Effects of nutrient enrichment on Georgetown Lake plant communities
by Peter Laurens Boveng

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University

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The Georgetown Lake Clean Lakes Project was designed to evaluate macrophyte control measures including herbicides, harvesting, and winter drawdown of the water level. Each of these measures has the potential for release of nutrients to the water. In the summer of 1982, enrichment experiments were conducted on isolated communities of macrophytes and phytoplankton to determine the short term fate of added phosphorus. Measurements of common limnological parameters including pH, alkalinity, conductivity, dissolved and total phosphorus, ammonia nitrogen, and chlorophyll were made at the enclosed sites. Similar measurements were made at open water sites to provide continuity with previous studies. Phytoplankton species composition and succession are described.

Limnological conditions in 1982 were similar to those described in studies made in 1973-1975 and 1981. The enrichment studies showed that some of the added phosphate appeared in the particulate fraction within several hours. However, most of the phosphorus was still unaccounted for at the end of the experiment and it appears that much of it may have simply precipitated owing to conditions of high pH and available calcium. No increase in nitrogen or phosphorus content was observed in the macrophyte tissue from the enriched site. Enrichment resulted in elevated densities of phytoplankton but did not cause appreciable shifts in the species composition. Rather, the major differences in species composition were between enclosed and open water sites.

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Peter Laurens Boveng

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date 27 MARCH 1985.

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ABSTRACT

The Georgetown Lake Clean Lakes Project was designed to evaluate macrophyte control measures including herbicides, harvesting, and winter drawdown of the water level. Each of these measures has the potential for release of nutrients to the water. In the summer of 1982, enrichment experiments were conducted on isolated communities of macrophytes and phytoplankton to determine the short term fate of added phosphorus. Measurements of common limnological parameters including pH, alkalinity, conductivity, dissolved and total phosphorus, ammonia nitrogen, and chlorophyll were made at the enclosed sites. Similar measurements were made at open water sites to provide continuity with previous studies. Phytoplankton species composition and succession are described.

Limnological conditions in 1982 were similar to those described in studies made in 1973-1975 and 1981. The enrichment studies showed that some of the added phosphate appeared in the particulate fraction within several hours. However, most of the phosphorus was still unaccounted for at the end of the experiment and it appears that much of it may have simply precipitated owing to conditions of high pH and available calcium. No increase in nitrogen or phosphorus content was observed in the macrophyte tissue from the enriched site. Enrichment resulted in elevated densities of phytoplankton but did not cause appreciable shifts in the species composition. Rather, the major differences in species composition were between enclosed and open water sites.

INTRODUCTION

The fate of a nutrient such as phosphorus or nitrogen, released into a freshwater lake, is an important aspect of the ecology of aquatic plant communities. Consider an atom of phosphorus, dissolved as phosphate ion in the water column. Whether its source was natural or cultural, its existence in the dissolved phase would likely be short lived. Planktonic and benthic plants and bacterioplankton are capable of taking dissolved phosphorus directly from the water column. In addition to biological processes which can remove nutrients from the dissolved phase, there are physical processes such as adsorption to suspended solids or to the sediments. This thesis describes a study of some of these processes as they occurred in Georgetown Lake, Montana in 1982.

Georgetown Lake is a reservoir located approximately 27 km northwest of Anaconda, Montana. The reservoir's importance as a multiple use resource has prompted several limnological studies (eg. Knight et al. 1975, Foris 1976, Garrison 1976, Geer 1977, Knight 1980, and Garrett 1983a,1983b). The data presented in this paper were collected as part of the most recent study, the Georgetown Lake Project, which was sponsored by the Environmental Protection Agency's Clean Lakes Program.

The Georgetown Lake Project sought, among other objectives, to evaluate the options available for controlling macrophyte growth while

maintaining the multiple use characteristics (Garrett 1983a). Among the alternatives considered for macrophyte control were treatment with herbicides, mechanical harvesting, and winter drawdown of the water level.

Each of these control measures has the potential for release of substantial quantities of nutrients to the water column. Herbicide treatment and mechanical harvesting, if not accompanied by removal of dead plant material, would release nutrients when the macrophyte tissue decayed. Nutrient release after a winter drawdown would probably be increased by the physical effects of ice disturbing the exposed littoral sediments (Dunst et al. 1974) as well as decomposition of plant material.

Economic considerations would probably limit harvesting or herbicide treatment to specific problem areas of the reservoir where dense macrophytes interfere most with recreational uses (Garrett 1983a). Consequently, under these treatments, there would be large portions of the lake in which undisturbed macrophyte communities would remain along with the corresponding plankton communities.

Winter drawdown would, likewise, only kill macrophytes in a limited area. The associated pulse of released nutrients would occur in the spring, at an early stage in the macrophyte's seasonal development, as contrasted with the summer release of nutrients from a harvest or herbicide application. These considerations lead to questions about the effect of increased nutrient load on both the attached and planktonic plants of Georgetown Lake.

With respect to the macrophytes, there is an obvious need to know whether spatially or temporally localized treatment of plants would simply aggravate problems with macrophyte density elsewhere, or at a later time. To a large extent, this would be determined by the effectiveness of phytoplankton competition with the macrophytes for the released nutrients.

Enrichment of a lake with nutrients may cause both quantitative and qualitative responses in the phytoplankton (Schindler and Fee 1974; Edmondson 1972). Quantitative responses are expressed as increased growth rates and/or increased standing crops. Such increases can be detrimental due to loss of aesthetic and recreational qualities. Qualitative responses are expressed as changes in the species composition of the phytoplankton community. More specifically, the frequencies of taxa which are capable of causing nuisance conditions (such as tastes, odors and toxins) often increase in lakes with increased nutrient loads (eg. Edmondson 1972). As Lynch and Shapiro (1981) have shown, the relative intensities of the quantitative and qualitative responses are dependent on a number of factors including the abundance of herbivores and their predators.

Experiments to determine the effects of nutrient enrichment on plant communities have been done on a 'whole lake' basis (Schindler 1974), but this was not a practical option for Georgetown Lake for several reasons. First, the heavy use of the reservoir for recreational purposes and of the shoreline for residential purposes, made a whole lake fertilization experiment unacceptable due to

potentially dramatic impacts on the users. Second, the size of the lake would make it economically difficult. Accordingly, it was decided in this study to enclose small portions of the lake for experimentation.

Enclosures of various types have apparently been used successfully in studies of nutrient dynamics (Lean and Charlton 1977) and aquatic plant community ecology (Lie 1979). Marine researchers have used enclosures to study the effects of metals and organic pollutants on several trophic levels from bacteria to fish (Menzel and Case 1977; Menzel 1977). Although enclosures provide advantages such as reducing the size of costly experiments, reducing complexity, and containing of harmful agents, the isolating structures themselves can have their own effects on the experimental system.

For example, during the 1981 field season of the Georgetown Lake Project, several enclosed littoral communities, which were scheduled to receive different treatments in a study of nutrient cycling, failed to track conditions in the natural communities by such a wide margin that they were deemed useless for the intended purpose. Because the use of enclosures --or mesocosms, as they are sometimes called-- is an attractive strategy (Odum 1984), this study will serve as an evaluation of the several types of enclosures used during the course of Georgetown Lake Project experiments.

Summarizing the ideas above, the objectives of this study were to:

1. Measure and describe relevant limnological parameters

in the reservoir during the course of Georgetown Lake Project experiments.

2. Describe the effects of nutrient enrichment on the density of phytoplankton.
3. Test the hypothesis that enrichment with nitrogen and phosphorus will lead to increased proportions of blue-green algae in the species composition.
4. Estimate the rate of removal of phosphorus from artificially enriched water by plant communities consisting of a) isolated phytoplankton, and b) macrophytes with phytoplankton.
5. Trace the fate of phosphorus in the plant communities on the time scale of a few hours, and attempt to construct a phosphorus budget for the entire growing season.
6. Evaluate the effectiveness of using enclosures for aquatic plant ecology research.

DESCRIPTION OF THE STUDY AREA

The historical, geographical, and geological features of Georgetown Lake and its drainage basin have been described several times, perhaps most completely by Knight (1980) and Garrett (1983b). Only a brief summary is given here.

Georgetown Lake is a reservoir located at latitude 46°10'16" N and longitude 113°10'42" W. The first impoundment was built in 1885 and was raised to its present level in 1919. At full pool, the mean depth is 4.89 m and maximum depth is 10.7 m. The surface area is 1219.2 ha and the surface elevation is 1959.7 m.

The area of the drainage basin is about 14,000 ha. Uses of the reservoir include summer and winter recreation, and permanent and seasonal residence. Logging, mining, and ranching are practiced in the surrounding basin.

METHODS AND MATERIALS

Sampling Sites and Schedule

Sampling sites were of two types, enclosed and open. The sites which were not enclosed will be refered to as open water sites, regardless of distance to shore or macrophyte coverage. Names and locations of sampling sites are shown in Figure 1. Site I was in open water near the dam at the deepest point (10 m) in the reservoir. The bottom at site I was smooth and silty, with no macrophyte growth. This site was sampled to provide continuity with the other Georgetown Lake studies, as it is the only one which has been consistently sampled (Knight, et al 1976; Garrett 1983b).

Several vinyl "limnocorrals" of various sizes were purchased from Kepner Plastics, Inc., Torrance, California. These enclosures were fabric-reinforced vinyl curtains with a flotation collar at the top and a heavy steel chain sewn into the bottom. The flotation collar extended above the water surface and the weighted bottom was embedded in the sediments to isolate the water column. The integrity of the seal was not tested directly, but the persistence of chemical, physical, and biological conditions which were dramatically different from the conditions outside the enclosures used in 1981 (Garrett 1983b; this study) implies that there was no substantial mixing.

Rigid frames were installed around all of the enclosures. These

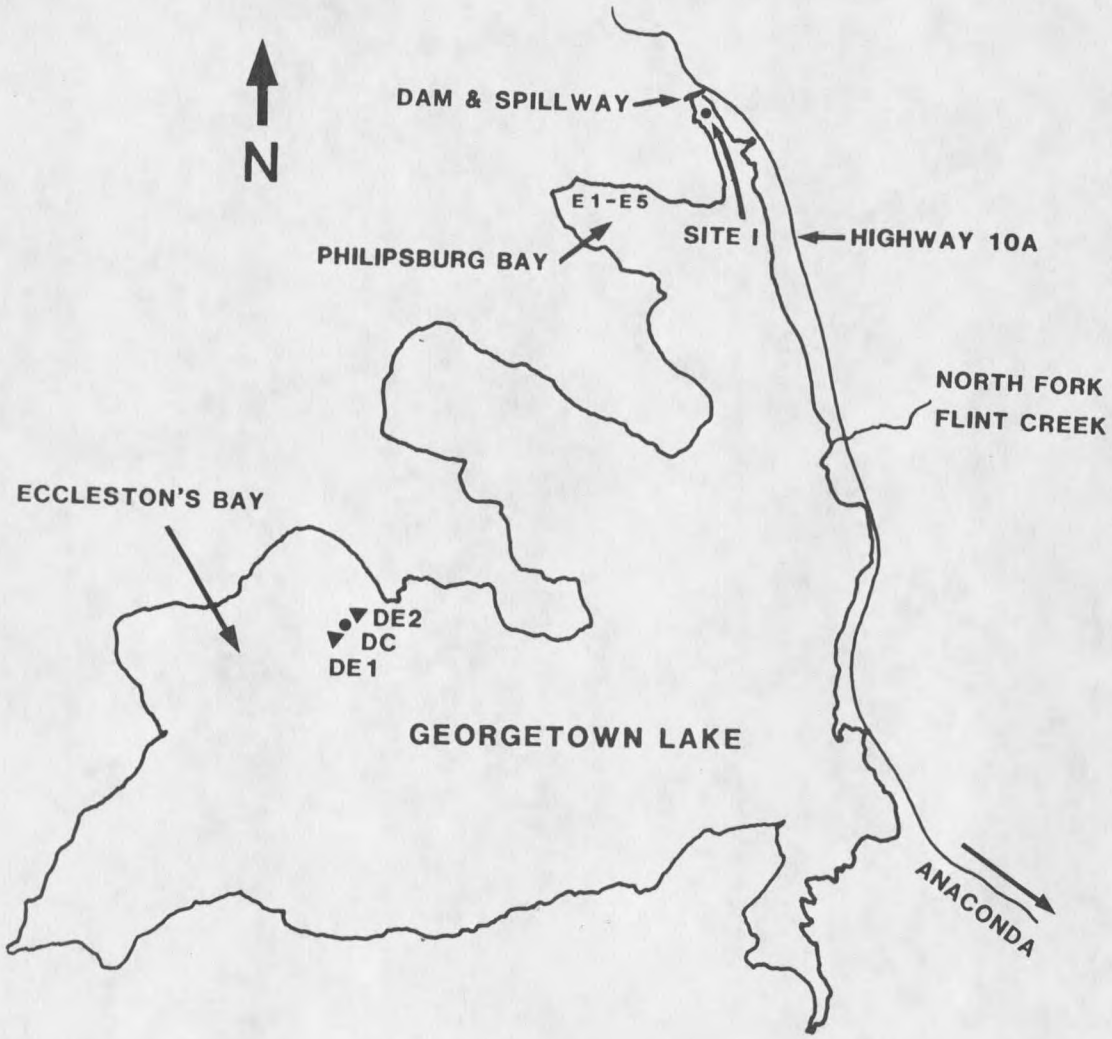

Figure 1. Map of Georgetown Lake showing sites sampled, 1981-82.

frames were wooden, in the form of triangles, 3.67 m on a side.

Five of the triangular enclosures were installed in Philipsburg Bay (designated E1-E5), surrounding shallow (about 2 m) macrophyte beds dominated by of Elodea. These five enclosures were maintained and sampled from July 1981 to June 1982. Garrett (1983a;1983b) reported some of the findings from analyses of water chemistry and other limnological parameters at these sites; Boveng (1983) reported on the phytoplankton communities in these enclosures. This study will summarize data relevant to evaluation of the performance of the enclosures.

For the summer 1982 field season, two new enclosures were made for use in deep water macrophyte communities. These enclosures were 5 m deep but otherwise the dimensions were the same as E1-E5. Clear vinyl windows were installed over about 85% of the wall surface area. These enclosures, designated DE1 and DE2, were installed over communities consisting entirely of Potamogeton praelongus in 4.7 m of water near the mouth of Eccleston's Bay (Figure 1). Site DE2 was chosen for fertilization treatment with phophorus and nitrogen. Site DE1 was used as an unfertilized control site to determine the effects of the enclosure itself on the community within. A third site at this location, designated DC, was an open water control site next to the enclosures, with the same type of plant community as DE1 and DE2.

Table 1 shows the dates during the summer of 1982 on which particular sites were sampled for water chemistry, chlorophyll, and phytoplankton. Site DC was sampled on 9 July 1982 to establish the

initial conditions at the experimental enclosure area. Enclosures DE1 and DE2 were installed immediately after sampling DC. At site DE2, all sampling for water chemistry and other limnological parameters was done immediately before each fertilization event. In addition to the routine sampling schedule reported in Table 1, three experiments were done to determine the short term fate of phosphorus added on 14 August, 26 August, and 9 September.

Table 1. Sampling schedule, summer 1982.

Date	Site			
	DC	DE1	DE2	I
9 July	X			X
21 July	X	X	X	X
28 July	X	X	X	X
3 August	X	X	X	X
13 August	X	X	X	X
25 August	X	X	X	X
7 September	X	X	X	X

Site DE2 was fertilized with phosphorus and nitrogen. Phosphorus was added as KH_2PO_4 and nitrogen was added as KNO_3, according to the schedule shown in Table 2. The fertilization rates were intended to fall in the range of concentrations that might be expected from nutrient release caused by the macrophyte control methods discussed in the introduction. These rates were based on an estimated 65 % areal coverage of macrophytes, a mean depth of 4.89 m, an average of 250 g/m^2 dry weight macrophyte biomass, 0.25 % phosphorus content, a P:N mass ratio of 1:7 (molar ratio of 1:15.5), and an 8 week decomposition period (Garrett 1983b).

Table 2. Fertilization schedule for site DE2, summer 1982. Enclosure DE2-S is described in the phosphorus fate section. Additions to enclosure DE2-S were counted in cumulative additions to DE2 because DE2-S was emptied into DE2 after each phosphorus fate experiment.

Date	Site	Phosphorus Added (g)	Cumulative P Added to Site DE2	Nitrogen Added (g)	Cumulative N Added to Site DE2	Target [P] (mg/l)
21 Jul	DE2	0.347	0.347	2.427	2.427	0.01
28 Jul	DE2	0.347	0.694	2.427	4.854	0.01
3 Aug	DE2	1.735	2.429	12.145	16.999	0.05
14 Aug	DE2-S	0.055		0.384		0.10
"	DE2	3.412	5.986	23.884	41.267	0.10
26 Aug	DE2-S	0.027		0.189		0.05
"	DE2	1.706	7.629	11.942	53.398	0.05
9 Sep	DE2-S	0.025		0.173		0.05
"	DE2	1.504	9.158	10.528	64.099	0.05

Sampling methods

All water samples were collected through Tygon tubing with a battery powered peristaltic pump. Depth stratified samples were made by lowering the end of the tube to the desired depth and then pumping, allowing time for the overlying water to flush through the pump. Depth integrated samples were collected by pulling the tube end through the desired range of depths while pumping. Samples for community metabolism studies were depth-stratified. All other samples were depth integrated from the surface to about 10 cm above the bottom.

A portion of each sample was filtered in the field using Whatman GF/C filters. The filters were placed in 90% aqueous acetone for extraction of chlorophyll. The filtrate was saved for determination of dissolved nutrients in the laboratory.

Water Chemistry

Analyses for phosphorus were done by the ascorbic acid method (APHA 1980). Soluble inorganic phosphorus (SIP) was defined as that quantity detectable in a filtered sample. Total soluble phosphorus (TSP) was that quantity detectable in a filtered sample after digestion with potassium persulfate. Total phosphorus (TP) was the quantity detectable in an unfiltered sample after persulfate digestion. Concentrations of all phosphorus species were computed and expressed as mg P/l.

Ammonia nitrogen was measured in filtered samples by the

phenolhypochlorite method (Solorzano, 1969). Concentrations of ammonia nitrogen were computed and expressed as mg N/l.

Alkalinity was measured using the pH potentiometric method (APHA 1980) with an endpoint of 4.5. Alkalinity values were computed and expressed as milliequivalents per liter (meq/l).

Conductivity was measured in the laboratory with a Yellow Springs Instruments model 31 conductivity bridge.

Chlorophyll

Measured volumes of water from each site were filtered with glassfiber (Whatman GF/C) filters in the field. The filters were immediately immersed in 20 ml of 90% acetone, placed on ice for transport to the laboratory, and stored in a freezer until analysis.

The optical densities of the acetone extracts were measured at 750 and 665 nm before and after acidification with 6 N HCl (Strickland and Parsons 1968). A recent study (Wilkinson 1983) has shown that the older acidification procedure is too vigorous and results in an absorbance shift for chlorophyll a greater than that which corresponds to the commonly used maximum acid ratio of 1.70 (The maximum acid ratio is the ratio of the absorbance of pure chlorophyll a before acidification to the absorbance after acidification.) From the results of Wilkinson (1983) a maximum acid ratio of 1.84 was computed for the chlorophyll a calculations of this study.

The equation used to compute chlorophyll a corrected for phaeopigments was

$$\text{Chl } a = (E_a - E_b) * (t/t-1) * k * (v/V * l)$$

where E_a is the extract absorbance at 665 nm minus the absorbance at 750 nm before acidification and E_b is the corresponding quantity measured after acidification, t is the maximum acid ratio (1.84), k is 1000 divided by the specific absorption coefficient (89 l*g/cm), v is the extract volume, V is the volume of water filtered, and l is the optical path length in cm (Wilkinson 1983).

Phytoplankton

A 125 ml subsample of the water collected for chemical analyses at each site was preserved with 3.0 ml of a mixture (FAA) of formalin, acetic acid, ethanol, and distilled water as in Prescott (1978). Fresh material, for use in taxonomic identification, was taken directly from the water chemistry samples in the laboratory.

Appropriate volumes of the preserved samples, dependent on the density of cells, were stained with iodine-potassium iodide solution (Prescott 1978) and concentrated onto Millipore HA membrane filters (25 mm diameter, 0.45 um pore size). Vacuum was limited to 167 mbar in order to minimize cell damage. Permanent microscope slide mounts were prepared from the filters after clearing with immersion oil (McNabb 1960).

A computer program was used to choose random coordinates on the slides for enumeration of the plankton. These coordinates were in

terms of the units on the Vernier scales of a movable microscope stage. The coordinates were checked for overlapping fields which were not counted. Records were kept of the locations of fields counted for each sample so that counts or taxonomy could be checked or repeated if necessary.

Counts were made under at least two magnifications between 150X and 1350X, depending on the size distribution of the predominant taxa. At each magnification, a number of fields sufficient to ensure observation of at least 100 individuals of the most abundant taxon were counted. Concentrations of phytoplankton in the lake were calculated by scaling the area counted to the total area on the filter and accounting for the volume of sample filtered.

Estimates of the standing crop of phytoplankton were made on a cell volume basis by multiplying cell numbers by an estimate of the representative cell volume for each taxon. Representative cell volumes were calculated in two ways. If the geometry of a cell was a simple one with a known volume formula, the appropriate cell dimensions were measured and the volume computed accordingly (Wetzel 1975). More complex shapes were modeled in sculptor's clay, and the displacement volumes of the models were scaled according to the actual cell dimensions.

Because preserving, staining and filtering distorts the cells of some taxa, fresh material from each sample was examined after concentration by gentle centrifugation. Lists of the taxa present and rough estimates of their relative abundance in the fresh material

were used to check the taxonomy of the preserved slides. Prescott (1962,1978), Patrick and Reimer (1966), Hustedt (1930), and Smith (1950) were used for taxonomic identification.

Phosphorus fate experiments

For the short term (approximately 36 hr) phosphorus experiments (14 August, 26 August and 9 September 1982), planktonic communities were isolated from macrophytes and sediments by using small-volume enclosures made from clear vinyl. These enclosures were tubes, 0.42 m in diameter and 4.0 m deep. The tubes were suspended vertically from float rings, and flat bottoms were sealed into the tubes with large pipe clamps. A bucket was used to fill each small enclosure with water from the appropriate site.

One of the small enclosures (DE2-S) was placed inside enclosure DE2, thereby isolating a fertilized plankton community from a fertilized whole community. Another small enclosure (DC-S) was placed at site DC, isolating a previously unfertilized plankton community from the intact community at the control site. The small enclosures were in place only during the three phosphorus experiments (i.e. were removed between experiments).

In the first phosphorus experiment, on 14 August, DE2-S was spiked with 54.8 mg of P and 383.6 mg of N (Table 2). In this, and the other two phosphorus experiments, DC-S was fertilized at the same rate as DE2-S. The community inside DE2 but excluded by DE2-S was spiked with an additional 3.412 g of P and 23.884 g of N (Table 2).

Monitoring the concentration of SIP at those sites during the subsequent 24 hours served to establish that in all sites there were detectable losses of P from the soluble inorganic pools.

In the other two phosphorus experiments (26 August, 9 September), the same enclosures were spiked according to the schedule in Table 2. In order to determine the fate of P disappearing from the dissolved inorganic pool, the levels of soluble inorganic phosphorus, total soluble phosphorus, and total phosphorus were all monitored. The P levels were measured immediately after spiking and at six times spread over the ensuing 36-38 hours in both experiments.

A laboratory experiment was conducted to determine whether orthophosphate is adsorbed by the vinyl material of the enclosure walls. Vinyl was incubated in known concentrations of phosphate ion at the same surface to volume ratio as existed in the enclosures. After 48 hours, no difference could be detected between the phosphate concentrations in solutions exposed to the vinyl and those not exposed to the vinyl.

Community metabolism

Measurements of community metabolism were made concurrently with the second and third phosphorus fate experiments by the diel pH-CO_2 method (Odum and Hoskin 1958; Park et al 1958; Beyers et al 1963). This method uses changes in pH to infer quantities of CO_2 fixed or released by the community. Community metabolism was measured in the enclosures (DE1, DE2) and the control (DC), as well as in plankton

isolates at each site (DE1-S, DE2-S and DC-S). Solar insolation during the community metabolism measurements was recorded with a Kipp and Zonen Model CM-3 pyranometer (Garrett 1983b) at the Montana Department of Fish, Wildlife and Parks cabin where U. S. Highway 10A crosses the North Fork of Flint Creek (Figure 1).

Macrophyte biomass and tissue analysis

On 28 July 1982 the heights of all Potamogeton praelongus stems in sites DE1 and DE2 were measured to the nearest 0.1 m. The measurements were made by SCUBA diving outside the enclosures and sighting against markers fixed in the enclosures.

The entire stands of Potamogeton praelongus at sites DE1, DE2, and DC were harvested at the termination of the field study on 20 September 1982 by SCUBA diving and gathering the plant stems into bags by hand. All the above-sediment biomass was collected from each site. The roots of this species are generally small and easy to pull from the sediments but a few stems broke in the harvesting process, leaving a small but unquantified portion of the root biomass in place.

The samples were frozen until just prior to analysis when they were dried at 70° C. Dry weights were recorded for each sample. Samples of leaf tissue and representative samples (approximately 20 g) of whole plant tissue were ground with a mortar and pestle and stored in a dessicator.

The samples were analyzed for carbon and nitrogen content using a Carlo-Erba model 1106 elemental analyzer standardized with

acetanilide by Dr. John C. Priscu, Biology Department, Montana State University. Total phosphorus was measured by the ascorbic acid method (APHA 1980) after ashing with magnesium nitrate and digestion in sulfuric acid.

RESULTS AND DISCUSSION

Conductivity

The specific conductance of the water decreased at all sites during the 1982 summer season (Figures 2 and 3). The conductance at site I (Figure 2), was lower initially but did not decrease by the end of the summer to levels as low as those at the sites in the experimental area (Figure 3). The trend was interrupted by an increase in conductance on 3 August at all sites. This increase occurred at the same time as the observed peak in phytoplankton standing crop at most sites.

There was an initial drop in conductance in the enclosures (DE1 and DE2) relative to the control (DC), but by 25 August the three sites were nearly the same. The conductance continued to decrease in fertilized DE2 but increased slightly at DC and DE1 by 7 September.

Alkalinity and pH

At most sites, the general trend was a decrease in alkalinity as the summer season progressed (Figures 4 and 5). The alkalinity increased slightly at site I at the beginning of the season and increased at site DC on the last sampling date. The alkalinity at DC was slightly higher than in the enclosures except on 25 August when the levels were 1.60 meq/l at DC and 1.64 meq/l in DE2.

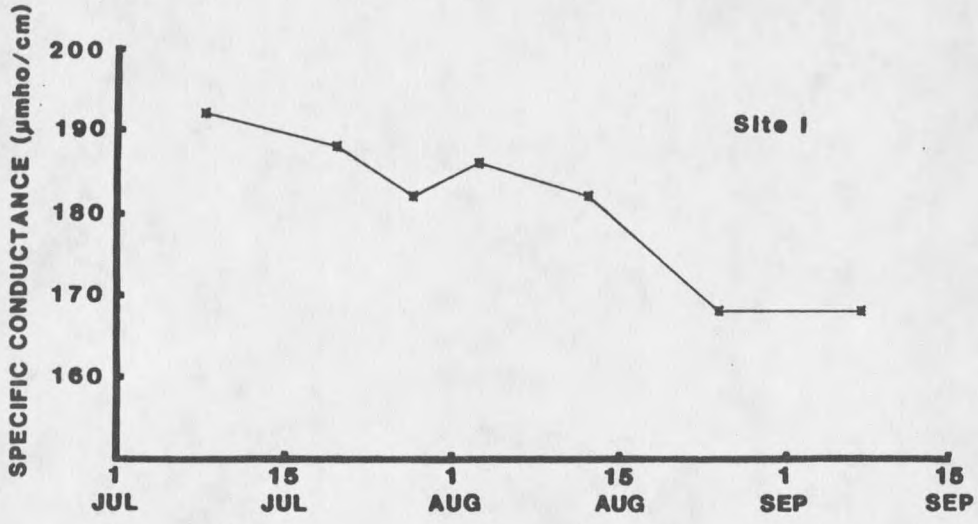

Figure 2. Specific conductance at site I.

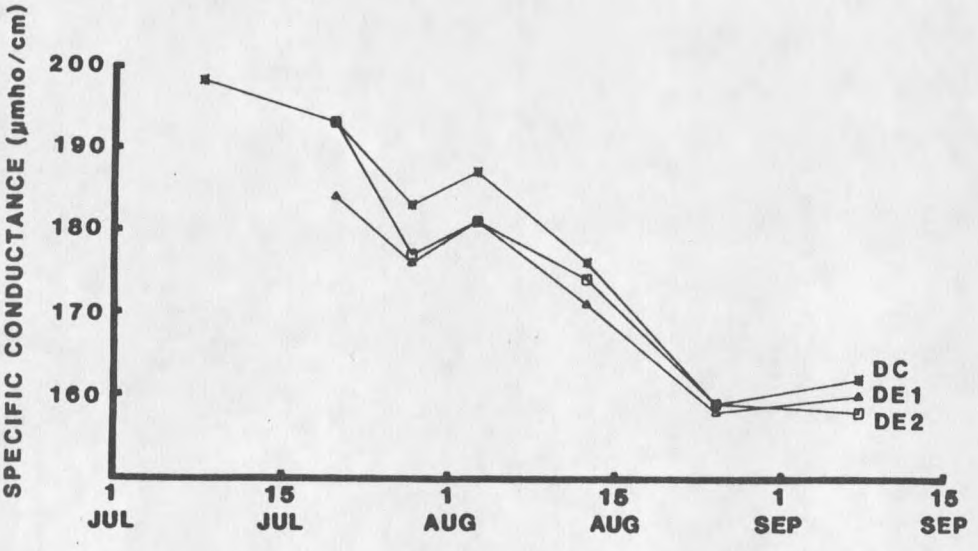

Figure 3. Specific conductance at sites DC, DE1, and DE2.

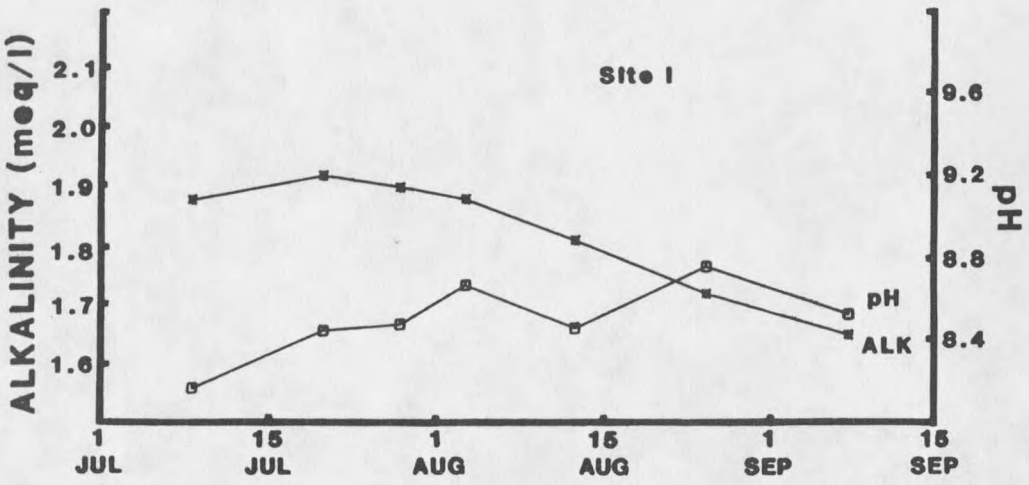

Figure 4. Alkalinity and pH at site I.

The pH values increased with time but the trends were somewhat less regular than those of the alkalinities. There was a peak in pH value common to all sites on 25 August. The highest pH observed was 9.16, at DE2 on that date (Figure 5). The pH values in Figures 4 and 5 were measured in the lab as initial points for the alkalinity titrations. Higher pH's were measured in situ during diel community metabolism measurements but they are not directly comparable to the lab values. As Knight (1981) and Garrett (1983b) showed, the high pH values of Georgetown Lake during periods of high production represent a condition of undersaturation of CO_2. The pH's measured in the lab may have have been lowered by absorption of atmospheric CO_2 after collection, but this should not have affected the alkalinity measurements (Stumm and Morgan 1981).

There was an initial drop in pH of the enclosed sites relative

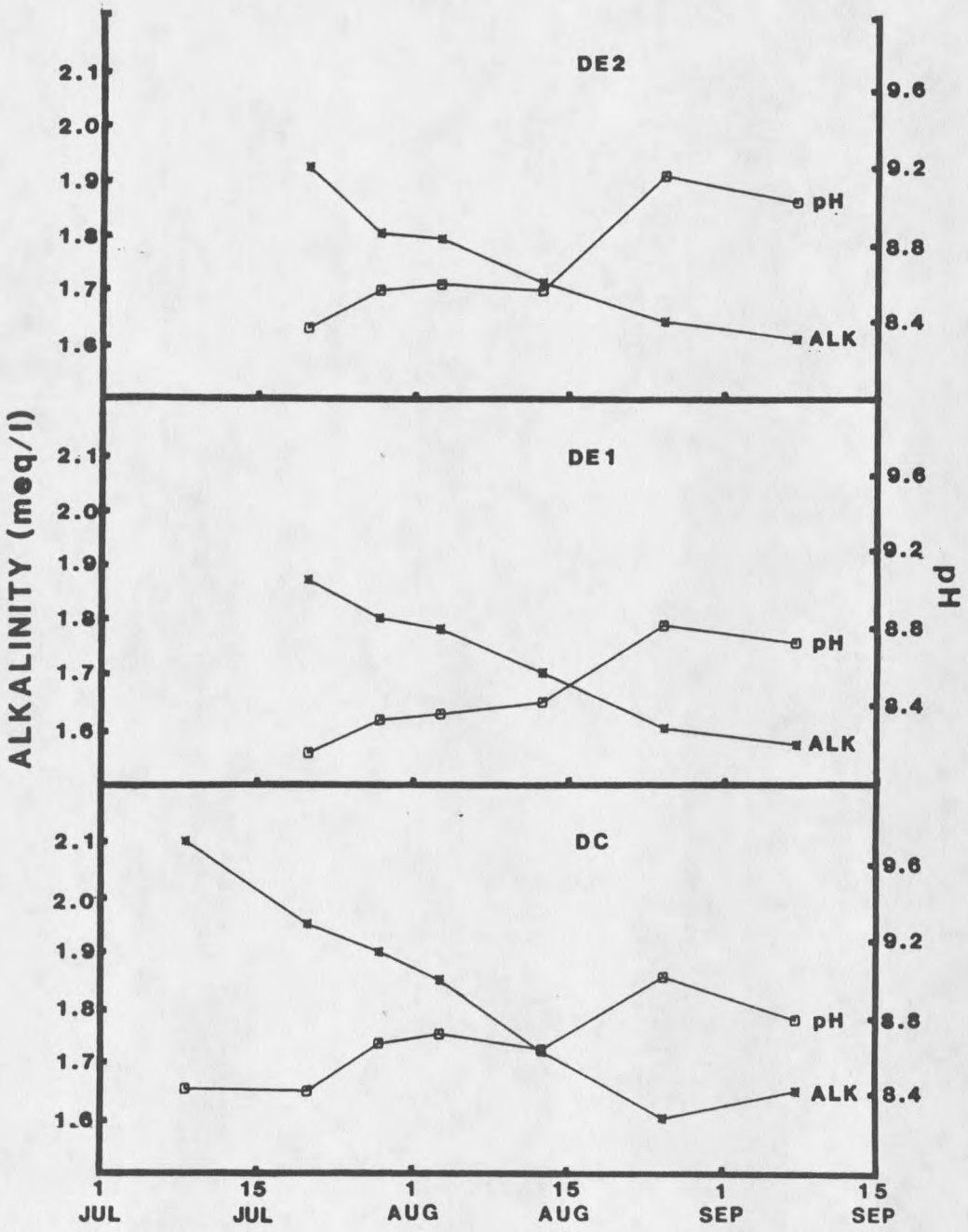

Figure 5. Alkalinity and pH at sites DC, DE1, and DE2.

to the control. The pH in DE1 remained below that of DC, but in DE2, the fertilized enclosure, the pH increased to levels above those of DC by the end of the experiment.

The observed trends in conductivity, alkalinity, and pH are commonly observed and can all be related to plant production and the inorganic carbon system of a calcium carbonate dominated lake such as Georgetown (Knight 1981). Photosynthetic removal of carbon dioxide from the water causes an increase in pH and, if accompanied by uptake of bicarbonate, ammonium, and phosphate, a decrease in alkalinity (Stumm and Morgan 1981). In addition, the increased pH can cause precipitation of calcium carbonate onto macrophyte leaf surfaces or in water from which it settles to the bottom (Wetzel 1975). The dissolution of $CaCO_3$ is much slower than the precipitation reaction which, along with the slow rate of invasion of atmospheric CO_2, produces a condition of undersaturation of CO_2 for much of the summer season. The observed decreases in conductivity presumably were the result of these biologically mediated removals of ionic species from the water column.

Ammonia nitrogen

Nitrogen detectable as ammonium ion (Table 3) dropped rapidly to levels below the detection limit at all sites by 28 July. The ammonium levels remained below detectable levels until 25 August, at which time there were low but detectable quantities at all sites. By 7 September, there were moderate levels of nitrogen detectable as ammonium at all sites.

Table 3. Concentrations of nitrogen present as ammonium ion, 1982. Dashed entry indicates concentration below level of detection.

Date	Ammonia Nitrogen (mg N/l) DC	DE1	DE2	I
9 July	.017			.005
21 July	---	.013	---	---
28 July	---	---	---	---
3 August	---	---	---	---
13 August	---	---	---	---
25 August	.001	.005	.003	.003
7 September	.007	.011	.007	.007

Phosphorus

The most notable features in the trajectory of soluble inorganic phosphorus (SIP) at site I were the two peaks occurring on 28 July and 25 August (Figure 6). On those dates, SIP constituted a relatively large portion of the total phosphorus (TP). SIP was low at sites DC and DE1 (Figure 7), except for a level of .009 mg P/l on 3 August. SIP increased in the fertilized enclosure to .012 mg P/l on 25 August and dropped to .007 mg P/l on 7 September.

The total soluble phosphorus (TSP) levels, which include both organic and inorganic fractions, seemed to track the SIP levels at all sites. This indicates that the soluble organic phosporus (TSP-SIP) maintained a fairly constant level and the fluctuations in total soluble phosphorus levels were primarily due to variation in the inorganic portion.

Variation in total phosphorus (TP) was generally slight when compared to the corresponding variation in the soluble components