The Impact of Nutrient Loading from Canada Geese (*Branta canadensis*) on Water Quality, a Mesocosm Approach

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ABSTRACT

We conducted a mesocosm experiment to determine the impact of Canada Goose (*Branta canadensis*) feces on water quality parameters. After 30 days of fecal additions (treatments of 2.419 g, 1.209 g and 12.090 g every 3 d) we found no significant impact on soluble reactive phosphorus, total phosphorus, ammonia, nitrate, total Kjeldahl nitrogen, chlorophyll-*a*, phycocyanin or turbidity for any of the treatment groups versus the control (no fecal addition). Nitrogen to phosphorus ratios were not affected by the fecal additions. Although there was no significant increase in chlorophyll-*a* concentration or phytoplankton biovolume, there was an increase in phytoplankton counts in the high treatment group. Phytoplankton diversity (using the Shannon index of diversity) was significantly decreased by the addition of goose feces ($H_1'=0.575$, $H_2'=0.433$, $t=17.43$, $p<0.001$, where H_1' is the control and H_2' is the 12.090 g treatment). We performed a settling experiment which suggested that nutrients in goose feces settle to the sediment quickly, prohibiting uptake by phytoplankton which explains the apparent lack of impact of fecal additions on water quality. Since most of the nutrients in goose feces settle to the sediment, it is likely that the impact of the nutrients will not become evident until a mixing event occurs or a benthic food web passes them to the organisms of the water column.

BIOGRAPHICAL SKETCH

The author was born [redacted] in Rochester, NY. He attended received his BS degree (1997) and MS degree (1999) from Cornell University. Upon completion of the MS degree he began teaching high school science, first at Beverly High School in Massachusetts, then at Penfield High School near Rochester, NY. He completed a Master of Science degree at the State University of New York at Brockport in the Spring of 2006 and began doctoral studies at the University of Rochester in the Fall of 2006.

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INTRODUCTION

In the midst of one of the greatest periods of extinction in the history of earth, there are a few species that seem to be doing extremely well. The Canada Goose (*Branta canadensis*) is one such species. Populations are growing at an exponential rate in many areas of the Northeast (Ankney, 1996). Several subspecies of Canada goose reside in western New York including the Mississippi Flyway Giant (*B. canadensis maxima*), Atlantic (*B. canadensis canadensis*) and Southern James Bay (*B. canadensis interior*) (U.S. Fish and Wildlife Service 2003). All populations of the subspecies increased (between 4 and 19 percent) in the Northeast from 2002 to 2003 except Southern James Bay Canada geese, which decreased less than 1% (U.S. Fish and Wildlife Service 2003). The causes of the increase include changes in agricultural land use, such as the development of rice fields in Texas and Louisiana or cereal grains in the Midwest and northeast, which ultimately increase the amount of available food for geese along the flyways (Abraham and Jeffries 1997).

With the increase in the goose population in North America, several major impacts on lake ecosystems have been suggested or demonstrated. These include, but are not limited to, greater abundance of pathogens, excess nutrients in the water column, nutrient stimulation of phytoplankton populations, changes in phytoplankton species composition, and the development of Cyanobacteria blooms and the related production of cyanotoxins (Pettigrew et al. 1998; Manny et al. 1975 and 1994; Kitchell et al. 1999; Marion et al. 1994; Harris et al. 1981; Bédard and Gauthier 1986). Schindler (1971) demonstrated that experimental additions of phosphorus and

nitrogen over a period of 17 weeks caused both an increase in algal biomass and changes in phytoplankton community structure. Much work has recently focused on contribution from sources other than humans such as agriculture (Makarewicz et al. 1990, 2002), fish (Perrson 1997), and nutrient cycling from the sediment (Rydin 2000, Baldwin et al. 2002). The two most comprehensive studies of waterfowl as nutrient vectors come from Manny et al. (1975 and 1994) at Wintergreen Lake, MI, and a series of studies at Bosque del Apache National Wildlife Refuge, NM, most notably Post et al. (1998) and Kitchell et al. (1999). At Wintergreen Lake, Canada geese added approximately 4,400kg (dry weight) of feces per year. The geese contributed 69%, 29% and 70% of the total load of carbon, nitrogen and phosphorus to the lake, respectively (Manny et al. 1994). At Grand-Lieu, France, Marion et al. (1994), found much lower percentages of nitrogen (0.7 to 0.4%) and phosphorus (2.4 to 6.6%), which were contributed by mostly European starlings (*Sturnus vulgaris*) and mallards (*Anas platyrhynchos*). However, unusually high pollution from agriculture and untreated sewage probably decreased the relative proportion of birds (Marion et al. 1994). At Lake 18d in Bosque del Apache, individual snow geese (*Anser caerulescens*) provided 3.15 g nitrogen per day and 0.45 g phosphorous per day by defecation, which amounted to about 40% of all nitrogen and 75% of all phosphorus addition to this system (Kitchel et al. 1999). Perhaps more important, different food types affected nutrient loads. Some forage had relatively low energy content and thus greater consumption rate, but a similar nutrient content that led to higher loading of nutrients to the lake system. For example, foraging on alfalfa

(*Medicago sativa*) produced feces that five times as much nitrogen and 2.6 times as much phosphorus to the lake system than from geese eating corn (*Zea mays*), and may have affected phytoplankton community composition (Kitchell et al. 1999).

Several research issues and gaps exist in the literature on the impact of geese populations on lake ecosystems. In this study, we tested several hypotheses through intermediate-duration mesocosm experiments. These included:

1. Water chemistry parameters, such as phosphorus, nitrogen and ammonia, are influenced by the addition of goose feces.

The small-scale (5 m by 5 m mesh frames) experimental study by Pettigrew et al. (1998) revealed no long-term increase in nutrient levels after the addition of goose feces. In contrast, larger scale (whole system) field studies (Manny et al. 1994, Post et al. 1998, and Kitchell et al. 1999) suggested that geese contribute significant amounts of nutrients to freshwater systems. We employed methodology similar to Pettigrew et al. but used higher fecal loading rates based on those discussed in the larger scale field studies. Another difference between our study and that of Pettigrew et al. is that we added feces regularly (every 3 d) while Pettigrew et al. added feces in two pulses four weeks apart.

2: Phytoplankton biomass should increase due to phosphorus from fecal additions.

Pettigrew et al. (1998) suggested that nutrient concentration in the water did not increase after feces additions because those nutrients were quickly taken up by phytoplankton. Pettigrew's work suggested that phytoplankton biomass should increase with increasing addition of goose fecal material. Similarly, Watson's

general work on the response of phytoplankton to phosphorus indicated that total phytoplankton biomass increased exponentially with log TP (Figure 1). In the current study, we employed the mesocosm approach to test the hypothesis that an increase in phytoplankton biomass should be evident after fecal addition because of the increased loading of phosphorus and other nurients.

3: Phytoplankton diversity will decrease with increased total phosphorus from fecal additions.

The relationship between phytoplankton species composition and total phosphorus (TP) concentration is presented in Figures 1 and 2. Phytoplankton taxonomic diversity is greatest in oligotrophic lakes and decreases with increasing eutrophication. In hypereutrophic lakes (approaching TP = 3.0 μg/L), phytoplankton were exclusively Cyanobacteria. Significant loss of phytoplankton diversity appears to occur when TP reaches concentrations typical of eutrophic lakes, as Cyanobacteria levels increase. This general pattern is consistent with other studies, however, species richness peaks at a slightly greater levels in some studies (see Dodson et al., 2000). We tested the hypothesis that addition of goose fecal material will decrease phytoplankton diversity.

4: Low N:P ratios caused by the addition of goose feces will lead to an increase in Cyanobacteria populations.

At Lake 18d in the Bosque Del Apache National Wildlife Refuge, nitrogen to phosphorus ratios in inflow water was 37:1, while goose feces contained ratios of 8:1 (Post et al. 1998). In freshwater systems, where phosphorus and nitrogen can act as

limiting factors, changes in nutrient ratio may increase Cyanobacteria as they thrive in low nitrogen to phosphorus ratio conditions. By adding phosphorus and keeping nitrogen constant, N:P ratios decrease, driving the community towards domination by Cyanobacteria which thrive at N:P ratios below 29:1 (Post et al. 1998). In lakes with high goose population densities and therefore high rates of nutrient loading, nutrient ratios (especially nitrogen to phosphorus) may provide conditions advantageous to harmful and nuisance phytoplankton such as Cyanobacteria. We tested the hypothesis that addition of goose fecal material will alter N:P ratios and lead to Cyanobacteria blooms is tested.

5: Increased nutrients and changes in nutrient ratios will lead to increases in toxic Cyanobacteria and therefore increases in cyanotoxin concentrations.

After the deaths of 76 people in Brazil from ingestion of cyanotoxins (Carmichael et al. 2001) concern has developed that goose-induced changes in nutrient ratio may lead to Cyanobacteria blooms and production of cyanotoxins. Two cyanotoxins are often associated with Cyanobacteria populations. Anatoxin-*a* is a neurotoxic alkaloid produced by *Anabaena flos-aquae* that acts as an acetylcholine agonist, stimulating the nerve, and inhibiting acetylcholinesterase (James and James 1993). Microcystins are cyclic hepatotoxins produced mostly by the genus *Microcystis*. Microcystin-LR is a protein phosphatase (PP-1 and PP-2A) inhibitor, which leads to hepatic hemorrhage (Dawson 1998). Both toxins have also impacted fish species (see Kopp and Heteša 2000). The logical connection between an increase in Cyanobacteria and an increased threat from cyanotoxins has not been investigated in the context of fecal

loading from geese. We monitored microcystin levels anticipating a Cyanobacteria bloom in mescocosms with additions of goose fecal material.

METHODS

Experimental Design

Mesocosm Setup

We placed mesocosms, modeled after Schindler *et al.* (1971), in pond number four, one of the eight experimental ponds at SUNY College at Brockport. Each mesocosm, constructed of *Layflat Polyethylene Tubing* (Action Plastic Sales, Minneapolis, MN), extended from 4 cm above the water's surface and were anchored into the sediment (a depth of 1.8 m) by two concrete blocks (Figure 3 and 4). At both ends the mesocosms were framed by 1.27 cm (0.5 in.) PVC piping formed into a circle and attached to the tubing with duct tape. Each mesocosm was supported by a square of 10.16 cm (4.0 in) PVC piping (Figure 5). Buoyant pipe insulation was attached to the PVC circle to provide further buoyancy, and the entire system was tethered to trees at three sides of the pond for additional stability.

Sampling Regimen

We took sixteen sets of samples in the morning from a small rowboat, one every third day (28 June 2004 to 12 August 2004) before fecal additions. Microcystin was measured less regularly due to mechanical difficulties with sampling equipment. We measured water temperature in each mesocosm using a YSI thermometer probe. Secchi depths were recorded before samples were taken to minimize the impact of the

sampling disturbance on transparency. Water samples for turbidity, conductivity, pH, alkalinity, nitrate-nitrogen (NO_3-N), ammonia (NH_3), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll-*a*, phycocyanin, total coliform and *Escherichia coli* measures were taken with a vertical Van Dorn bottle at a depth of 1m. We placed Chlorophyll-*a* samples in opaque bottles. Both SRP and NO_3-N water samples were filtered using a Magna 0.45 µm nylon filter and frozen. We collected Coliform samples in sterile 50 mL centrifuge tubes. Phytoplankton samples were also taken with the vertical Van Dorn bottle, preserved in 25% glutaraldehyde, and kept in the dark. Zooplankton samples were collected using a 12 L Schindler trap and preserved in 10% buffered formalin acetate.

For microcystin, we used a pump to filter pond water through a Whatman 1.5 µm glass microfibre filter until the filter clogged. We returned the filtrate to the appropriate mesocosm to ensure that nutrients in the water were not lost. The residue and the filter were placed in a 50 ml centrifuge tube. On occasions when the pump was not working correctly, 20 L samples were transported to the lab and filtered using a vacuum pump. We placed all samples on ice in a cooler for transport back to the lab, except for microcystin, SRP and NO_3-N samples, which were frozen in a cooler of dry ice immediately and zooplankton and phytoplankton samples which were kept at ambient temperature.

Experimental Setup

We arranged the six mesocosms in a two-by-three pattern with PVC square frames attached to each other. Fecal additions were assigned to mesocosms using a random number generator. Two of the mesocosms received no feces (control), two received moderate fecal loading (50% of peak season) and two received 100% of peak season estimates (Figure 6 and Appendix A). After 15 d with little change in chlorophyll-*a* or TP, we changed the 50% treatments to 500% on 25 July 2004.

Fecal Additions

Manny et al. (1975) found that migrant geese defecated an average of 28 times d^{-1} with an average fresh and dry dropping weight of 5.56 g and 1.17 g per event, respectively. Kear (1963) estimated Atlantic Canada Goose dropping frequency at 92 d^{-1} with an average dry weight of 1.9 g. Using the more conservative estimates of Manny, we calculated experimental loading in each mesocosm receiving full feces to be 0.806 g wet weight per day. This value was based on "typical" geese abundance and water volume (Table 3 and Appendix 1). Feces were collected from local roosting areas (e.g., Cobb's Hill Park in Rochester, NY) and analyzed for nitrate-nitrogen, ammonia, total Kjeldahl nitrogen, soluble reactive phosphorus, total phosphorus, fresh weight and coliform. Fresh feces were stored in a watertight container and added every 3 d for 33 d (10 July 2004 to 12 August 2004) in a 1 liter slurry and mixed gently by lowering and raising a small desk fan blade.

Sample Analysis

Water Chemistry Analysis

See Table 4 for parameters measured and associated methodology.

Coliform Analysis

We filtered Coliform samples through a 0.45 µm sterile Millipore filter and plated them on absorbent pads with m-coliblue24 broth and incubated for 24 h at 36° C. Total coliform colonies appeared red while *E. coli* colonies appeared blue. We diluted most samples to 20% in order to increase colony resolution and counted colonies using a stereo microscope (Millipore Corporation, 1991).

Microcystin Analysis

We sonicated the frozen microcystin samples in 15 ml 50% methanol for five 20 second pulses. Samples were centrifuged and the supernatant was filtered through a type A/E glass fiber filter. We used protein phosphatase inhibition assay to determine concentration of microcystin in the filtrate (Carmichael and An, 1999).

Plankton Analysis

We identified and quantified phytoplankton divisions on a Wild inverted microscope using procedures described in section 10200 of Standard Methods for the Examination of Water and Wastewater, 20th Edition and various algae keys (Prescott 1962, Ward and Whipple 1918, Prescott 1954, Dillard 1999, Wehr and Sheath Eds. 2003).

Statistical Analysis

For each parameter, we performed one-way ANOVAs on data for the first, middle and final four collection days in the experiment. We used the first four days to establish homogeneity between mesocosm tubes, the middle four to determine whether there was any impact of the 50% treatment and the final four to assess impact, if any, analysis of the 100% and 500% (increased from 50% early in the experiment) treatments. In each of these analyses, we considered each mesocosm individually and did not average values for identical treatments (n=7). When ANOVA indicated significant differences, we performed Tukey Multiple Comparison tests for the treatments.

We also plotted each parameter against date with error bars representing two times the standard error of the mean of the seven data points (pond, two 0%, two 100% and two 50/500% treatments) for that date (Figures 7 to 20). Five parameters were also plotted against feces added (proportional to total phosphorus added – 1 g feces contains 3.147 mg total phosphorus) (Figures 21 to 25). In these plots, only those treatments that received feces are included.

In order to examine the impact of seasonal fluctuations in water chemistry parameters, we performed multiple regression analysis for feces added and date.

We analyzed the microcystin data using a Kruskal-Wallis test performed between the all four treatments (including the pond) and the three mesocosm-based treatments alone. Using a paired t-test, we looked for differences between microcystin levels at the beginning and end of the experiment.

We used the Shannon index of diversity ($H' = -\Sigma p_i \log(p_i)$) to measure diversity in each sample and the samples were compared using a two sample t-test proposed by Hutcheson (Zar 1999). In order to compare the proportions cyanobacteria to the total phytoplankton, we used a hypothesis test about the difference between two proportions.

RESULTS

All nitrate-nitrogen measurements were non-detectable. Before the experiment started, only alkalinity ($p=0.049$), pH ($p<0.001$) and total coliform ($p<0.001$) were significantly different among mesocosms and the pond (Table 5). A Tukey Multiple Comparisons (Table 6) indicated significant differences in alkalinity between the pond and the 50% treatment ($p=0.035$) and in pH and coliform levels between the pond and the three treatments ($p<0.001$).

For the middle period of the experiment (7/19/05 to 7/28/05), a significant difference ($p=0.050$) in alkalinity (Table 7) existed among treatments and Secchi depth and chlorophyll-*a* approached significance. However, a Tukey Multiple Comparison (Table 8) found no significant differences between individual treatments. For the final four dates (Table 9), significant differences were found for SRP ($p=0.040$), turbidity ($p=0.019$), secchi depth ($p=0.001$) and total coliform ($p=0.045$). Tukey Multiple Comparisons (Table 10) revealed significant differences for turbidity between the pond and 100% treatment ($p=0.022$; 100% treatment is higher) and for

Secci depth between the pond and the all treatments ($p=0.008$ for 0% treatment, pond had a greater average depth; $p=0.038$ for 100% treatment, pond had a greater average depth; $p<0.001$ for the 500% treatment, pond had a greater average depth). Therefore, water clarity was decreased and the amount of suspended organic material was increased by the addition of goose fecal material.

We plotted data for each water chemistry parameter against time for all sample dates for all treatments (Figures 7 to 20). These data demonstrate that significant differences did not occur among the treatments during periods not considered by ANOVA. For example, Chlorophyll-*a* (Figure 10) appears to be high at the beginning of the experiment, but later settled to within the error range, almost as soon as the 50% level was increased to 500%. All other fluctuations above and below the error range were erratic and short-lived. Phycocyanin (Figure 13) increased throughout the experiment for all treatments, but there was very little distinction between treatments. The Secchi depth (Figure 15) for the pond was consistently greater than the treatment groups. Total phosphorus (Figure 20) was highest for all treatments shortly before fecal additions began (7/10), and took about 12 d to decrease, and was relatively constant for the last 20 d. All other parameters failed to show any patterns, but many seemed to follow a parabolic shape, beginning high, then decreasing until the middle of the experiment, then increasing again at the end.

Initial plots of the five parameters against feces added (Figures 21 to 25) may be misleading since normal seasonal changes (from June to August) were not taken

into account. Multiple regression analysis (Table 11) showed that there was a significant negative relationship (B=-76.371, t=3.960, p<0.001) between date and total phosphorus (as expected based on Figure 20). Phycocyanin exhibited a significant positive relationship to date (B=2.621, t=4.667, p<0.001). Although the scatter plot of phycocyanin versus feces added (Figure 22) seemed to indicate a relationship between feces added and phycocyanin, the multiple regression analysis indicated that date is the significant factor in the relationship. Since feces were added regularly every three days, the relationship between feces added and phycocyanin appeared to be significant when in fact it was only an artifact. Feces added had a marginally significant impact on Secchi depth, although the slope was near zero (B=5.07E-03, t=2.016, p=0.050, Table 11). Total Coliform was dependent on date (B=93.104, t=3.516, p=0.001) and feces added (B=-33.379, t=-2.547, p=0.014). Total Kjeldahl nitrogen was significantly impacted by both date (B=-18.283, t=-2.877, p=0.006) and feces added (B=8.418, t=2.676, p=0.010), but again with opposite slopes. Finally, feces added had a significant negative impact on turbidity (B=-0.116, t=-3.028, p=0.004).

Microcystin

Microcystin samples collected on the last two sampling days of the experiment were analyzed. The average concentration for all treatments was 0.025 mg/L (0.004, 0.017, 0.053 and 0.015 for the pond, 0%, 50/500% and 100% treatments respectively). A Kruskal-Wallis test determined that there was no significant difference among the four treatments (Chi-square=5.742, df=3 p=0.125) or the three

mesocosm-based treatments (Chi-square=1.417, df=2, p=0.492). Furthermore, a paired t-test found no significant difference between samples at the beginning and end of the experiment. (t=0.198, df=12, p=0.846). Because there were no significant differences, microcystin samples collected during the middle of the experiment were not analyzed.

Upon visual examination of the mesocosms, there were no obvious differences among the six treatments.

Phytoplankton Diversity

We determined phytoplankton diversity on for the final day of the experiment in the pond and 50/500% treatments (Table 12 and Figures 26 and 27). The 50/500% treatment had an average count (cells/mL) of nearly three times the average from the control treatment (Figure 26). Much of that difference was due to an increased presence of chrysophytes and unidentified flagellates. The biovolume (μm^3/mL) of each treatment actually showed the opposite: the control had a greater volume than the 50/500% treatment (Figure 27) with pyrrophytes greater in the control and chrysophytes again greater in the 50/500% treatments. Overall diversity, based on phytoplankton counts, (Shannon index of diversity) was significantly higher in the control group compared to the 50/500% treatment ($H_{control}$'=0.575, $H_{50/500\%}$'=0.433, t=17.43, p<0.001). We did not determine phytoplankton diversity for the 100% treatment.

DISCUSSION

We found that the fecal additions had almost no impact on water quality. The only parameters that were found to be significantly different ny ANOVA from the pond after the fecal additions were Secchi depth and turbidity. Multiple regression analysis found that date was the best predictor of many of the water chemistry parameters. Phytoplankton diversity and biomass (chlorophyll-*a*) decreased with increased fecal loading. Cyanobacteria as a proportion of the total phytoplankton community did increase with fecal additions, but microcystin was not impacted.

At least two schools of thought exist about the impact of waterfowl on water quality. The first, the impact school, based on the work of Manny et al. (1975 and 1994), Harris et al. (1981), Post et al. (1998) and Marion et al. (1994), is that waterfowl contribute significant nutrients in some freshwater systems. Each study estimates the percent contribution of nitrogen and phosphorus by birds to reach as high as 40% of nitrogen and 75% of phosphorus input to a lake. Accordingly, this level of fecal loading must lead to changes in water quality parameters, nutrient ratios, phytoplankton abundance and species diversity. The second view, the non-impact school, suggests that there is little or no impact from waterfowl fecal loading (Pettigrew et al. (1998) and Bédard et al. (1980)). Support for this hypothesis results from field-based experimental evidence. In this study, we attempted to bridge the gap between the two schools of thought by using fecal loading rates derived from the work of the "impact school" while employing an experimental design similar to that of the "non-impact school".

My results support the "non-impact" school of thought. Waterfowl fecal loading had little or no impact on water quality or phytoplankton. Over 213 mg of phosphorus was added to the 50/500% mesocosms during the experiment. Ambient levels of P as fecal material should have reached 262.7 µg P/L, but this was not observed. Total phosphorus levels never exceeded 156.4 µg/L (other than anomalous high levels before additions began) and ended at 30.3 µg/L in mesocosm 2 and 43.0 µg/L in mesocosm 6. Fecal material was added as slurry from the surface and mixed with a suspended fan blade. No tears or rips of the mesocosm were observed. Therefore, the added phosphorus must have either sunk through the mesocosm to the bottom or been taken up and passed through aquatic food web.

Despite the slurry form of the fecal additions and mixing with a fan blade, it is likely that most of the nutrients and organic material and nutrients in the mesocosm simply sank to the bottom of the pond. A laboratory settling experiment supported this suggestion. Fecal slurry, as created for the field experiments, was added to a column of water (1900 ml, approximately 500 mm) and turbidity measured over 3 days. Turbidity decreased exponentially ($y = 4.7491e^{-0.0078t}$, $R^2=0.9706$) with time in hours (Figure 28). In fact, within 100 min of the fecal addition, turbidity decreased from 101 NTU to 4.84 NTU. Unfortunately, nutrient loading into the sediment at the bottom of the mesocosms was not measured. It important to note that the method of fecal loading by slurry used in this study much was more likely to dissolve in water than "fecal" inputs from a goose which would likely sink.

Pettigrew et al. (1998) also concluded that phosphorus and nitrogen did not remain in the water column after nutrient additions. Nutrients were assimilated by plankton, adsorbed into the sediment or denitrified (nitrogen only). It is likely nutrient concentration in sediments would be similar in all mesocosms, and therefore difficult to differentiate, since the bottom of the pond was largely decaying plant material (similar to the contents of the feces). If the fate of most of the fecal nutrients is to end up in the sediment, the impact of those nutrients on water quality may not be manifested until a mixing event occurs. Although the mesocosms were gently mixed with a fan blade with each addition of slurry, this was probably not enough to free nutrients from the sediment. Nutrients may have also passed quickly through the food web and ended up in zooplankton communities, but there is no evidence for this in either water chemistry data or phytoplankton community data.

The differences in water chemistry parameters (Secchi depth and turbidity) among the treatments were likely artifacts of the mesocosm approach. The Secchi depth (Figure 15) for the pond was consistently greater than the treatment groups, most likely because the mesocosms, although clear plastic, blocked some sunlight. The explanation for greater pond secchi depth is partially supported by the turbidity measurements (Figure 16) which were highly variable, but did not show consistently higher measurements in the pond. Since the pond and the control mesocosm were significantly different according to a Tukey Multiple Comparison test, the lack of water flow or sunlight is the most plausible reason for the observed differences.

Phytoplankton diversity did decrease with the increased total phosphorus load from fecal additions (Table 12). We predicted that phytoplankton biomass would increase with increased total phosphorus from fecal loading as fecal-produced phosphorus was taken up by phytoplankton. However, the experimental results indicate that chlorophyll-*a* actually decreased (Figures 10 and 21) suggesting that phytoplankton are not a sink for phosphorus.

The expectation that cyanobacteria would dominate the community in the 50/500% treatments was not realized as the N/P ratio in experimental columns did not change significantly (Figure 29). Average cyanobacteria counts (cells/mL) were significantly higher ($z=11.12$, $p<0.001$) as a proportion of total phytoplankton in the 50/500% treatments while biovolume was actually less ($z=25.02$, $p<0.001$) (Table 12). In fact, no cyanobacteria were found in mesocosm 6 (one of the 50/500% treatments). It follows that no increase in cyantoxins was observed.

Much of the work of the "impact school" (Manny et al. 1974 and 1994, Scherer et al. 1995, Kear 1963) was based on large lakes and bays and may not provide an accurate measure of the per capita impact of geese on smaller ponds with reduced volume and flow rates. Those studies never claimed an changes in water chemistry or phytoplankton community from nutrients additions, simply that the nutrients were being added in significant amounts even in large lakes.

Future Research

The logical follow-up to this study is to examine the impact of feces on the sediment. The first question to be addressed is whether or not the nutrients added in feces can be accounted for in the sediment. This type of study may be difficult in ponds since sediment levels of nutrients are likely very high. Stable isotope studies would allow researchers to track the path of specific nutrients. If nutrients are ending up in the sediment, then the next question to examine is what happens to those nutrients during a mixing event. If the nutrients are released into the water column then some of the original concerns discussed in this study may again be relevant. Finally, if there is a significant amount of loading to the sediment, then is there a change in the sediment community and the detritus food web? These bottom-up (both trophic and depth) effects may lead to significant changes in water chemistry and plankton community structure.

CONCLUSIONS

In the short term nutrient loading by geese seems to have no measurable impact on water quality in the mesocosms, but the limited impact on the phytoplankton community is difficult to explain. We suggest that the bulk of the nutrients contained in the feces simply sank to the sediment where they either became part of a benthic detritus food web or cycled back into the water column during a mixing event. Because Cyanobacteria populations were unaffected by fecal loading, we therefore observed no increase in cyanotoxin concentrations in the high treatment groups.

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Table 1: Relative proportions of nutrient loading to lakes from various sources; omits nitrogen fixation and groundwater flow (from Post et al. 1998).

Nutrient Loading Source	% Nitrogen	% Phosphorus
Surface Flow	59	25
Atmospheric	<1	0
Geese	40	75

Table 2: Trophic status of lakes based on total phosphorus concentration (Watson et al. 1997).

Trophic Status	TP	Log TP
Oligotrophic	0-10µg/L	<1µg/L
Mesotrophic	10-30µg/L	1-1.48µg/L
Eutrophic	30-100µg/L	1.48-2µg/L
Hypereutrophic	>100µg/L	2µg/L

Table 3. Goose fecal loading rates from four studies (geese m^{-2} and m^{-3} are the number of geese per square meter and cubic meter in each study).

Study	**Manny (1975)**	**Marion (1994)**	**Oliver (1998)**	**Post (1998)**
Water Body	Wintergreen Lake	Lake Grand-Lieu (France)	Okefenokee	Bosque del Apache NWR
# of Geese	2100	1,728,300 (all birds)	8000	40,000 lesser & snow geese
Area (m^2)	150,000	63,000,000	1.8×10^9	4,940,000
Volume (m^3)	350,239	ND	ND	ND
Geese m^{-2}	0.014	0.027	4.4×10^{-6}	8.1×10^{-3}
Geese m^{-3}	6.0×10^{-3}	ND	ND	ND
Dropping mass ($g\ m^{-2}\ d^{-1}$)	2.18	4.20	6.8×10^{-4}	1.26
Dropping mass ($g\ m^{-3}\ d^{-1}$)	0.934	ND	ND	ND

Table 4. Methodology for water chemistry analysis (Wetzel and Likens 2000, American Public Health Association et al. 1998).

Parameter	Method	Notes
Chlorophyll-*a*	See Wetzel and Likens, 2000; Turner Model 111 Fluorometer	Analyzed day of sample
Phycocyanin	Turner TD-700 Fluorometer	
Conductivity	YSI Model 32 conductance meter	Analyzed day of sample
Alkalinity	See Wetzel and Likens, 2000; Titration to pH 4.5	Analyzed day of sample
pH	Beckman ΦpH meter and AccuTupH probe	Analyzed day of sample
Turbidity	Micro 100 Turbidimeter	Analyzed day of sample
Ammonia	Orion model 95-12 has ammonia sensing electrode	Analyzed within 3 days of sample
TKN	EPA Method 351.2 (Colorometric, Semi-Automated Block Digester, AAII).	Technicon Autoanalyzer (within 20 days)
NO_3^-	See Standard Methods: cadmium reduction method – 4500-NO_3^- F.)	Technicon Autoanalyzer (within 20 days)
SRP	See Standard Methods: automated ascorbic acid method 4500-P F.	Technicon Autoanalyzer (within 20 days)
TP	See Standard Methods: ascorbic acid method with persulfate digestion – 4500-P F. and 4500-P B.5	Technicon Autoanalyzer (within 20 days)

Table 5. ANOVA for averages over first four sampling dates (06/28/05 – 07/07/05) comparing four treatments for various parameters (listed above).

		Sum of Squares	df	Mean Square	F	Sig.
SRP	Between Groups	163.181	3	54.394	1.773	.179
	Within Groups	736.386	24	30.683		
	Total	899.567	27			
TP	Between Groups	163.181	3	54.394	1.773	.179
	Within Groups	736.386	24	30.683		
	Total	899.567	27			
NH3[a]	Between Groups	.263	3	.088	1.094	.371
	Within Groups	1.924	24	.080		
	Total	2.187	27			
NO3	Between Groups	.000	3	.000	.	.
	Within Groups	.000	24	.000		
	Total	.000	27			
TKN	Between Groups	571208.929	3	190402.976	2.829	.060
	Within Groups	1615162.500	24	67298.438		
	Total	2186371.429	27			
CHLA	Between Groups	394.341	3	131.447	1.579	.220
	Within Groups	1998.304	24	83.263		
	Total	2392.644	27			
PHYC	Between Groups	57.292	3	19.097	.316	.813
	Within Groups	1448.377	24	60.349		
	Total	1505.670	27			
Turbidity[b]	Between Groups	61.903	3	20.634	1.001	.409
	Within Groups	494.597	24	20.608		
	Total	556.500	27			
SECCHI	Between Groups	.095	3	.032	1.374	.275
	Within Groups	.554	24	.023		
	Total	.650	27			
Alkalinity[c]	Between Groups	126.713	3	42.238	3.021	**.049**
	Within Groups	335.523	24	13.980		
	Total	462.236	27			
pH[b]	Between Groups	1.071	3	.357	24.824	**.000**
	Within Groups	.345	24	.014		
	Total	1.416	27			
COLIFORM	Between Groups	4511747.607	3	1503915.869	24.541	**.000**
	Within Groups	1470785.250	24	61282.719		
	Total	5982532.857	27			

[a]Starts 7/7 and continues for 4 sample dates
[b]Starts 7/4 and continues for 4 sample dates
[c]Starts 7/1 and continues for 4 sample dates

Table 6. Tukey Multiple Comparison Tests for averages over first four sampling dates (06/28/05 – 07/07/05) comparing four treatments for various parameters. Significant differences are bold.

			Mean Diff. (I-J)	Std. Error	Sig.	95% Confidence Interval	
Dependent Variable	(I) TREATMENT	(J) TREATMENT				Lower Bound	Upper Bound
Alkalinity[a]	0%	50%	1.4225	1.86950	.871	-3.7347	6.5797
		100%	-1.3312	1.86950	.891	-6.4885	3.8260
		Pond	-5.2713	2.28966	.126	-11.5875	1.0450
	50%	0%	-1.4225	1.86950	.871	-6.5797	3.7347
		100%	-2.7537	1.86950	.469	-7.9110	2.4035
		Pond	-6.6938	2.28966	**.035**	-13.0100	-.3775
	100%	0%	1.3312	1.86950	.891	-3.8260	6.4885
		50%	2.7537	1.86950	.469	-2.4035	7.9110
		Pond	-3.9400	2.28966	.335	-10.2563	2.3763
	Pond	0%	5.2713	2.28966	.126	-1.0450	11.5875
		50%	6.6938	2.28966	**.035**	.3775	13.0100
		100%	3.9400	2.28966	.335	-2.3763	10.2563
pH[b]	0%	50%	.0400	.05996	.908	-.1254	.2054
		100%	.0100	.05996	.998	-.1554	.1754
		Pond	.5738	.07344	.000	.3712	.7763
	50%	0%	-.0400	.05996	.908	-.2054	.1254
		100%	-.0300	.05996	.958	-.1954	.1354
		Pond	.5337	.07344	.000	.3312	.7363
	100%	0%	-.0100	.05996	.998	-.1754	.1554
		50%	.0300	.05996	.958	-.1354	.1954
		Pond	.5637	.07344	.000	.3612	.7663
	Pond	0%	-.5738	.07344	.000	-.7763	-.3712
		50%	-.5337	.07344	.000	-.7363	-.3312
		100%	-.5637	.07344	.000	-.7663	-.3612
COLIFORM	0%	50%	-23.00	123.777	.998	-364.45	318.45
		100%	77.38	123.777	.923	-264.08	418.83
		Pond	-1123.38	151.595	.000	-1541.57	-705.18
	50%	0%	23.00	123.777	.998	-318.45	364.45
		100%	100.38	123.777	.849	-241.08	441.83
		Pond	-1100.38	151.595	.000	-1518.57	-682.18
	100%	0%	-77.38	123.777	.923	-418.83	264.08
		50%	-100.38	123.777	.849	-441.83	241.08
		Pond	-1200.75	151.595	.000	-1618.94	-782.56
	Pond	0%	1123.38	151.595	.000	705.18	1541.57
		50%	1100.38	151.595	.000	682.18	1518.57
		100%	1200.75	151.595	.000	782.56	1618.94

[a]The mean difference is significant at the .05 level.
[b]Starts 7/4 and continues for 4 sample dates

Table 7. ANOVA for averages over middle four sampling dates (07/19/05 – 07/28/05) comparing four treatments for various parameters. These are the last dates before the 50% treatment was changed to 500%. Significant differences are bold.

		Sum of Squares	df	Mean Square	F	Sig.
SRP	Between Groups	11.890	3	3.963	.440	.727
	Within Groups	216.300	24	9.013		
	Total	228.190	27			
TP	Between Groups	1466.492	3	488.831	.080	.970
	Within Groups	147264.583	24	6136.024		
	Total	148731.074	27			
NH3	Between Groups	.041	3	.014	.159	.923
	Within Groups	2.068	24	.086		
	Total	2.109	27			
NO3	Between Groups	.000	3	.000	.816	.498
	Within Groups	.000	24	.000		
	Total	.000	27			
TKN	Between Groups	84060.714	3	28020.238	.274	.844
	Within Groups	2454350.000	24	102264.583		
	Total	2538410.714	27			
CHLA	Between Groups	962.216	3	320.739	2.451	.088
	Within Groups	3140.931	24	130.872		
	Total	4103.147	27			
PHYC	Between Groups	259.392	3	86.464	.673	.577
	Within Groups	3084.838	24	128.535		
	Total	3344.230	27			
TURBIDIT	Between Groups	51.524	3	17.175	1.955	.148
	Within Groups	210.841	24	8.785		
	Total	262.365	27			
SECCHI	Between Groups	.474	3	.158	2.732	.066
	Within Groups	1.388	24	.058		
	Total	1.862	27			
ALK	Between Groups	97.676	3	32.559	3.000	**.050**
	Within Groups	260.460	24	10.853		
	Total	358.136	27			
PH	Between Groups	.041	3	.014	.270	.846
	Within Groups	1.216	24	.051		
	Total	1.257	27			
COLIFORM	Between Groups	1028635.714	3	342878.571	.913	.449
	Within Groups	9011775.000	24	375490.625		
	Total	10040410.714	27			

Table 8. Tukey Multiple Comparison for averages over middle four sampling dates (07/19/05 – 07/28/05) comparing four treatments for various parameters. These are the last dates before the 50% treatment was changed to 500%.

			Mean Diff. (I-J)	Std. Error	Sig.	95% Confidence Interval	
Dependent Variable	(I) TREATMENT	(J) TREATMENT				Lower Bound	Upper Bound
ALK	0%	50%	2.2350	1.64716	.537	-2.3089	6.7789
		100%	-.3837	1.64716	.995	-4.9276	4.1601
		Pond	4.9937	2.01735	.090	-.5713	10.5588
	50%	0%	-2.2350	1.64716	.537	-6.7789	2.3089
		100%	-2.6187	1.64716	.403	-7.1626	1.9251
		Pond	2.7587	2.01735	.531	-2.8063	8.3238
	100%	0%	.3837	1.64716	.995	-4.1601	4.9276
		50%	2.6187	1.64716	.403	-1.9251	7.1626
		Pond	5.3775	2.01735	.061	-.1876	10.9426
	Pond	0%	-4.9937	2.01735	.090	-10.5588	.5713
		50%	-2.7587	2.01735	.531	-8.3238	2.8063
		100%	-5.3775	2.01735	.061	-10.9426	.1876

Table 9. ANOVA for averages over final four sampling dates (08/03/05 – 08/12/05) comparing four treatments for various parameters. Significant differences are bold.

		Sum of Squares	df	Mean Square	F	Sig.
SRP	Between Groups	8.720	3	2.907	3.228	**.040**
	Within Groups	21.610	24	.900		
	Total	30.330	27			
TP	Between Groups	108.402	3	36.134	.897	.457
	Within Groups	967.132	24	40.297		
	Total	1075.534	27			
NH3	Between Groups	.001	3	.000	.214	.886
	Within Groups	.040	24	.002		
	Total	.041	27			
NO3	Between Groups	.001	3	.000	.267	.848
	Within Groups	.028	24	.001		
	Total	.028	27			
TKN	Between Groups	138096.429	3	46032.143	.388	.763
	Within Groups	2851000.000	24	118791.667		
	Total	2989096.429	27			
CHLA	Between Groups	3.581	3	1.194	.074	.974
	Within Groups	388.806	24	16.200		
	Total	392.387	27			
PHYC	Between Groups	191.626	3	63.875	.038	.990
	Within Groups	40246.901	24	1676.954		
	Total	40438.527	27			
TURBIDITY	Between Groups	50.117	3	16.706	4.027	**.019**
	Within Groups	99.554	24	4.148		
	Total	149.671	27			
SECCHI	Between Groups	.989	3	.330	7.971	**.001**
	Within Groups	.992	24	.041		
	Total	1.981	27			
ALKALINITY	Between Groups	817.552	3	272.517	.635	.600
	Within Groups	10306.059	24	429.419		
	Total	11123.611	27			
PH	Between Groups	.056	3	.019	1.335	.286
	Within Groups	.333	24	.014		
	Total	.388	27			
COLIFORM	Between Groups	16246546.429	3	5415515.476	3.112	**.045**
	Within Groups	41771525.000	24	1740480.208		
	Total	58018071.429	27			

Table 10. Tukey Multiple Comparison for averages over final four sampling dates (08/03/05 – 08/12/05) comparing four treatments for various parameters. Significant differences are bold.

			Mean Diff. (I-J)	Std. Error	Sig.	95% Con. Interval	
Dependent Variable	(I) TREATMENT	(J) TREATMENT				Lower Bound	Upper Bound
SRP	0%	500%	-.1250	.47445	.993	-1.4338	1.1838
		100%	-1.1125	.47445	.116	-2.4213	.1963
		Pond	-1.3125	.58108	.136	-2.9155	.2905
	500%	0%	.1250	.47445	.993	-1.1838	1.4338
		100%	-.9875	.47445	.188	-2.2963	.3213
		Pond	-1.1875	.58108	.200	-2.7905	.4155
	100%	0%	1.1125	.47445	.116	-.1963	2.4213
		500%	.9875	.47445	.188	-.3213	2.2963
		Pond	-.2000	.58108	.986	-1.8030	1.4030
	Pond	0%	1.3125	.58108	.136	-.2905	2.9155
		500%	1.1875	.58108	.200	-.4155	2.7905
		100%	.2000	.58108	.986	-1.4030	1.8030
TURBIDITY	0%	500%	.1613	1.01834	.999	-2.6480	2.9705
		100%	-2.3862	1.01834	.116	-5.1955	.4230
		Pond	1.5213	1.24721	.621	-1.9193	4.9618
	500%	0%	-.1613	1.01834	.999	-2.9705	2.6480
		100%	-2.5475	1.01834	.085	-5.3567	.2617
		Pond	1.3600	1.24721	.699	-2.0806	4.8006
	100%	0%	2.3862	1.01834	.116	-.4230	5.1955
		500%	2.5475	1.01834	.085	-.2617	5.3567
		Pond	3.9075	1.24721	**.022**	.4669	7.3481
	Pond	0%	-1.5213	1.24721	.621	-4.9618	1.9193
		500%	-1.3600	1.24721	.699	-4.8006	2.0806
		100%	-3.9075	1.24721	**.022**	-7.3481	-.4669
SECCHI	0%	500%	-.0850	.10168	.837	-.3655	.1955
		100%	.1563	.10168	.432	-.1242	.4367
		Pond	-.4437	.12453	**.008**	-.7873	-.1002
	500%	0%	.0850	.10168	.837	-.1955	.3655
		100%	.2412	.10168	.110	-.0392	.5217
		Pond	-.3587	.12453	**.038**	-.7023	-.0152
	100%	0%	-.1563	.10168	.432	-.4367	.1242
		500%	-.2412	.10168	.110	-.5217	.0392
		Pond	-.6000	.12453	**.000**	-.9435	-.2565
	Pond	0%	.4437	.12453	**.008**	.1002	.7873
		500%	.3587	.12453	**.038**	.0152	.7023
		100%	.6000	.12453	**.000**	.2565	.9435
COLIFORM	0%	500%	-51.25	659.636	1.000	-1870.93	1768.43
		100%	-1745.00	659.636	.063	-3564.68	74.68
		Pond	-228.75	807.886	.992	-2457.39	1999.89
	500%	0%	51.25	659.636	1.000	-1768.43	1870.93
		100%	-1693.75	659.636	.074	-3513.43	125.93
		Pond	-177.50	807.886	.996	-2406.14	2051.14
	100%	0%	1745.00	659.636	.063	-74.68	3564.68
		500%	1693.75	659.636	.074	-125.93	3513.43
		Pond	1516.25	807.886	.264	-712.39	3744.89
	Pond	0%	228.75	807.886	.992	-1999.89	2457.39
		500%	177.50	807.886	.996	-2051.14	2406.14
		100%	-1516.25	807.886	.264	-3744.89	712.39

* The mean difference is significant at the .05 level.

Table 11. Multiple regression analysis for various parameters with date and feces added as regressors. Significant differences are bold.

Parameter	R	R^2	F	Sig.	Date slope	Date SE	Date t value	Date sig.	Feces Slope	Feces SE	Feces t value	Feces sig.
Total Phos.	.422	.178	4.884	**.012**	-76.371	31.408	3.960	**.000**	12.278	15.545	.790	.434
Chlorophyll-a	.442	.195	5.455	**.008**	-0.348	.272	-1.280	.207	-0.105	0.135	-.779	.440
Phycocyanin	.836	.685	52.113	**.000**	2.621	.562	4.667	**.000**	0.456	0.278	1.639	.108
SRP	.371	.138	3.602	**.035**	-5.72E-02	.050	-1.156	.254	-1.25E-02	0.025	-.509	.614
Secchi depth	.290	.084	2.070	.138	-9.06E-03	.005	-1.785	.081	5.07E-03	0.003	2.016	**.050**
Tot. Coliform	.468	.219	6.293	**.004**	93.104	26.481	3.516	**.001**	-33.379	13.107	-2.547	**.014**
Nitrate	.160	.026	0.591	.558	4.41E-04	.001	.556	.574	3.69E-05	0.000	.096	.924
TKN	.401	.161	4.34	**.019**	-18.283	6.355	-2.877	**.006**	8.418	3.416	2.676	**.010**
Ammonia	.385	.148	3.916	**.027**	-6.40E-03	.005	-1.377	.175	-7.79E-04	0.002	-.339	.736
Turbidity	.447	.200	5.629	**.007**	0.122	.077	1.577	.122	-.116	.038	-3.028	**.004**

Table 12. Phytoplanton taxa counts (cell/mL) and biovolume (µm/mL) in representative samples of the control and 50/500% treatments.

	Control (0% Treatment)		50/500% Treatment	
Taxa	Count (cells/ml)	Biovolume (μm^3/ml)	Count (cells/ml)	Biovolume (μm^3/ml)
BAC	370.1	0.0	460.4	0.0
CHL	233.8	53448.7	486.2	55185.6
CHR	3838.9	170920.1	10934.7	601331.2
COL	231.5	7039.6	57.2	2290.0
CRY	210.8	23768.1	228.7	24212.9
CYA	408.5	3393.6	473.7	1582.3
EUG	150.8	395017.3	70.5	245085.0
PYR	48.5	1242835.8	24.5	864887.5
UNI	381.8	12561.2	2883.9	14667.4
TOTALS	5874.8	1908984.4	15619.7	1809241.9

BAC=Bacillariophyceae; CHL=Chlorophyceae, CHR=Chrysophyceae, COL= Colorless flagellate, CRY=Cryptophyceae, CYA=Cyanophyceae, EUG=Euglenophyceae, PYR=Pyrrophyceae, UNI=Unidentified flagellate

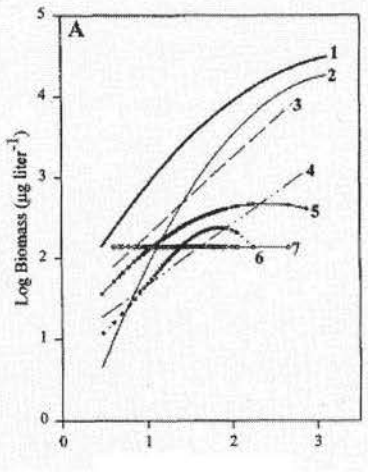


Figure 1. Biomass of phytoplankton groups with increasing log total phosphorus (1 = Total biomass; 2 = Cyanobacteria; 3 = Bacillariophyceae; 4 = Chlorophyta; 5 = Cryptophyta; 6 = Dinophyta; 7 = Chrysophyceae) (Watson et al. 1997).

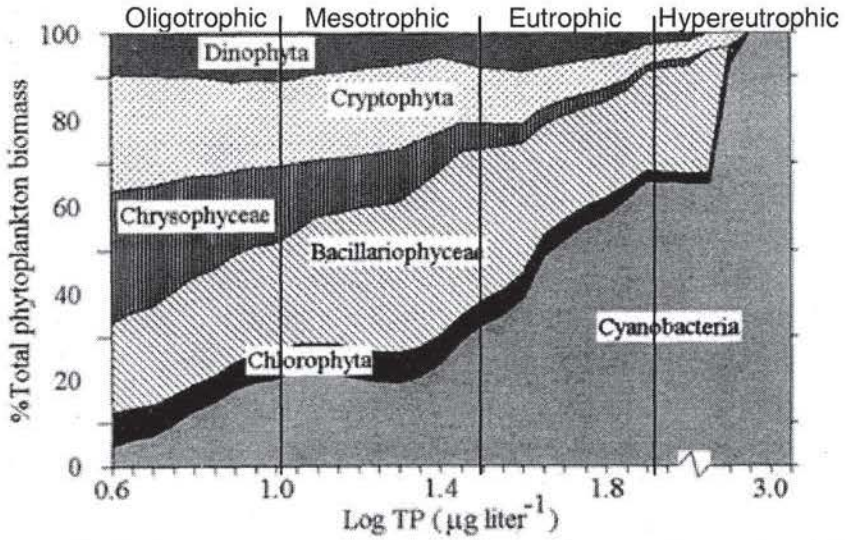


Figure 2. Phytoplankton abundance with increasing total phosphorus (modified from Watson et al. 1997)

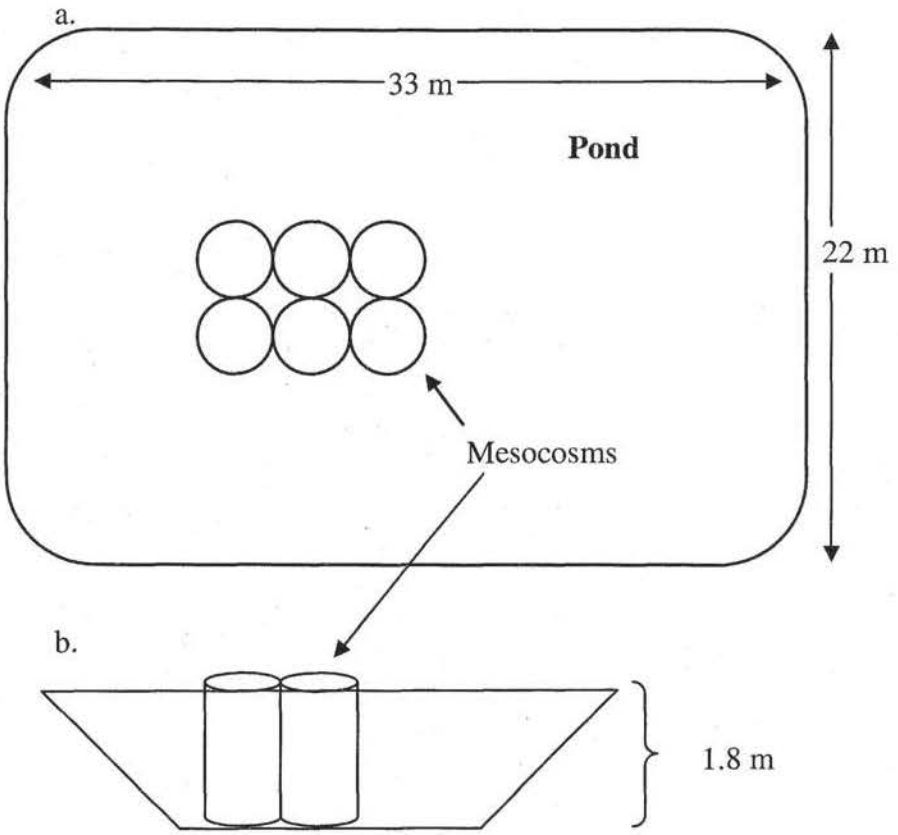
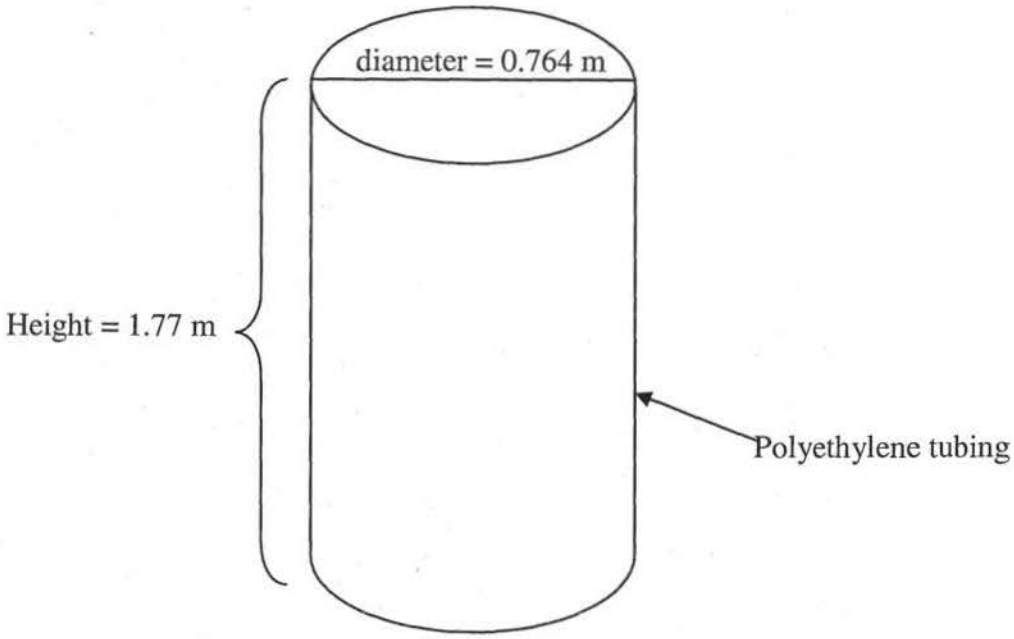


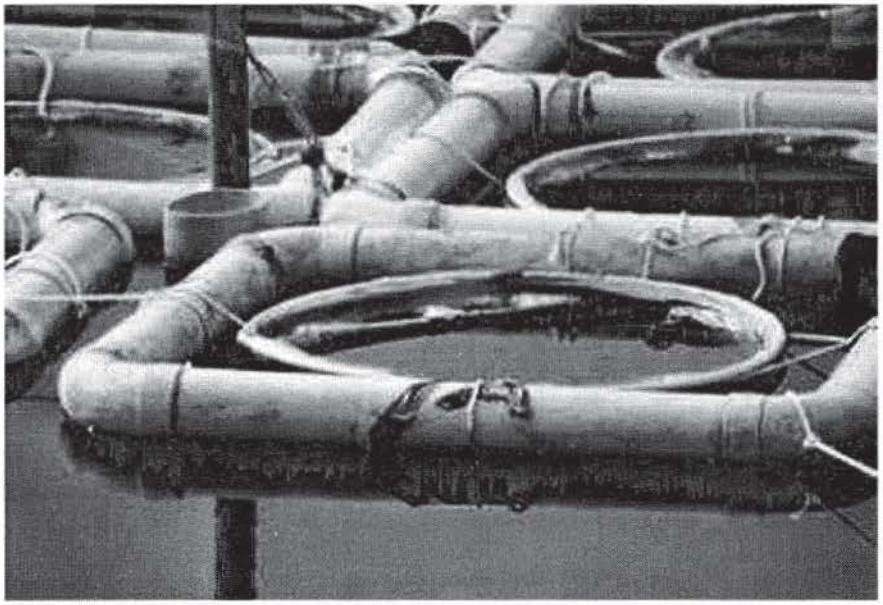
Figure 3. Diagram of the experimental setup at SUNY Brockport aquaculture ponds, Pond #4, a) aerial view, and b) cross sectional view from narrow end of pond. Pond volume was 880 m^3.



Ring circumference = 2.40 m
Ring radius = 0.382 m
Ring area = 0.4584 m^2
Mesocosm volume = 0.811 m^3

Figure 4. Mesocosm dimensions for SUNY Brockport aquaculture ponds.

a)



b)

Figure 5. Photographs of the experimental setup at SUNY Brockport Aquaculture Ponds, Pond #4: a) view of all six mesocosm, and b) mesocosm #1.

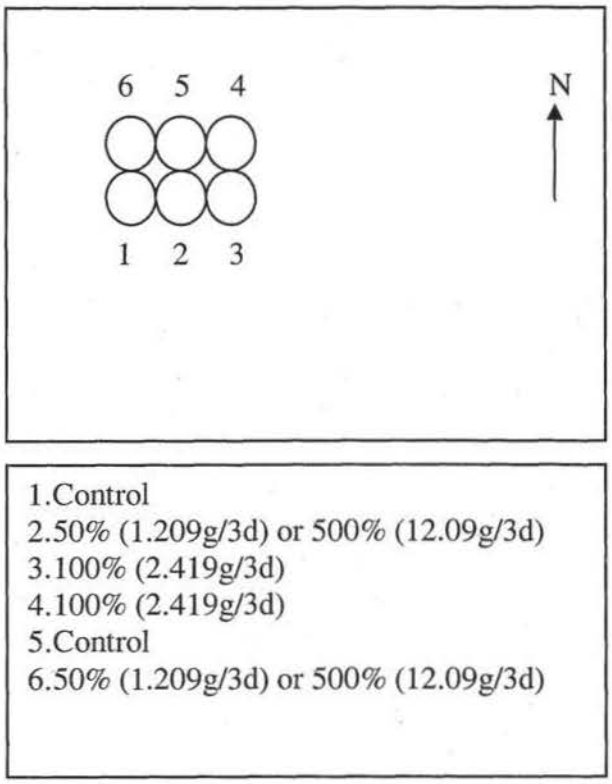


Figure 6. Mesocosm assignments and amount of fecal additions.

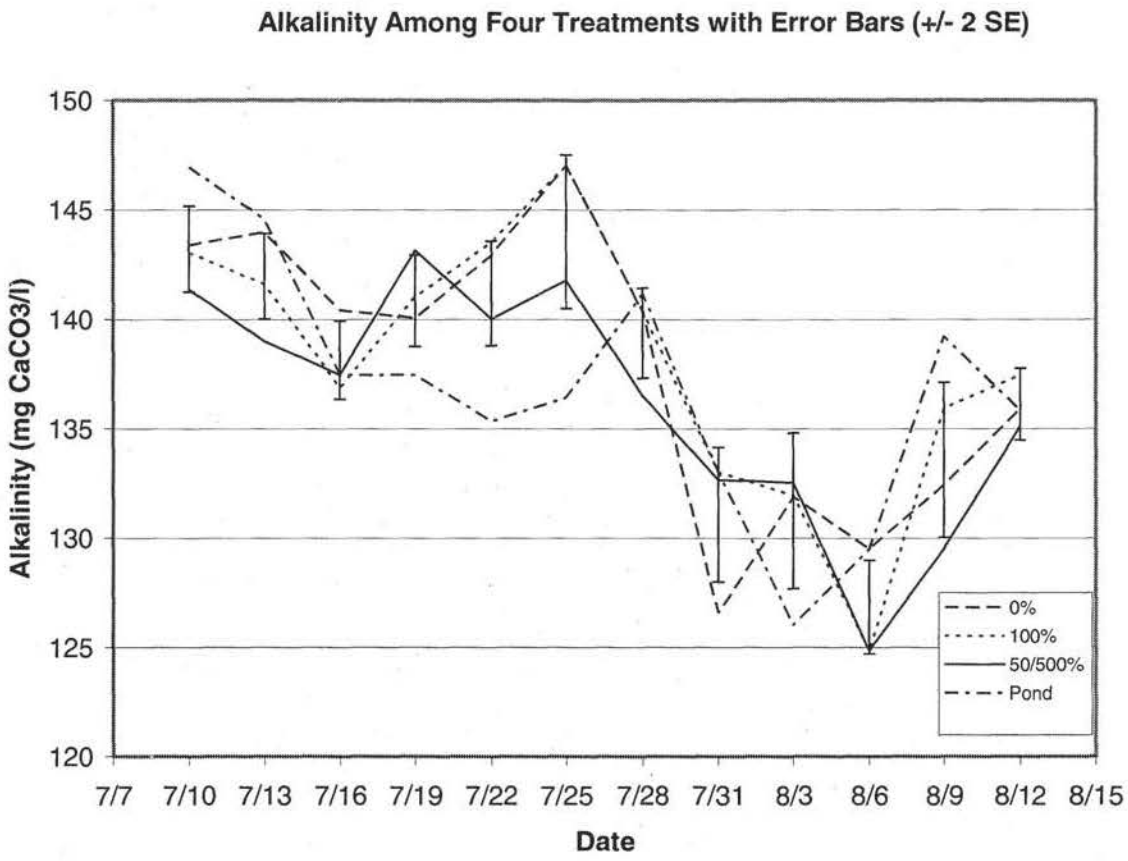


Figure 7. Alkalinity over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

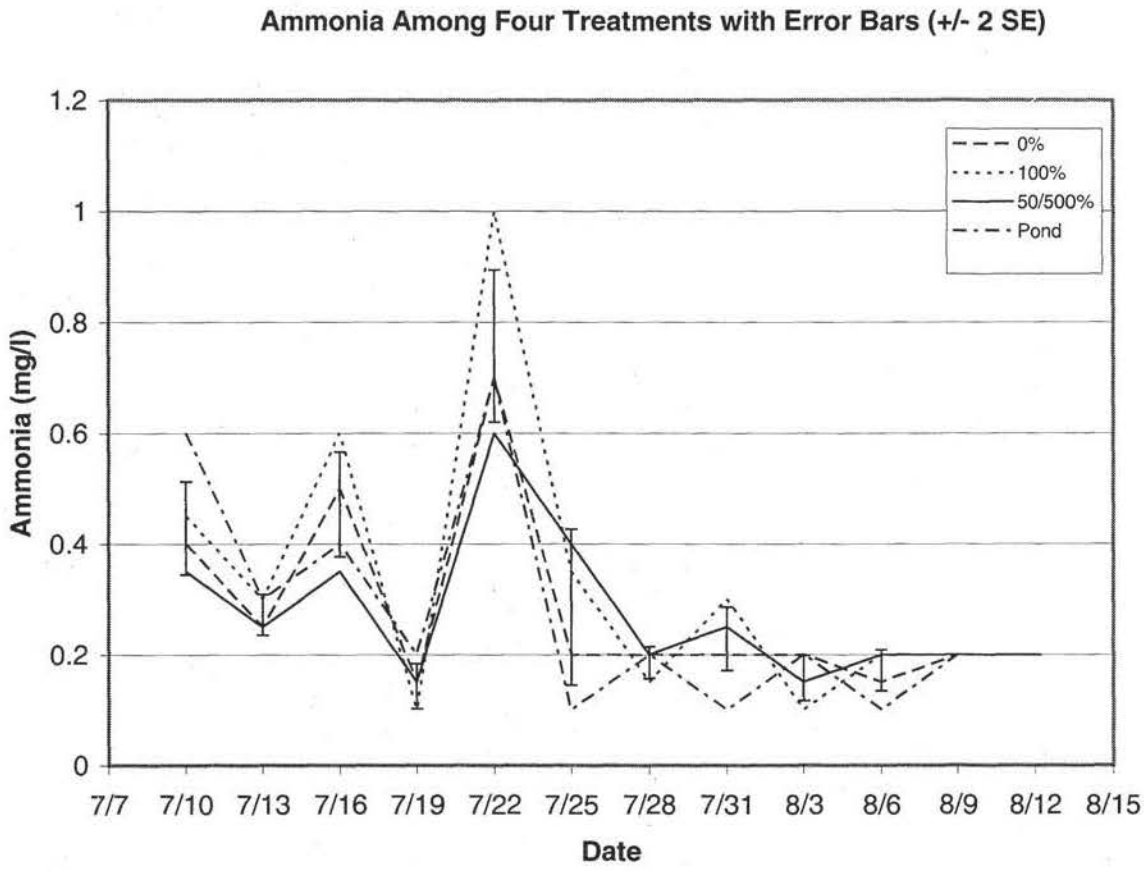


Figure 8. Ammonia concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

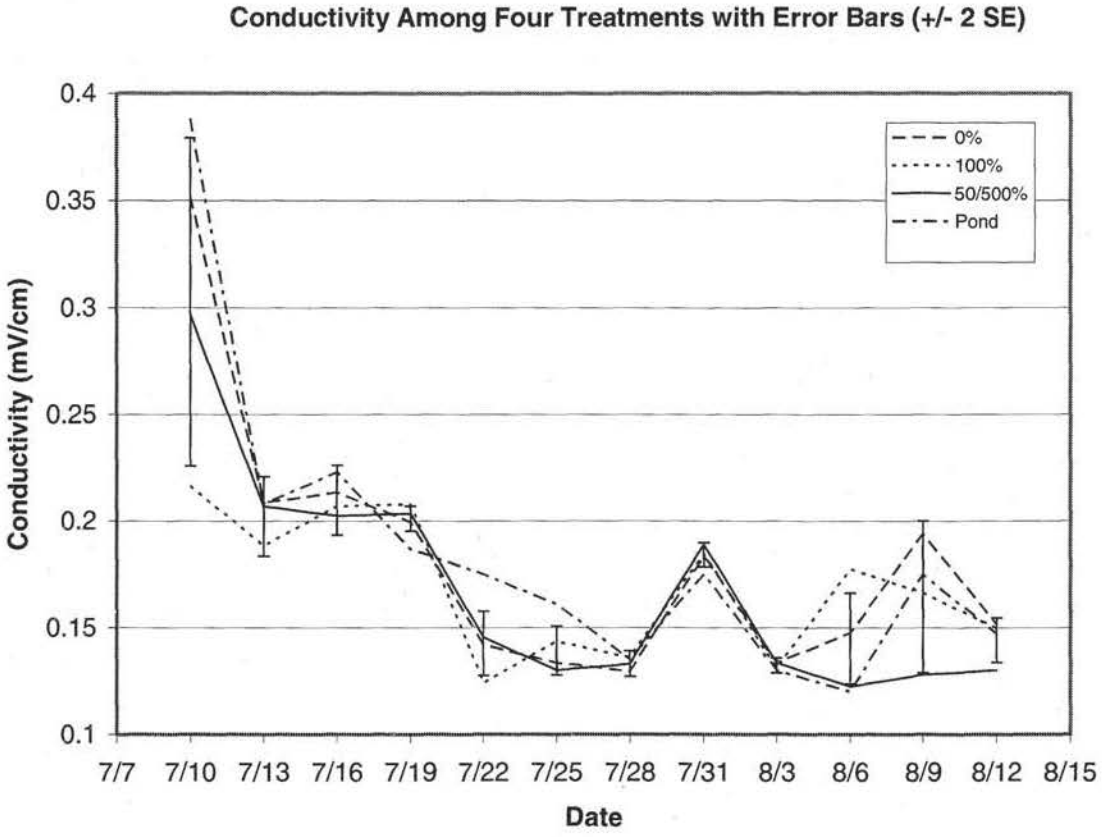


Figure 9. Conductivity over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

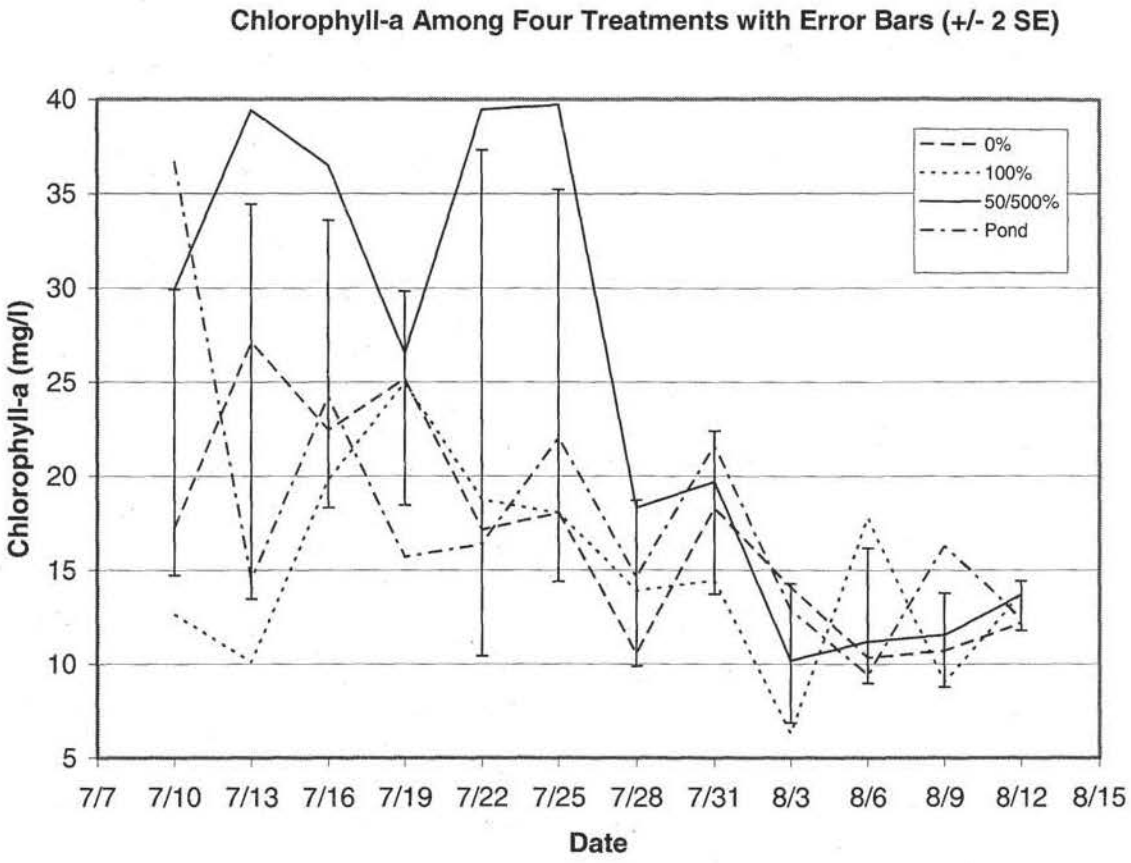


Figure 10. Chlorophyll-*a* concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

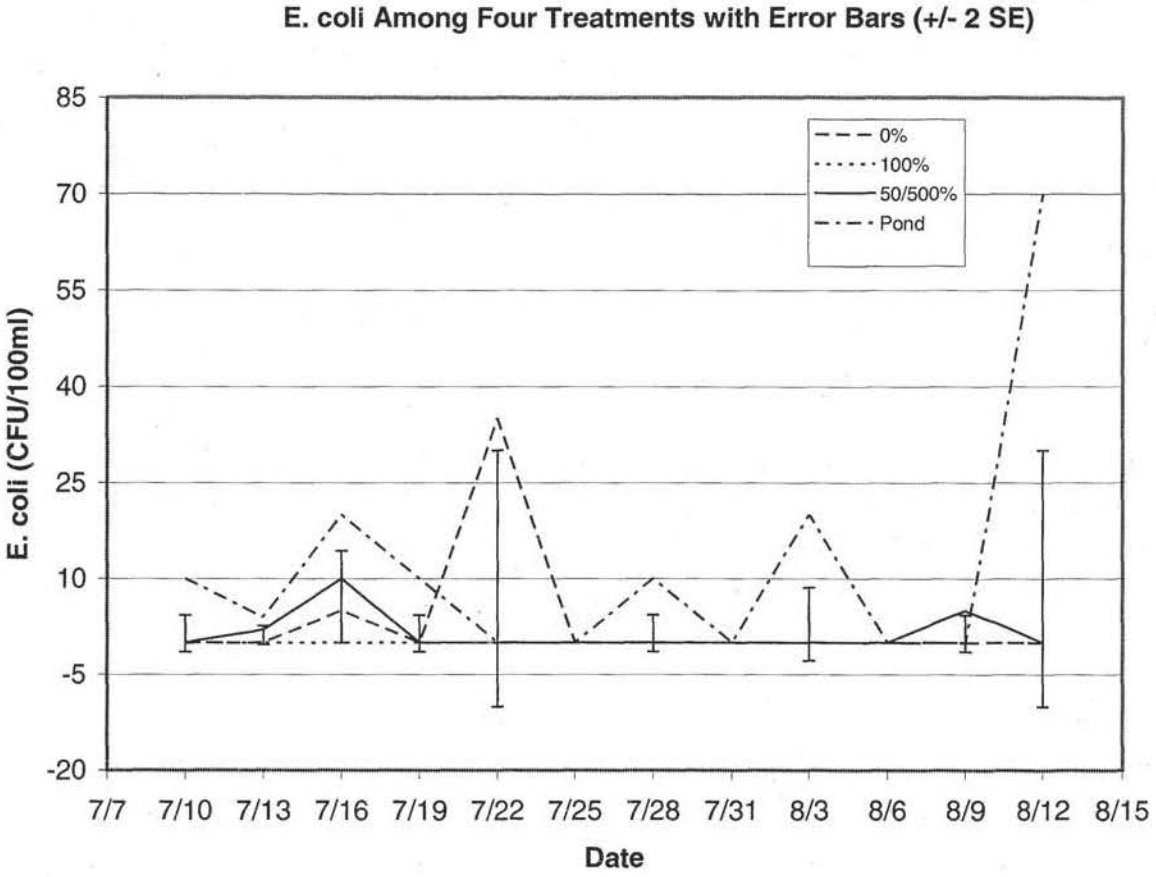


Figure 11. *Escherichia coli* abundance over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

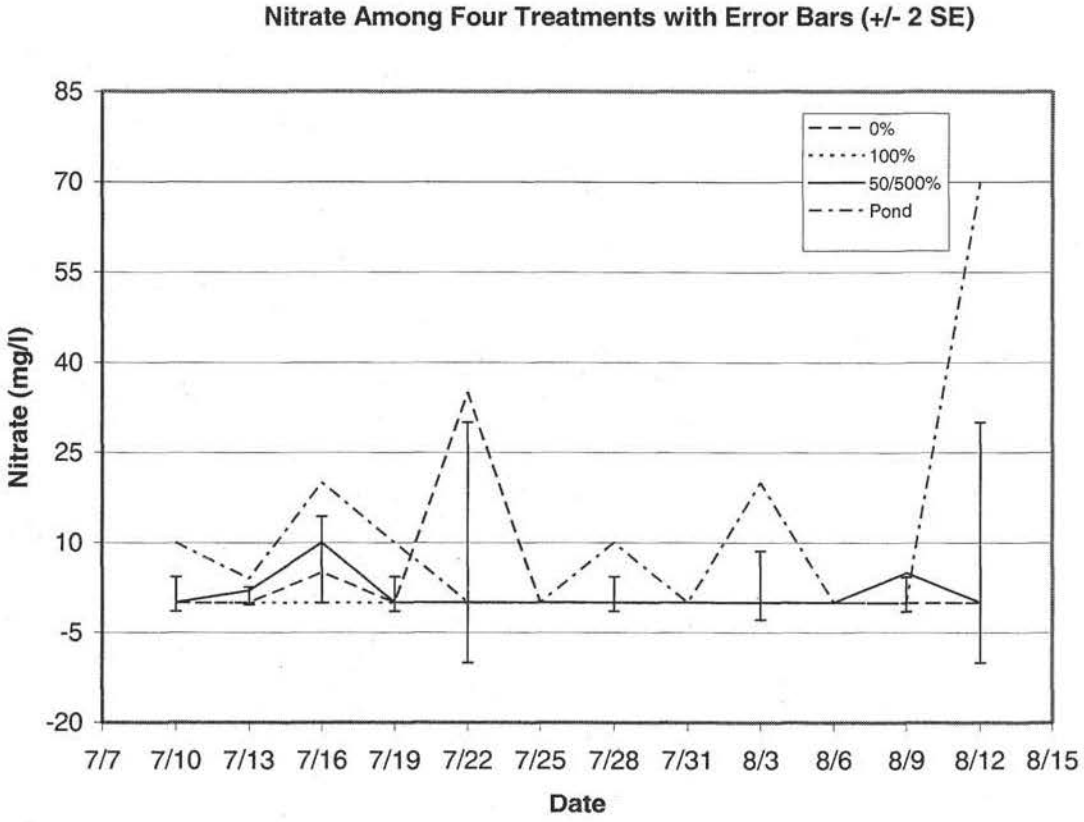


Figure 12. Nitrate concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

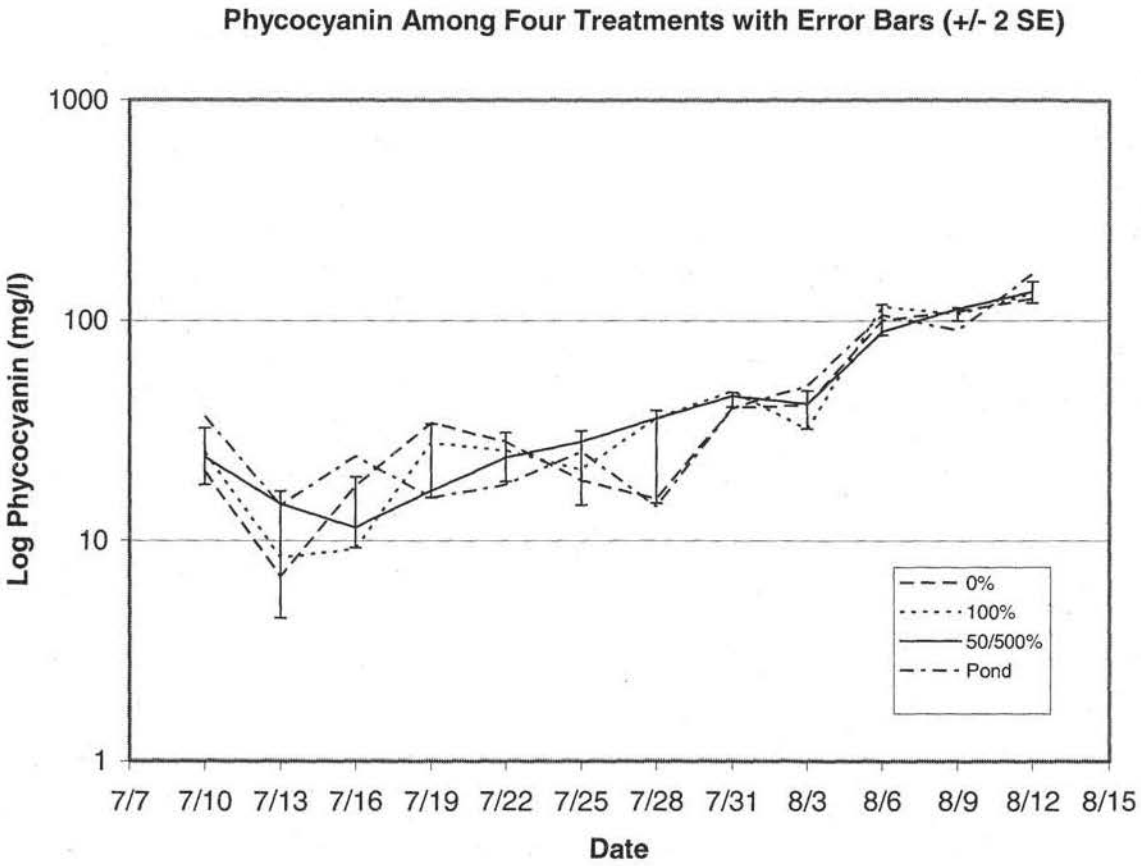


Figure 13. Log Phycocyanin concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

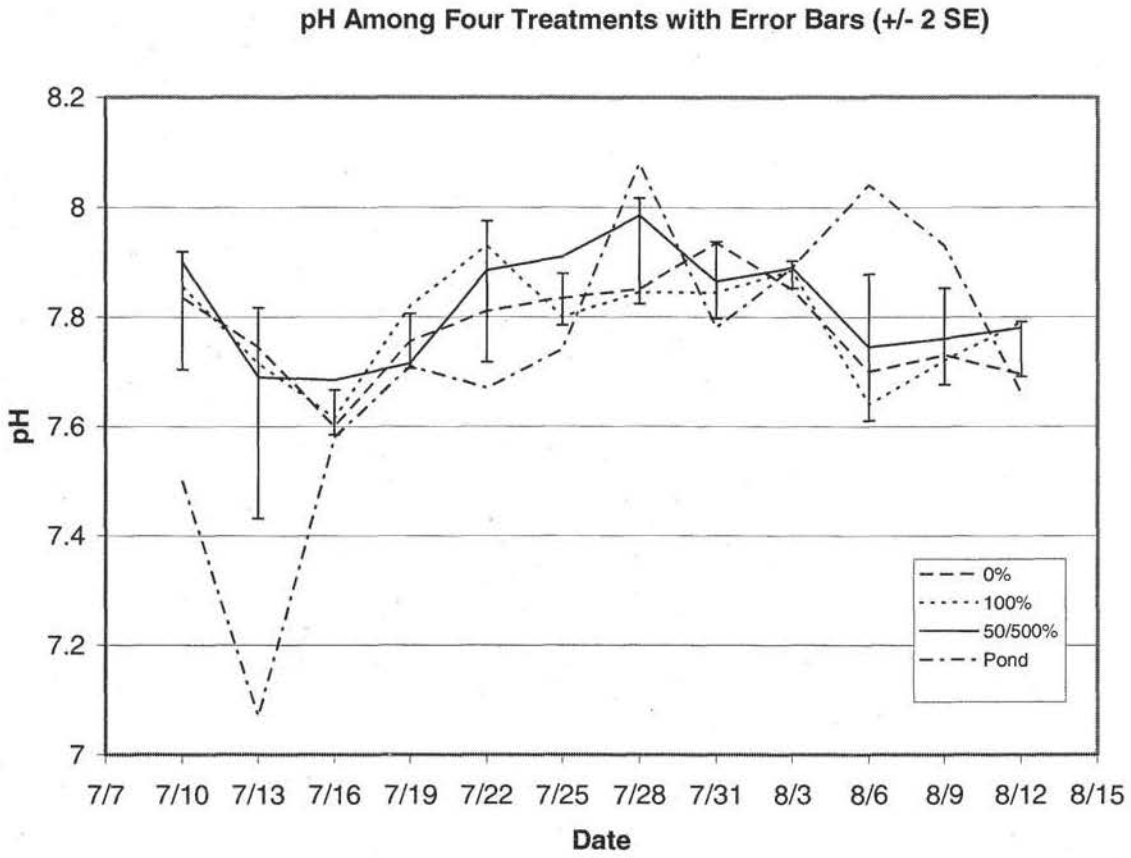


Figure 14. pH over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

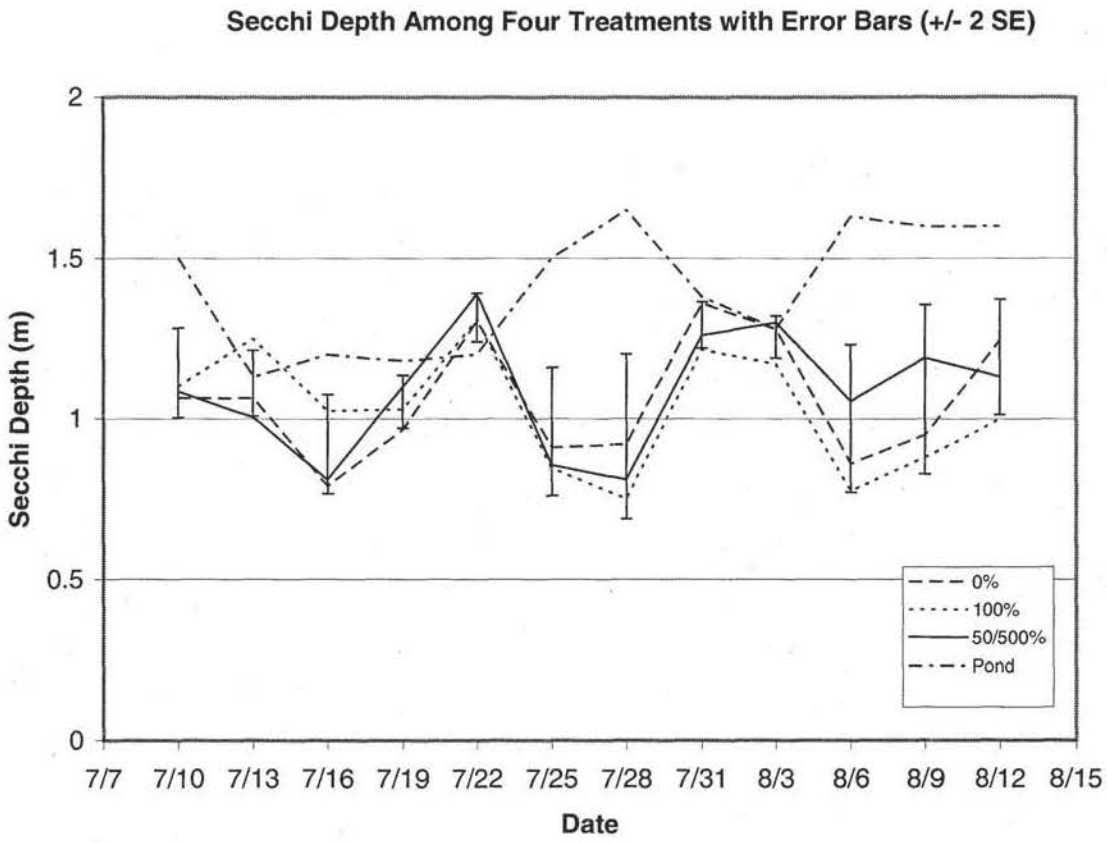


Figure 15. Secchi Depth over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

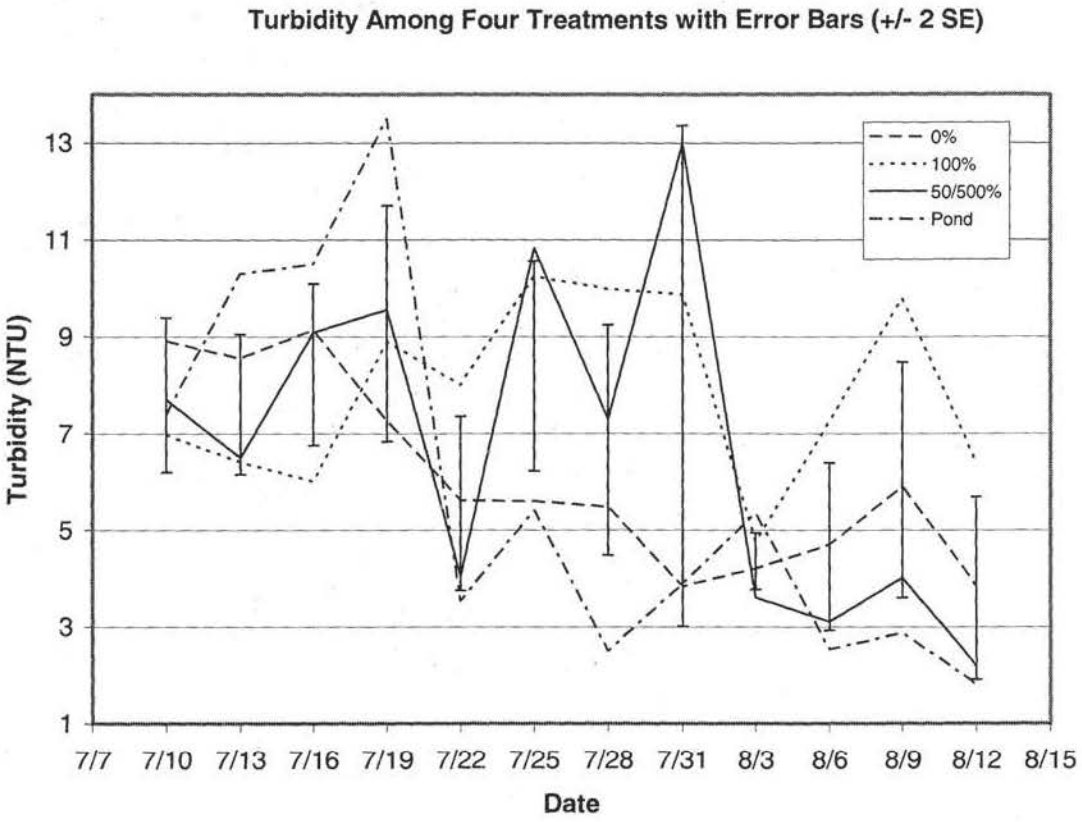


Figure 16. Turbidity over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

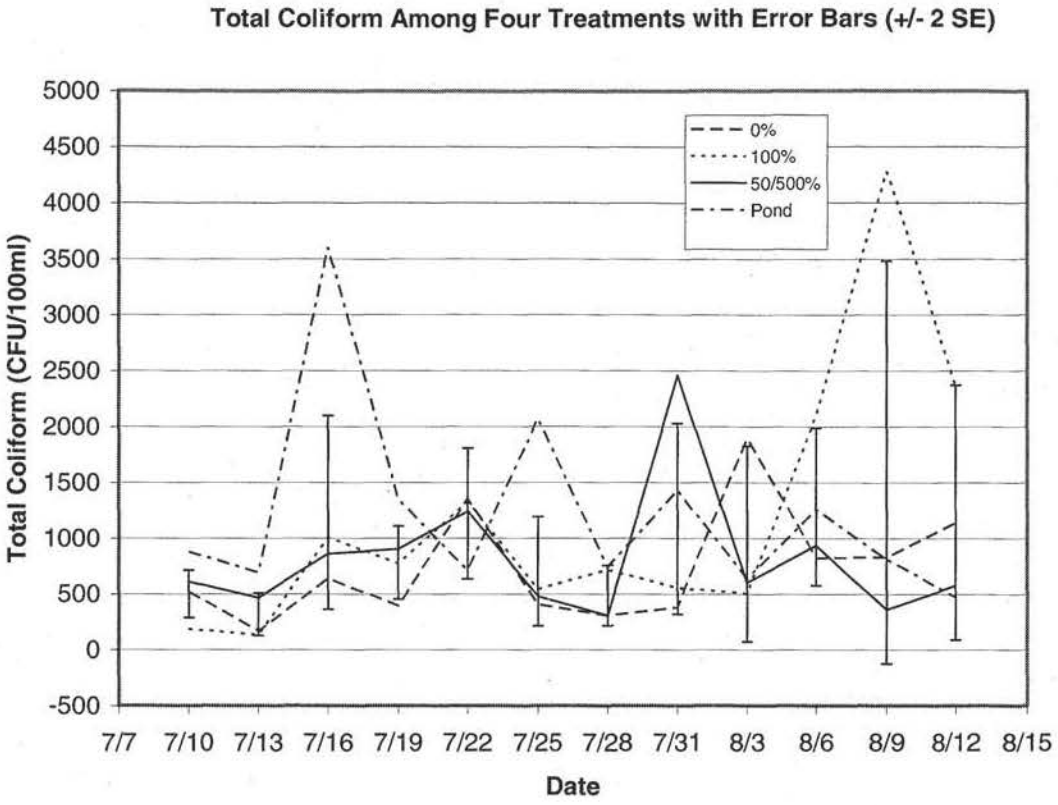


Figure 17. Total Coliform over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

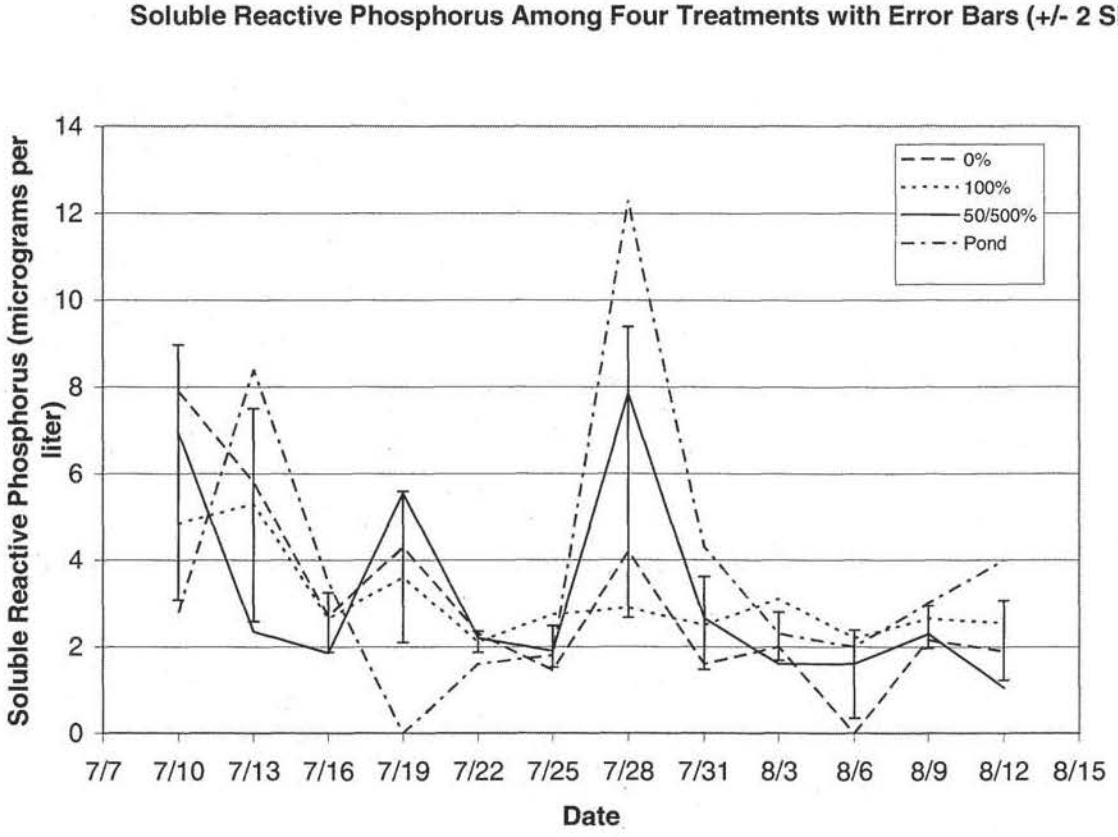


Figure 18. Soluble reactive phosphorus concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

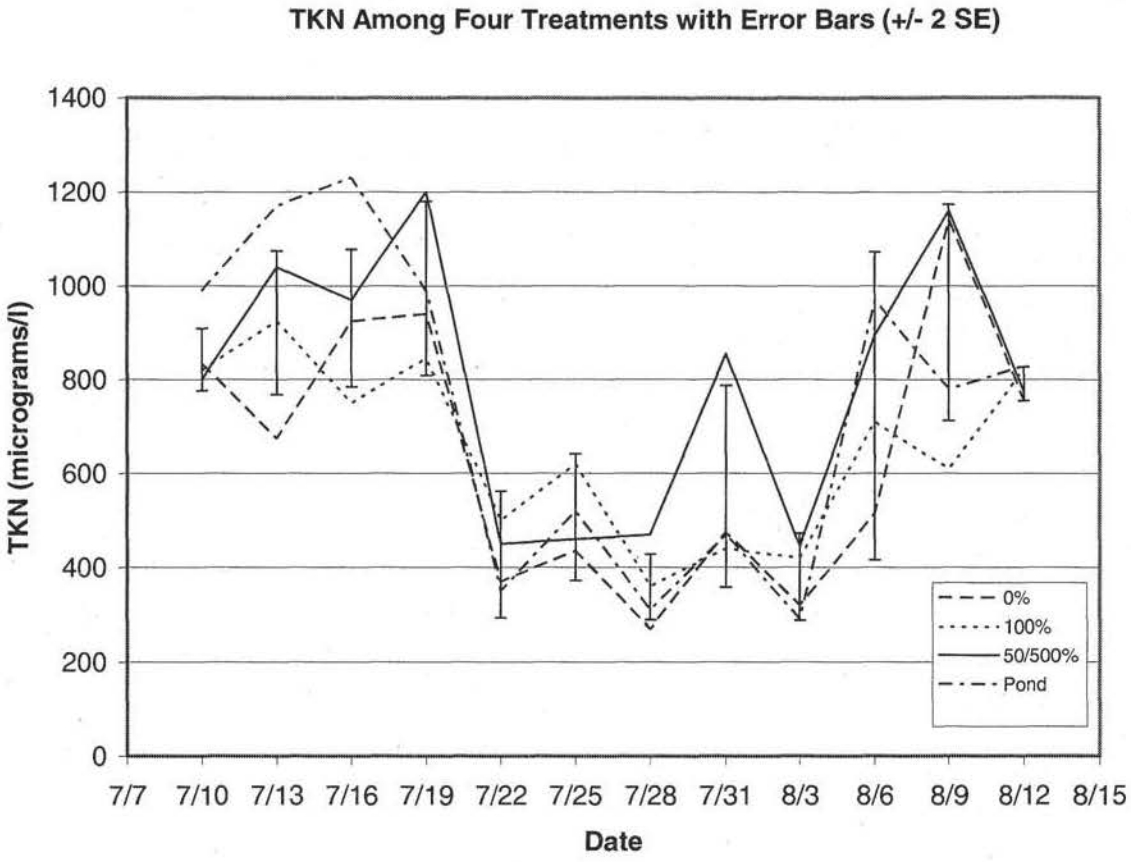


Figure 19. Total Kjeldahl Nitrogen concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

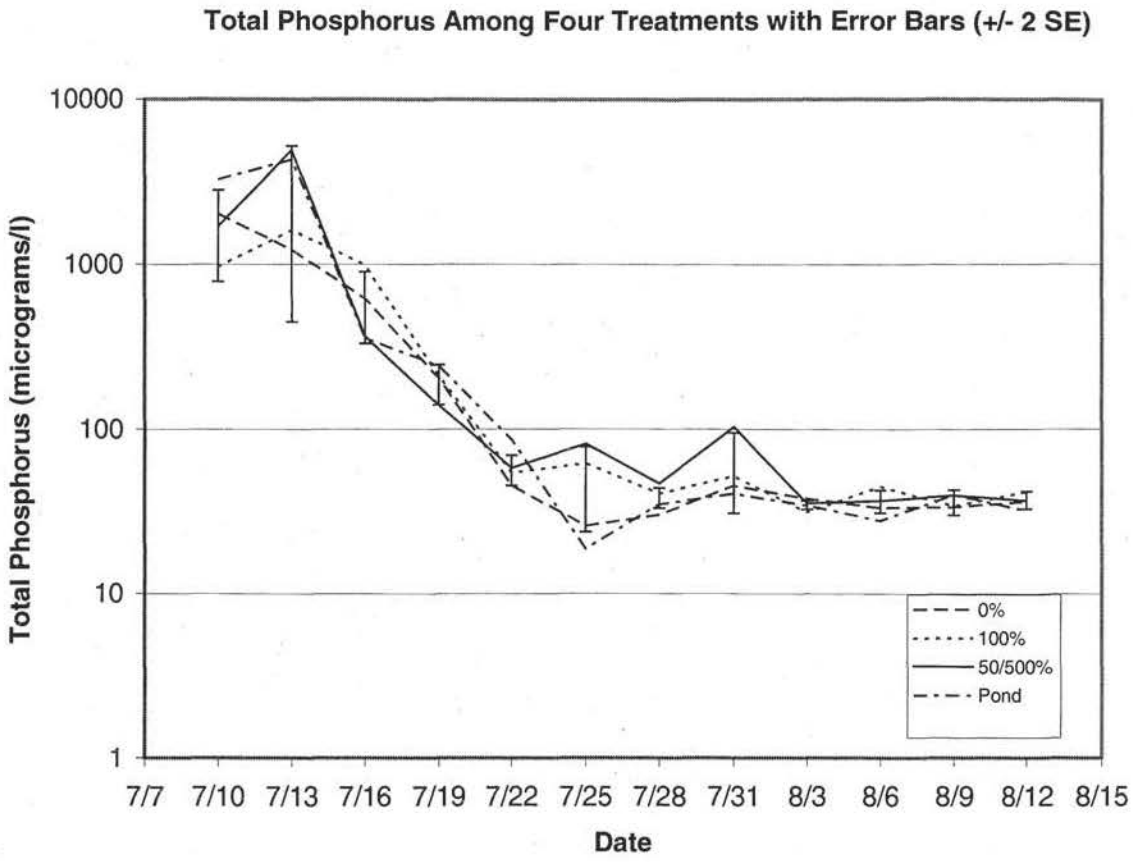


Figure 20. Total phosphorus concentration over time for three treatments and pond. Error bars (±2 SE for 6 mesocosms and pond) are included. Treatment percentages are based on daily loading of 0.806 g (from Manny 1975 and Kear 1963). 50/500% began as ½ of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004.

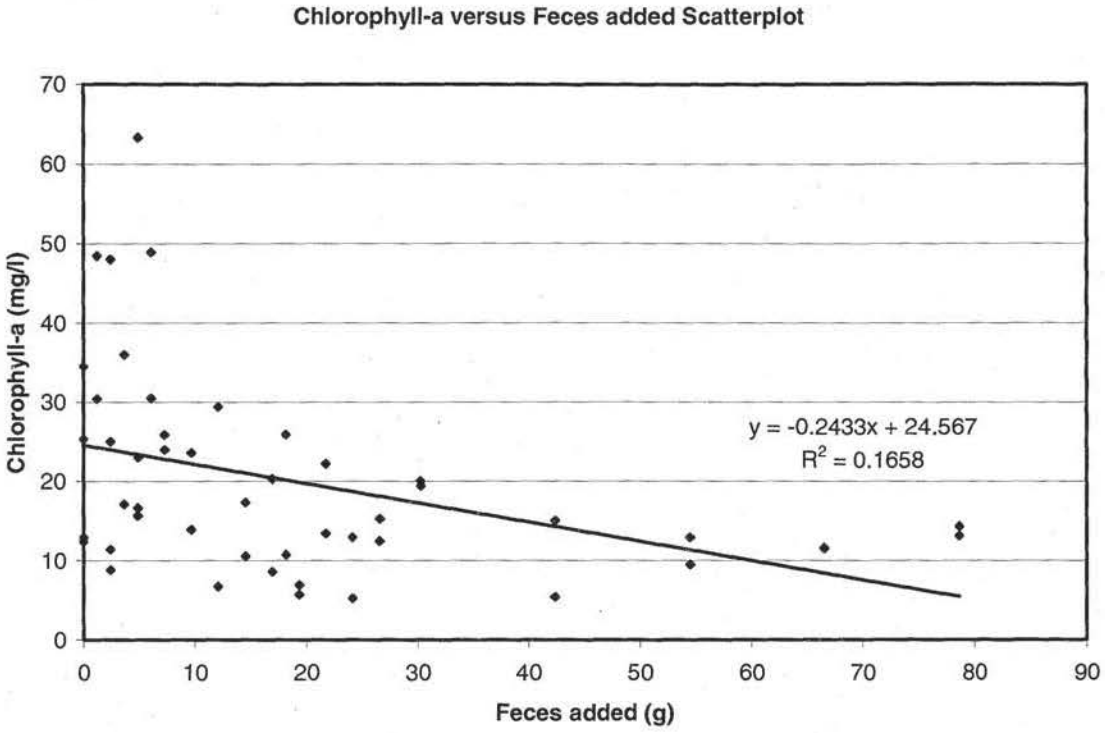


Figure 21. Scatterplot of chlorophyll-*a* concentration versus feces added for treatments receiving fecal additions only.

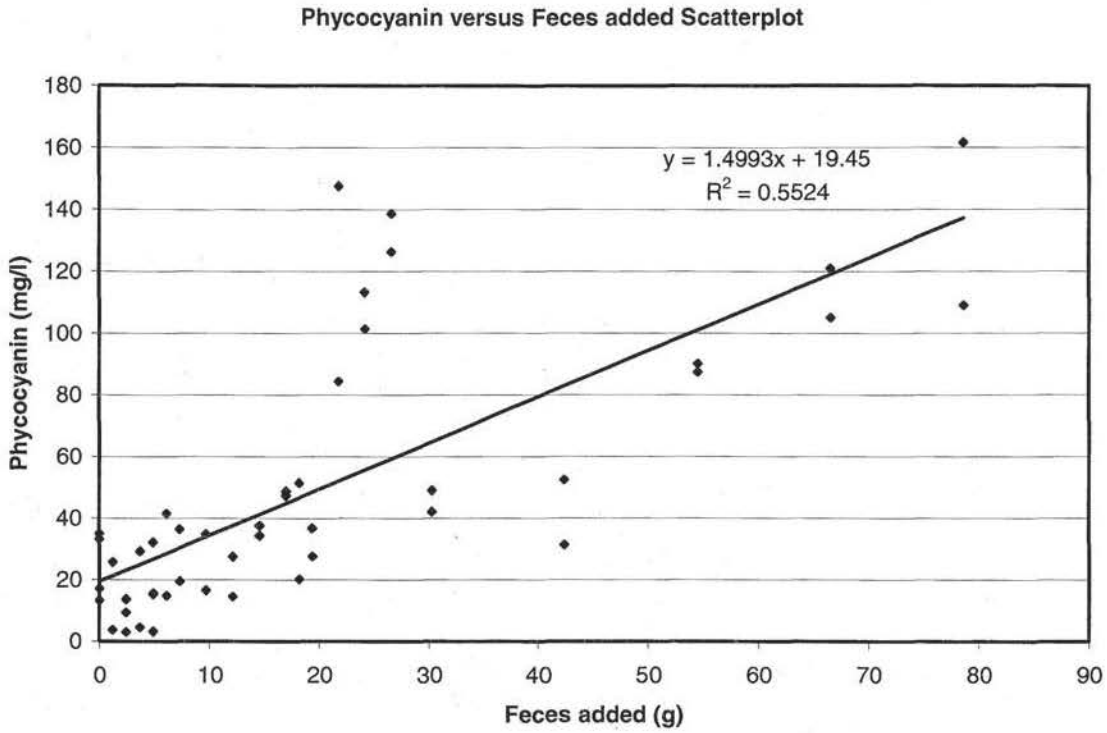


Figure 22. Scatterplot of phycocyanin concentration versus feces added for treatments receiving fecal additions only.

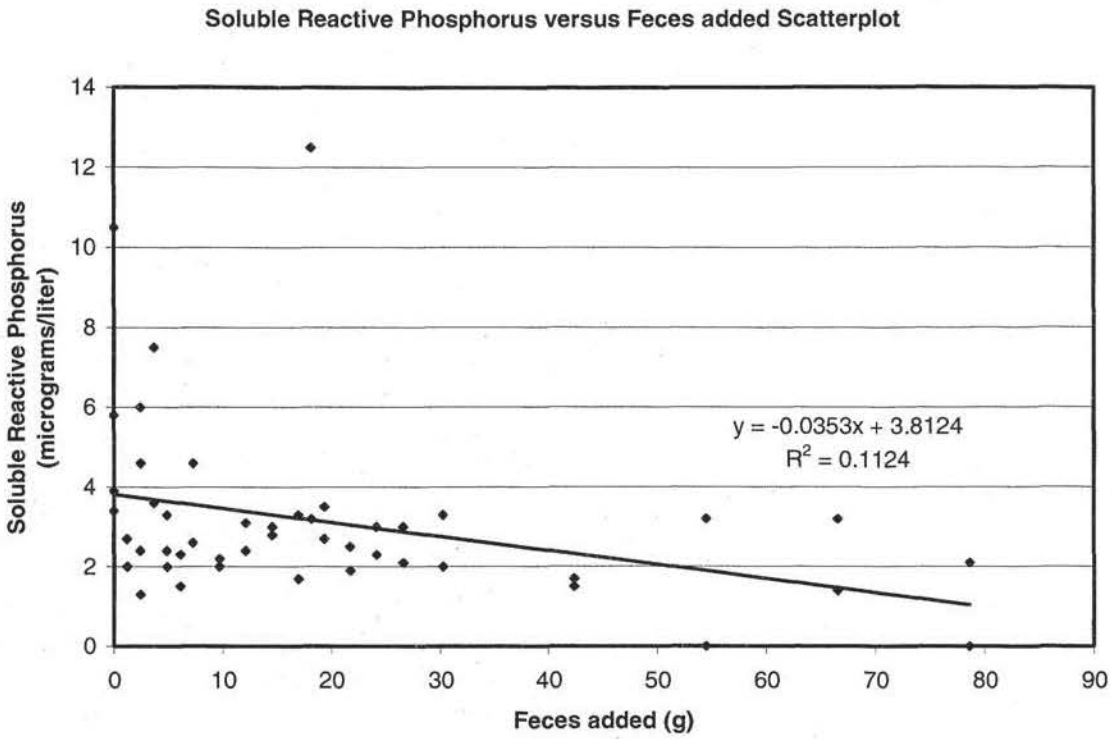


Figure 23. Scatterplot of soluble reactive phosphorus concentration versus feces added for treatments receiving fecal additions only.

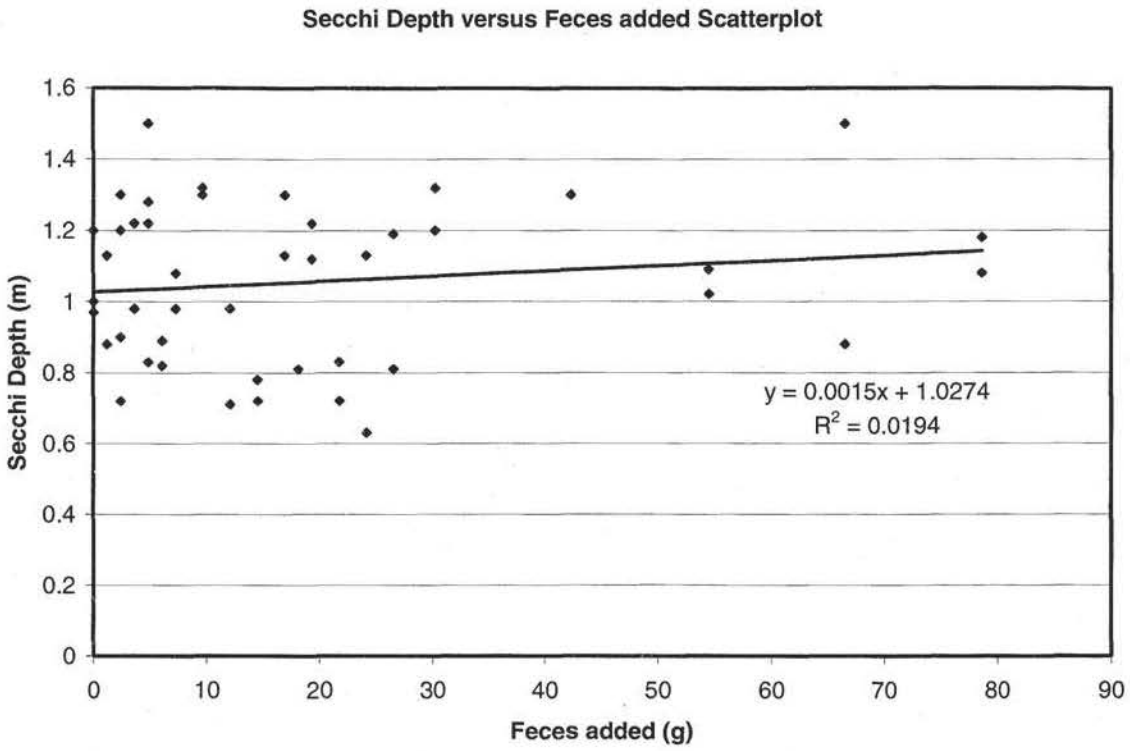


Figure 24. Scatterplot of Secchi depth versus feces added for treatments receiving fecal additions only.

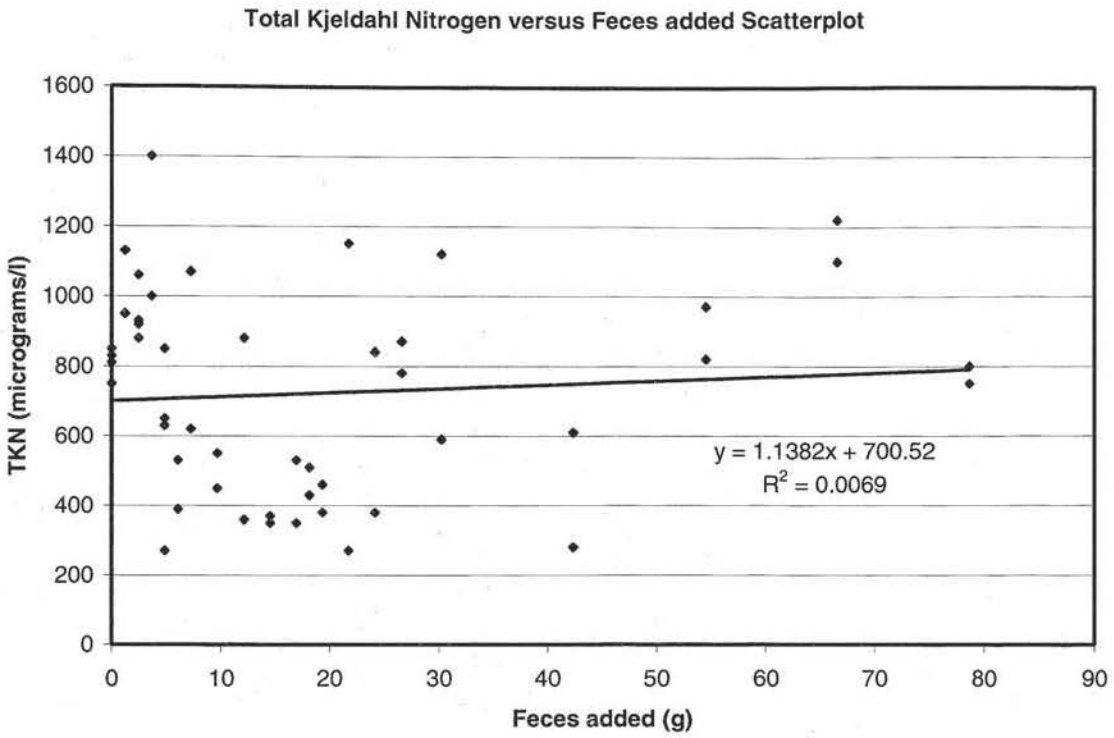


Figure 25. Scatter plot of total Kjeldahl nitrogen concentration versus feces added for treatments receiving fecal additions only.

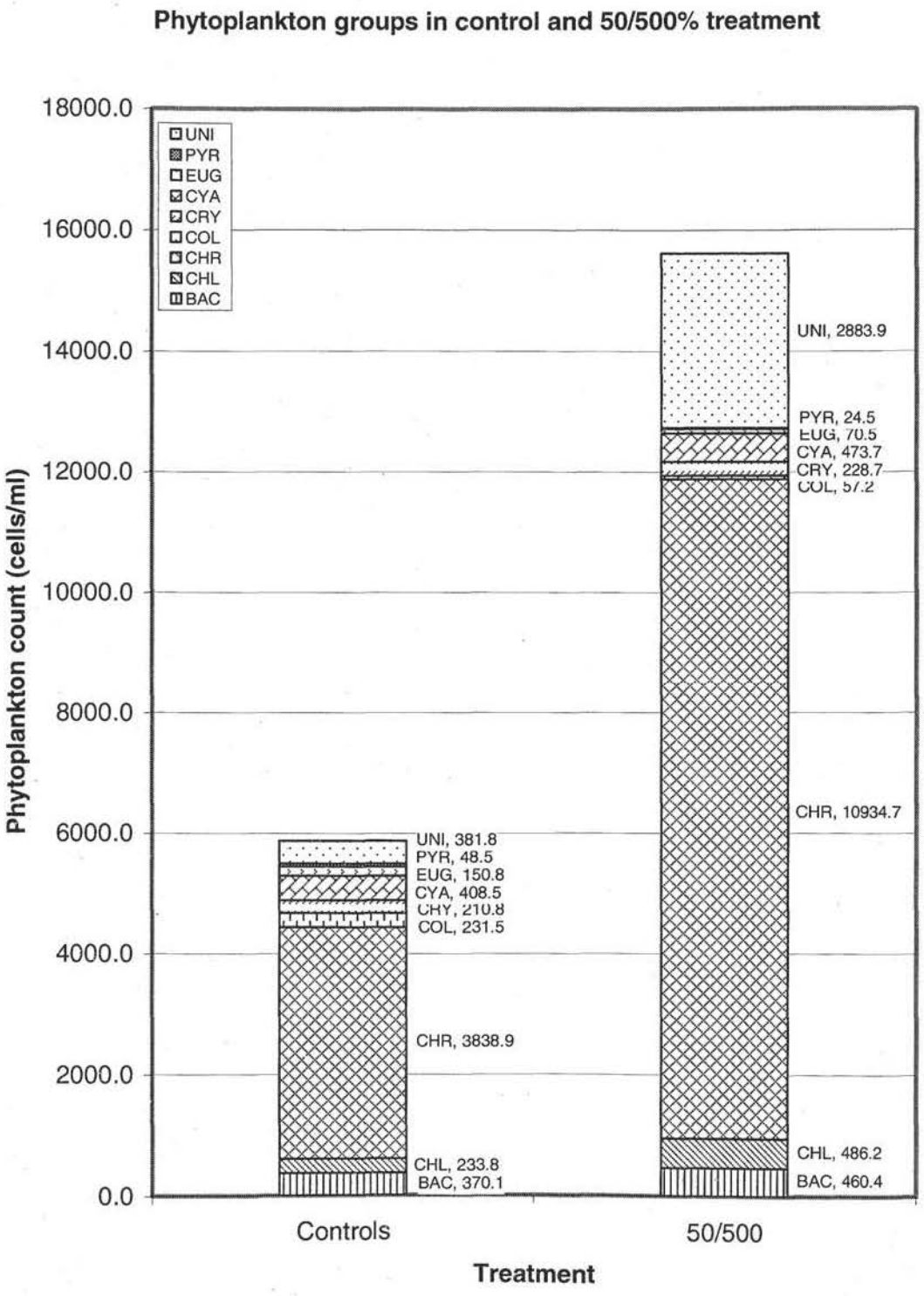


Figure 26. Counts of phytoplankton in control and 50/500% treatment at day 33 (final day of the experiment).

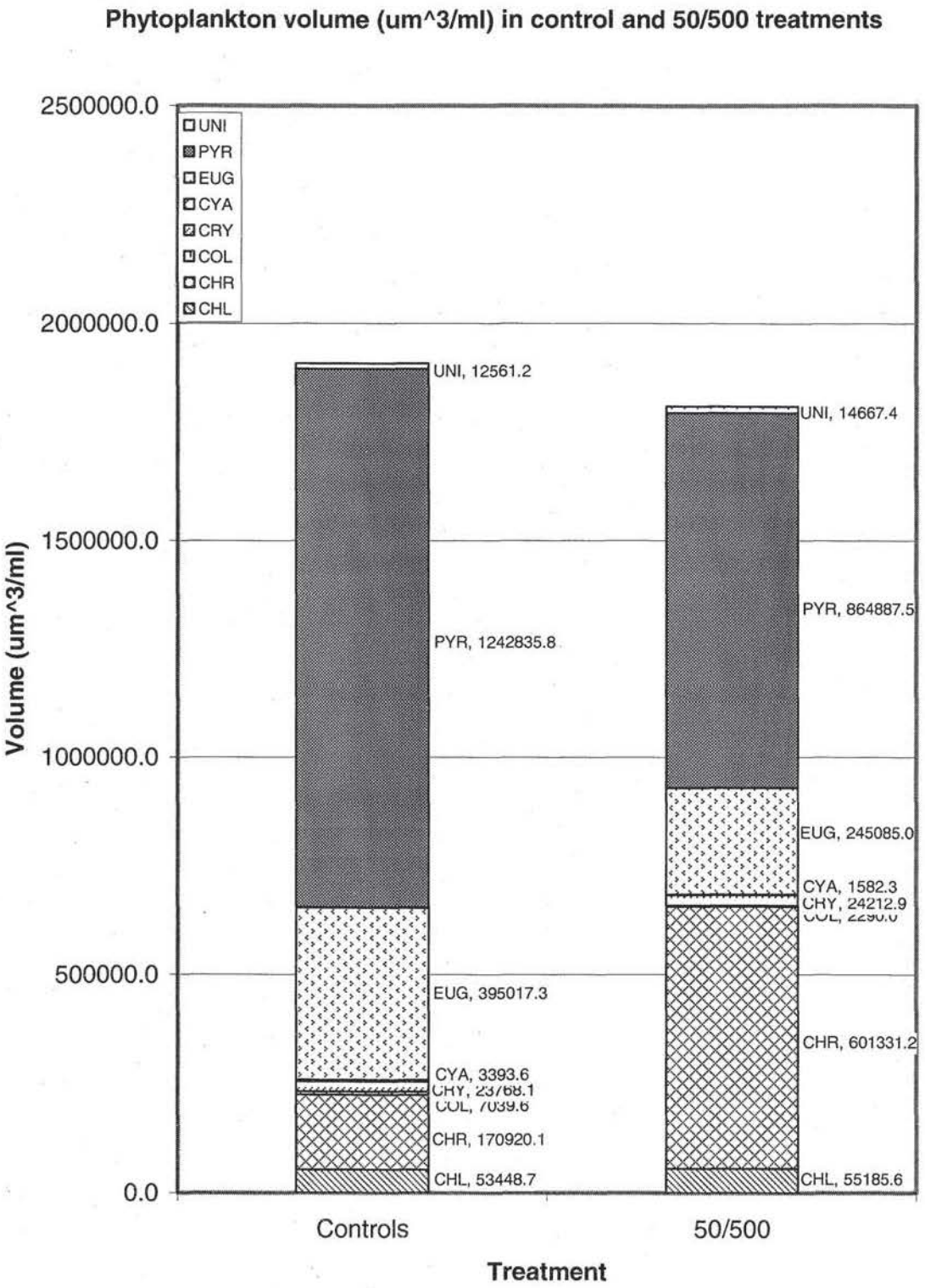


Figure 27. Biovolume of phytoplankton in control and 50/500% treatment at day 33 (final day of the experiment).

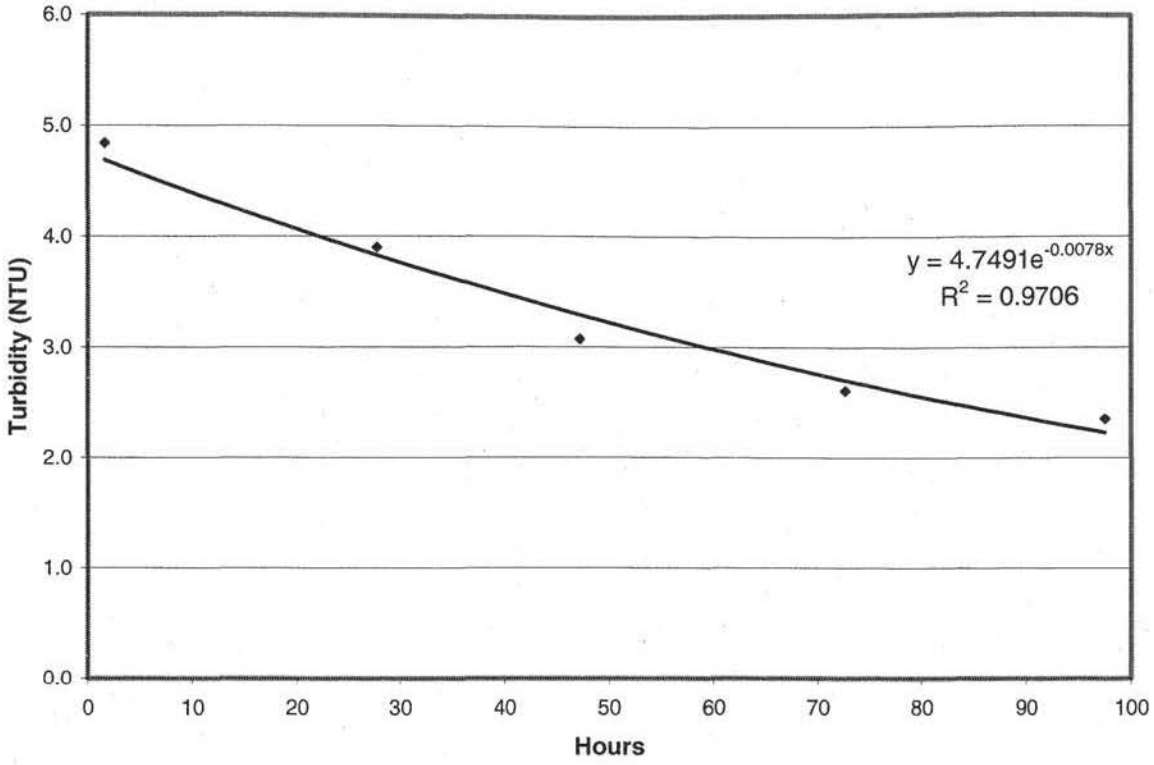


Figure 28. Scatterplot of turbidity (NTU) over time for a feces settling experiment.

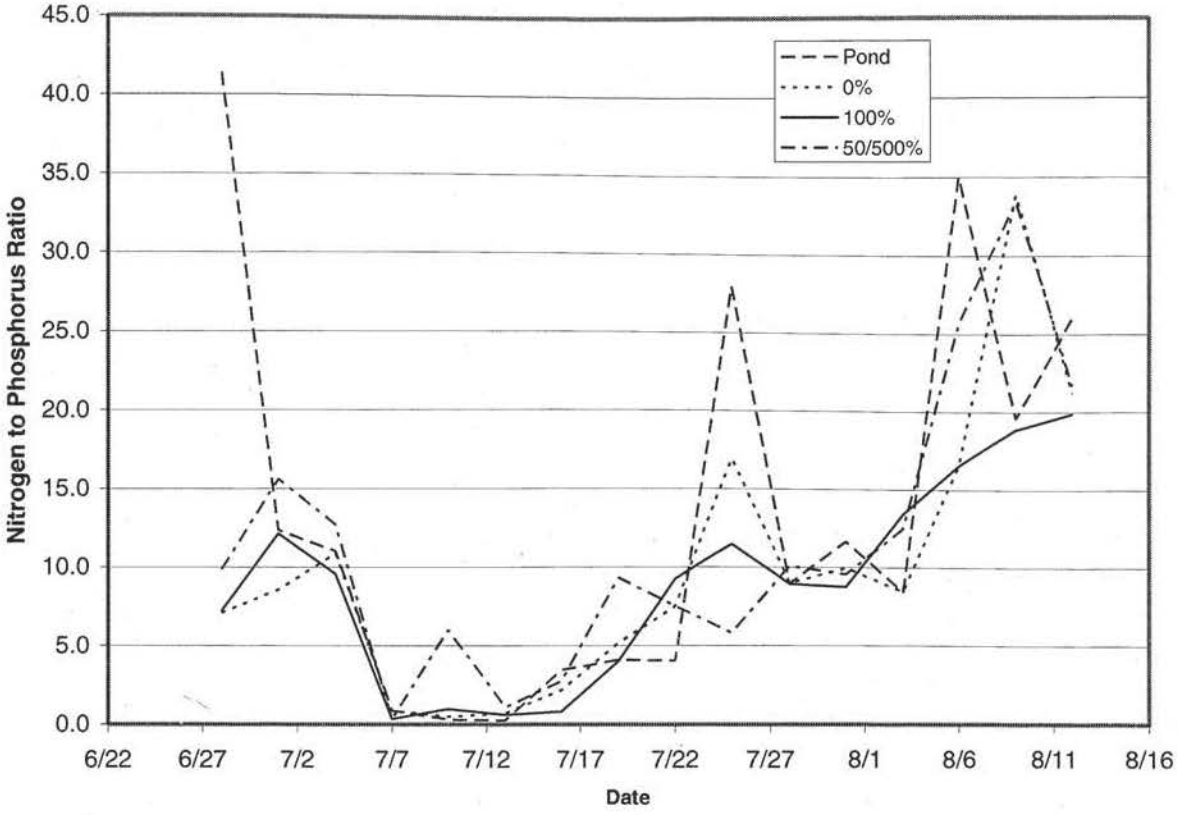


Figure 29. Nitrogen to phosphorus ratios in four treatments during the experiment.

Appendix 1

Fecal Addition Calculations.

0.175 g P per dropping (Manny 1994)
3.147×10^{-3} g P per g fresh weight feces (5.56 g fresh weight per dropping) (Manny 1974)
3.147 mg P per g fresh weight feces

34 kg P in January from waterfowl (Sherer et al. 1995)
10794 kg dry weight in January (3.147×10^{-3} g P per g fresh weight)
348.18 kg fresh weight d^{-1} in January (31 d)
348182.284 g fresh weight d^{-1}

0.994 g fresh weight d^{-1} m^{-3} (Manny 1974)
0.806 g feces (fresh weight) added d^{-1} (based on 0.811 m^3)

2.419 g feces added every three d for 100% value
1.209 g feces added every three d for 50% value
12.09 g feces added every three d for 500% value