RELATIVE IMPORTANCE OF NUTRIENT LIMITATION AND ZOOPLANKTON GRAZING ON PRODUCTIVITY OF ALGAL COMMUNITIES

BIOS 569 - Practicum in Aquatic Biology

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ABSTRACT

In situ enclosure experiments were conducted over the summer of 1994 in Morris Lake, Gogebic County, Michigan to measure the effects of nutrient (nitrogen and phosphorus) enrichment and zooplankton herbivory on the phytoplankton community. Chlorophyll *a* concentrations were measured to assess the phytoplankton production and nutrient (N and P) concentrations were also measured to determine nutrient uptake.

Nutrient enrichment stimulated increases in phytoplankton, while herbivorous zooplankton suppressed phytoplankton. Nutrient enrichment caused phytoplankton density to increase in the low density and high density zooplankton communities. There were much higher levels of chlorophyll a in the mesocosms that were nutrient enriched than those that had a reduction in the zooplankton population.

These results indicate that the top-down, bottom-up trophic dynamic theories should both be recognized as directing phytoplanktonic community interactions. Phytoplankton densities were positively affected by a decrease in zooplankton herbivory, but were influenced more by addition of nutrients.

INTRODUCTION

Ecologists have differing views of how community structure is controlled by interactions. The "top-down" theory is based on population dynamics and species replacement sequences. The organisms higher on the food chain (birds, fish) control the lower populations of zooplankton and phytoplankton. The "bottom-up" theory is centered on nutrient cycling and primary production. The growth rates of the phytoplankton control the population growth of the higher organisms.

Some scientific studies show that freshwater phytoplankton grow at rates that are measurably less than their maximum physiological capability because of nutrient limitation (Lehman, 1985). Others feel that grazing by zooplankton is a major influence on phytoplankton abundance and community structure (Vanni, 1987). Changes in phytoplankton abundance and community structure associated with alterations of zooplankton size may be due to secondary effects of grazing as well as direct herbivory. For example, nutrient excretion by zooplankton may produce small-scale patches of nutrients readily taken up by phytoplankton (Lehman and Scavia, 1982).

Zooplankton have at least two counteracting effects on phytoplankton: grazing, which reduces standing algal crop and nutrient regeneration, which can stimulate algal growth (Bergquist,1986). Some experimenters have found that heavy grazing depressed primary production (Henrickson et al. 1980, Lynch and Shapiro 1981, Elliott et al. 1983). Other studies detected little or no effect of herbivory on primary productivity (Coveney et al. 1977). Other results showed positive correlations between the density of grazers and chlorophyll *a* concentration (O'Brien and DeNoyelles 1974) or primary productivity (Korstad 1980).

I studied the relative responses of phytoplankton growth to the reduction of zooplankton and the addition of nutrients. This will integrate resource (bottom-up) and consumer (top-down) control. It is easier to see the effects of grazing on a phytoplanktonic community when we know that the vital nutrients are not limited as they may be in normal circumstances. Zooplankton biomass and nutrient levels were manipulated in bags that acted as enclosed lake ecosystems (lacking the fish) to determine responses of total phytoplankton biomass. Productivity of phytoplanktonic communities were as measured through chlorophyll *a* concentration.

MATERIALS AND METHODS

I hypothesized that the effect on the phytoplankton is a combination of the bottom-up, top-down theories; the decrease of grazing and the removal of nutrient limitation will have a composite result of increasing algal biomass.

Two experiments were conducted, each using four treatment combinations and replicated with time. The first treatment was labeled the control group and no manipulations were made to that particular environment. The second treatment was supplied with nutrient additions of nitrogen and phosphorus. The third treatment had a 75% reduction in zooplankton with no additional nutrients. The fourth and final treatment was supplied with nutrients as well as a 75% reduction in zooplankton concentration.

Mesocosms of a freshwater lake were constructed using translucent plastic sheeting to form a bag using a heat gun. Each tube was approximately 2.2 m long and 0.65 m in diameter (all with volumes of 400 liters). The four bags were open at the top and attached to bicycle tubes which were then tied to a raft. The treatments were assigned randomly to locations on the raft which was placed in the middle of the lake to prevent disturbance from macrophytes, the lake bottom or shore animals. The bags were tied at the bottom and had small weights attached to keep the polyethylene bags from floating to the top or being disturbed by weather. Each bag was filled with epilimnetic lake water by the use of buckets and by manually pulling the bags through the water.

Zooplankton to be used in bags were collected and concentrated by vertical hauls of a plankton net. The net had a diameter of 29.5 cm and the length of the line attached was 4.50 m, so one vertical haul of the net went through 307.6 L of water. For the control and the experimental treatment of added nutrients, we pulled the zooplankton net twice through 4.50 m of water. For the reduced zooplankton we only pulled it once through 2.25 m of water so that there was approximately 75 % less zooplankton in those bags. It should be noted that none of the experimental treatment combinations contained fish.

In the first experiment, replicated once, there was one nutrient addition of phosphorus in the form of K_2HPO_4 and nitrogen in the form of KNO_3. .055 g of K_2HPO_4 and 1.47 g KNO_3 were added to keep the ratio at 16:1 (N:P). Water samples were taken for five days following the addition. Several earlier experiments showed that incubations of 4 days produced significant responses in treatment bags (Bergquist 1985). In the second set of experiments nutrients were added (.331 g K_2HPO_4 and 9.004 g KNO_3 each day) for three days, and then water samples were collected the following three days.

The nutrient additions had a 16:1 ratio of nitrogen to phosphorus, which approximated the natural ratio in the lake. Phytoplankton productivity was measured using pigment analysis and chlorophyll *a* concentrations to estimate the total biomass. Samples for pigment analysis were filtered onto Whatman GF/F filters and frozen for at least 24 hours, extracted with acetone and then analyzed with a HACH spectrometer. The trichromatic method was used with a 90% acetone solvent to determine chlorophyll *a* levels (Jeffery and Humphrey, 1975). The concentration of photosynthetic pigments is used extensively to estimate phytoplankton biomass. The concentration of dissolved inorganic nitrogen and soluble reactive phosphorus in each bag were also measured daily using a HACH kit.

Study Site

Morris Lake is a fairly shallow lake located at the University of Notre Dame Environmental Research Center in Gogebic County, Michigan. It had a Secchi disk reading of 1.44 m, Chl a level of 25.05 mg/L, alkalinity of 10.8 mg/L, a pH of 7.5 and a conductivity of 95 umhos. (UNDERC unpublished and personal observation).

RESULTS

The data are too few to detect statistical trends but one can see that phytoplankton chlorophyll responded positively to both nutrient addition, zooplankton reduction, and the combination of the two (See Fig. 1, Fig. 2). There was a greater chlorophyll response in mesocosms with lower zooplankton concentrations. The greatest chlorophyll response occurred in the mesocosms that had both added nutrients and reduced zooplankton (Fig. 1, Fig. 2). The chlorophyll level dropped near day 4 of the experiment, slightly in Exp. 1A and more noticeably in Exp. 1B.

In each nutrient-enriched enclosure total chlorophyll *a* concentration was greater than in its corresponding unenriched counterpart. In both enriched and unenriched bags, chlorophyll *a* concentration was negatively correlated with zooplankton concentration.

In both Experiment 1A and 1B, the nutrient concentrations (phosphorus and nitrogen) dropped after the initial addition (Fig. 3,4,5,6). There was a large increase in the nitrogen level in Experiment 1A on the fourth day in both the nutrient-enriched mesocosm and the nutrient-enriched, zooplankton reduced mesocosm (Fig. 4). The nitrogen level was greater in the bags with normal zooplankton population, while the phosphorus level was greater in the mesocosms with a reduced zooplankton concentration.

In the experiments with a repeated addition of nutrients (Exp. 2A, Exp. 2B), the chlorophyll levels were highly respondent to the nutrient additions (Fig. 7, Fig. 8). The reduction of the zooplankton concentration had a very small negative effect on the chlorophyll levels in Exp. 2A (Fig. 7). In both experiments, the nutrient enriched bags that also had a reduction of zooplankton had a slightly smaller increase of chlorophyll concentration than the nutrient enriched bags with a normal zooplankton population.

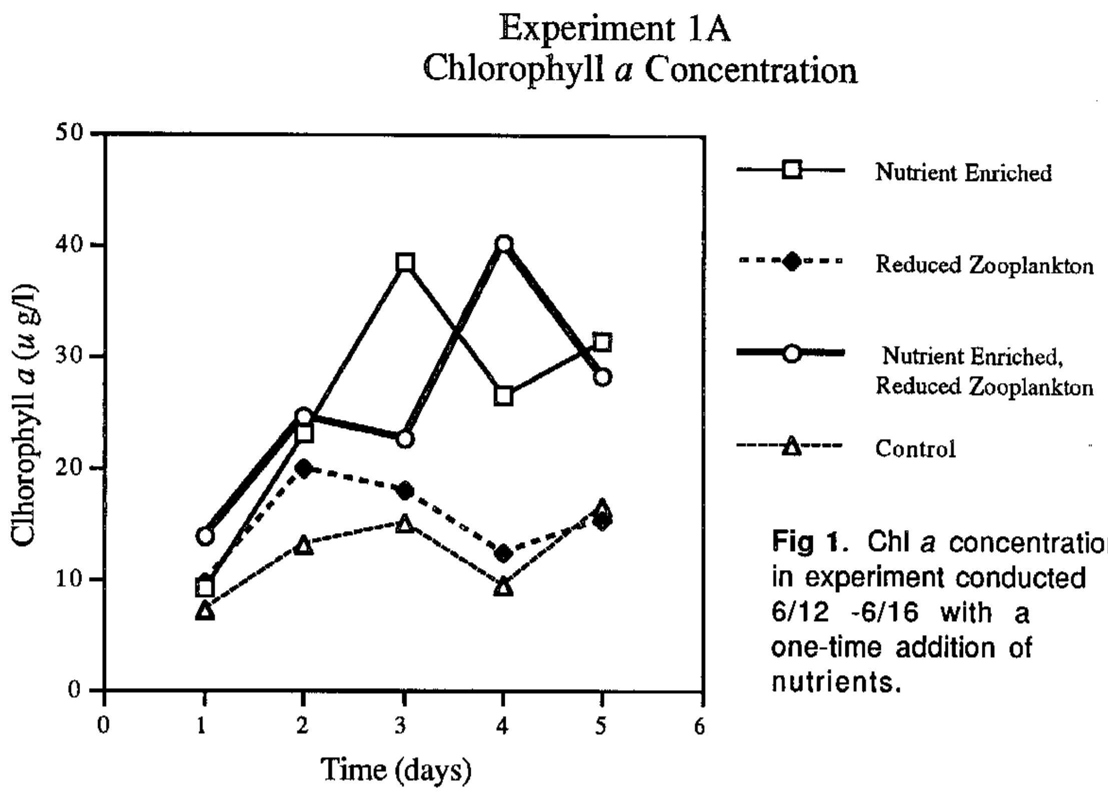

Fig 1. Chl *a* concentrations in experiment conducted 6/12 -6/16 with a one-time addition of nutrients.

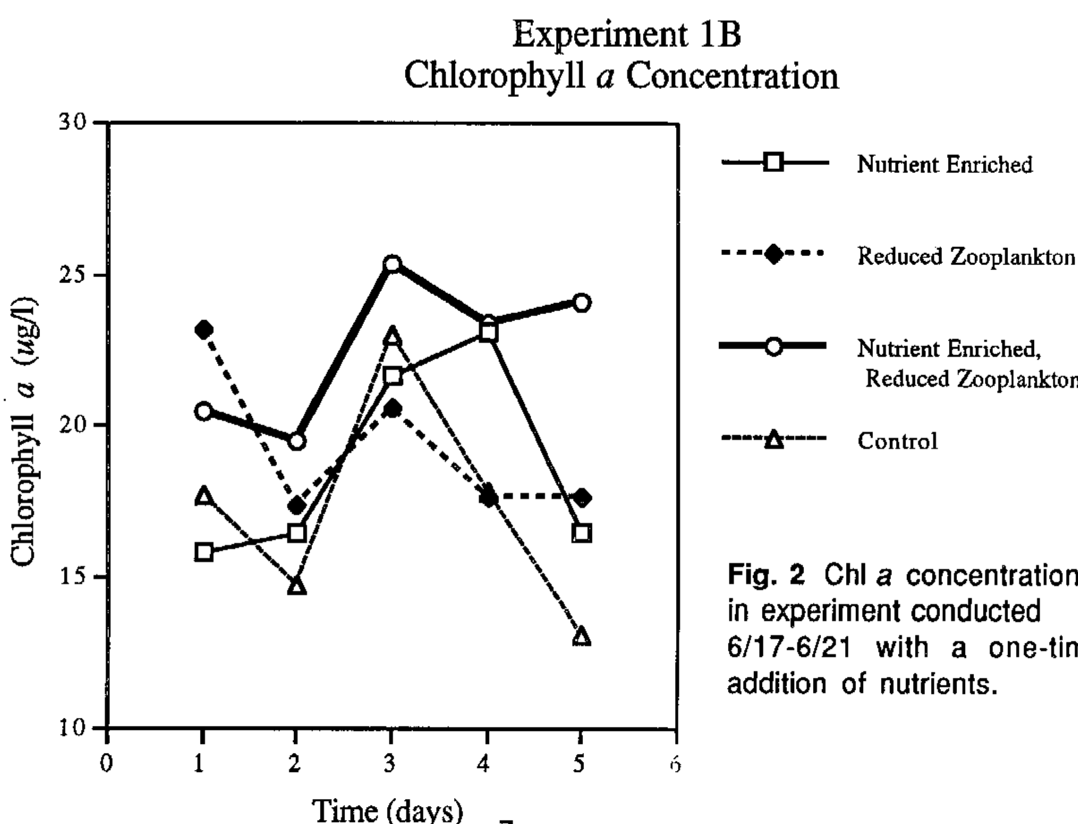

Fig. 2 Chl *a* concentrations in experiment conducted 6/17-6/21 with a one-time addition of nutrients.

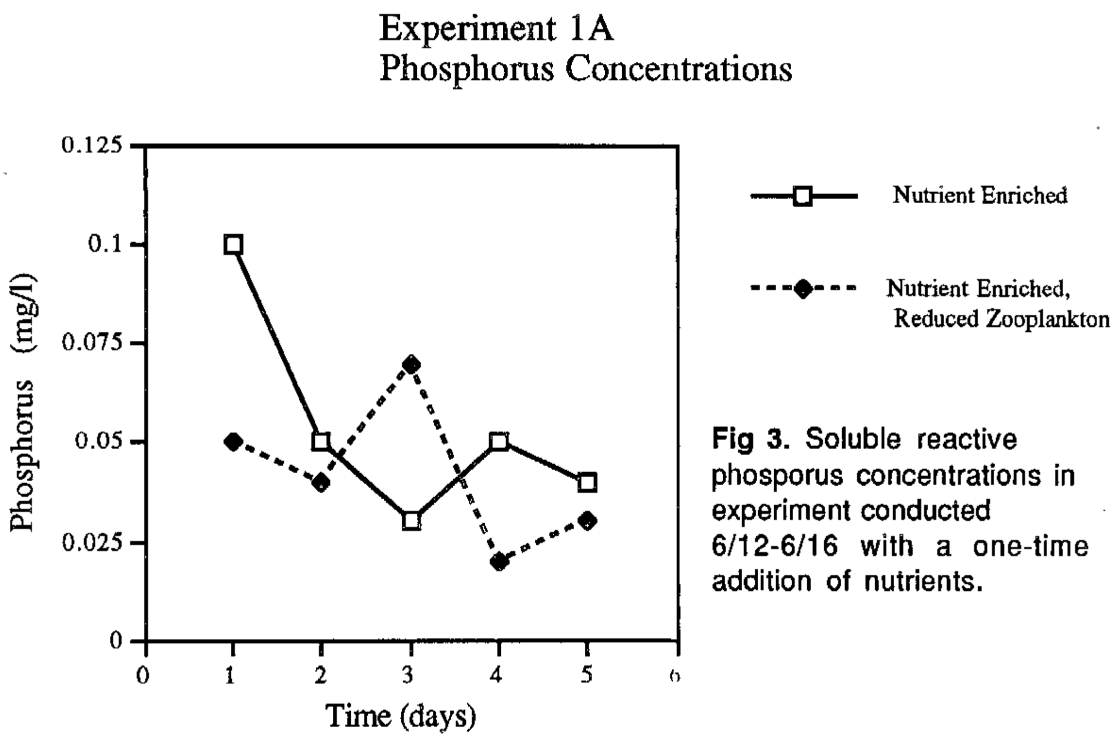

Fig 3. Soluble reactive phosporus concentrations in experiment conducted 6/12-6/16 with a one-time addition of nutrients.

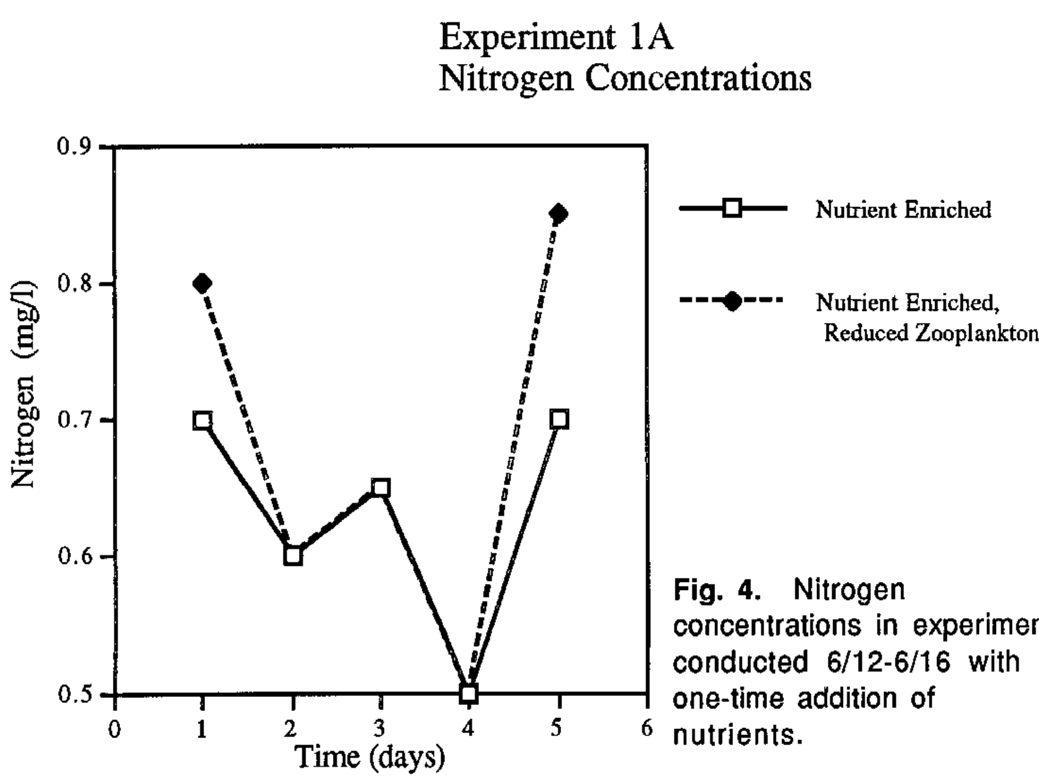

Fig. 4. Nitrogen concentrations in experiment conducted 6/12-6/16 with a one-time addition of nutrients.

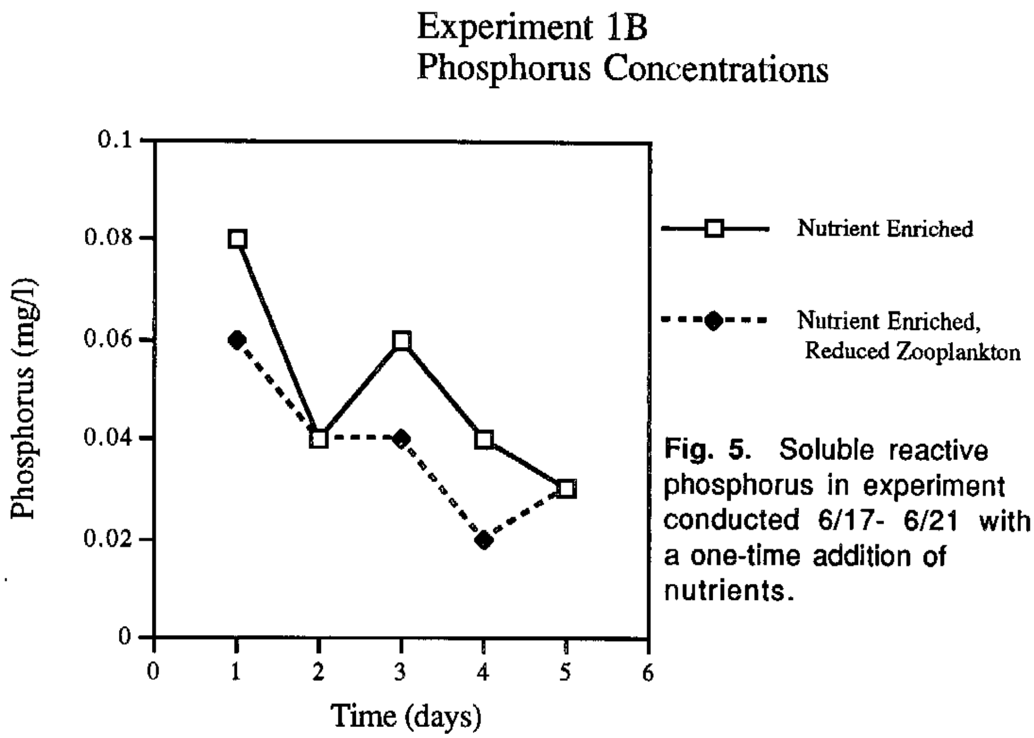

Fig. 5. Soluble reactive phosphorus in experiment conducted 6/17- 6/21 with a one-time addition of nutrients.

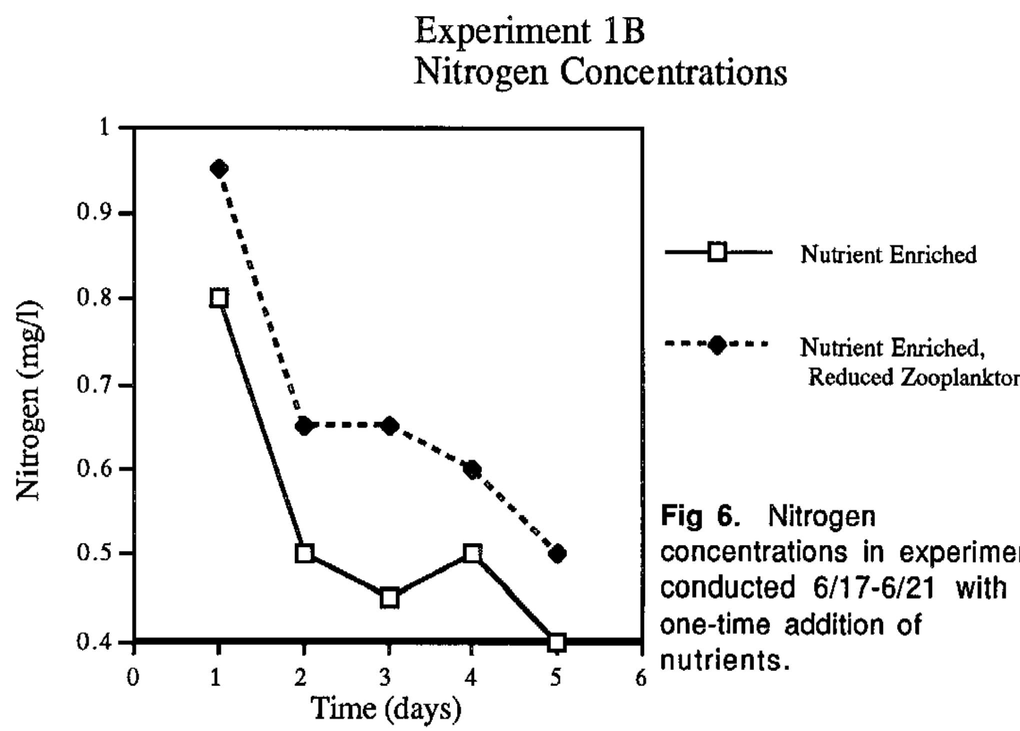

Fig 6. Nitrogen concentrations in experiment conducted 6/17-6/21 with a one-time addition of nutrients.

Experiment 2A
Chlorophyll *a* Concentrations

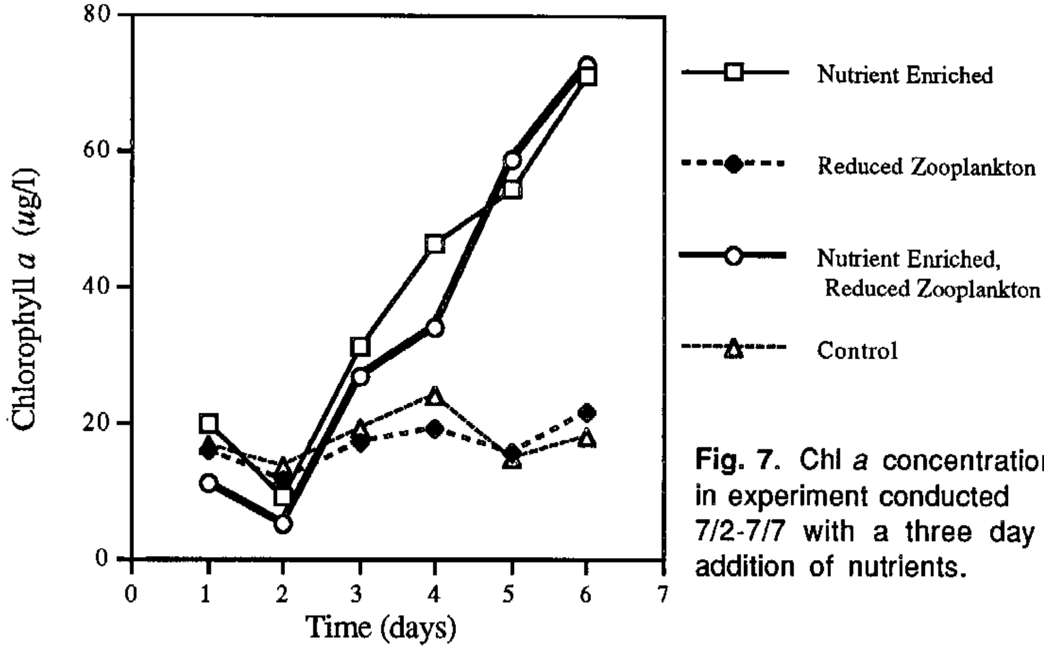

Fig. 7. Chl *a* concentrations in experiment conducted 7/2-7/7 with a three day addition of nutrients.

Experiment 2B
Chlorophyll *a* Concentrations

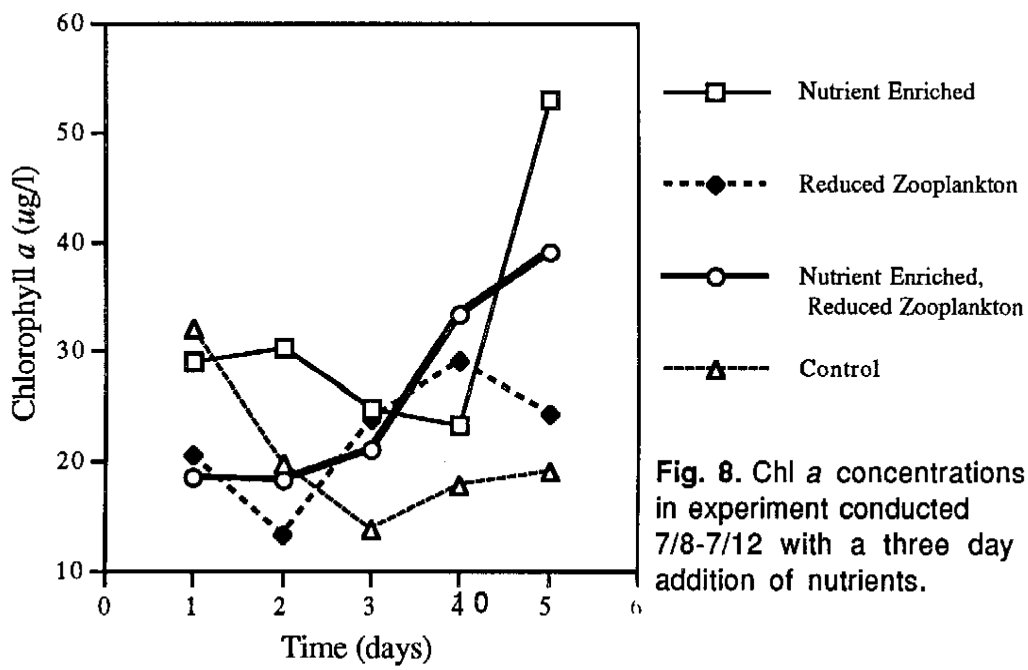

Fig. 8. Chl *a* concentrations in experiment conducted 7/8-7/12 with a three day addition of nutrients.

Algal Response to Nutrients, Herbivory

There was a much greater chlorophyll response to the three day addition of nutrients (Exp. 2A and 2B) than to the experiment with one addition in Exp. 1A and Exp. 1B (Fig. 1,2,7,8). The chlorophyll levels were still increasing at the end of the experiment (day 6) and did not level off or decrease as in Exp. 1A and Exp. 1B.

The nitrogen levels in Exp. 2A and Exp. 2B increased greatly the first three days and then fell off the following days (Fig. 9, Fig. 10). In both experiments the nitrogen level was higher for the first three days in the mesocosms with a reduced zooplankton concentration than in the mesocosms with a normal zooplankton population. After the fourth day the nitrogen level was slightly higher in Exp. 2A in the normal zooplankton mesocosm than in the reduced zooplankton mesocosm.

The phosphorus concentrations were irregular in Exp. 2A, decreasing for two days then increasing then decreasing again (Fig. 11) In Exp. 2B they increased for the first three days and then decreased the following three days (Fig. 12).

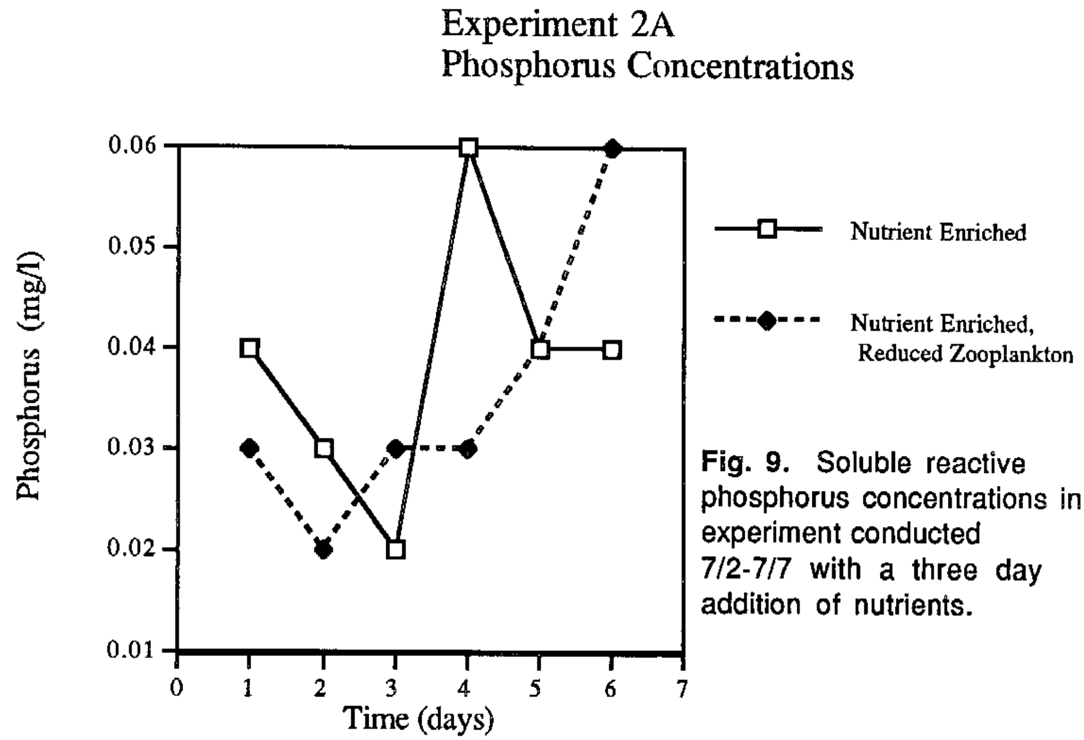

Fig. 9. Soluble reactive phosphorus concentrations in experiment conducted 7/2-7/7 with a three day addition of nutrients.

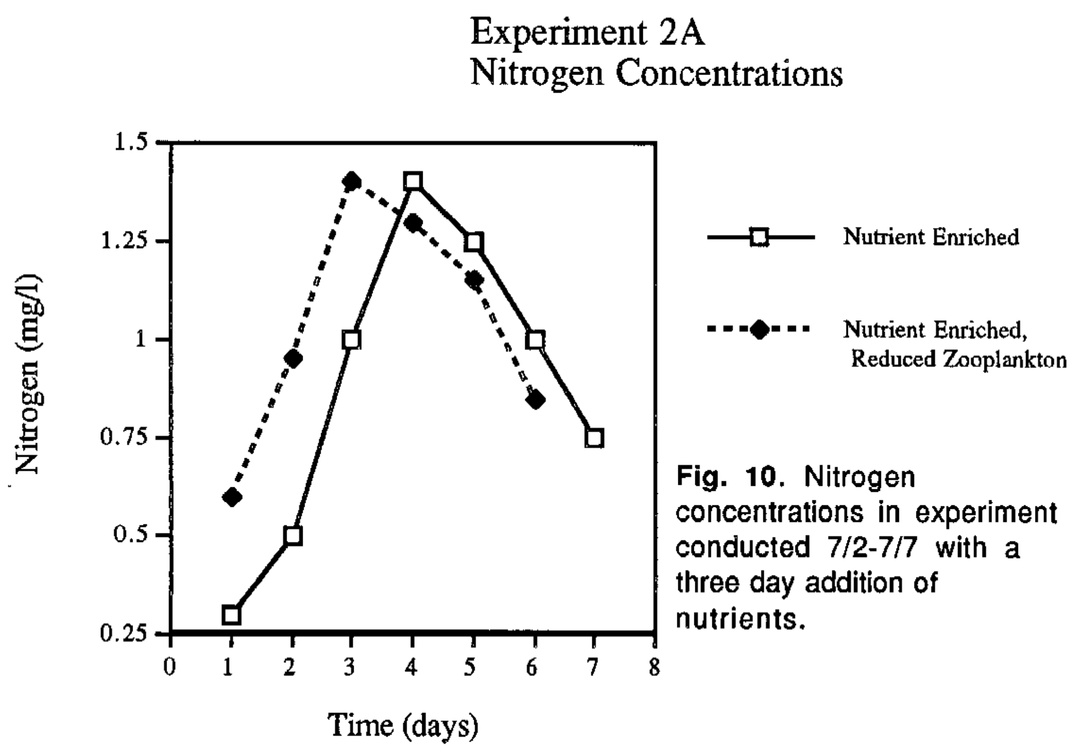

Fig. 10. Nitrogen concentrations in experiment conducted 7/2-7/7 with a three day addition of nutrients.

Experiment 2B
Phosphorus Concentrations

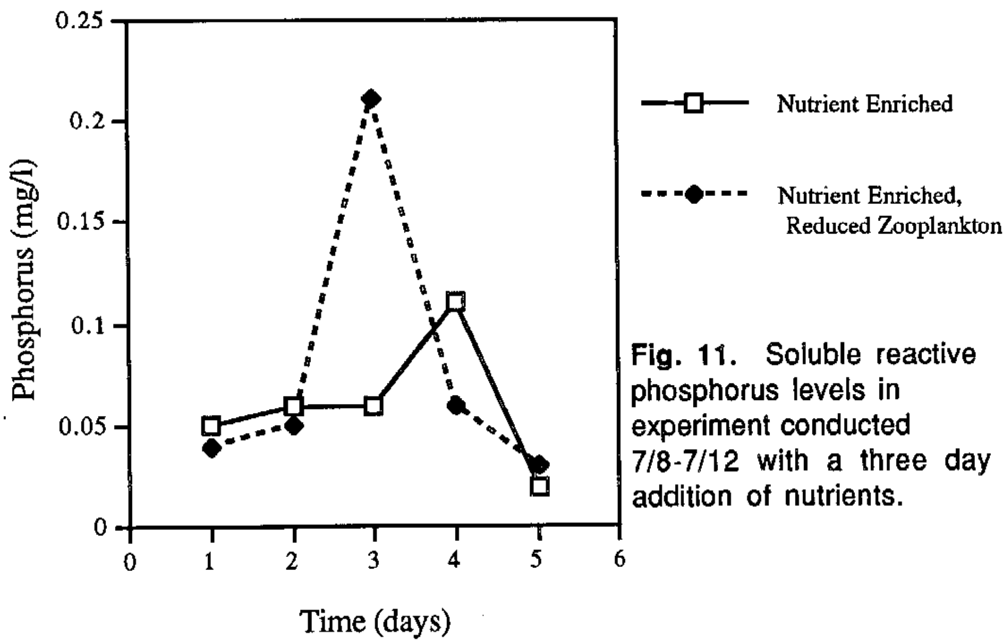

Fig. 11. Soluble reactive phosphorus levels in experiment conducted 7/8-7/12 with a three day addition of nutrients.

Experiment 2B
Nitrogen Concentrations

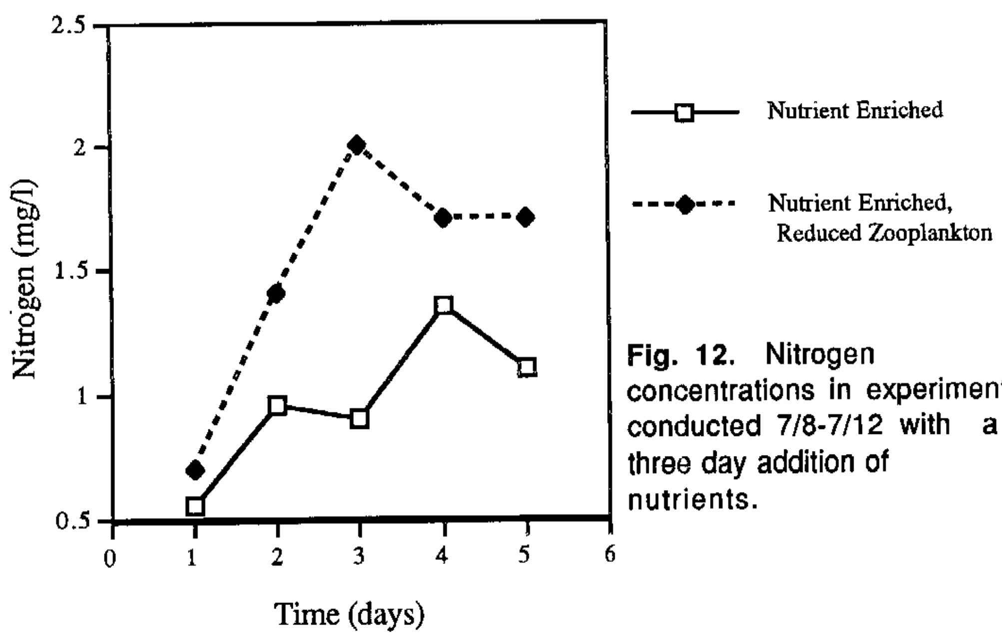

Fig. 12. Nitrogen concentrations in experiment conducted 7/8-7/12 with a three day addition of nutrients.

DISCUSSION

As found in other studies, nutrient enrichment increased phytoplankton chlorophyll, but the increase was somewhat reduced in the mesocosms of normal zooplankton levels. The greatest chlorophyll response was found in the mesocosms that had nutrient additions and zooplankton reduction. In the absence of herbivory and the removal of nutrient limitation, the phytoplanktonic communities thrived.

Nutrient regeneration by zooplankton (that is, excretion of nutrients, making them available to nearby phytoplankton) may affect phytoplankton communities, depending on the regeneration rates of specific nutrients and the requirements of the different phytoplanktonic species (Lehman and Scavia,1982). This might be why the nutrient enriched mesocosms in Exp. 2A and Exp. 2B showed a higher chlorophyll concentration than the nutrient enriched bags with low zooplankton populations even though herbivory was reduced (Fig. 7, Fig. 8).

Two zooplankton effects were displayed: nutrient recycling, which stimulated algal growth at low levels of zooplankton biomass, and grazing losses, which reduced standing crop when zooplankton grazing pressure was high. So the reduction of zooplankton gave the phytoplankton the nutrients they need while also taking away the danger of herbivory.

The chlorophyll *a* levels were much higher in Exp. 2A and Exp. 2B, than in Exp. 1A and Exp. 1B, which shows that the phytoplankton had a greater response to repeated nutrient additions than just a one-time addition (Fig. 1,2,7,8). One future study that could come from this is to compare the phytoplankton communities in mesocosms that had the same amount of total nutrients added; one with small nutrient additions daily and the other with the entire nutrient addition in the beginning.

The results of our additions of nitrogen and phosphorus provided some evidence that algae were phosphorus limited in their natural lake environment. Soluble reactive phosphorus was taken up fairly rapidly when it was made available (Fig. 3, Fig. 5). Figure 6 shows that nitrogen was also taken up, although figure 4 displays an interesting increase in nitrogen concentration on day 5 of Experiment 1A. This is probably due to some foreign material (for example: bird excretion or insect remains) that was introduced into the mesocosm.

In Exp. 2A and Exp. 2B, the addition of nutrients for the first three days is shown as a substantial increase in the nitrogen concentrations (Fig. 10, Fig. 12). This is what was expected. The phosphorus, on the other hand, seemed to be taken up rapidly in the first three days and then increased inexplicably (Fig. 9). This again, could be due to some foreign substance that was introduced into the mesocosm.

In order to decrease artifacts and to have the data to analyze statistically, these experiments should be conducted with more replication. One might also gain insight if it was conducted under a longer experimental time period. We also should have collected samples at the same time every day, but that was impossible in our situation. Some related experiments that could be conducted would include a mesocosm experiment with nutrient addition of nitrogen and phosphorus separately in different bags. One could also vary zooplankton size structures or look at how community structure changes both in phytoplankton and zooplankton populations.

In these experiments, bottom up trophic dynamics (nutrient addition) had a bigger impact on the phytoplanktonic communities than top down trophic dynamics (herbivory by zooplankton), although they both contributed. By measuring the trophic interactions in lake systems one can better understand the fundamental concepts about the functioning of lake ecosystems and the applicability of food web manipulation for water quality management (Gulati et al. 1990, Carpenter and Kitchell 1993).

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