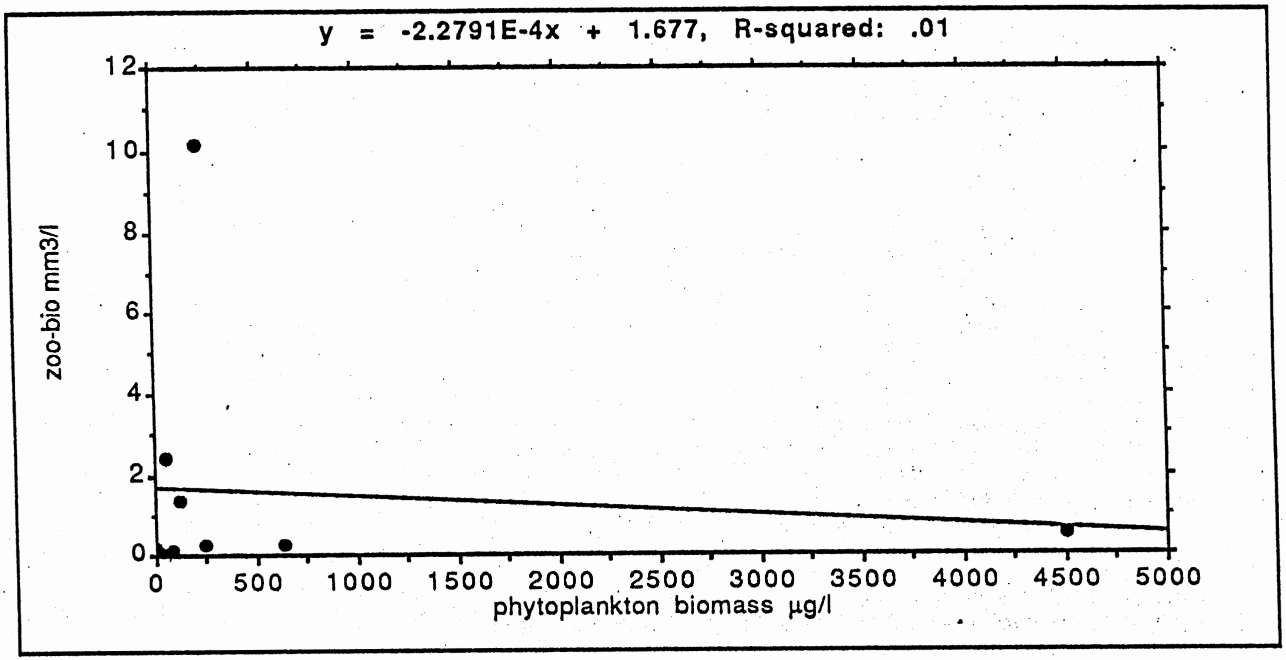


Fig. 2 The Effect of Phytoplankton Biomass on Zooplankton Biomass

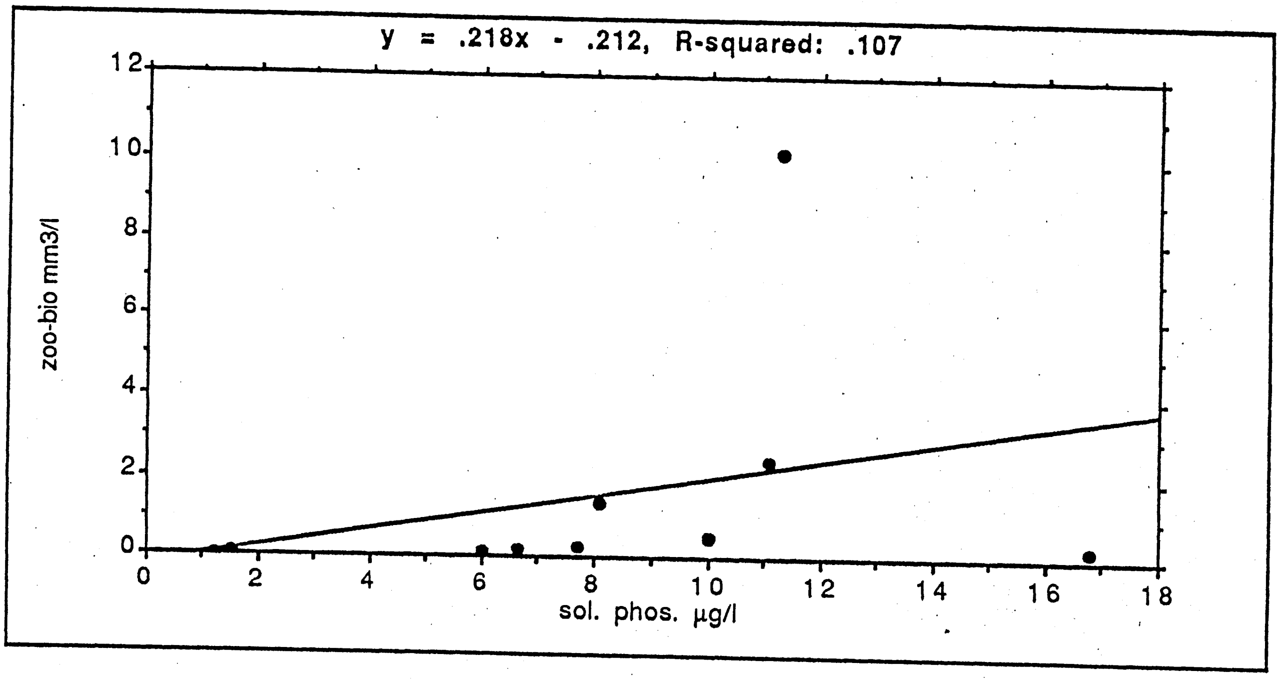


Fig. 3 The Effect of Soluble Phosphorus on Phytoplankton Biomass

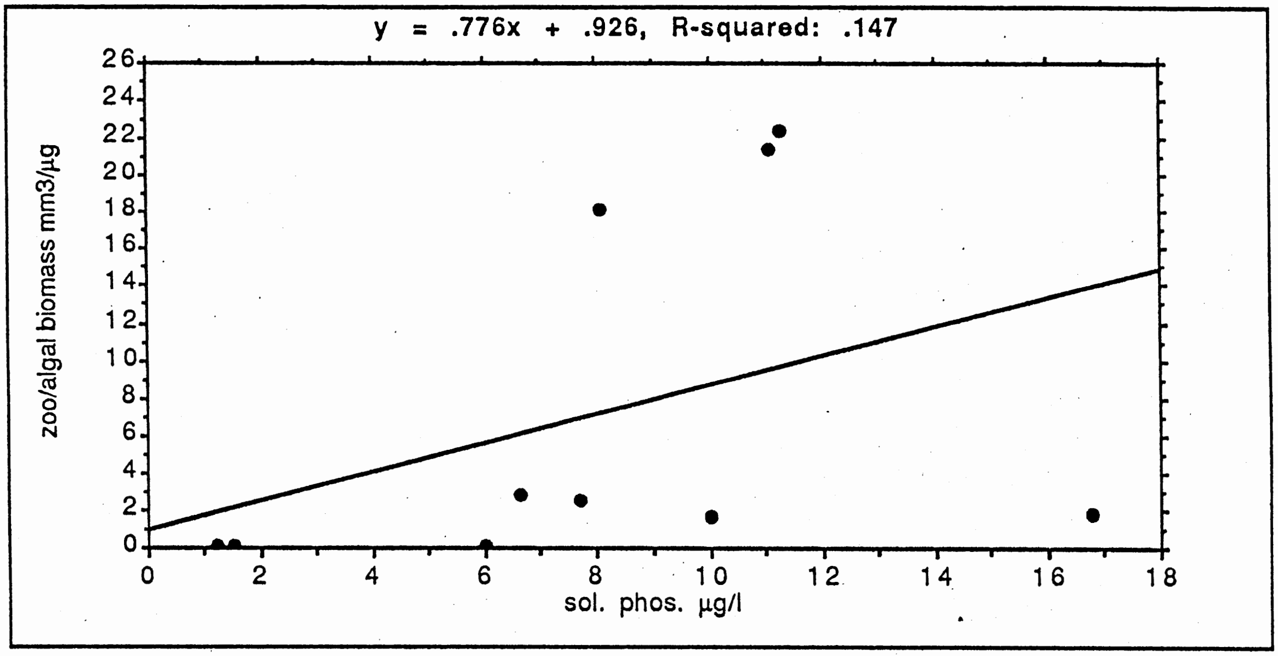
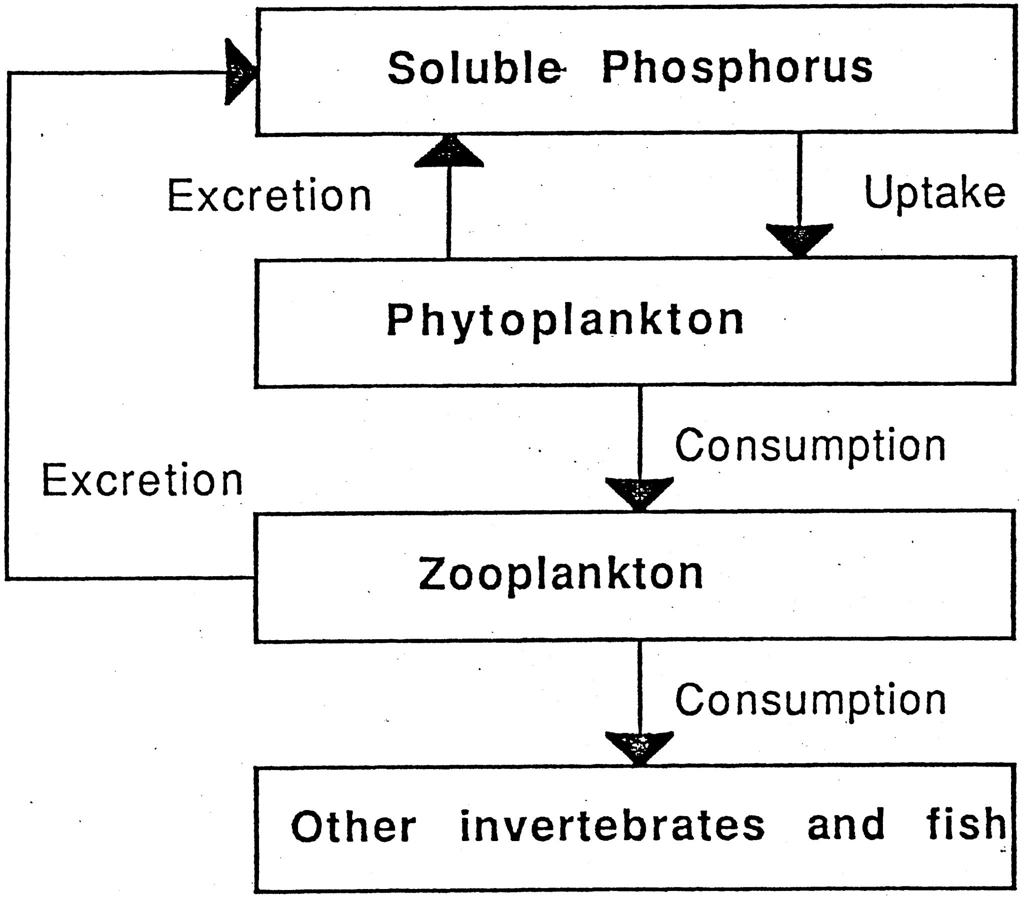


Fig. 4 The Effect of Soluble Phosphorus on the Turnover Rate of Phytoplankton


Soluble Phosphorus
Excretion
Uptake
Phytoplankton
Consumption
Excretion
Zooplankton
Consumption
Other invertebrates and fish

COMPARATIVE LAKE SURVEY

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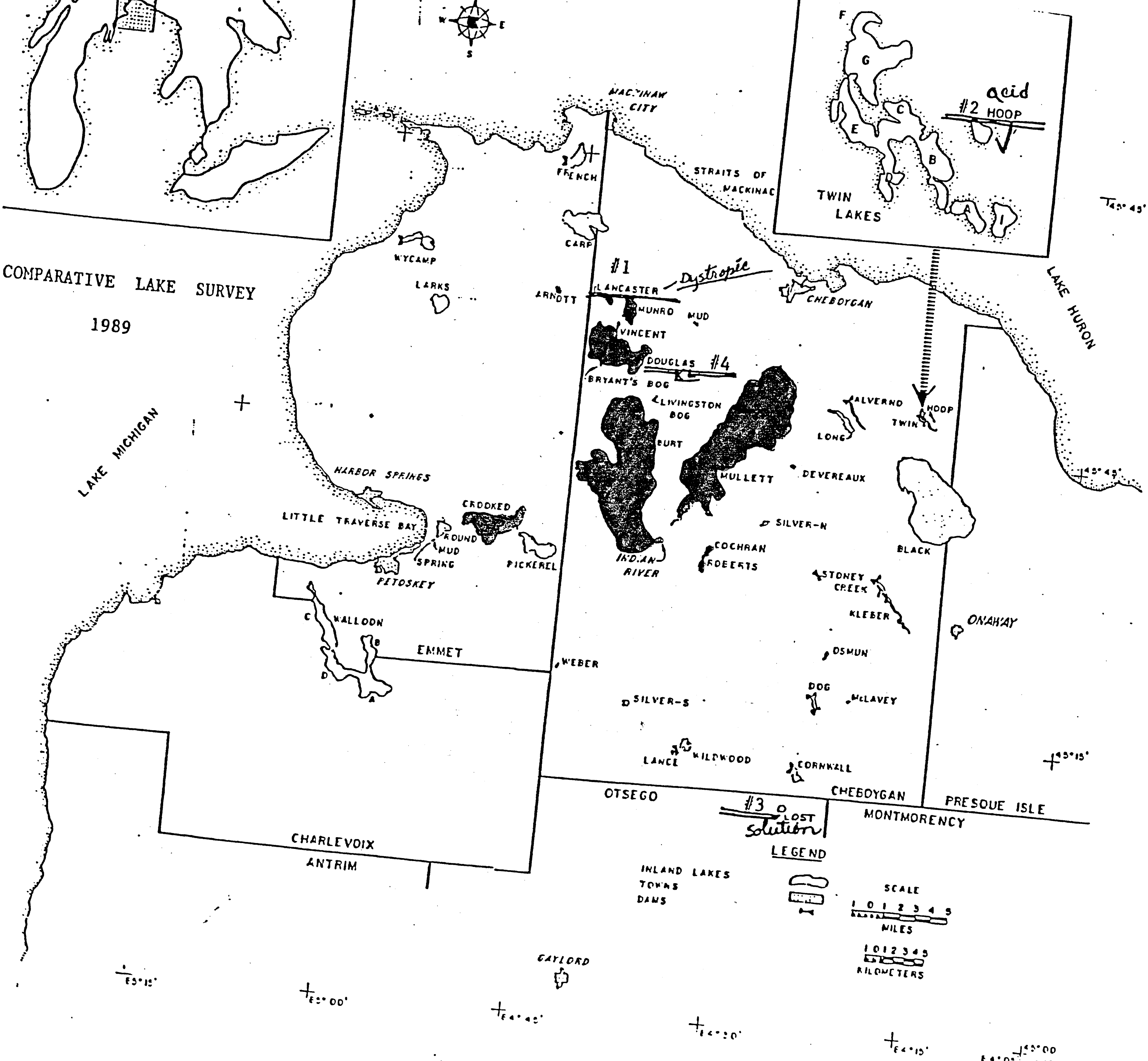

Map I