INFLUENCE OF INORGANIC AND ORGANIC NUTRIENT ENRICHMENT ON BLUE-GREEN ALGAL ACTIVITY AND RELATIVE BIOMASS IN A EUTROPHIC SOUTHWEST MONTANA RESERVOIR

by

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VITA

Thomas David Miller was born to Thomas and Ann Miller in South Bend, Indiana on July 26th, 1961. He graduated from Cathedral High School, St. Cloud, Minnesota in May 1979. In August 1980 he entered active duty in the United States Air Force and was honorably discharged in 1984. In the Fall of 1984 he started college at St. John's University where he stayed until receiving a Bachelor of Science degree in Natural Sciences in December 1987. He began studies toward a Master of Science degree at Montana State University in March 1988.

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ABSTRACT

Nutrient enrichment experiments were conducted over two ice-free seasons in a blue-green algal dominated southwest Montana reservoir to determine seasonal trends in nutrient deficiency. Additional experiments examined the influence of inorganic N, phosphate and dissolved organic carbon (mannitol) on the relative activity of blue-green and non-blue-green algal components of the community. Results showed that the whole phytoplankton community (i.e., all size classes) was generally N-deficient. Phosphorous addition alone stimulated growth and photosynthesis of the N_2-fixing Anabaena or Aphanizomenon component of the community in only two of ten experiments. The non-blue-green algal component was most consistently stimulated by N. Activity of nitrogenase, the enzyme catalyzing atmospheric nitrogen fixation, was stimulated by P and by mannitol on several occasions whereas N addition consistently reduced nitrogenase activity. Nitrogenase activity was found to have a positive relationship with temperature and total P, and a negative relationship with the DIN:SRP ratio. A multiple linear regression model showed that the relative abundance of nitrogen fixing blue-green algae was positively correlated with the dissolved inorganic N to soluble reactive P ratio, and to total N. This study provides evidence that P is not always the primary nutrient that controls productivity of lakes and reservoirs, and that N must also be considered when making water quality decisions, even in systems dominated by N_2-fixing blue-green algae.

INTRODUCTION

Phosphorous has traditionally been thought to limit phytoplankton productivity in lakes (Hecky and Kilham 1988; Schindler 1977). This view has been challenged in recent years by studies showing nitrogen deficiency for many freshwater systems (e.g. Canfield et al. 1989; Dodds et al. 1989; Elser et al. 1988; Prepas and Trimbee 1988; Priscu and Priscu 1984; Vincent et al. 1984; White et al. 1985). Elser et al. (1990) reviewed phytoplankton nutrient enrichment experiments and found nitrogen to be more important than previously recognized. Competition for nutrients in limited supply also plays a significant role in determining phytoplankton community structure (Reynolds 1984). Consequently, a better understanding of nutrient deficiencies will provide water quality managers with important information on the development of bloom formation by nuisance algal species.

The ability of scum-forming blue-green algae (cyanobacteria, e.g., Anabaena and Aphanizomenon) to outcompete other groups in nitrogen deficient systems, or systems with low nitrogen to phosphorus ratios, allows them to dominate many lakes and reservoirs (McQueen and Lean 1987; Tilman et al 1986; Priscu 1987). Nitrogen deficiency can result in blue-green algal blooms that proliferate to

nuisance levels. Systems dominated by these nuisance organisms experience diminished natural resource value. Aesthetic quality and recreational use are hampered by unsightly surface scum and odor. Fish populations are affected by oxygen depletion following collapse of blue-green algal blooms (Ayles et al. 1976; Barica 1975) and by inefficient transfer of primary production to higher trophic levels (Carpenter et al. 1987; Shapiro 1980). Neuro- and hepata-toxins produced by blue-green algae (Gorham and Carmichael 1988) pose a serious hazard to animals and occur more frequently than usually perceived (Sonzogni et al. 1988). Recreation in waters with blue-green algal scum has resulted in cases of contact dermatitis. Algal extracellular products can pose other health problems in municipal water supplies in addition to taste and odor problems. These organics can act as precursors of trihalomethanes (THM's), carcinogenic chemicals formed during chlorination (Cooke 1986). The consequences of blue-green algal blooms underscore the importance of understanding factors regulating blooms to aid in management.

Researchers have reported various factors that contribute to blue-green algal dominance in lakes. Characteristics of blue-green algae that promote their dominance include bouyancy (Reynolds et al. 1987; Klemer and Konopka 1989), immunity to grazing (Porter 1977; Sterner 1989; Holm et al. 1983; Nizan et al. 1986), excretion of

iron chelators that inhibit the growth of other algae (Murphy and Lean 1976; Keating 1978), possession of accessory photosynthetic pigments (Carr and Whitton 1982; Tilzer 1987), ability to exist at low CO_2 levels (Shapiro 1973; Pearl and Ustach 1982), elevated water temperatures (Tilman and Kiesling 1984; Tilman et al. 1986; Smith et al. 1987), water column stability (Reynolds 1984; Priscu 1987), and low underwater light availability (Mur et al. 1978; Tilzer 1987; Smith 1986, 1990). Although blue-green algal picoplankton are abundant in many oligotrophic waters (Stockner 1988), blue-green algae, particularly filamentous, scum forming species, generally contribute more to the phytoplankton biomass in eutrophic waters (Trimbee and Prepas 1987; Wetzel 1983). Most eminent, in terms of management, is the generalization that the relative abundance of nuisance blue-green algae is promoted by increased total P (Trimbee and Prepas 1987) and low N to P ratios (i.e., N-deficiency) in the lake water (Schindler 1977; Smith 1983).

The capability of heterocystous blue-green algae (e.g., Aphanizomenon and Anabaena) to fix N_2, via the enzyme nitrogenase, plays a key role in allowing them to dominate N-deficient systems (Schindler 1977; Carr and Whitton 1982; Wetzel 1983). It follows that the factors regulating nitrogenase activity influence this ability to outcompete other phytoplankton in N-deficient waters. The roles of

macronutrients (N and P), micronutrients (Fe, Mo and Cu) and O_2 have been reviewed by Horne and Commins (1987), Rueter and Petersen (1987) and Pearl (1990), respectively. Influences of nutrients include inhibition by dissolved inorganic N, Cu and O_2, and stimulation by P, low N:P, Mo and Fe. Nitrogenase activity is light (energy) and temperature dependent (Carr and Whitton 1982; Priscu 1987). Pearl (1990) also associated dissolved organic carbon (DOC) and bacteria with increased nitrogenase activity.

Because of the importance of nutrients in the literature, and our developing ability to manage nutrient inputs from point and non-point sources in the watershed, this study focused on the influence of nutrients on blue-green algae. The objectives of this study were:

1. To determine seasonal phytoplankton nutrient deficiency in a blue-green algal dominated reservoir.

2. To examine the influence of N, P and organic-C enrichment on relative blue-green algal abundance.

3. To examine the influence of N, P and organic-C enrichment on the relative activity of blue-green and non-blue-green algal components of the phytoplankton community.

4. To investigate the influence of N, P and organic-C on blue-green algal nitrogenase activity.

METHODS

Study Site

The reservoir chosen for this study was Hebgen Lake, Montana (lat. 44°51'51, long. 111°20'09", elev. 1991 m), the first impoundment on the Madison River (Fig. 1). Hebgen Lake is a storage reservoir operated by Montana Power and Gas Company for hydroelectric production downstream. The reservoir has a storage capacity of 476.5×10^6 m^3, maximum depth of 25 m at the dam, average annual discharge of 891×10^6 m^3, and a 2344 km^2 drainage basin which lies largely within Yellowstone National Park (U.S.G.S. 1984). Permanent sampling stations visited during routine trips are marked on Figure 1 as: 1, Grayling Arm; 2, Madison Arm; 3, Mid-Lake; 4, Dam. Water for all nutrient enrichment experiments was collected from the Grayling Arm at station 1. The Grayling Arm is a hydrologically distinct lobe of Hebgen Lake with its own inflows and a single outflow through a narrow channel connecting it with the main lake. Ground water fluxes have not been quantified. The Grayling Arm has a surface area of 7.8 km^2, volume of 29.9×10^6 m^3, mean depth of 3.8 m and maximum depth of 8 m at full pool. It is polymictic, but thermally stratifies occasionally. This lobe of the lake experiences dense blooms of often toxic N_2-fixing blue-green algae which dominate the phytoplankton

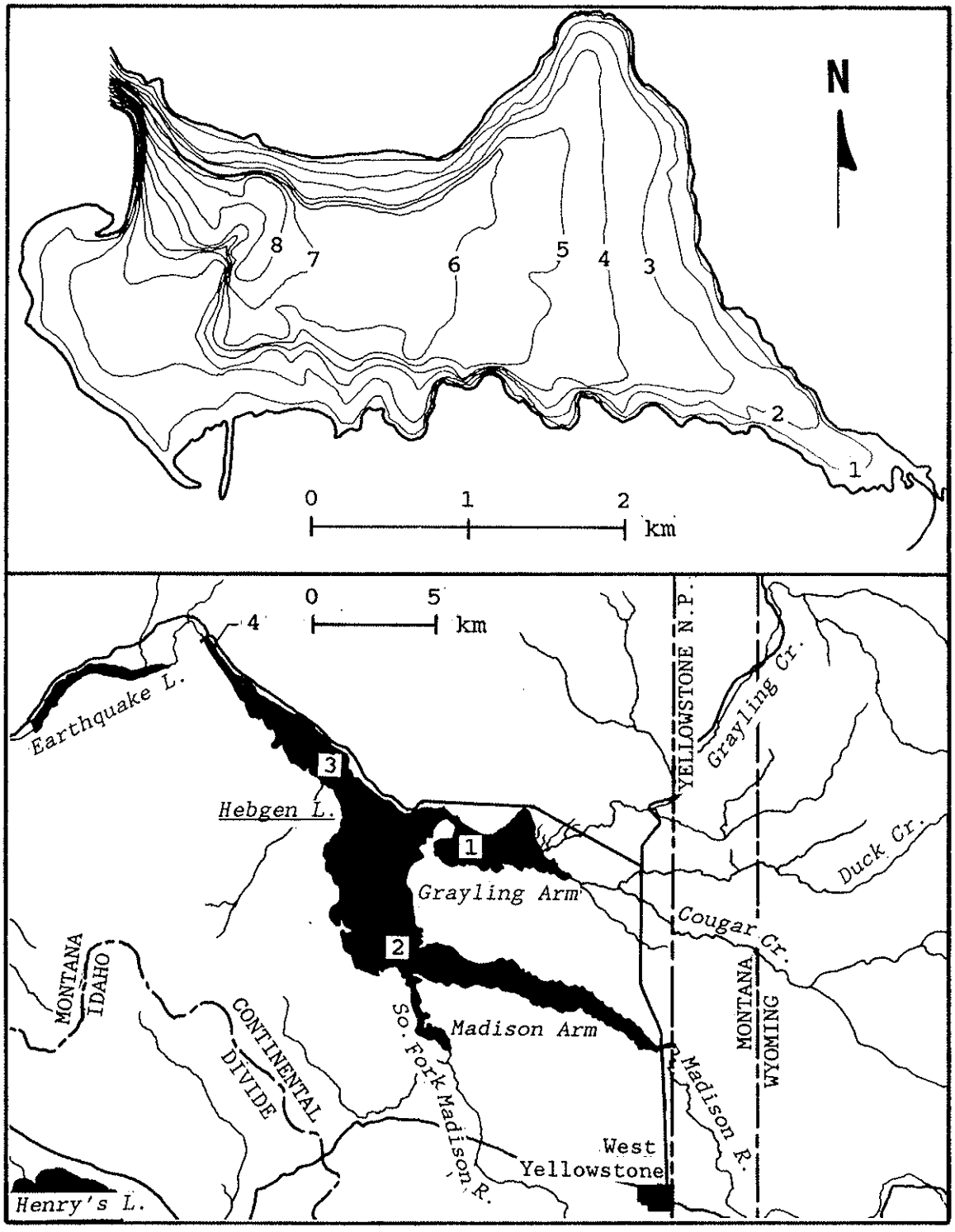

Figure 1. Map of Hebgen Lake, Montana, with permanent sampling stations marked 1, 2, 3 and 4 (bottom) and contour map of Grayling Arm (top). Contour interval 1 m.

community during most of the ice-free season. A detailed description of Hebgen Lake was presented by Martin (1967) and Martin and Arneson (1978).

Field Monitoring

Routine sampling trips to Hebgen Lake were conducted approximately biweekly during the ice-free seasons (mid-May through early November) of 1988 and 1989. In 1988 data were collected at buoys set at the four permanent sampling locations marked on Figure 1. Sampling focused on the Grayling Arm in 1989, with the addition of three sampling dates at the Mid-Lake station. Water samples for nutrient chemistry, phytoplankton enumeration, and measurement of phytoplankton photosynthesis and nitrogenase activity were collected with a 4-l Van Dorn sampler from discrete depths (0, 1, 3, 5, 10, 15 and 20 m) at each station. These profiles extended down to 5 m at station 1, 10 m at station 2, and 15 or 20 m at stations 3 and 4, depending on water level. Secchi depth and dissolved oxygen profiles were recorded during each site visit. Samples for dissolved and particulate nutrient analyses and phytoplankton enumeration were stored in clear high density polyethylene bottles on ice until returned to the laboratory.

One light and one dark bottle for phytoplankton carbon uptake and one bottle for nitrogenase activity (also a kill from 1 m) were incubated for 4 to 6 hours during midday at the depth and location of sampling (see phytoplankton

photosynthesis measurement and nitrogenase activity assay sections below). Photosynthesis was terminated by putting carbon uptake bottles into a light-proof box for transport to the laboratory. Extremely rough water precluded incubations at the Dam station on several occasions and retrieval of incubation bottles from the Madison Arm twice during 1988. Leakage of the acetylene flask precluded nitrogenase activity incubations at station 1 on 23 August 1989.

Dissolved Nutrient Analyses

Soluble reactive phosphorous (SRP) was determined by the molybdate method modified for AsO_4^- interference (Downes 1978) and total dissolved phosphorous (TDP) by the acid hydrolysis procedure (Solórzano and Sharp 1980) followed by orthophosphate determination (Stainton et al. 1977). Concentrations of NH_4^+ were measured by the phenol hypochlorite method (Solórzano 1969), NO_3^- by cadmium reduction (Eppley 1978), and total dissolved nitrogen by persulfate digestion (D'Elia et al. 1977) followed by determination of NO_3^- by cadmium reduction. These analyses were performed on samples that had been prefiltered through Whatman GF/C filters and frozen in acid-washed high density polyethylene bottles before analysis. Dissolved organic carbon (DOC) was measured with a Dorhmann Carbon Analyzer on acidified (pH<3) samples. Dissolved inorganic carbon (DIC) was determined using the bromcresol green - methyl red

titration method for alkalinity (A.P.H.A. 1971). Alkalinity (mg $CaCO_3$ l^{-1}) was converted to DIC (mg C l^{-1}) by multiplying the former by 0.24, based on the molecular weights and milli-equivalencies of C and $CaCO_3$.

Particulate Matter Analyses

The Whatman GF/C filters used for dissolved nutrient sample filtration were retained for particulate analyses. Pheaophytin corrected chlorophyll a (CHL a) was determined by fluorometry (Strickland and Parsons 1972), standardized with known amounts of pure CHL a (Sigma). The acid hydrolysis procedure (Solórzano and Sharp 1980) with subsequent orthophosphate measurement on the digest (Stainton et al. 1977) was used to measure particulate phosphorus (PP). Particulate carbon (PC) and particulate nitrogen (PN) were determined with a Carlo Erba model 1106 elemental analyzer calibrated with acetanilide. Total nitrogen (TN) and total phosphorus (TP) are the sum of the total dissolved and particulate fractions of each respective element.

Phytoplankton Enumeration

Phytoplankton species and numbers were determined from samples preserved with Lugol's solution. Uttermohl chambers (Uttermohl 1958) were filled with an appropriate amount of sample (5-25 ml), depending upon algal density, and settled for at least 4 h cm^{-1} of water in the chamber. The settled

phytoplankton were identified and counted with a calibrated Zeiss inverted microscope (Lund et al. 1957) and measured for biovolume determination. Equations for volumes of geometric shapes that approximated each cell type and appropriate average dimensions for each species were used to determine biovolume, which was converted to biomass under the assumption that the specific gravity of phytoplankton equals that of water. Data were grouped by divisions: Cyanophyta (blue-green algae), Chrysophyta, Cryptophyta, Pyrrophyta, Chlorophyta and LRGT (not an algal division but a group representing all "Little Round Green Things" less than 2 μm in diameter).

Phytoplankton Photosynthesis Measurement

During field monitoring and mesocosm and limnocorral experiments, the rate of phytoplankton photosynthetic C-uptake (primary productivity = PPR) was determined by adding [^{14}C]-$NaHCO_3$ as a tracer (final activity of about 0.05 μCi ml^{-1}) to 150 ml aliquots of sample. Sterile aqueous [^{14}C]-$NaHCO_3$ solution with a specific activity of 50 mCi $mmol^{-1}$ (ICN Radiochemical Inc.) was diluted with sterile, deionized water to a final working activity of about 6 μCi ml^{-1}. After adjusting the pH to 10.8 with NaOH, the working stock was ampulated in 5 or 10 ml volumes and autoclaved. The final activity was determined by internal standardization with a ^{14}C-toluene standard (ICN). Standardization was done in the presence of ethanolamine (Fisher Scientific) to avoid loss

of CO_2 to the atmosphere. One light and one dark bottle were used for each depth for field monitoring. Three light bottles and one dark bottle from each treatment were incubated for the experiments. Darkened samples were included to correct for non-photosynthetic ^{14}C uptake. Bottles were incubated in-situ for approximately 4 h near midday. Photosynthesis was terminated by placing samples in dark boxes and subsequent filtration onto Whatman GF/C filters, followed by three washes with 10 ml deionized water. The filters were placed into 20 ml scintillation vials and acidified with 250 μl of 3.0 N HCl to eliminate unincorporated [^{14}C]-$NaHCO_3$; after drying, activity remaining on the filter was determined with standard liquid scintillation spectrophotometry (Beckman LS-100C scintillation counter). Efficiency (used to convert CPM to DPM) was computed by the external standard channels ratio, with a quench curve using acetone as a quenching agent and ^{14}C-toluene as the standard radiation source. Disintegrations per minute (DPM) of ^{14}C tracer was converted to carbon uptake using the following equation.

$$\mu g\ C\ l^{-1}h^{-1} = ((LtDPM-DkDPM)\ x\ DIC\ x\ 1.06)/ (\mu Ci\ x\ 2.2x10^6\ x\ time)$$

LtDPM-DkDPM : light bottle DPM - dark bottle DPM

DIC : dissolved inorganic carbon (based on alkalinity titration) ($\mu g\ C\ l^{-1}$)

1.06 : isotope discrimination factor to correct for the slight preference for ^{12}C during photosynthesis.

μCi : ^{14}C activity of tracer added to bottle in μCurries.

2.2 x 10^6 : converts DPM to μCi (2.2×10^6 DPM μCi^{-1})

time : incubation time (h)

Size Fractionation

On one day during each experiment (except June 1988 mesocosm experiment), separation of the phytoplankton community into blue-green algal and non blue-green algal size fractions was accomplished to investigate the relative photosynthetic activity of each. Size fractionation of each treatment was done by pouring a subsample from each light or dark bottle through 20 μm, 100 μm or 210 μm Nitex netting and collecting the phytoplankton that passed through on a GF/C filter. The radioactivity on the filter was used to compute what is reported herein as DPM ml^{-1}, or $\mu g\ C(l \times h)^{-1}$ for the < 20, < 100, or < 210 μm (non-blue-green algal) fraction, depending on which mesh size was chosen to effectively exclude the filamentous N_2-fixing blue-green algae from the rest of the community. This activity was subtracted from the activity calculated for an aliquot of whole sample from the same bottle to yeild activity in the > 20, > 100, or > 210 μm (blue-green algal) fraction.

Nitrogenase Activity Assay

Rates of atmospheric nitrogen fixation were estimated using the acetylene reduction method to measure nitrogenase activity (NA) (Flett et al. 1976). This technique employs the ability of the nitrogenase enzyme to reduce acetylene (C_2H_2) to ethylene (C_2H_4). For each treatment, four 55 ml aliquots were decanted into 70 ml serum vials and sealed with rubber septa. Formalin (2.5 ml) was added to one of the vials (kill) for background ethylene determination. Injection of 6.0 ml high purity acetylene was followed by notation of start time and gentle shaking for 10 s to equilibrate acetylene with the aqueous phase. After approximately 4 h incubations, vials were shaken vigorously for 30 s to equilibrate gases between the aqueous and gaseous phases. The stop time was noted when 1.5 ml of headspace gas was transferred to a 4 ml vacuutainer. Analysis of 0.5 ml gas from each vacuutainer was made with a Carle 100-AGC gas chromatograph fitted with a flame ionozation detector connected to a Shimadzu model C-R3A integrator. The system was calibrated with high purity ethylene (Matheson Gas Co.) to yield nmol ethylene injection^{-1}. Rates of acetylene reduction (ethylene production) were calculated using the following equation.

$$\text{nmol } C_2H_4 \text{ ml}^{-1} \text{ h}^{-1} = ((\text{nmol } C_2H_4 \times 15 \text{ ml})/(0.5 \text{ ml} \times \text{time} \times 55 \text{ ml} \times \text{trans. coeff.})) \times 3.31$$

nmol C_2H_4 : C_2H_4 produced in sample - formalin kill

15 ml : volume gas phase

0.5 ml : volume injected into gas chromatograph

55 ml : volume aqueous phase

3.31 : correction for dilution in vacuutainers

trans. coeff. : transfer coefficient of ethylene from aqueous to vapor phase

The transfer coefficient of ethylene from aqueous to vapor phase is actually the proportion of ethylene transferred to the vapor phase, which is temperature dependent and varied from 0.620 at 9 °C to 0.690 at 20 °C for this study. This coefficient depends upon the bunsen absorption coefficient for ethylene, water temperature, and aqueous:vapor phase ratio (Kellar et al. 1980). On 17 August 1988 a concentrated sample (117 μg CHL a l^{-1}) of Anabaena from the Grayling Arm was used to check the validity and optimization of my incubation times and acetylene injection size. Hourly samples over a 12 h incubation showed a linear response, indicating that 4 h incubation times should not deplete acetylene. even during dense blooms. The response of samples injected with 1,2,3..., or 12 ml of acetylene indicated that the 6.0 injection elicited rates of acetylene reduction near maximum.

Experimental Procedures

02JUN88 Experiment

On 02 June 1988 water collected from 0.5 m in the Grayling Arm was put into four 1-l polyethylene bottles. Three bottles were inoculated with either 200 μg l^{-1} NH_4^+-N, 20 μg l^{-1} PO_4^{-3}-P, or both; the fourth sample served as an unammended control. The inoculated samples were placed in a laboratory incubator at the temperature and light period of collection under cool-white fluorescent light (150 μmol quanta m^{-2} s^{-1}). Twelve hours after nutrient inoculation, triplicate subsamples from each treatment were incubated with ^{14}C-bicarbonate for 4 h at the same light and temperature as above. The ^{14}C-labeled samples were size fractionated with 20 μm mesh onto GF/C filters and counted.

River Water Experiments

Bioassays designed to investigate the influence of the river inputs to the Grayling Arm on phytoplankton were conducted in May (16-21), July (26-30) and October (09-13) of 1989. The inclusion of N and P additions facilitated interpretation of the responses. A 4 l bulk sample of water from 0.5 m was transported to the laboratory and inoculated with [^{14}C]-$NaHCO_3$ (final activity of about 0.008 μCi ml^{-1}). Zooplankton were not removed. Aliquots of the ^{14}C-inoculated lake water and ammendments were added to three 250 ml polycarbonate flasks for each treatment as follows:

control (200 ml lake water)

+N (200 ml lake water + 200 μg l^{-1} NH_4^+-N)

+P (200 ml lake water + 50 μg l^{-1} PO_4^{-3}-P)

N+P (both +N and +P)

25%R.W. (150 ml lake water + 50 ml river water)

50%R.W. (100 ml lake water + 100 ml river water)

The river water used for these additions was a 1:1:1 mix of water from Grayling Creek, Duck Creek and Cougar Creek, the three inflows to Grayling Arm. Nutrient concentrations and alkalinity were determined for the lake and river water at the inception of each experiment.

The 250 ml flasks were incubated at the temperature and light period of collection under cool-white fluorescent light (150 μmol quanta m^{-2} s^{-1}). Subsamples from each replicate were filtered on days 2 and 4 (days 3 and 5 in May) for determination of ^{14}C-uptake by algae. Size fractionations (20 μm in May and July; 210 μm in October) were accomplished on the last day of each experiment. In-vivo fluorescence of the phytoplankton in each replicate was determined on 3 ml aliquots with a Turner 112 fluorometer (fitted with standard filters for CHL a analysis) to yield a relative measure of biomass. Results from river water treatments were corrected for dilution of biomass and isotope. A fourth replicate was included with each treatment during the October river water experiment in which nitrogenase activity and CHL a were measured on day 5.

Limnocorral Experiments

Two experiments employed larger scale (2000 l) polyethylene tubes (limnocorrals) suspended by rafts anchored at the Grayling Arm station. The 1.15 x 2.3 m tubes, constructed out of clear Canvex™ (Raven Industries), were closed at the bottom and shaped with integral PVC rings placed at 1 m intervals. Limnocorrals were filled with 0-1 m water at the station by submersing the top and allowing them to fill as the bottom sank. Thorough mixing after nutrient additions and before each sampling was accomplished with a Secchi disk. Samples were collected from limnocorrals at 1 m with an opaque Van-Dorn bottle. Background nutrient samples were collected at the inception of these experiments. Incubations for carbon uptake and nitrogenase activity were conducted in the same manner as for mesocosm experiments.

Limnocorral experiment 1 (03-19 June 1989) included two enclosures: control (no ammendments) and +N (c.a. 200 μg l^{-1} NH_4^+-N). Additions were made initially and on days 5 and 10 of this 16-day experiment. Samples for photosynthetic C-uptake, phytoplankton enumeration, and CHL a were collected on days 1, 3, 5, 10 and 16, and for nitrogenase activity on days 1, 5 and 10. Photosynthetic C-uptake was size fractionated (20 μm) on days 3, 5 and 16.

Limnocorral experiment 2 (29 June-13 July 1989) employed four limnocorrals, each with a different N:P ratio. Three limnocorrals were enriched with 280 μg l^{-1} NH_4^+-N. P

was added to each limnocorral at 56, 14 or 7 μg l^{-1} PO_4^{-3}-P, respectively, yielding N:P enrichment ratios of 5:1, 20:1 and 40:1, respectively. The fourth limnocorral was not enriched and served as a control. Nutrient additions were made at the beginning of the experiment and on days 5 and 10. Samples for phytoplankton photosynthetic C-uptake, size fractionated (20 μm) C-uptake, nitrogenase activity, CHL a concentration and phytoplankton enumeration were collected on days 5, 10 and 14 from each limnocorral.

Mesocosm Experiments

Five day time-course nutrient enrichment bioassays were conducted in June, August and October of 1988 and 1989 in the Grayling Arm. Water was collected from 0.5 m at a station located in the deepest part of the Grayling Arm and prescreened through 280 μm Nitex netting to remove large zooplankton (except in October 1988 and August and October 1989 when prescreening would have removed a large number of filamentous blue-green algal aggregates). For the June and August experiments, one 20 l collapsible polyethylene carboy (mesocosm) for each treatment was filled with sample and suspended in-situ at the station for the duration of the experiment. Water for the October experiments was transported 150 km to our laboratory (due to logistical constraints) where one mesocosm was incubated for each treatment in an incubator at the temperature and light period of collection under cool-white fluorescent light (150

μmol quanta m^{-2} s^{-1}). Experiments began on 22 June, 21 August and 23 October in 1988, and on 19 June, 07 August and 19 October in 1989. Seven nutrient treatments and an unammended control were included with each experiment (Table 1). Nutrient additions using NH_4Cl, KH_2PO_4, mannitol (MANN) and Na_2MoO_4 (1988 only)were made as a single pulse at the beginning (day 0) of 1988 experiments and on days 0, 1, 2, 3 and 4 of 1989 experiments. Multiple additions were made in 1989 to ensure that the added nutrients were not depleted during the incubation period. Chlorophyll a (CHL a), nutrient concentrations, and phytoplankton primary productivity ($^{14}CO_2$ uptake) were determined for all treatments on each day of the experiments. Bottles for $^{14}CO_2$ uptake (3 light, 1 dark) were incubated for about 4 h near midday alongside the treatment microcosms. Phytoplankton samples were taken from the water used for the experiment (day 0) and from each treatment at the end of each experiment.

Statistical Models

Monitoring data were used to build multiple linear regression models to facilitate determination of key environmental factors regulating N_2-fixing blue-green algal dominance and nitrogenase activity in the Grayling Arm. A statistical text (Neter et al. 1985) was consulted for appropriate methods and interpretations. The dependent variables were the arcsine of the square root of the percent

Table 1. Nutrient ammendments ($\mu g\ l^{-1}$) to water from Hebgen Lake (Grayling Arm, 0.5 m) for mesocosm experiments.

TREATMENT	JUNE 1988	AUGUST 1988	OCTOBER 1988
Control	-- --	-- --	-- --
NH_4^+-N	100.0	100.0	100.0
NO_3^--N	100.0	100.0	100.0
Mo	9.6	9.6	9.6
NO_3^--N + Mo	100.0 9.6	100.0 9.6	100.0 9.6
PO_4^{-3}-P	50.0	50.0	50.0
Mannitol (0.5 MAN)	91.1	91.1	91.1
Mannitol (1.0 MAN)	182.2	182.2	182.2

TREATMENT	JUNE 1989	AUGUST 1989	OCTOBER 1989
Control	-- --	-- --	-- --
NH_4^+-N	140.0	140.0	140.0
NO_3^--N	140.0	140.0	140.0
PO_4^{-3}-P	93.0	93.0	93.0
NH_4^+-N + PO_4^{-3}-P	140.0 93.0	140.0 93.0	140.0 93.0
Mannitol (MAN)	91.1	91.1	91.1
Mannitol + NH_4^+-N (M+N)	91.1 140.0	91.1 140.0	91.1 140.0
Mannitol + PO_4^{-3}-P (M+P)	91.1 93.0	91.1 93.0	91.1 93.0

N_2-fixing blue green algae (%FXBG) and the natural log of the biomass specific rate of nitrogenase activity. One primary model was constructed for each dependent variable using Grayling Arm data only, because my experiments all manipulated Grayling Arm water. A secondary model for each dependent variable included pertinent data points (those with values for the dependent variable greater than 0, see Appendix 1) from all stations to supplement the Grayling Arm data. This allowed me to check the validity of the primary models. The natural log of the following independent variables were used in the modelling process.

TEMP	TP	TDN	NH_4^+-N:SRP
SRP	NH_4^+-N	DON	NO_3^--N:SRP
TDP	NO_3^--N	TN	DIN:SRP
DOP	DIN	DOC	TN:TP

Data used in the models consisted of an areal values resulting from trapezoidal integration of each factor over the epilimnion (0-5 m) of the water column (see Appendix 1: integrated values). The only exception was the use of the mean temperature of the epilimnion. A forward stepwise regression procedure (Statgraphics version 1.2) was employed to select variables that are most closely associated with either dependent variable based on an F-ratio equivalent to $p=0.05$. A linear model was produced using the selected variables. Residual plots were examined for random distribution to assure that proper transformations were

used. The ridge trace procedure was then employed to produce standardized partial regression coefficients that were adjusted for potential intercorrelation between independent variables. These standardized coefficients offer a means of comparing the relative importance of each independent variable in the model.

RESULTS

Field Monitoring Data

Data collected during routine sampling trips are presented in Appendix 1 (lake station data) and Appendix 2 (inflow and outflow data). These data were collected primarily for statistical modelling, and to interpret experimental results in the proper ecological perspective. These data will not be discussed in detail here. Grayling Arm and Grayling Arm inflow data are summarized in Table 2. During 1988, blue-green algae (Cyanophyta) in the Grayling Arm (Fig. 2) were predominated by the N_2-fixing species Anabaena spiroides until September, when Aphanizomenon flos-aquae became dominant. The majority of blue-green algae were Anabaena circinalis during June of 1989. In July of 1989, Aph. flos aquae became dominant and remained so into October. Anabaena flos-aquae, Lyngbya bergei, Microcystis aeruginosa and Gomphospheria sp. were also identified in Grayling Arm samples. When N_2-fixing blue-green algae were present at other stations, they were mainly Aph. flos-aquae, otherwise L. bergei were the predominant blue-green algal genera.

Table 2. Mean (range) of all data collected (0 and 1 m only for PPR and NA) from routine feild monitoring trips for Grayling Arm and the three Grayling Arm inflows (Grayling, Duck, and Cougar Creeks). BLD = below limit of detection (approx. 1 $\mu g\ l^{-1}$ for those noted). Phyto = total phytoplankton biomass. All in units $\mu g\ l^{-1}$ unless noted.

	GRAYLING ARM		INFLOWS	
SECCHI (m)	1.4	(0.7-2.0)	- -	
°C	13.2	(0.9-20.6)	- -	
CHL *a*	16.3	(1.1-275.2)	- -	
Phyto	6808	(190-98800)	- -	
PPR($\mu gC\ l^{-1}h^{-1}$)	26.0	(2.6-134.7)	- -	
NA(nmol $l^{-1}h^{-1}$)	297.1	(0-2582.8)	- -	
NH_4^+-N	11.4	(0.3-57.2)	6.9	(BLD-34.9)
NO_3^--N	27.1	(1.8-93.5)	11.9	(2.6-63.0)
DIN	38.6	(2.5-128.9)	18.7	(4.3-90.6)
TDN	249.1	(98-530)	115.8	(18-300)
PN	202.1	(22-1535)	29.5	(BLD-157)
TN	453.2	(153-2014)	143.7	(38-308)
SRP	13.0	(1.0-60.4)	10.4	(1.3-41.5)
TDP	33.7	(5.2-129.8)	20.4	(4.9-43.6)
PP	23.4	(6.3-166.8)	8.6	(1.8-31.8)
TP	57.1	(199.4-14.8)	24.8	(7.0-57.8)
DOC	7370	(2276-73400)	1820	(1020-2920)
PC	1536	(450-15285)	662	(256-1938)
DIN:SRP (g:g)	3.8	(0.4-16.8)	2.3	(0.6-7.5)
TN:TP (g:g)	8.4	(4.0-18.3)	7.0	(2.0-19.7)
PN:PP (g:g)	7.8	(1.6-21.3)	- -	

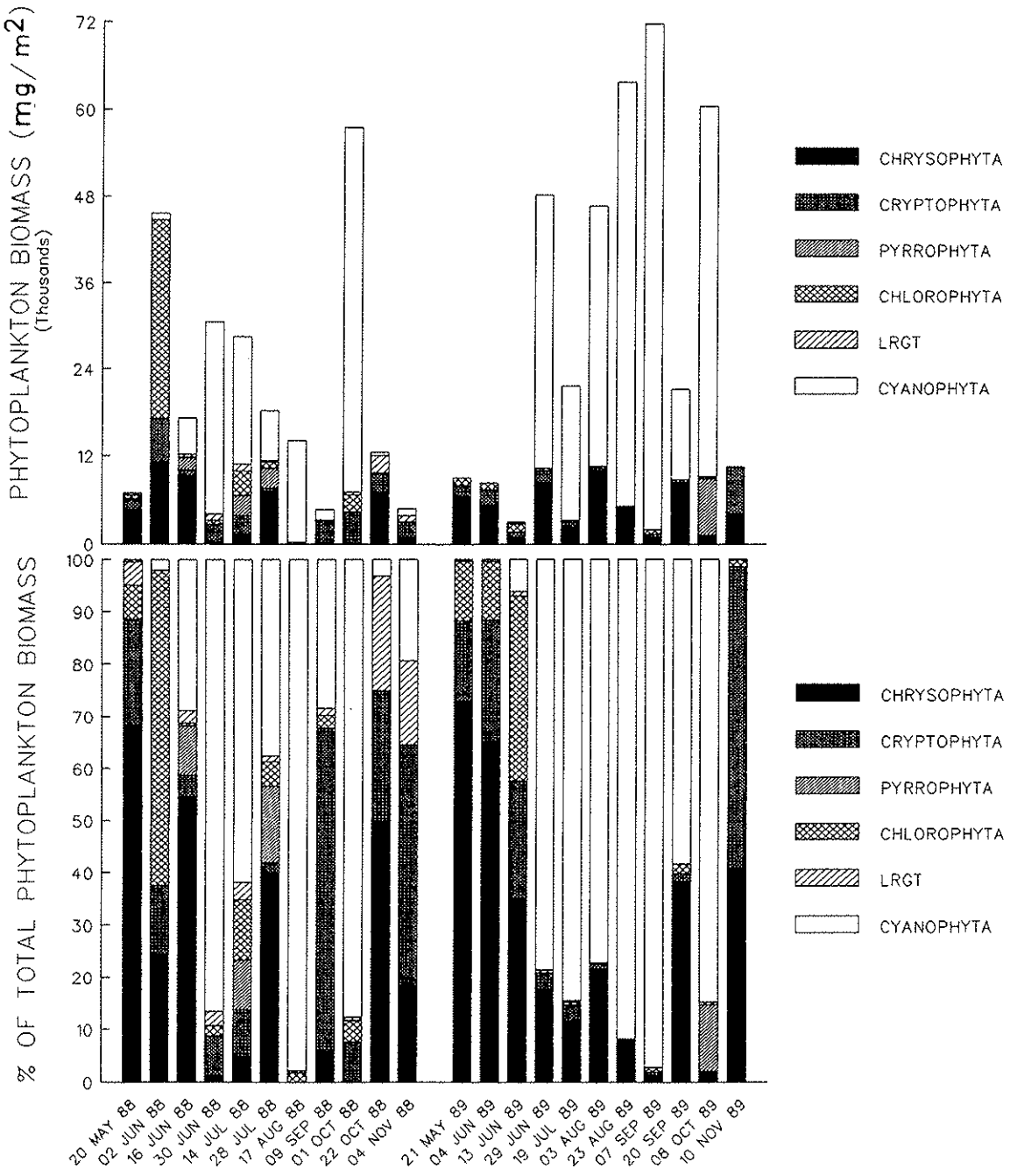

Figure 2. Phytoplankton biomass and relative distribution by divisions for the Grayling Arm of Hebgen Lake during the study period.

Experimental Results

03JUN88 Experiment.

At the time of this bioassay, Chlorococcus was the dominant phytoplankton genus; the 2.0 % blue-green algae (Cyanophyta) reported for 02JUN88 (Fig. 2) was due to a few cells of Anabaena at 5 m. Temperature was 11 °C, CHL a 6.3 $\mu g\ l^{-1}$, and PN:PP (g:g) was 5.96 (see Appendix 1, 02 June 1988 Grayling Arm for other parameters). Uptake of ^{14}C (DPM ml^{-1}) was stimulated significantly ($p<0.01$) by NH_4^+ and NH_4^+ plus PO_4^{-3} in both the > 20 μm and < 20 μm fractions. PO_4^{-3} did not significantly ($p>0.05$) increase activity.

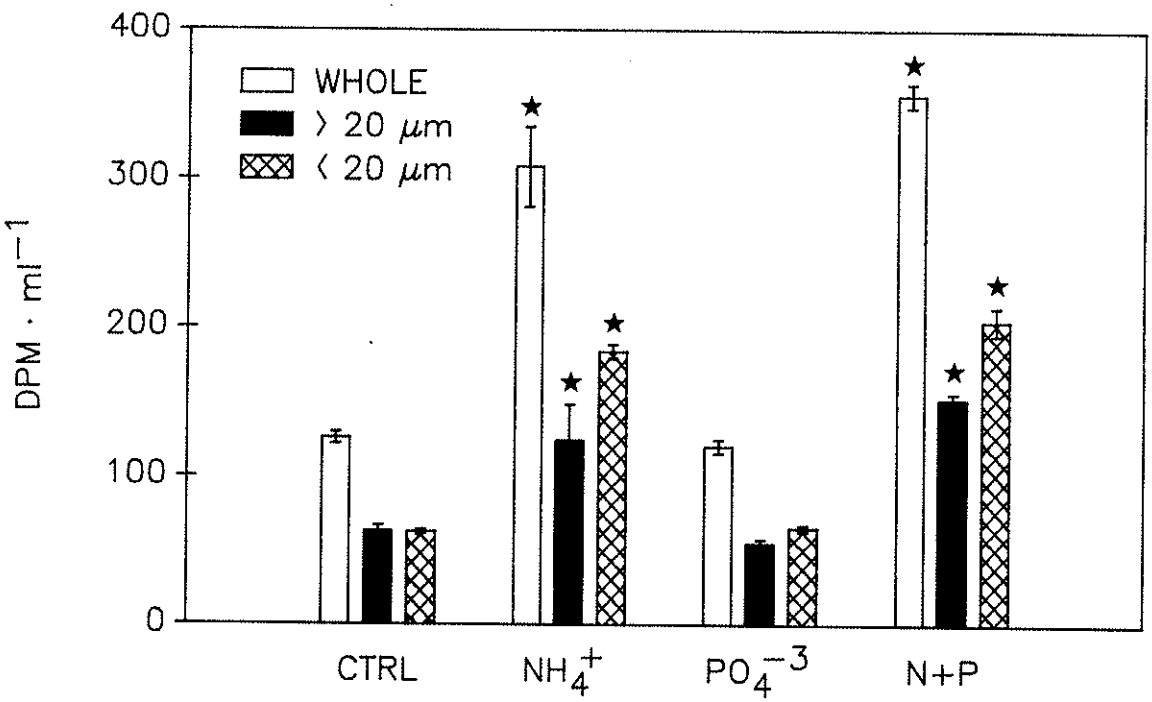

Figure 3. 03JUN88 experiment: C-uptake for whole community and size fractions. ANOVA results (compared to control): ★=$p<0.01$.

River Water and Limnocorral Experiments

Initial Conditions. Conditions at the inception of each 1989 river water and limnocorral experiment are presented in Table 3. River water conditions are given for comparison.

May 1989 River Water Experiment. Blue-green algae were not found in the water used for this experiment. Enrichment with NH_4^+, NH_4^+ plus PO_4^{-3} (N+P) and 25% and 50% river water stimulated ^{14}C uptake (Fig. 4) and in-vivo fluorescence (Table 4) significantly ($p<0.01$). The same treatments stimulated the < 20 μm size fraction photosynthetic activity (Fig. 4). The > 20 μm fraction activity was increased by NH_4^+ and NH_4^+ plus PO_4^{-3} but not by river water. Addition of PO_4^{-3} alone had no effect ($p>0.05$).

July 1989 River Water Experiment. Stimulation of ^{14}C uptake (Fig. 5) by PO_4^{-3} and NH_4^+ plus PO_4^{-3} was significant ($p<0.01$). Unreplicated size fractionations showed that both the > 20 (blue-green algal) and < 20 μm (mainly Chrysophyta) fractions were stimulated by PO_4^{-3}. In-vivo fluorescence (Table 4) was stimulated ($p<0.01$) by NH_4^+, PO_4^{-3} and NH_4^+ plus PO_4^{-3}. River water additions did not stimulate phytoplankton in this experiment.

October 1989 River Water Experiment. ^{14}C uptake (Fig. 6) was stimulated significantly by NH_4^+, PO_4^{-3}, 50% river water ($p<0.05$) and NH_4^+ plus PO_4^{-3} ($p<0.01$). Uptake in the

Table 3. Ambient temperature (°C), CHL a ($\mu g\ l^{-1}$) and nutrient concentrations ($\mu g\ l^{-1}$) of water collected from Grayling Arm for 1989 River Water (RW) and Limnocorral (LIMNO) experiments. Phyto (Ana = Anabaena; Aph = Aphanizomenon; Cyc = Cyclotella; Dino = Dinobryon) refers to the dominant (comprise > 60% of biomass) phytoplankton genus or combination of genera. Ratios at the bottom are g:g.

	MAYRW		JULRW		OCTRW			
	L.W.	R.W.	L.W.	R.W.	L.W.	R.W.	LIMNO1	LIMNO2
°C	10.0	- -	21.0	- -	10.1	- -	10.4	15.4
CHL a	4.9	- -	88.2	- -	6.8	- -	2.8	17.8
Phyto	Cyc	- -	Aph	- -	Aph	- -	Dino	Ana
NH_4^+-N	3.3	6.6	2.5	23.0	32.7	9.0	9.7	5.0
NO_3^--N	47.1	59.0	5.0	33.1	91.3	10.4	6.5	6.7
TDN	134	173	132	96	336	414	158	131
PN	- -	- -	1014	47	93	33	92	268
TN	- -	- -	1146	143	429	447	250	399
SRP	13.5	41.5	2.3	25.6	24.1	16.3	8.4	3.7
TDP	22.4	40.4	14.4	52.0	57.2	24.4	14.0	11.9
PP	- -	- -	- -	- -	21.4	6.7	15.3	13.7
TP	- -	- -	- -	- -	78.6	31.1	29.3	25.6
PC	- -	- -	5704	860	826	330	670	1366
DIN:SRP	3.7	1.6	3.3	2.2	5.1	1.2	1.9	3.2
TN:TP	8.1*	- -	6.9*	- -	5.5	14.4	8.5	15.6
PN:PP	7.4*	- -	11.1*	- -	4.4	4.9	6.0	19.6
PC:PN	7.1*	- -	5.6	18.3	8.9	10.0	7.3	5.1
PC:PP	52.7*	- -	70.8*	- -	38.6	49.3	43.8	99.7

* = sample not from experiment but from same station within 5 days of experiment.

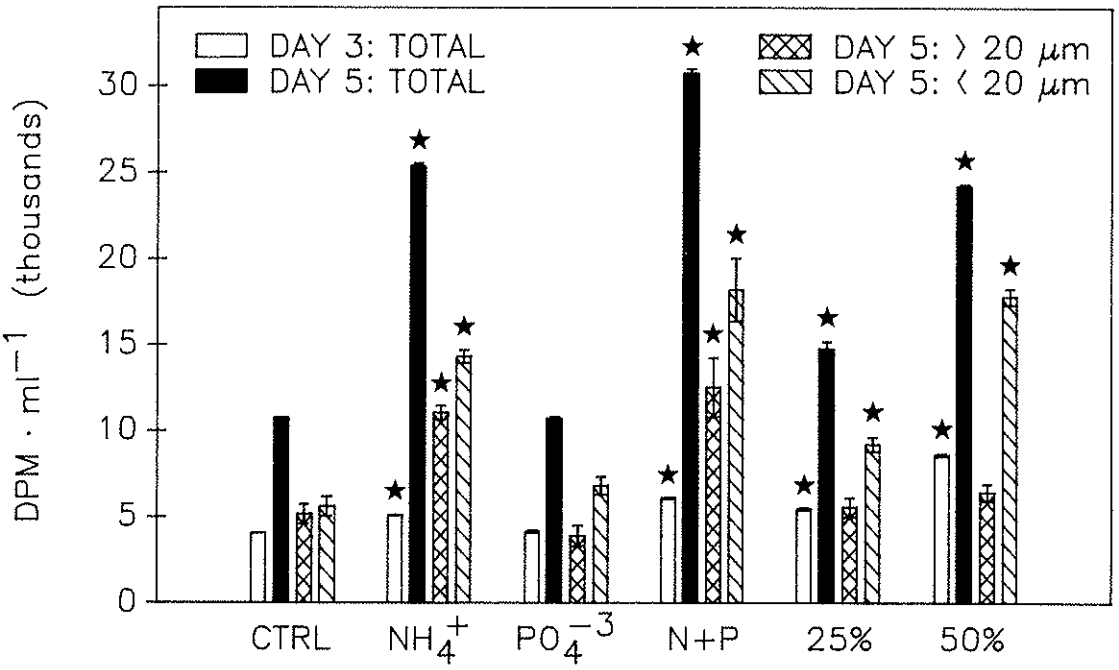

Figure 4. May 1989 river water experiment: C-uptake for whole community and size fractions. 25% and 50% refer to river water additions. ANOVA results (compared to control): ★=p>0.01.

Table 4. In-vivo fluorescence results for May and July river water experiments, and chlorophyll a ($\mu g\ l^{-1}$) and nitrogenase activity (nmol C_2H_4 (ml h)$^{-1}$) results from October river water experiment. Number in parenthesis = 1 SE. *=differs significantly from control (p<0.01).

River Water Experiment	Treatment					
	CTRL	NH_4^+	PO_4^{-3}	N+P	25%RW	50%RW
May	21.6 (0.28)	38.6* (0.30)	21.9 (0.37)	44.3* (0.70)	25.5* (0.27)	32.7* (0.74)
July	34.1 (1.23)	52.1* (4.03)	49.9* (1.72)	54.0* (1.77)	44.0 (1.65)	40.1 (4.94)
October(CHL a)	8.9 (1.00)	12.6 (1.16)	11.7 (1.72)	12.9 (0.63)	12.1 (1.73)	7.1 (1.27)
(NA)	1.26 (0.18)	1.37 (0.30)	2.15* (0.25)	1.40 (0.11)	- - - -	0.77 (0.21)

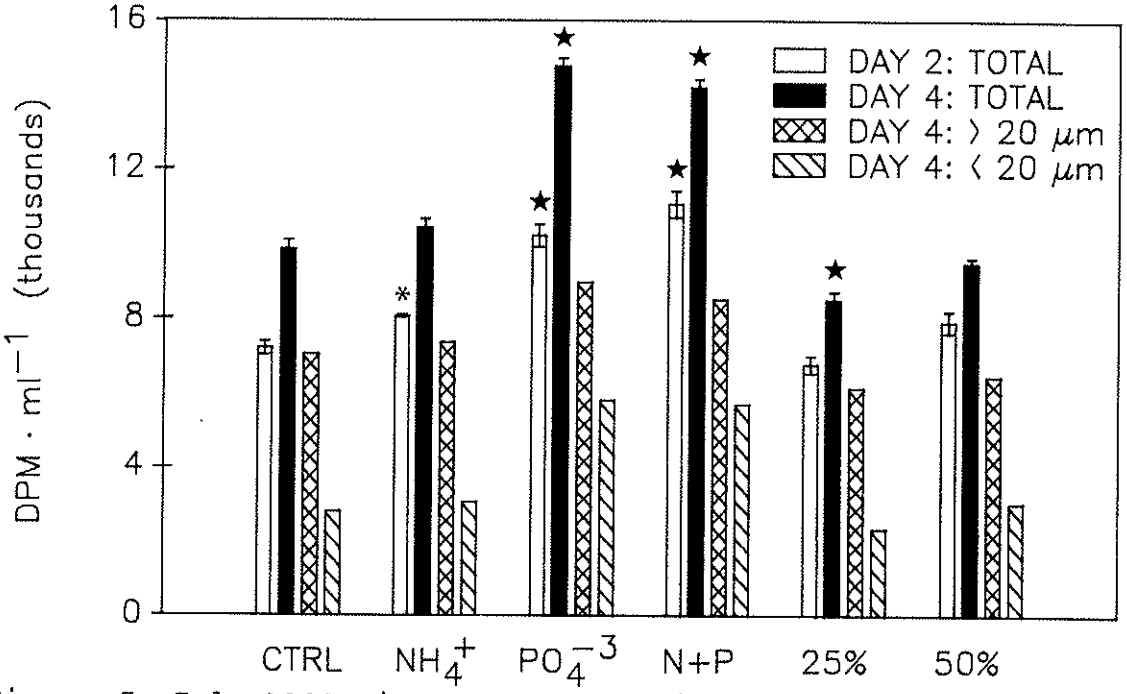

Figure 5. July 1989 river water experiment: C-uptake for whole community and size fractions. 25% and 50% refer to river water additions. ANOVA results (compared to control): *=p<0.05; ★=p<0.01.

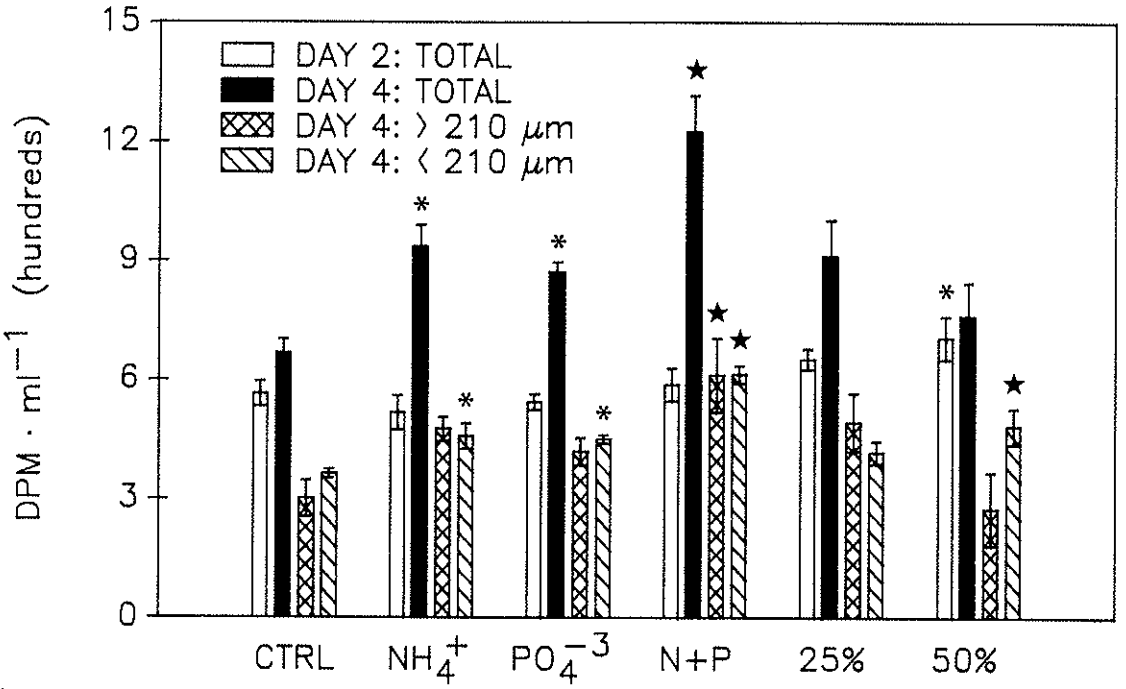

Figure 6. October 1989 river water experiment: C-uptake for whole community and size fractions. 25% and 50% refer to river water additions. ANOVA results (compared to control): *=p<0.05; ★=p<0.01.

NH_4^+ plus PO_4^{-3} treatment was significantly ($p<0.05$) greater than either the NH_4^+ or PO_4^{-3} treatments. Only the < 210 μm (mainly Chrysophyta and Chlorophyta) size fraction was stimulated significantly by addition of NH_4^+, PO_4^{-3} ($p<0.05$) and 50% river water ($p<0.01$). Addition of both NH_4^+ and PO_4^{-3} was required to significantly ($p<0.01$) increase uptake by the > 210 μm (blue-green algal) fraction. CHL a was not enhanced ($p>0.05$) by any of the treatments. PO_4^{-3} enrichment enhanced nitrogenase activity (Table 4) significantly ($p<0.01$).

Limnocorral Experiment 1. Phytoplankton photosynthetic C-uptake (Fig. 7A) and CHL a (Fig. 7B) increased significantly ($p<0.01$; $p<0.05$ for day 10 CHL a) in the +N limnocorral through day 10. This enhancement was substantial, with community carbon uptake exceeding the control by six fold on day 3. Size fractionations on days 3 and 5 showed that both the > 20 (blue-green algal component) and < 20 μm (non-blue-green algal) size fractions were stimulated by N. No difference from the control was detected by ANOVA ($p>0.05$) on day 16. No nitrogenase activity was detected on day 1, but on day 5 (CTRL=6.3$\pm$1.26, +N=0.77$\pm$0.14) and day 10 (CTRL=12.8$\pm$0.67, +N=4.9$\pm$0.48) nitrogenase activity in the +N treatment was significantly less than control ($p<0.01$). Addition of N elicited a relative increase in non-blue-green algal biomass compared to the control limnocorral (Fig. 8); the blue-green algal

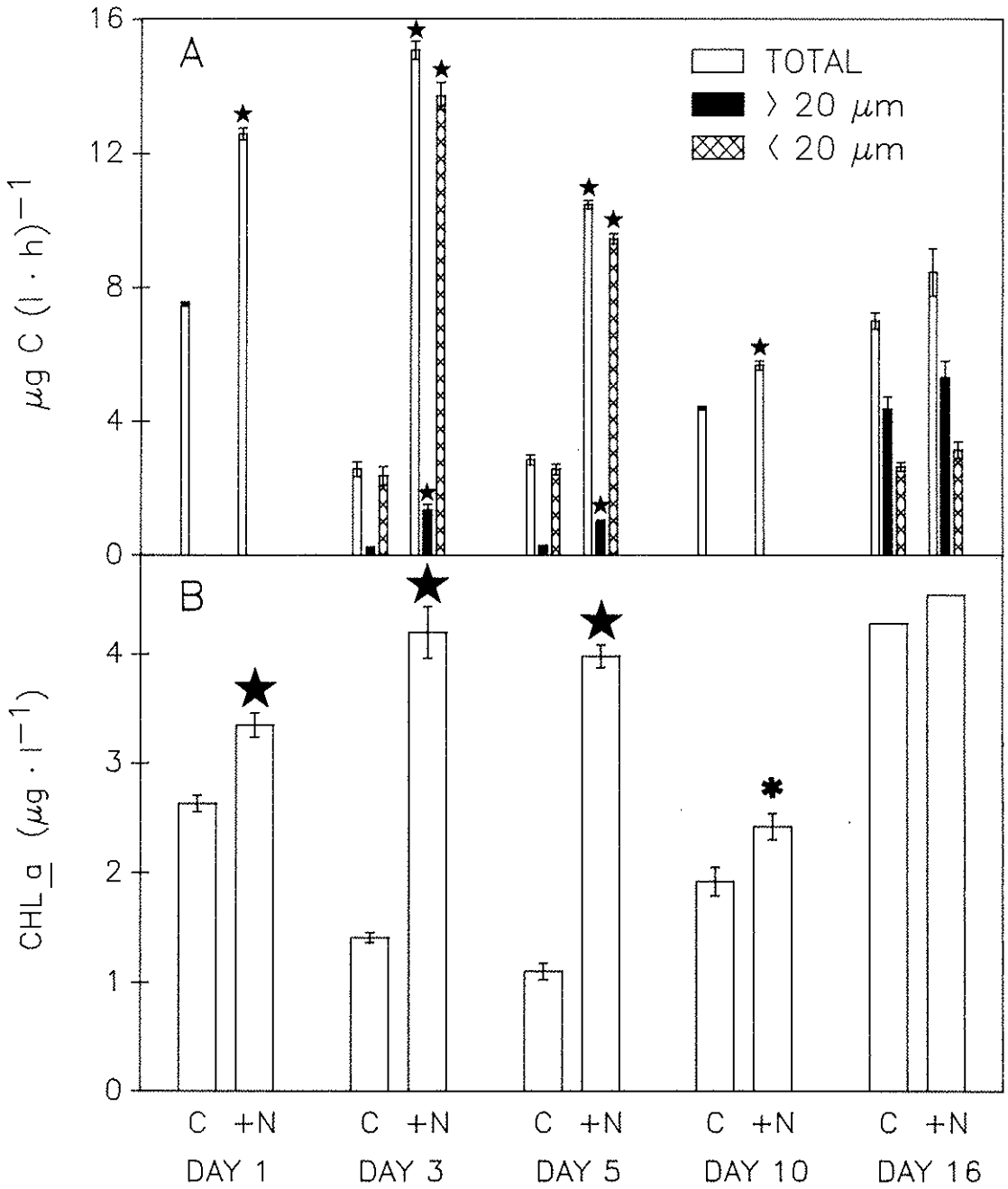

Figure 7. Limnocorral experiment 1 (June 1989): C-uptake for whole community and size fractions (A) and CHL a concentrations (B). ANOVA results (compared to control): ★=p<0.05; ✱=p<0.01. C=control.

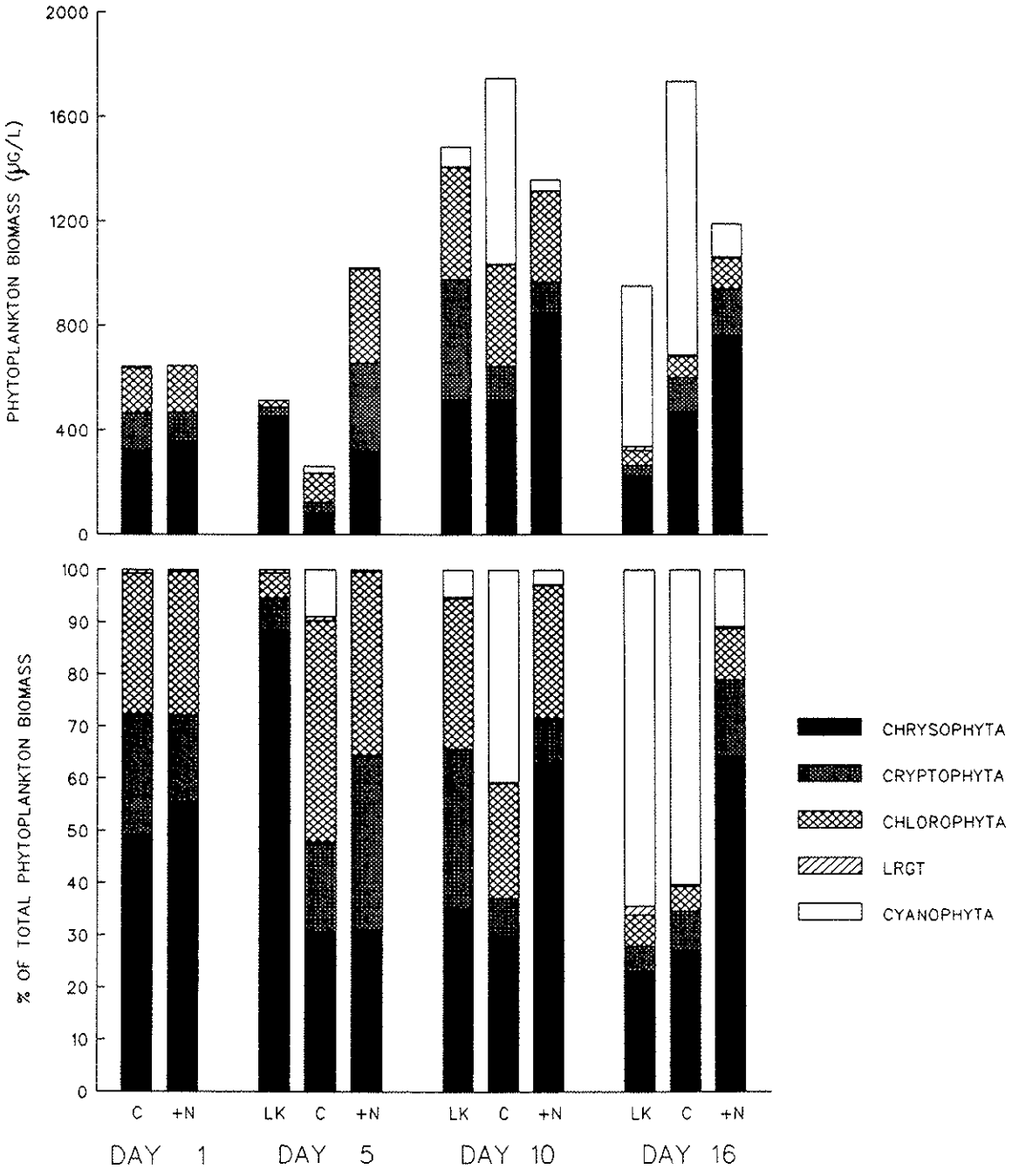

Figure 8. Limnocorral experiment 1 (June 1989): phytoplankton biomass and relative distribution by division. C=control; LK=lake sample.

biomass in the control yielded greater total phytoplankton biomass than in +N. The relative abundance of N_2-fixing blue-green algae steadily increased over the experiment to 60% in the control, but increased to only 10% in the +N treatment. Phytoplankton samples taken at the same times from the lake just outside the limnocorrals showed that the control community structure was equivalent to the lake community by the end of the experiment, particularly with respect to the blue-green algal component.

Limnocorral Experiment 2. Addition of N and P at a 5:1 ratio (g:g) stimulated carbon uptake significantly ($p<0.01$) on days 5 and 10 (Fig. 9A). The 5:1 treatment enhanced the > 20 μm (blue-green algal component) fraction uptake significantly ($p<0.01$) on days 5, 10 and 14; the < 20 μm (mainly Chrysophyta and Cryptophyta) fraction was significantly more active than the control on day 5 ($p<0.01$) but significantly less on day 14 ($p<0.01$). The relative contribution of carbon uptake by the > 20 μm size fraction was enhanced by the 5:1 treatment (Fig. 9B). CHL a was significantly greater than control ($p<0.01$) on day 5 in the 5:1 limnocorral only (Fig. 10). The 20:1 and 40:1 treatments did not increase carbon uptake or CHL a on the days assayed. Nitrogenase activity was stimulated significantly by the 5:1 enrichment on day 5 ($p<0.05$) and day 14 ($p<0.05$) (Fig. 10). The 20:1 treatment inhibited nitrogenase activity on day 10 ($p<0.01$). By day 10, total phytoplankton biomass had

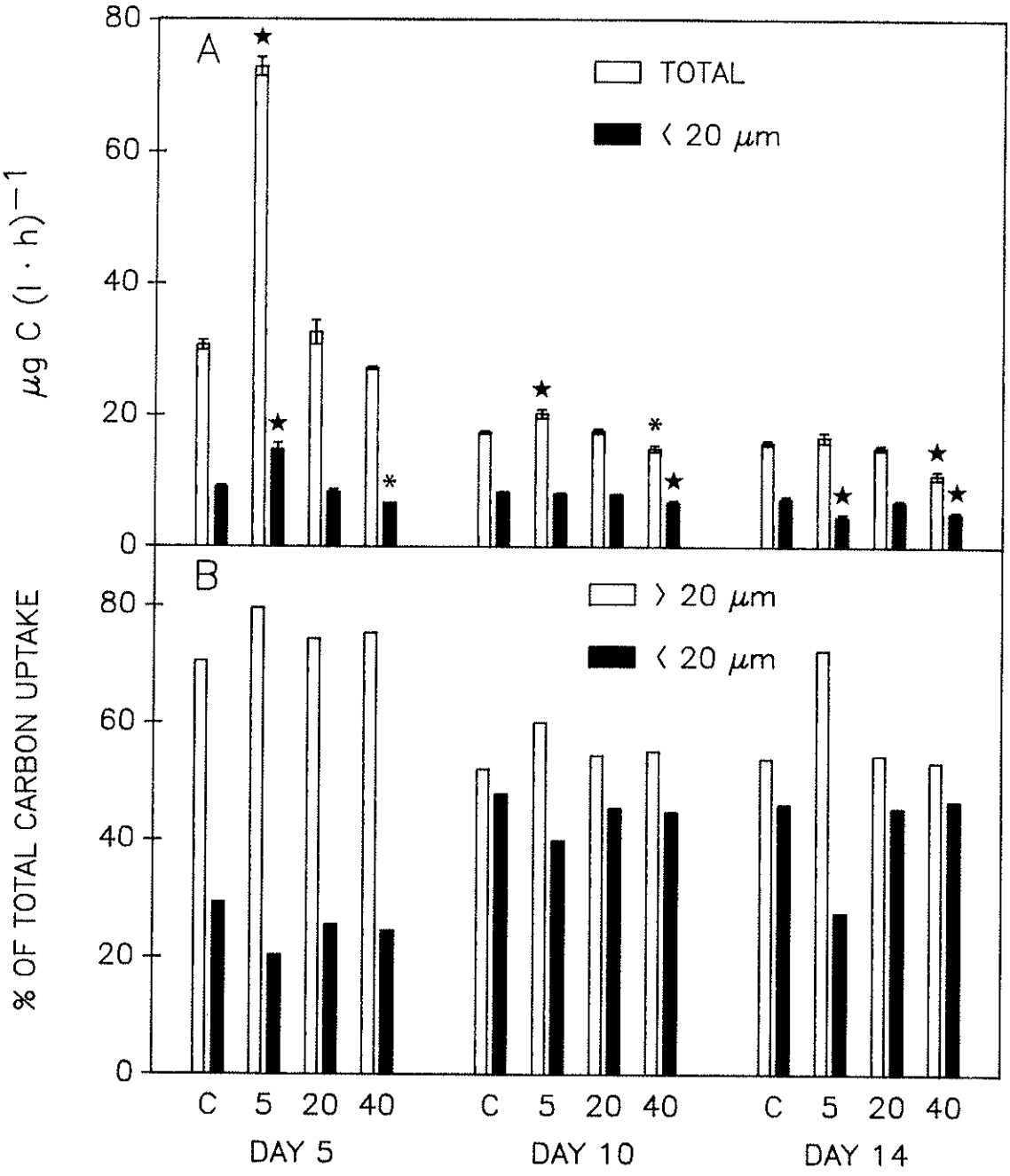

Figure 9. Limnocorral experiment 2 (July 1989): (A) C-uptake (ANOVA results: *=p<0.05; ★=p<0.01) and (B) relative contribution of size fractions. C = control; 5, 20 and 40 refer to 5:1, 20:1 and 40:1 N:P (g:g).

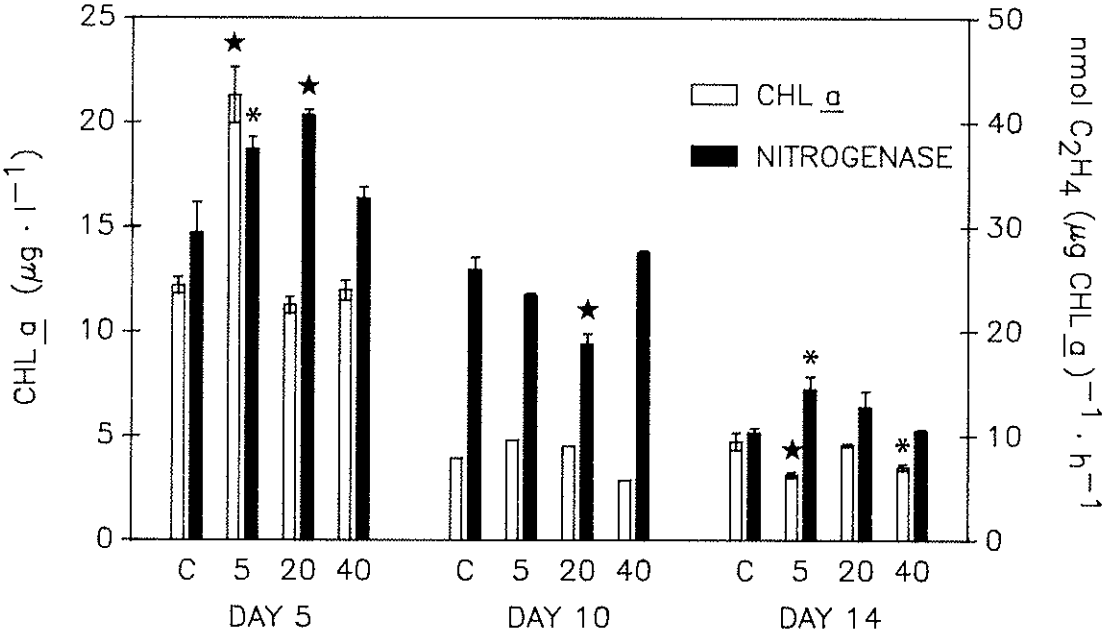

Figure 10. Limnocorral experiment 2 (July 1989): CHL a and nitrogenase activity (ethylene production). ANOVA results: *=p<0.05; ★=p<0.01. C=control. 5, 20 and 40 refer to the 5:1, 20:1 and 40:1 treatments.

increased 130% in the 20:1 treatment and decreased 30% in the 5:1 treatment (Fig. 11). The relative abundance of blue-green algae exceeded the control by three fold in the 5:1 limnocorral and more than two fold in the 20:1 limnocorral on day 10. Differences in phytoplankton composition between treatments decreased by day 14.

1988 and 1989 Mesocosm Experiments

Mesocosm Initial Conditions. N_2-fixing blue-green algae dominated the phytoplankton community at the beginning of all six mesocosm experiments, with Anabaena sp. in June 1988, August 1988 and June 1989, and Aphanizomenon sp. in October 1988 and August and October 1989 (Table 5). The

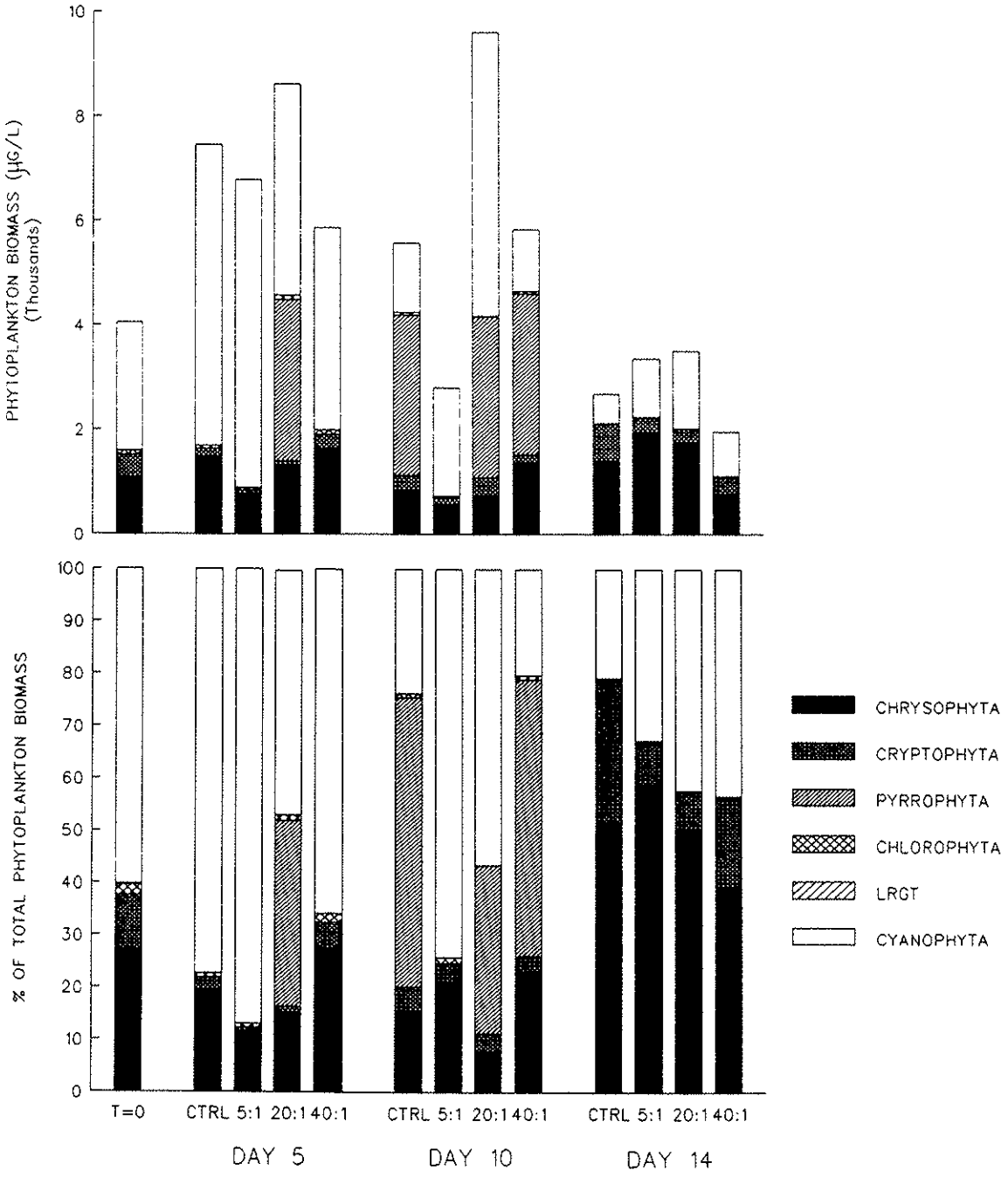

Figure 11. Limnocorral experiment 2 (July 1989): phytoplankton biomass and relative distribution by division.

Table 5. Ambient temperature (°C), CHL *a* (μg l^{-1}) and nutrient concentrations (μg l^{-1}) of water collected from Hebgen Lake (Grayling Arm) for mesocosm experiments. Phyto (Ana = *Anabaena*; Aph = *Aphanizomenon*; Ast = *Asterionella*; Frag = *Fragallaria*) refers to the dominant (comprise > 60% of biomass) phytoplankton genus or combination of genera. Ratios at bottom are g:g.

	1988			1989		
	22 JUN	21 AUG	23 OCT	20 JUN	08 AUG	19OCT
°C	16.9	22.0	11.5	15.6	19.2	10.1
CHL *a*	30.3	15.6	144.5	4.5	5.0	48.5
Phyto	Ana	Ana	Aph & Ast	Ana	Aph & Frag	Aph
NH_4^+-N	3.8	61.1	12.5	9.9	4.2	6.0
NO_3^--N	2.6	64.0	5.6	10.2	7.9	94.1
TDN	140	570	390	176	146	255
PN	514.8	299.1	1192.2	137.2	74.2	244.9
TN	654.8	869.1	1582.2	313.0	220.2	499.9
SRP	2.8	39.1	7.7	18.1	5.1	18.1
TDP	10.4	57.1	22.5	28.0	17.8	38.4
TP	-- --	-- --	-- --	44.9	27.7	84.1
DOC	2834	7012	7749	2839	6960	6552
DIN:SRP	2.3	3.2	2.4	1.1	2.4	5.5
TN:TP	12.9*	9.2*	16.7*	7.0	7.9	5.9
PN:PP	12.5*	8.9*	16.5*	8.1	7.5	5.4
PC:PN	6.6	7.6	6.5	5.5	7.5	5.6
PC:PP	80.3*	47.4*	107.5*	45.0	56.5	29.8

* = sample not from experiment but from same station within 5 days of experiment.

diatoms Asterionella sp. and Fragillaria sp. were co-dominant with the blue-green algae in October 1988 and August 1989, respectively. Dissolved inorganic nitrogen (DIN = NH_4^+-N + NO_3^--N) and SRP were highest at the beginning of the August 1988 experiment when the NH_4^+ and NO_3^- additions resulted in an 80% enrichment; PO_4^{-3} addition enriched SRP by 125%. Water for all experiments had low (less than 6 by weight) DIN:SRP ratios; the lowest was 1.1 for June 1989. Although no PP samples were taken for 1988 experiments, data from samples collected within a few days of each experiment show that TN:TP and PN:PP were highest at the start of the June and October 1988 experiments. The highest CHL a concentration encountered was for the October 1988 experiment (144.5 $\mu g\ l^{-1}$), during an Aphanizomenon bloom.

June 1988 Experiment. Biomass specific rates of carbon fixation (PPR = μg C (μg CHL a h)$^{-1}$) showed maximum stimulation with P enrichment (Fig. 12A) which was significantly greater than the unammended control ($p<0.01$) (Table 6). No other treatments were significantly different from the control ($p>0.05$). CHL a specific nitrogenase activity was stimulated by P for the entire week ($p<0.01$) and by 1.0 MAN on day 2 ($p<0.05$); no inhibition by N was detected (Fig. 12C). The PO_4^{-3} treatment also significantly increased CHL a values relative to the control ($p<0.01$) with a maximum 55% increase over control on day 3 (Fig. 12B). No C-uptake size fractions were conducted and the NO_3^- mesocosm

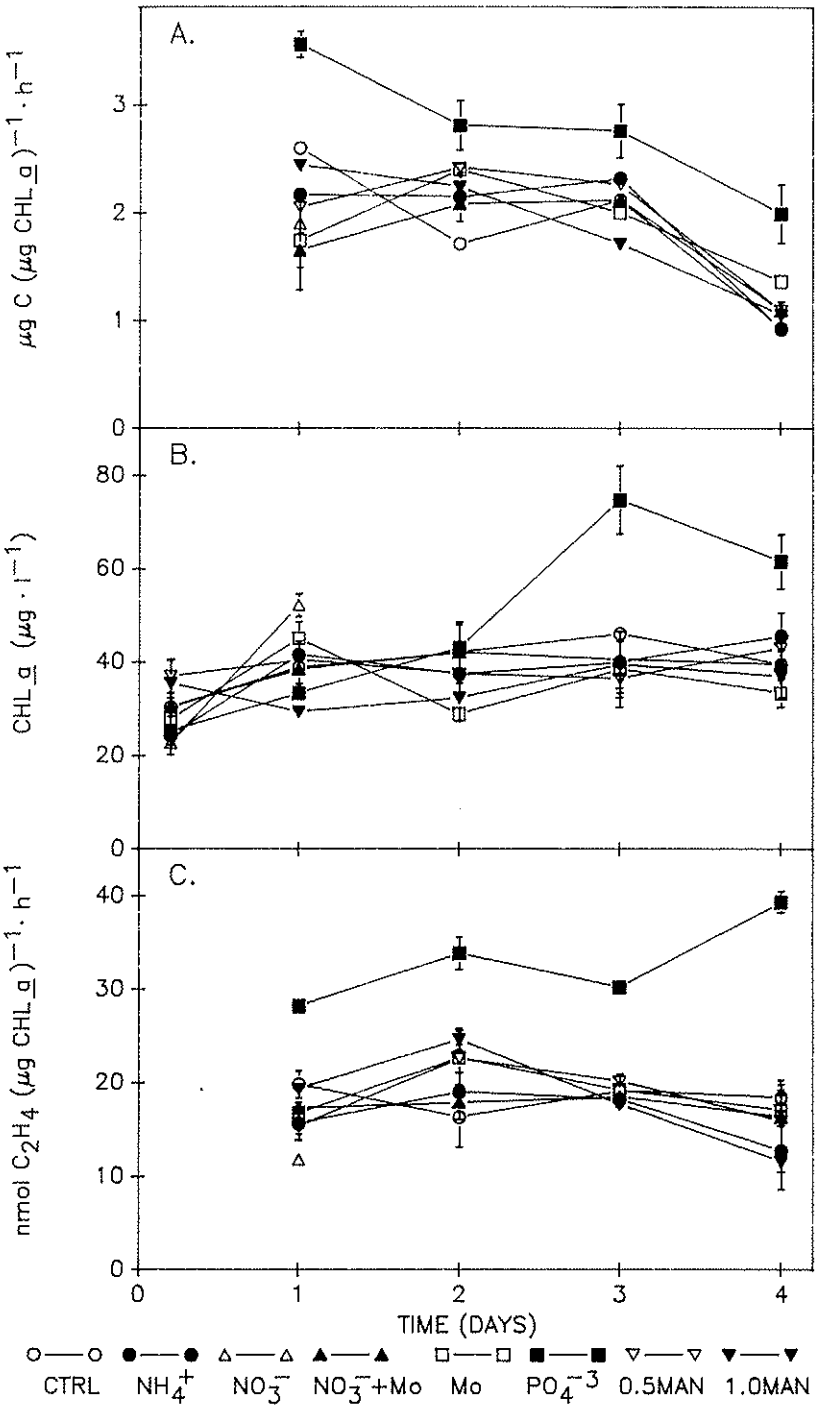

Figure 12. June 1988 experiment: time courses of (A) biomass specific C-uptake rates (PPR), (B) CHL a and (C) nitrogenase activity (ethylene production). See Table 1 for explanations of treatments.

Table 6. Effect of nutrient additions on phytoplankton activity and biomass in mesocosm experiments. Results of one-way ANOVA coupled with least significant difference test. PPR = chlorophyll a specific carbon uptake including all time points. CHL = chlorophyll a concentrations including last two days only. Size fractionated carbon uptake (i.e., >20 = C-uptake of organisms that did not pass through 20 μm mesh). NASE = nitrogenase activity. -- = not different from unammended control; +,++ = significantly greater than control at $P<0.05$, $P<0.01$; o,oo = significantly less than control at $P<0.05$, $P<0.001$, respectively. ND = no data collected. See Table 1 for explanation of treatments.

	JUNE 1988					AUGUST 1988					OCTOBER 1988				
TREATMENT	PPR	CHL	>20	<20	NASE	PPR	CHL	>20	<20	NASE	PPR	CHL	>20	<20	NASE
NH_4^+	--	--	ND	ND	--	--	--	++	++	--	--	+	--	++	--
NO_3^-	LOST					--	--	++	++	o	+	--	--	++	oo
Mo	--	--	ND	ND	--	--	--	--	--	--	--	--	--	+	oo
NO_3^- +Mo	--	--	ND	ND	--	--	++	+	++	--	++	--	--	++	oo
PO_4^{-3}	++	++	ND	ND	++	--	--	--	--	--	+	--	--	--	oo
0.5 MAN	--	--	ND	ND	--	--	--	oo	oo	--	--	--	--	oo	oo
1.0 MAN	--	--	ND	ND	--	--	--	--	oo	--	+	--	--	oo	oo

Table 6. (continued)

TREATMENT	JUNE 1989					AUGUST 1989					OCTOBER 1989				
	PPR	CHL	>20	<20	NASE	PPR	CHL	>20	<20	NASE	PPR	CHL	>100	<100	NASE
NH_4^+	++	++	++	++	oo	--	+	++	++	oo	o	++	--	++	oo
NO_3^-	--	++	--	++	oo	--	--	++	++	o	oo	++	--	++	oo
PO_4^{-3}	--	--	--	--	--	--	--	++	--	++	oo	--	o	--	--
$NH_4^+ + PO_4^{-3}$	++	++	++	++	oo	++	++	++	++	oo	--	+	--	++	--
MAN	--	--	--	--	--	--	--	--	--	+	oo	--	--	o	--
$MAN+NH_4^+$	+	++	+	+	oo	--	--	++	+	oo	--	--	--	+	o
$MAN+PO_4^{-3}$	--	--	--	--	--	--	--	--	--	++	oo	--	o	--	o

was lost on day 1. Phytoplankton biomass at the end of the experiment was higher than control in the PO_4^{-3} treatment only (Fig. 13). Major changes in relative blue-green algal abundance were not apparent at the end of this experiment.

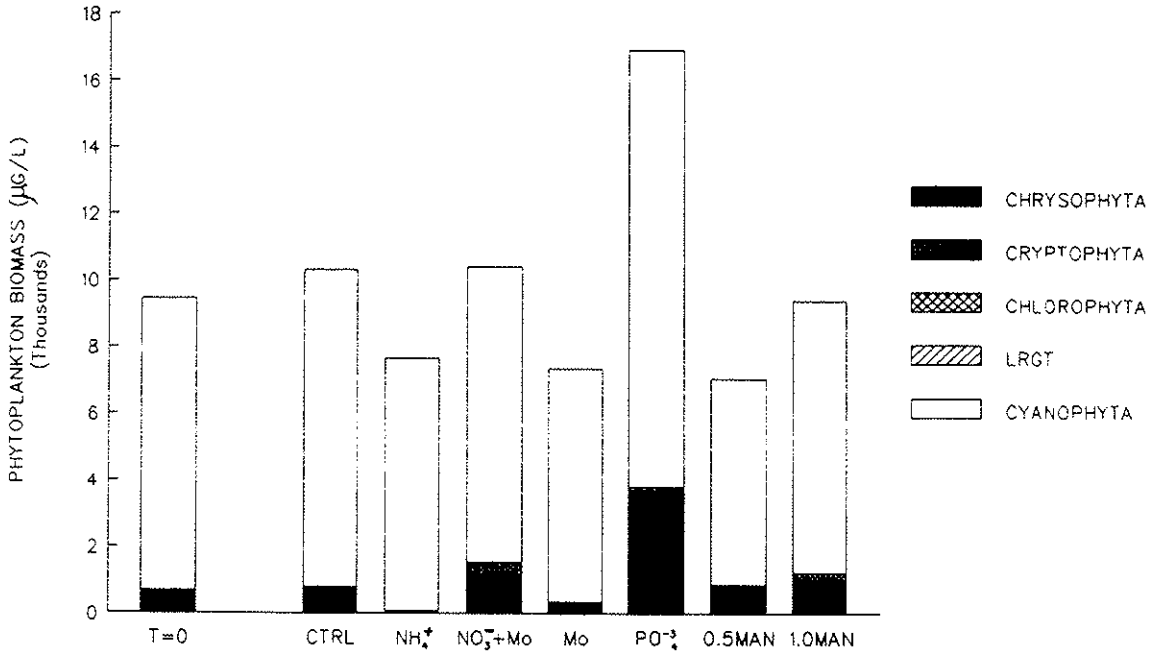

Figure 13. June 1988 experiment: phytoplankton biomass by division. See Table 1 for explanation of treatments.

August 1988 Experiment. None of the nutrient ammendments stimulated PPR significantly ($p>0.05$) with respect to the control, although all ammendments except Mo enhanced PPR on day 1 (Fig. 14A). Size-fractionated volume specific photosynthetic carbon uptake rates (e.g., NH_4^+ >20μm fraction = μg C l^{-1} h^{-1} for phytoplankton in the NH_4^+ mesocosm that did not pass through 20 μm mesh) were measured

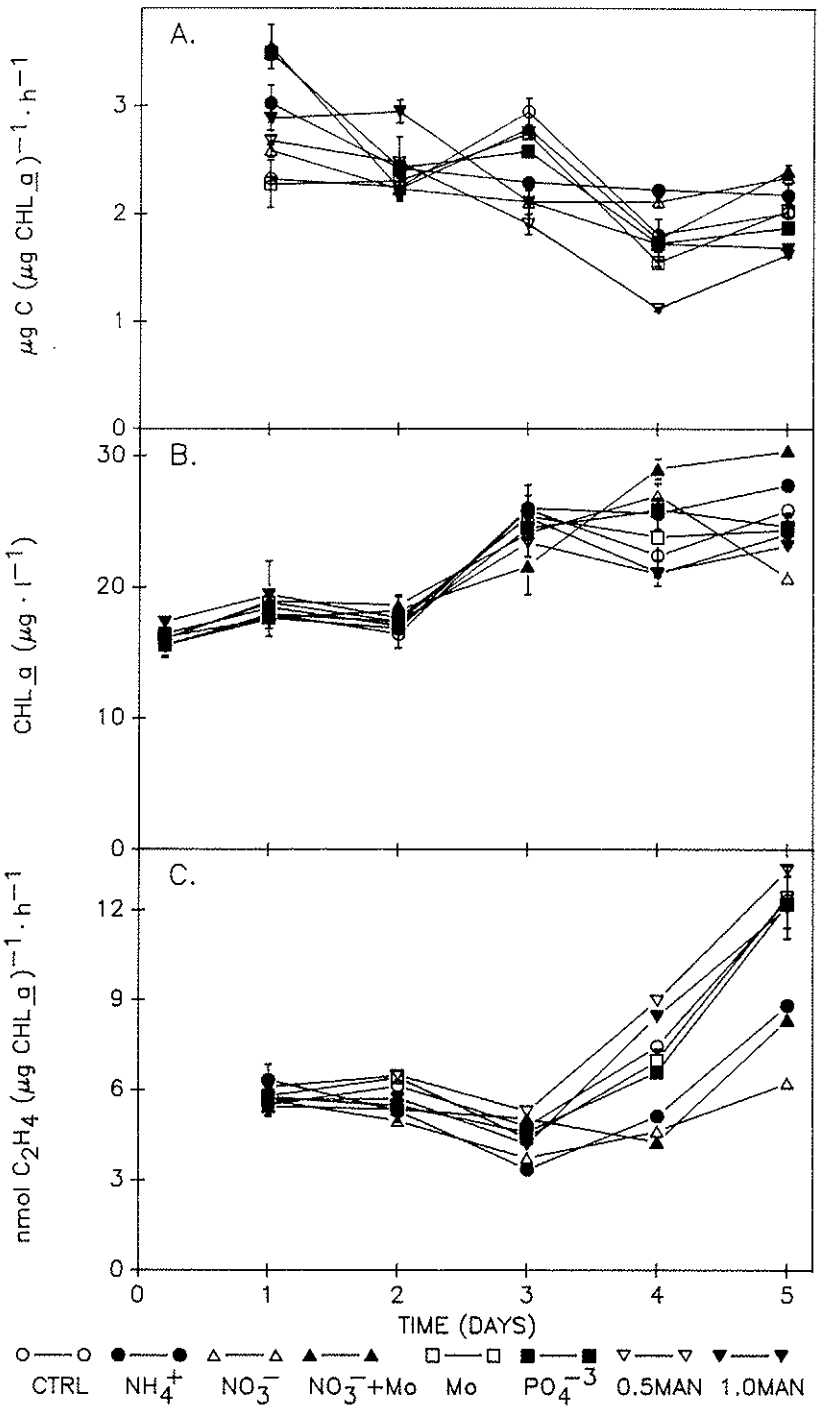

Figure 14. August 1988 experiment: time courses of (A) PPR, (B) CHL a and (C) nitrogenase activity (ethylene production). See Table 1 for treatment details.

on day 4. The NH_4^+, NO_3^- and NO_3^-+Mo >20 μm (blue-green algal) and <20 μm (non-blue-green algal) fractions were significantly greater than control ($p<0.05$); 1.0 MAN <20 μm and 0.5 MAN >20 μm and <20 μm fractions were significantly less than control (Fig. 15). Biomass specific nitrogenase activity (Fig. 14C) significantly ($p<0.01$) decreased in all N additions by the end of the experiment, when the NO_3^- treatment was less than 50% of control. Although ANOVA, including data for the entire week, did not reveal significant changes with mannitol addition (Table 6), mannitol additions stimulated nitrogenase activity significantly ($p<0.01$) on day 4. CHL a increased significantly ($p<0.01$) with NO_3^-+Mo addition (Fig. 14B). Total phytoplankton biomass increase was greatest with NH_4^+ addition; NO_3^- and NO_3^-+Mo elicited the greatest decrease in relative blue-green algal abundance (Fig. 16).

October 1988 Experiment. PPR was stimulated significantly by NO_3^-, NO_3^-+Mo, PO_4^{-3} and 1.0 MAN ($p<0.05$) for the entire experiment; other treatments were not significantly different from the control (Fig. 17A, Table 6). Nitrogenase activity significantly ($p<0.01$) declined in all treatments except NH_4^+, which stimulated nitrogenase activity slightly on the first 2 days (Fig. 17C). CHL a increased to over 1.6 times the control with NO_3^- addition on day 2 and decreased to control levels thereafter. Only NH_4^+ enrichment resulted in CHL a significantly greater than

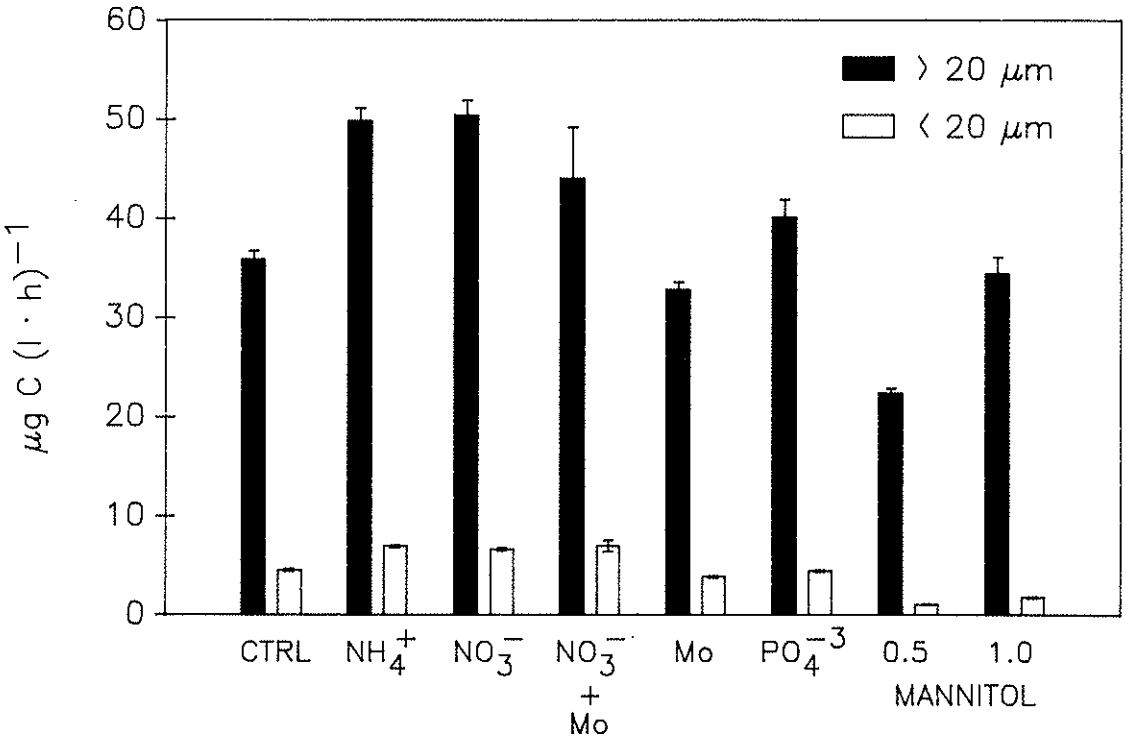

Figure 15. August 1988 experiment: C-uptake for size fractions. See Table 1 for treatment details.

the control ($p<0.05$) by the end of the experiment (Fig. 17B). On day 5, NH_4^+, NO_3^-, Mo and NO_3^-+Mo <20 μm (mainly Chrysophyta) fractions were enhanced significantly ($p<0.05$), and both MAN (mannitol) treatments <20 μm fractions were significantly less than the control ($p<0.01$). None of the treatments showed an increase in the >20 μm (blue-green algal) fraction (Fig. 18, Table 6). Phytoplankton biomass increased with NO_3^- and NO_3^-+Mo addition and relative blue-green algal abundance was 20% less than control in the NO_3^- +Mo treatment (Fig. 19).

June 1989 Experiment. Addition of NH_4^+, NH_4^+ plus PO_4^{-3} and MAN+NH_4^+ stimulated PPR (Fig. 20A) and CHL a (Fig. 20B)

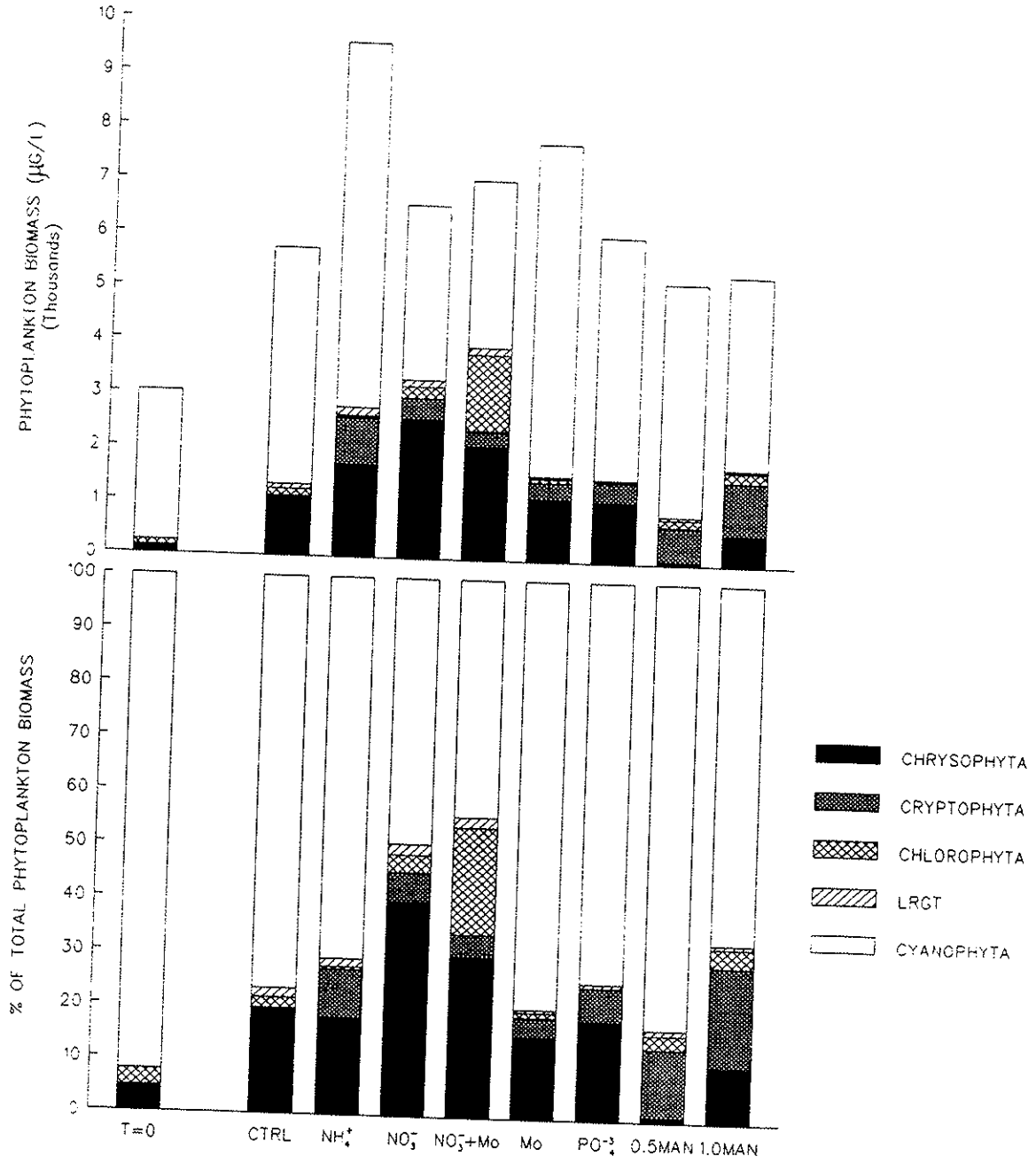

Figure 16. August 1988 experiment: phytoplankton biomass and relative distribution by division. See Table 1 for explanation of treatments.

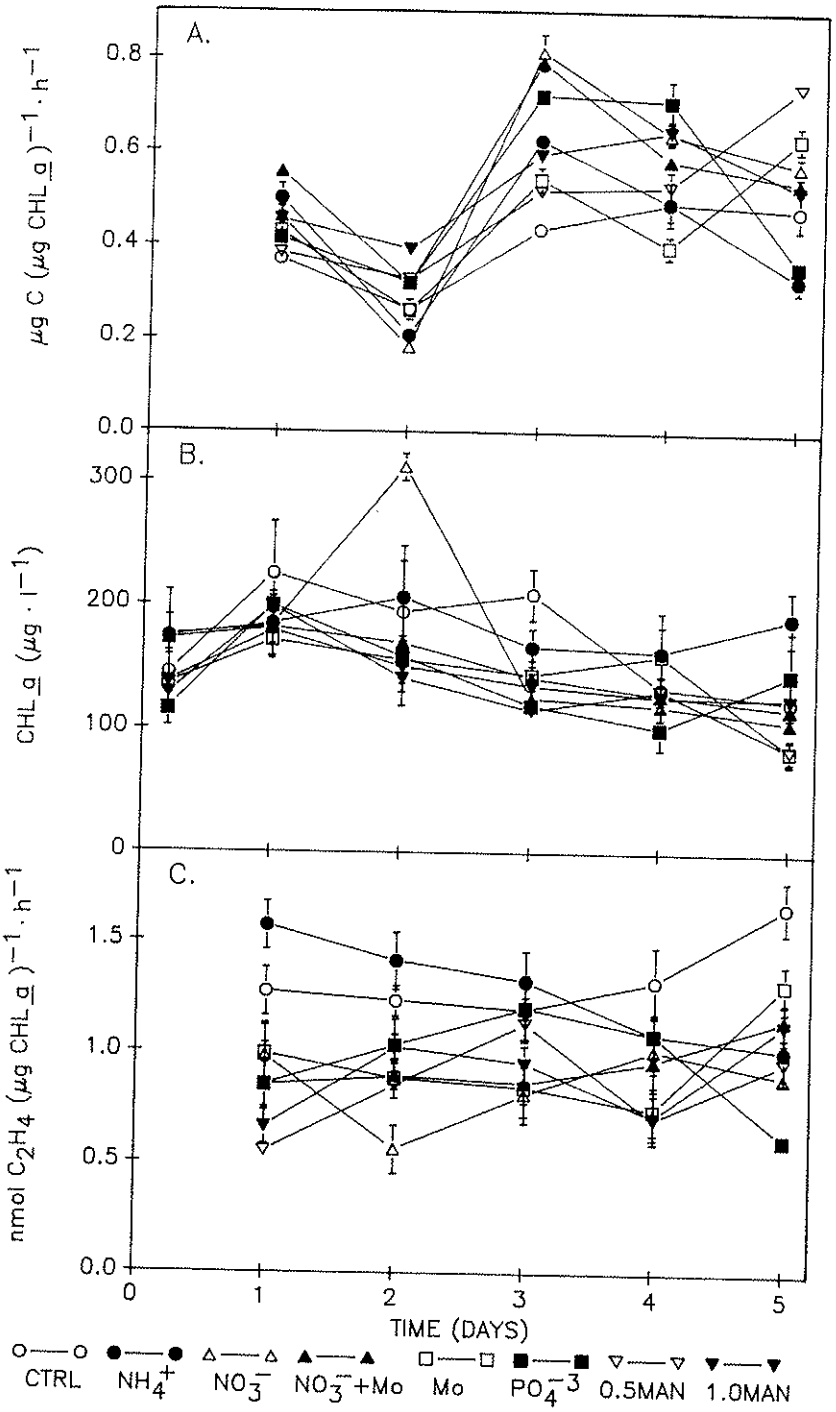

Figure 17. October 1988 experiment: time courses of (A) PPR, (B) CHL a and (C) nitrogenase activity (ethylene production). See Table 1 for treatment details.

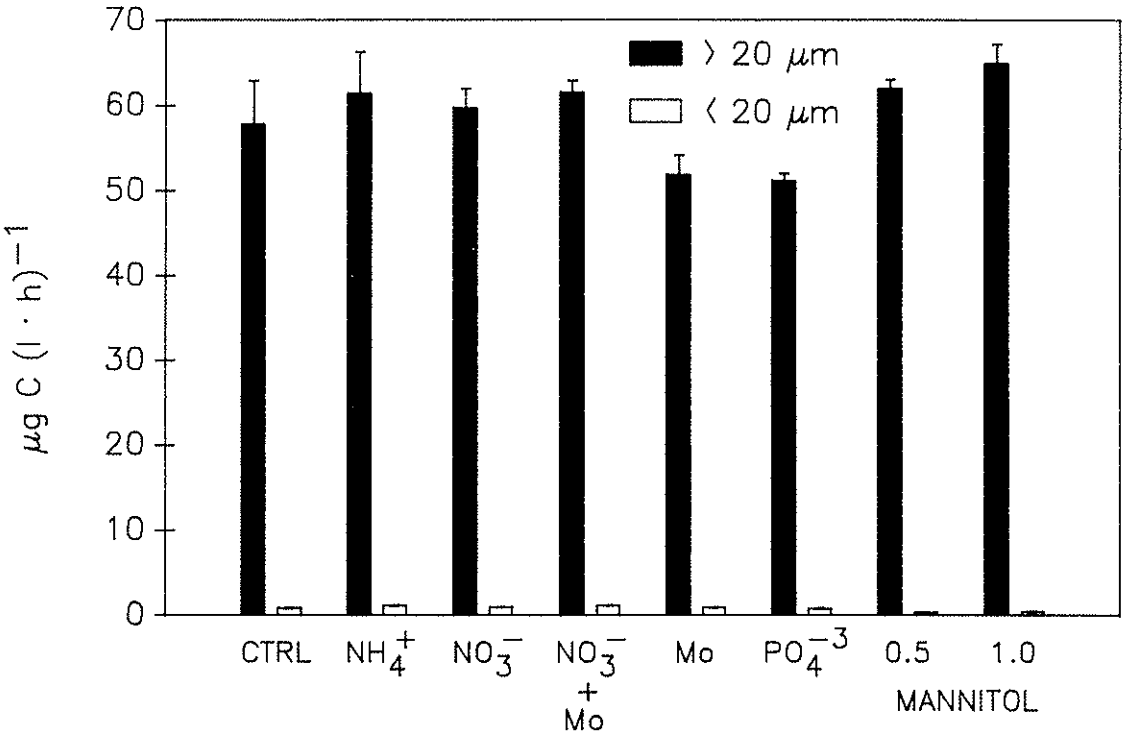

Figure 18. October 1988 experiment: C-uptake for size fractions. See Table 1 for explanation of treatments.

significantly ($p<0.05$) (Table 6), while PO_4^{-3} and MAN had no significant stimulatory effect. The PPR and CHL a response of NH_4^+ and $NH_4^+ + PO_4^{-3}$ were similar, as were those for NO_3^- and $MAN+NH_4^+$. Size fractionations done on day 5 showed that the NH_4^+, NO_3^-, $NH_4^+ + PO_4^{-3}$ and $MAN+NH_4^+$ <20 μm fractions were significantly ($p<0.05$) greater than control, as were the NH_4^+, $NH_4^+ + PO_4^{-3}$ and $MAN+NH_4^+$ >20 μm fractions (Fig. 21). N enrichment increased the relative amount of <20 μm (mainly Chrysophyta) fraction uptake and contemporaneously decreased the contribution of the >20 μm (blue-green algal) fraction. Addition of N inhibited nitrogenase activity significantly

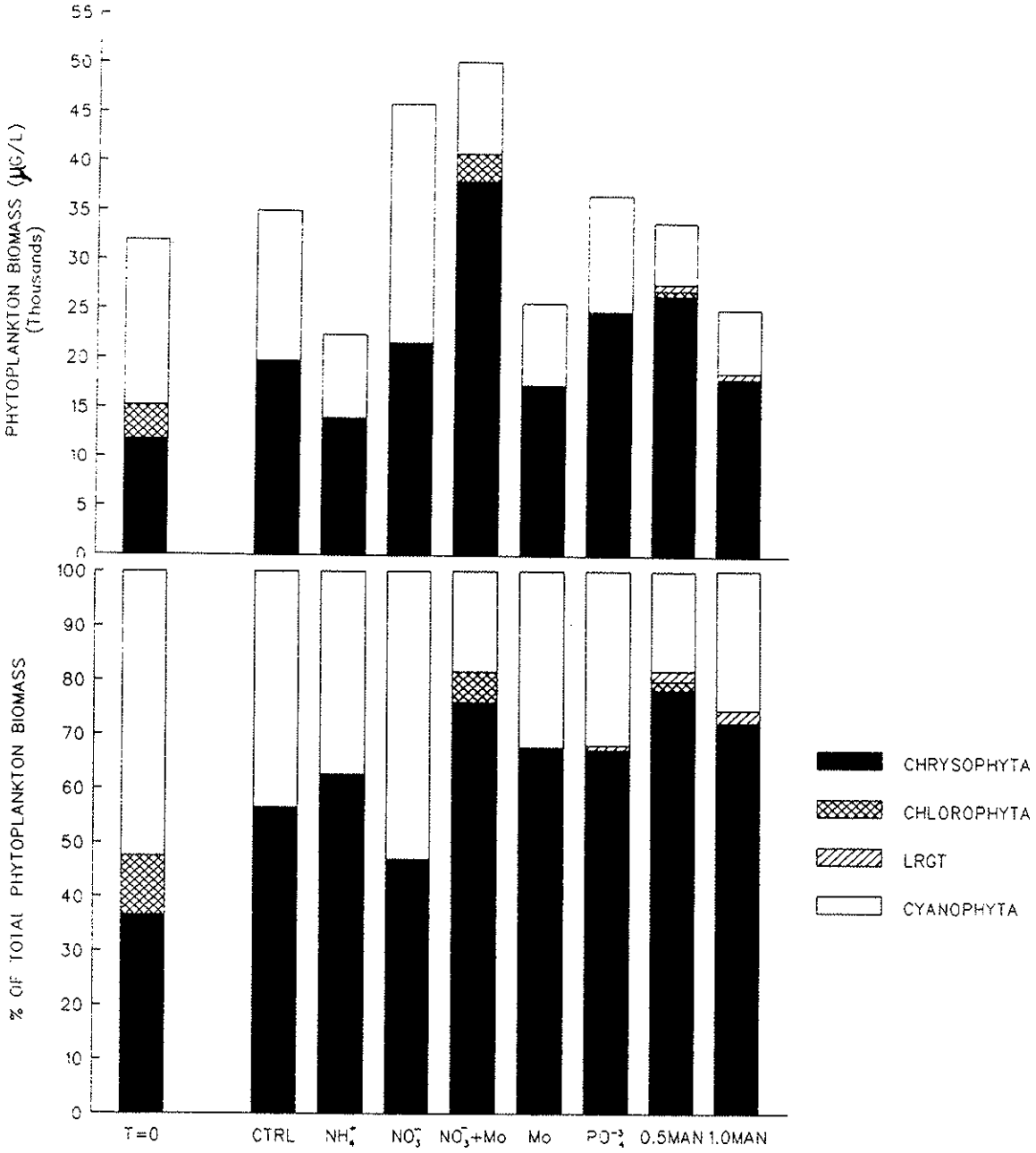

Figure 19. October 1988 experiment: phytoplankton biomass and relative distribution by division. See Table 1 for explanation of treatments.

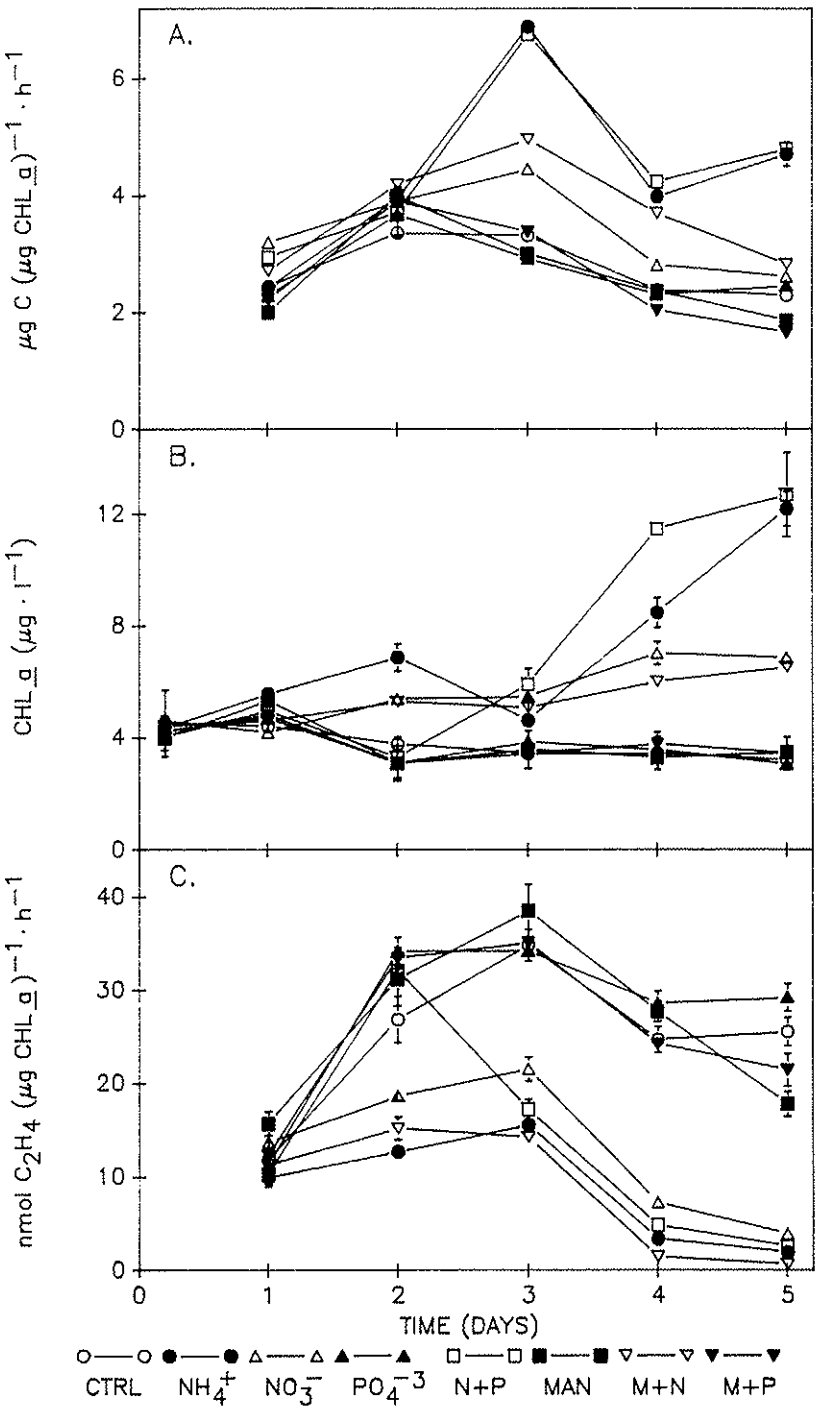

Figure 20. June 1989 experiment: time courses of (A) PPR, (B) CHL a and (C) nitrogenase activity (ethylene production). See Table 1 for treatment details.

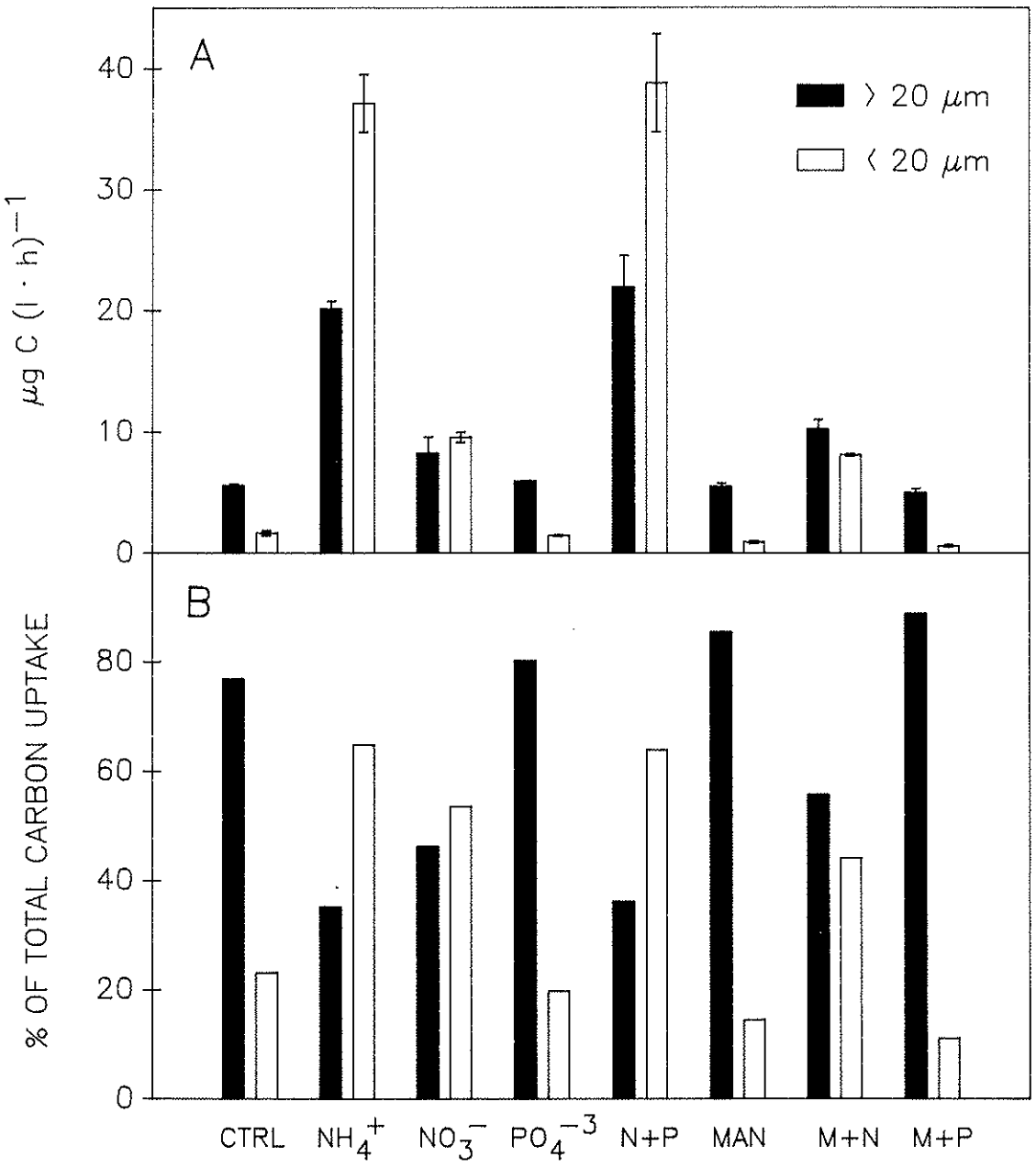

Figure 21. June 1989 experiment: (A) C-uptake and (B) relative contribution for size fractions. See Table 1 for explanation of treatments.

($p<0.01$) in all cases to less than 15% of control by day 5 (Fig. 20C). Stimulation of nitrogenase activity by P or MAN was not detected. Phytoplankton biomass was more than three times the control in NH_4^+, $NH_4^+ + PO_4^{-3}$, PO_4^{-3} and $MAN + PO_4^{-3}$; $MAN + NH_4^+$ was the only treatment that was not greater than control (Fig. 22). The relative abundance of blue-green algae decreased with N addition (especially NO_3^-) and increased with PO_4^{-3} addition.

August 1989 Experiment. Stimulation of PPR in the $NH_4^+ + PO_4^{-3}$ treatment was significant ($P<0.01$), whereas no significant effect occurred when NH_4^+ or PO_4^{-3} was added alone (Fig. 23A). The response of CHL a was similar (Fig. 23B), with $NH_4^+ + PO_4^{-3}$ significantly (7 times) greater than the control ($p<0.01$) and NH_4^+ twice the control ($p<0.05$). On day 3, photosynthetic C-uptake by the >20 μm (blue-green algal) and <20 μm (predominantly Chrysophyta) fractions increased significantly over the control in all N enrichments ($p<0.01$); only the >20 μm fraction was significantly ($p<0.01$) stimulated by PO_4^{-3} (Fig. 24, Table 6). The relative photosynthetic contribution of each size fraction changed with $NH_4^+ + PO_4^{-3}$ addition which increased carbon uptake in the <20 μm fraction and decreased it in the >20 μm fraction (Fig. 24). PO_4^{-3}, $MAN + PO_4^{-3}$ and MAN enhanced nitrogenase activity significantly ($p<0.01$) with both P treatments more than 220% greater than control on day 4 (Fig. 23C). Enrichment with N resulted in greatly reduced nitrogenase

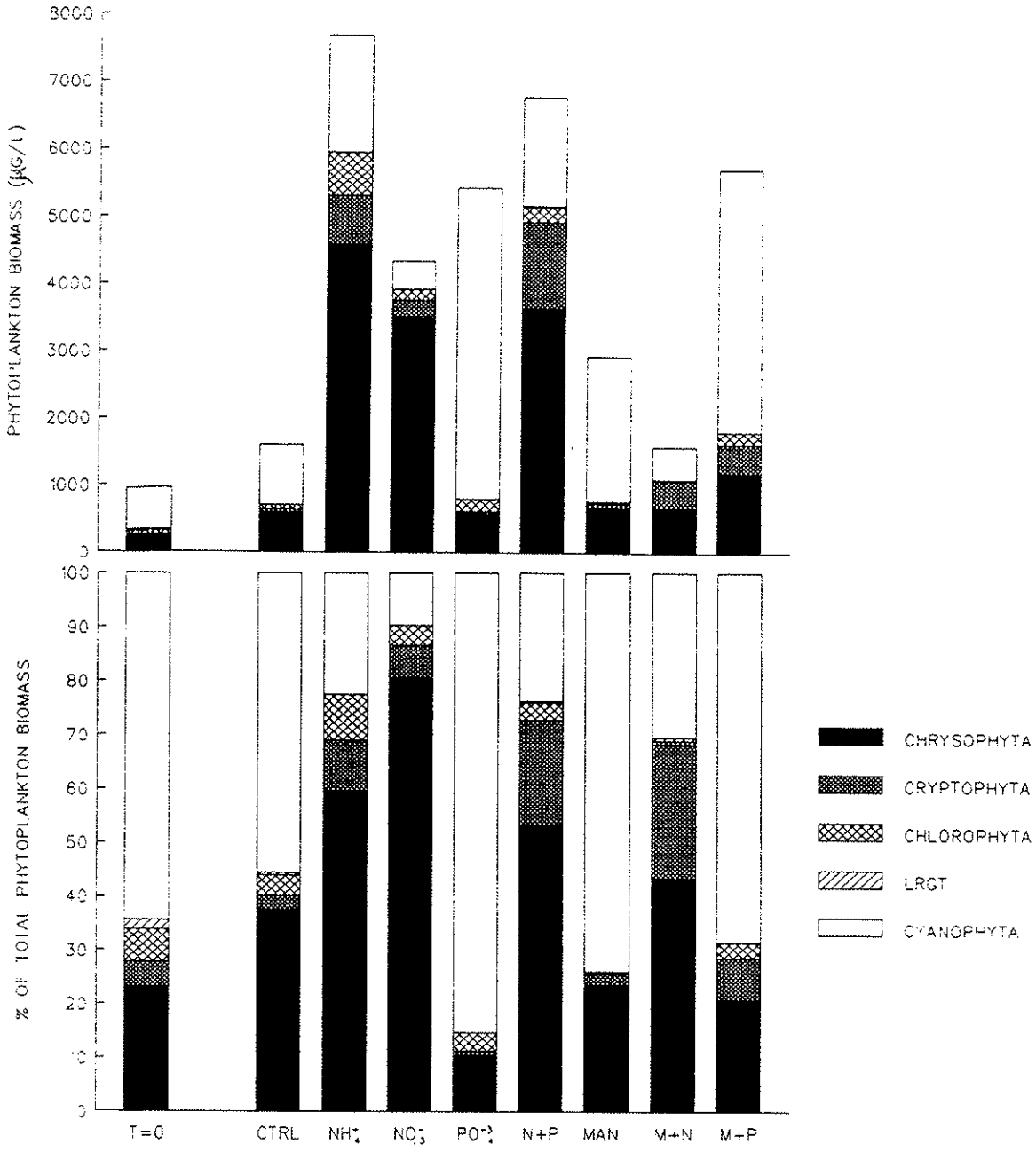

Figure 22. June 1989 experiment: phytoplankton biomass and relative distribution by division. See Table 1 for explanation of treatments.

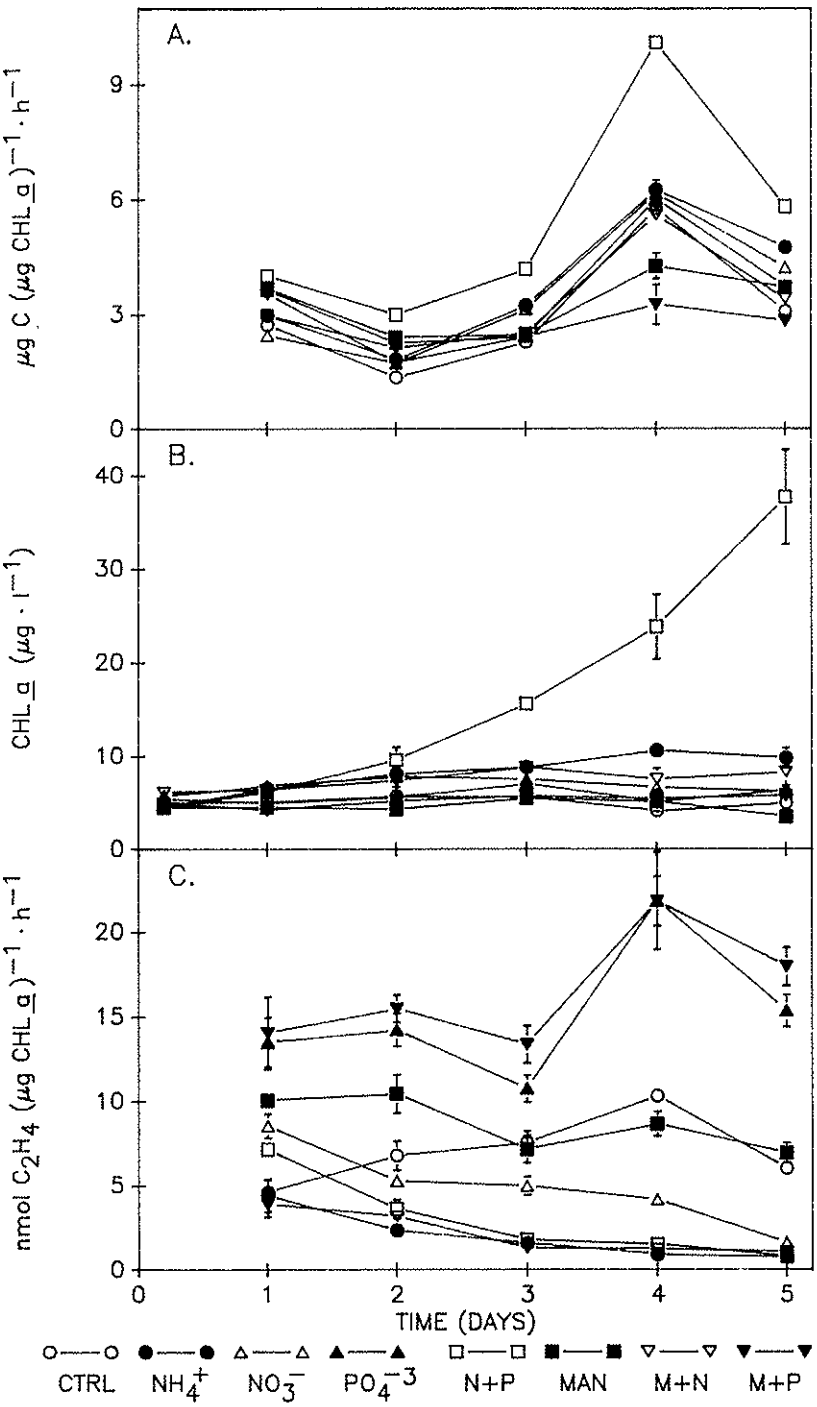

Figure 23. August 1989 experiment: time courses of (A) PPR, (B) CHL a and (C) nitrogenase activity (ethylene production. See Table 1 for treatment details.

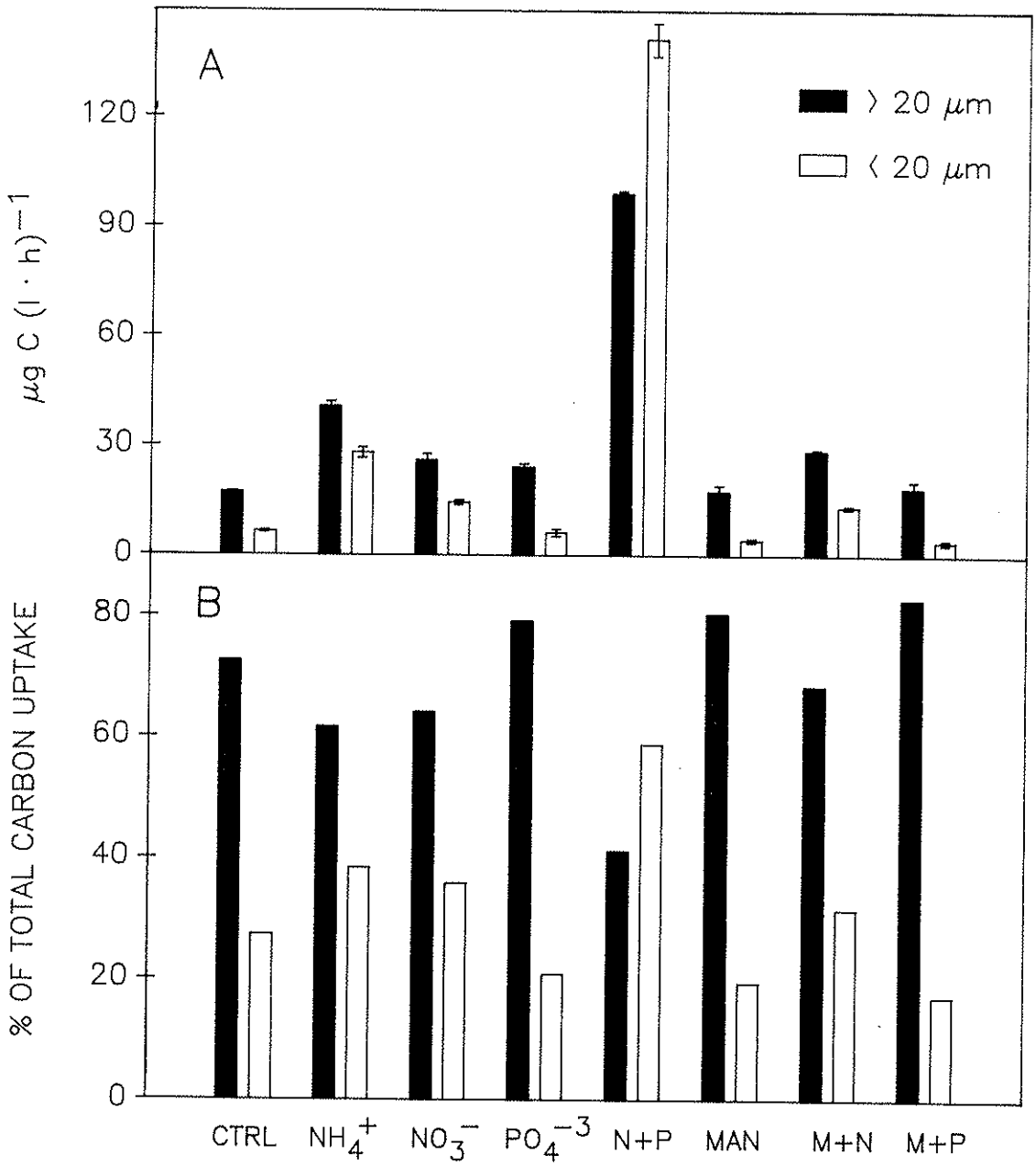

Figure 24. August 1989 experiment: (A) C-uptake and (B) relative contribution for size fractions. See Table 1 for explanation of treatments.

activity in all treatments ($p<0.01$; $p<0.05$ for NO_3^-). Phytoplankton biomass (Fig. 25) was stimulated by the addition of NH_4^+, NO_3^- and $NH_4^+ + PO_4^{-3}$. PO_4^{-3}, MAN and MAN+PO_4^{-3} increased, while NH_4^+, NO_3^- and $NH_4^+ + PO_4^{-3}$ decreased the relative abundance of blue-green algae.

October 1989 Experiment. All treatments except $NH_4^+ + PO_4^{-3}$ and MAN+NH_4^+ (which showed no effect) significantly decreased ($p<0.05$) PPR relative to the control (Fig. 26A). Decreased nitrogenase activity was significant following addition of NH_4^+, NO_3^- ($p<0.01$) (Table 6), MAN+NH_4^+ and MAN+PO_4^{-3} ($p<0.05$); other treatments were not significant (Fig. 26C). Addition of NH_4^+, NO_3^- and $NH_4^+ + PO_4^{-3}$ resulted in CHL a significantly ($p<0.05$) greater than the control (Fig. 26B, Table 6)). N amendments significantly ($p<0.01$) stimulated the <100 μm (mainly Chrysophyta) fraction on day 5, while none of the treatments stimulated the >100 μm (blue-green algal) fraction (Fig. 27). Phytoplankton biomass in the October 1989 mesocosm experiment showed the greatest increase with addition of $NH_4^+ + PO_4^{-3}$ (Fig. 28). No shifts in relative abundance of blue-green algae were apparent in any treatment.

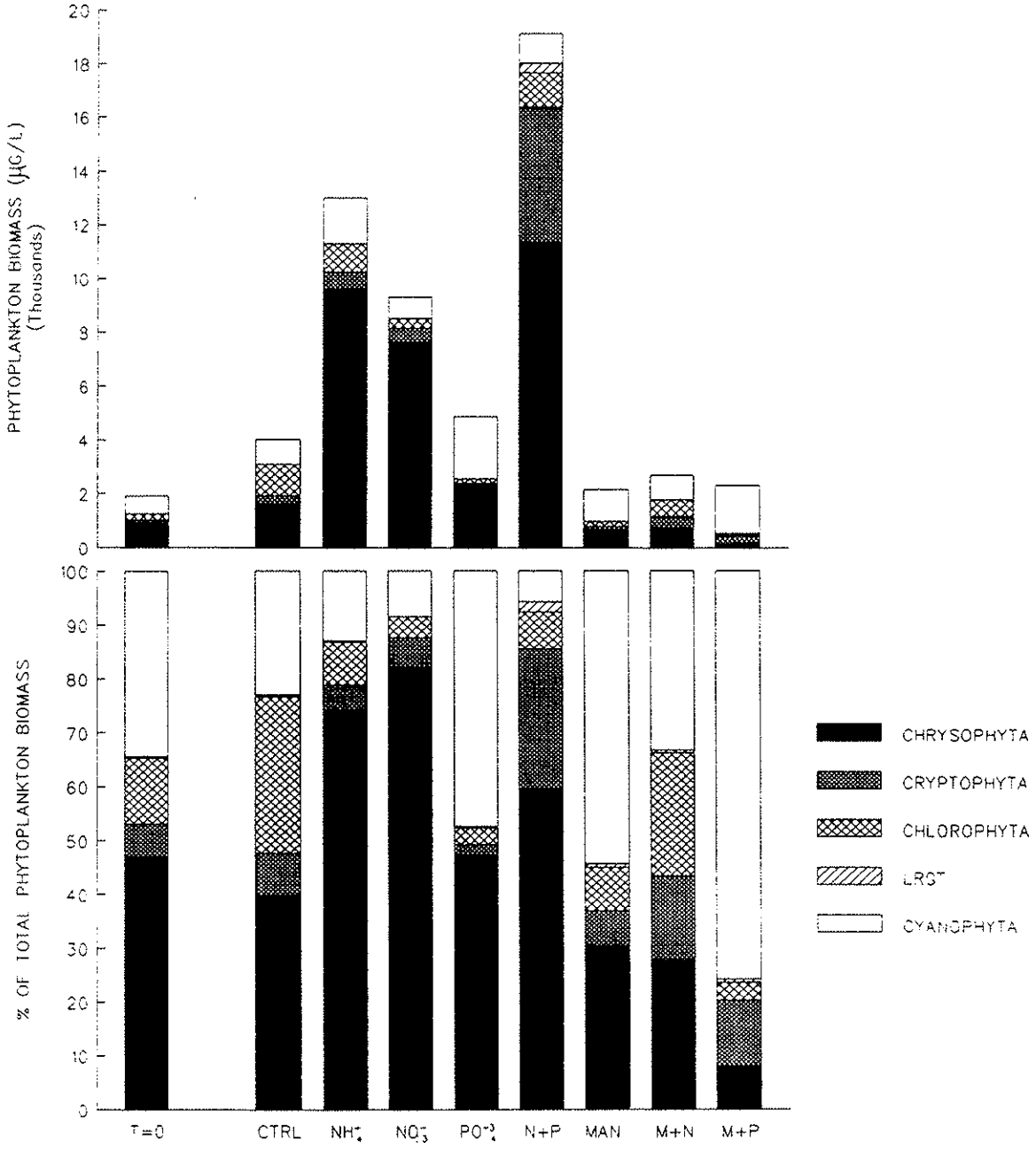

Figure 25. August 1989 experiment: phytoplankton biomass and relative distribution by division. See Table 1 for explanation of treatments.

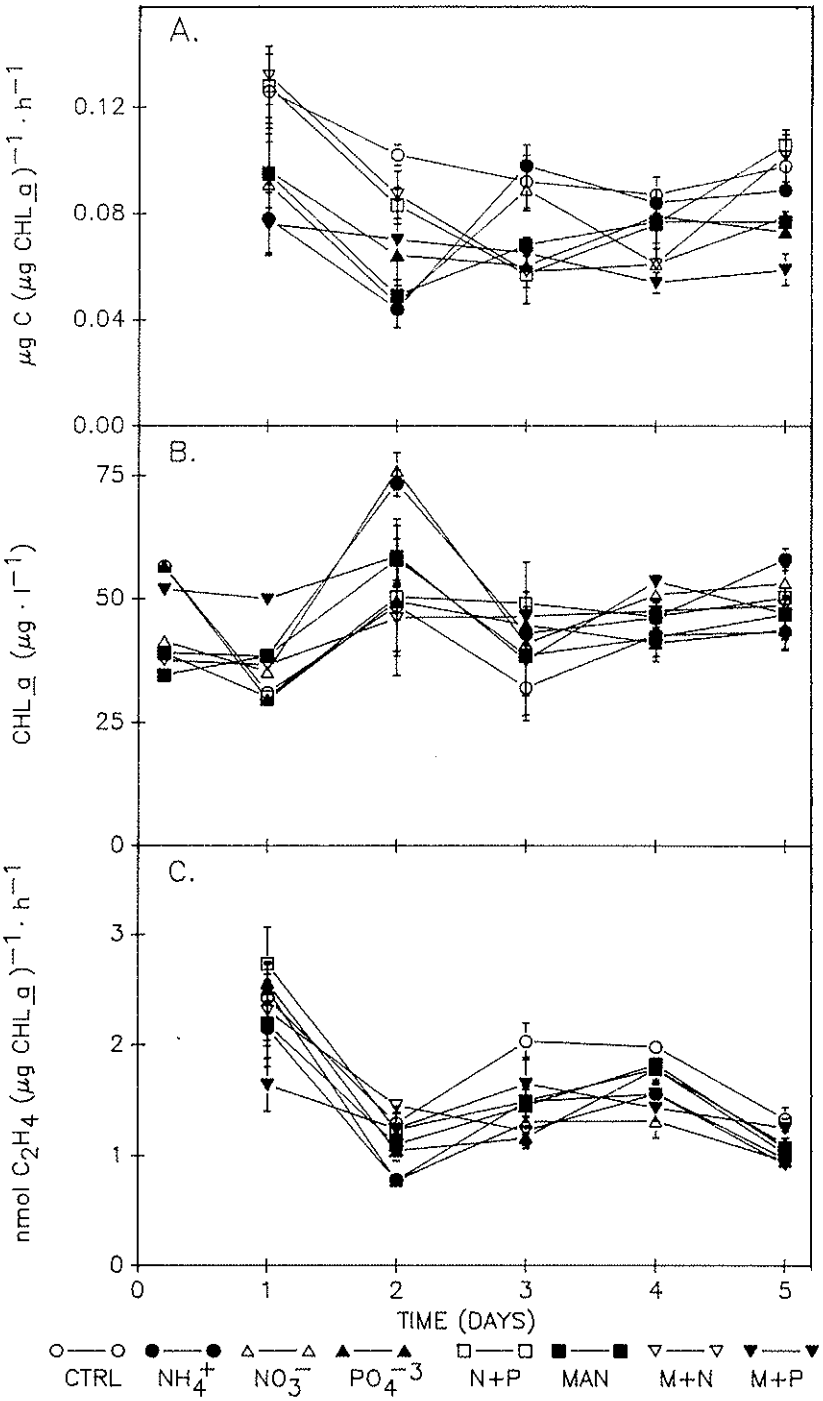

Figure 26. October 1989 experiment: time courses of (A) PPR, (B) CHL a and (C) nitrogenase activity (ethylene production). See Table 1 for treatment details.

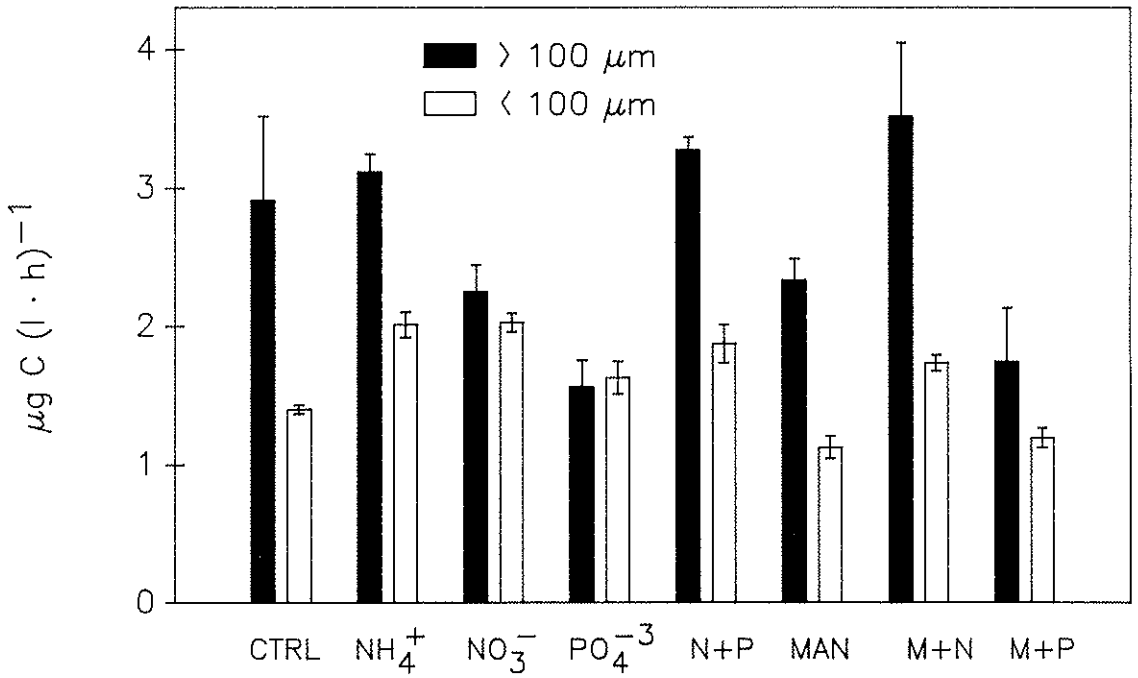

Figure 27. October 1989 experiment: C-uptake for size fractions. See Table 1 for explanation of treatments.

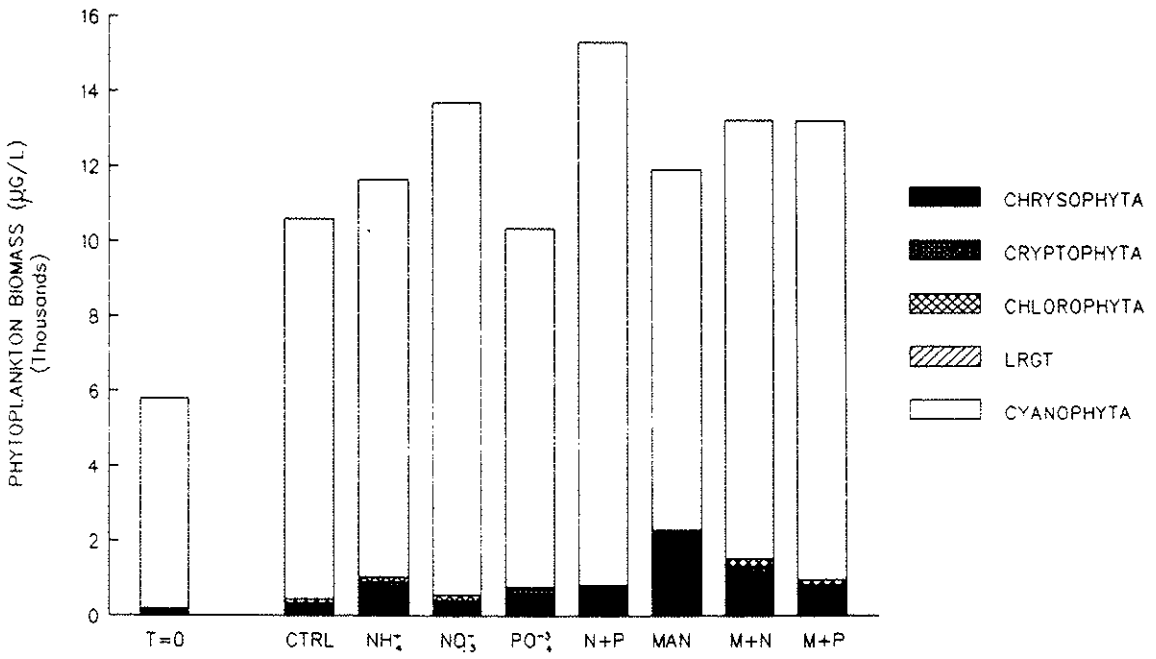

Figure 28. October 1989 experiment: phytoplankton biomass. See Table 1 for explanation of treatments.

Statistical Models

Multiple linear regression models of various environmental parameters (independent variables) and the dependent variables, % N_2-fixing blue-green algae (relative blue-green algal abundance) and nitrogenase activity, are presented below. Relative measures of the importance of each model and each independent variable, to be discussed later, are also presented. Models for Grayling Arm data (A) and the entire lake (Grayling Arm plus all other lake stations) (B) are given for both dependent variables.

% N_2-fixing Blue-Green Algae (%FXBG)

(A) $\text{Arcsin } (\%FXBG/100)^{0.5} = -6.034 + 0.838 \ln (TN) + 0.307 \ln (DIN:SRP)$

Adjusted $R^2 = 0.732$; $n = 22$

Standardized partial regression coefficients:

$\ln (TN) = 0.457$

$\ln (DIN:SRP) = 0.277$

(B) $\text{Arcsin } (\%FXBG/100)^{0.5} = -2.470 + 0.311 \ln (NO_3^-\text{-}N:SRP) + 1.089 \ln (TP)$

Adjusted $R^2 = 0.525$; $n = 54$

Standardized partial regression coefficients:

$\ln (NO_3^-\text{-}N:SRP) = 0.404$

$\ln (TP) = 0.249$

Nitrogenase activity (C_2H_4): nmol C_2H_4/(μg BG x h)

(A) $\ln (C_2H_4) = -0.677 + 1.861 \ln (TEMP) - 0.734 \ln (DIN:SRP)$

Adjusted $R^2 = 0.321$; n = 21

Standardized partial regression coefficients:

ln (TEMP) = 0.496

ln (DIN:SRP) = -0.148

(B) $\ln (C_2H_4) = -9.032 + 2.057 \ln (TEMP) + 1.223 \ln (TP) - 0.768 \ln (NH_4^+\text{-N:SRP})$

Adjusted $R^2 = 0.288$; n = 40

Standardized partial regression coefficients:

ln (TEMP) = 0.353

ln (TP) = 0.206

ln (NH_4^+-N:SRP) = -0.137

DISCUSSION

Nutrient Deficiencies

My experiments detected nutrient deficiencies for photosynthesis and/or CHL *a* of the entire phytoplankton community (i.e., blue-green plus non-blue-green algae) in all cases. Nitrogen addition most consistently elicited positive responses, stimulating community PPR, CHL *a*, phytoplankton biomass, or all three, in the majority of the experiments. N-deficiency could be expected since the DIN:SRP ratio of the Grayling Arm and its inflows and TN:TP of the inflows (Table 2) are usually below the Redfield ratio of N:P (7.2:1; g:g) (Redfield 1958). Phosphorus was clearly the deficient nutrient for photosynthesis of the entire community in only three experiments (June 1988, Limnocorral 2 and July river water) during N_2-fixing blue-green algal blooms when TN:TP, PN:PP and PC:PP were relatively high (Tables 3 and 4). Dodds and Priscu (1990), working in Flathead Lake , Montana, found that predictions of nutrient deficiency based on deviations from particulate C:N:P ratios (g:g:g) of 41:7.2:1 (those which occur during balanced growth) agreed with their long-term bioassay results. My results corroborate their conclusions.

Mannitol treatments, included primarily to examine the effect of dissolved organic carbon enrichment on nitrogenase

activity, resulted in stimulation of PPR in only one case (1.0 MANN, October 1988) without increasing CHL *a*, nitrogenase activity or phytoplankton biomass. This may have been due to increased nutrient cycling by bacteria, owing to increased activity, or possibly an undetected increase in nitrogenase activity. Mannitol had several negative effects on carbon uptake (especially the smaller size fraction) which may also have been due to increased bacterial (decompositon) activity.

The inclusion of Mo treatments in the 1988 experiments was designed to satisfy the requirement of the NO_3^- reductase enzyme and the nitrogenase enzyme for this cofactor (Rueter and Petersen 1987), and to separate responses to Mo from NO_3^- responses. Mo deficiency has been shown to limit phyoplankton growth in lakes and oceans (Rueter and Peterson 1987). Goldman (1960), for example, found Mo to be a factor limiting primary productivity in Castle Lake, California, and suggested that the N deficiency there was indirectly due to Mo deficiency. A study by Howarth and Cole (1985) concluded that Mo deficiency, which they found to limit nitrogen fixation and phytoplankton primary productivity in Baltic Sea water, is caused by inhibition of Mo assimilation by high sulfate concentrations. No substantial changes resulted from Mo enrichment and it was therefore omitted from the 1989 experiments.

Addition of river water elicited substantial responses of photosynthesis in only the May experiment. The result was similar to that of NH_4^+ addition. This is not surprising since the NH_4^+ concentration of the river water was twice that of the Grayling Arm water (Table 3) and separate nutrient bioassays showed NH_4^+ to be deficient in the Grayling Arm. Even though PO_4^{-3} addition stimulated the phytoplankton in the July river water experiment, and the river water SRP concentration was 10 times the lake water, no positive response of photosynthetic C-uptake resulted from river water addition alone. This suggests that the river water contained something inhibitory or that some other factor was made deficient by dilution with river water. Both NH_4^+ and PO_4^{-3} concentrations were lower in the river water during the October river water experiment, which explains the lack of stimulation of photosynthesis by river water then. It is evident that nitrogen and phosphorus can both be of primary importance in limiting phytoplankton production in the Grayling Arm of Hebgen Lake, with nitrogen deficiency predominating.

My nutrient bioassay results agree with results presented in a recent review of experimental nutrient enrichments (Elser et al. 1990). Elser et al. concluded that nitrogen should not be considered a secondary nutrient in freshwaters since the frequency of nitrogen versus phosphorus responses by phytoplankton did not differ, and

that nitrogen plus phosphorus was often required to elicit substantial phytoplankton growth response (see also Dodds et al. 1989). The convention that P is the major nutrient controlling primary productivity in freshwater systems is contradicted by a growing body of evidence (e.g., Hecky and Kilham 1988; Schindler 1975,1977; Smith 1984; Dodds and Priscu 1990; Priscu et al. 1989). My results also support the findings of Sommer (1989) that a shallow, hypertrophic lake dominated by Aphanizomenon was most often N-deficient. It is important for limnologists and lake managers to consider both P and N when studying or managing a system.

The occurrence of simultaneous N and P deficiency, as in the August 1989 experiment, was addressed by Dodds et al. (1989) as attributable to differential N and P deficiencies for distinct components of the phytoplankton community. Differences in requirements and competitive ability of algal species that may explain contemporaneous N and P deficiency have been well documented (Tilman et al. 1986). The lack of stimulation of the <20 μm fraction with concomitant stimulation of the >20 μm fraction following PO_4^{-3} addition, and the requirement for N plus P to substantially increase community primary productivity in the August 1989 experiment are similar to findings of Dodds et al. (1989). These authors found that while single N or P additions stimulated the phytoplankton community in Canyon Ferry Reservoir, Montana, which was dominated by Aphanizomenon, only N

stimulated productivity when the large filamentous blue-green algae were removed. The view that different fractions of the phytoplankton community can be limited by different nutrients is further supported by the stimulation of C-uptake by N addition in only the <20 μm fraction in October 1988 and <100 fraction in October 1989 (these fractions excluded nitrogen fixing blue-green algae). This, and the concurrent lack of stimulation of the larger size fractions (primarily Aphanizomenon) by N enrichment agrees with the concept that the ability to fix atmospheric nitrogen imparts a competitive advantage to heterocystous blue-green algae in N deficient waters (Schindler 1977; Flett et al. 1980). In my experiments on the Grayling Arm, virtually all the blue-green algae were heterocystous N_2-fixing species. I did, however, find that both the N_2-fixing blue-green and non-blue-green portions of the community could be N deficient in terms of photosynthetic C-uptake. The shifts in relative carbon uptake towards non-blue-green fractions in the N treatments of June 1989 (Fig. 17) and the N+P treatment in August 1989 (Fig. 23) depict increases in growth of the smaller organisms indicating changes in community structure following changes in nutrient supply.

Relative Blue-green Algal Abundance

Substantial shifts in the relative importance of individual phytoplankton groups occurred in most experiments after 5 days of nutrient enrichment. Responses included both

increases in non-blue-green algal dominance with N enrichment, and increases in blue-green algal dominance with P enrichment. My nutrient additions caused incipient changes in N:P ratios that have been shown to be important in controlling blue-green algal dominance (Smith 1983; Stockner and Shortreed 1988; Pick and Lean 1987; Priscu 1987). Observations that N_2-fixing blue-green algae tend to become increasingly dominant as TN:TP drops below about 30 have been taken to indicate that the ability to use atmospheric N_2 explains a large part of blue-green algal dominance. This view was corroborated by our experiments with Grayling Arm water. Sterner (1989) showed experimentally that competition for N was strong in Pleasant Pond, Minnesota, and that addition of N decreased the dominance of blue-green algae, further suggesting the important role of N deficiency in promoting blue-green algal abundance. Whole lake manipulations (Barica et al. 1980; Stockner and Shortreed 1988) have been successful in reducing or eliminating blue-green algal blooms by addition of N (increasing N:P). Although some of my experiments showed increased blue-green algal C-uptake with N addition, the possibility of obtaining results similar to whole lake manipulations by adding N to the Grayling Arm of Hebgen Lake is suggested by my experimental results.

The multiple linear regression models produced for relative abundance of N_2-fixing blue-green algae (%FXBG)

showed positive relationships with TN, TP, DIN:SRP and NO_3^--N:SRP. The R^2 for the Grayling Arm model indicates that TN and DIN:SRP explained 73% of the variability in %FXBG. The stepwise regression procedure on data from all stations revealed that NO_3^--N:SRP and TP explained 52% of the %FXBG variation. TN and TP have been shown by other researchers to be key factors in influencing relative biomass of blue-green algae. A multiple linear regression analysis on data from 22 lakes worldwide (Smith 1986) indicated that TN, TP and irradiance are primary contributors to planktonic blue-green algal relative biomass. The same study also showed that at a constant light level blue-green algal relative abundance increases as the TN:TP ratio decreases, but concluded that manipulation by raising influent N:P may not be sufficient to reduce blue-green algal dominance, and that reduction of TP loading may also be necessary. Trimbee and Prepas (1987), studying lakes in Alberta, Canada, found that TP was a better predictor of relative blue-green algal biomass than TN or TN:TP. They refuted the conclusions of Smith (1986), but acknowledged that differences between systems may be responsible. TN and TP were also positively correlated (TN more strongly) with blue-green algal biomass in a study of Florida lakes (Canfield et al. 1989).

Although the inclusion of TN and TP in my models supports the above findings, the positive relationship of %FXBG with DIN:SRP and NO_3^--N:SRP contradicts the literature

and my own experimental results. This positive relationship is probably due to the fact that these ratios did not reach levels that could deter the dominance of N_2-fixing blue-green algae. NO_3^--N:SRP never exceeded 12 in my data set and DIN:SRP never exceeded 6 (Appendix 1). In my study, experimental N additions usually resulted in DIN:SRP ratios greater than 15:1. It may be that blue-green algae can benefit from increasing ambient N:P ratios up to a level where they lose the competitive advantage they hold over other algae when competing in N-deficient waters. This contention is not inconsistent with what has been described by others. In the Experimental Lakes Area (ELA), Canada, blue-green algae were not dominant at TN:TP ratios above 30, but when the ratio was dropped to 5 by experimental changes in loading, N_2-fixing blue-green algae became dominant (Schindler 1975). Flett (1980) found that nitrogen fixation in ELA lakes was induced when the TN:TP ratio (g:g) was reduced to 12, and suggested that this is a ratio below which N_2-fixing blue-green algae may have a competitive advantage over non-N_2-fixing phytoplankton. The experiments of Barica et al. (1980), discussed earlier, were done in lakes dominated by N_2-fixing blue-green algae with TN:TP ratios usually below 5. The experimental additions they made, which suppressed blue-green algal dominance, always resulted in TN:TP ratios greater than 30. Smith (1983), studying 17 lakes world wide, concluded that blue-green

algae tend to be rare in lakes with TN:TP above 29, but also showed a full range of blue-green algal relative abundance covering TN:TP ratios up to that level. The occurrence of blue-green algal dominance in the intermediate range of N:P ratios between about 5 and 30 have yet to be studied in depth and no consistent models exist to describe their dominance. The disparity in results between my model predictions and experimental results elucidates the need for multiple approaches to gathering information to be used in making lake management decisions.

Nitrogenase Activity

Nitrogenase activity was consistently reduced by N-enrichment. This was expected because atmospheric nitrogen fixation is energetically expensive (Carr and Whitton 1982) and is not an efficient means of securing N when it is available in an dissolved ionic form. Results showing depressed nitrogenase activity with addition of inorganic N (NH_4^+ and NO_3^-) at concentrations used here are consistent with those of most researchers. Horne and Fogg (1970) found N_2-fixation in lakes to be confined to periods when NO_3^--N was less than 300 $\mu g\ l^{-1}$. Experiments at Lake Titicaca (Wurtsbaugh et al. 1985) showed greatly reduced nitrogenase activity with addition of 70 $\mu g\ NH_4^+$-N $l^{-1}d^{-1}$ in all their experiments. Wurtsbaugh and Horne (1983), studying Clear Lake, California, showed consistent depression of nitrogenase activity of Aphanizomenon and Anabaena at NO_3^--N

concentrations of about 200 μg l^{-1}. Filamentous blue-green algae in coastal waters of Puerto Rico responded to NH_4^+ and NO_3^- additions in the range of naturally occurring concentrations (0-140 μg N l^{-1}) with a gradient of nitrogenase activity depression (Diaz et al. 1990). A recent review by Horne and Commins (1987) concluded that total inorganic nitrogen is the primary regulator of nitrogenase activity, and that nitrogenase activity is usually not detected until total inorganic nitrogen falls below 50-100 μg l^{-1}. It is clear that the success of N_2-fixing blue-green algae is assured by expending energy on nitrogenase activity only when availability of dissolved inorganic N is low.

P-enrichment stimulated nitrogenase activity only in cases when P-enrichment was found to stimulate phytoplankton activity. Similar findings of inconsistent stimulation of nitrogenase activity by P can be found in the literature (e.g., Wurtsbaugh and Horne 1983; Horne and Commins 1987; Wurtsbaugh et al. 1985). Because nutrient limitation of nitrogenase activity can lead to N-deficits in aquatic systems, Wurtsbaugh et al. (1985) investigated the response of nitrogenase activity to nutrient additions in subsamples of water from Lake Titicaca. They detected stimulation by P (64 μg $l^{-1}d^{-1}$) in only about half of their experiments, much like my study. The review by Horne and Commins (1987) cited above reported that SRP addition only occasionally stimulated nitrogenase activity in lakes. Enrichment with P

at the low rate of 7.0 μg $l^{-1}week^{-1}$ elicited a five-fold increase in annual N_2-fixation (based on acetylene reduction) in the Bay of Quinte, Lake Ontario (Liao 1977). The lack of consistent stimulation of nitrogenase activity with P enrichment is probably due to limitation by other environmental constraints such as light, water column stability, temperature, or micronutrients. When these other requirements are met, P can regulate the rate of nitrogenase activity.

Stimulation of nitrogenase activity following addition of mannitol occurred in two out of six cases. Pearl et al. (1987) consistently stimulated nitrogenase activity with mannitol, fructose, glucose, sucrose and maltose addition to coastal North Carolina Waters. They concluded that the stimulatory effect was probably due to development of O_2-reduced microenvironments (microzones) brought about by increased bacterial activity. Another possibility is that blue-green algae can utilize dissolved organic C directly for energy that can be utilized subsequently for nitrogenase activity. The increased nitrogenase activity with mannitol addition I detected (probably due to lowered O_2 via bacterial respiration) did not result in increased productivity or biomass of blue-green algae.

My multiple linear regression nitrogenase activity models corroborate many of the experimental results for N and P additions discussed above. The negative relationship

in the Grayling Arm model between DIN:SRP and nitrogenase activity is equivalent to depression of nitrogenase activity with N addition (DIN:SRP reduction). The adjusted R^2 for the model with only Grayling Arm data indicates that temperature and DIN:SRP ratios together explain only 32% of the variation in NA, but both make a significant contribution to the model. When data points from the rest of the lake are included, TP also enters into the model. The independent variables together explain only 28% of the variability in NA, but the model reveals TP as another factor that is important in determining nitrogenase activity rates. Smith (1990b) manipulated data from several lakes to show that there is a unimodal relationship between N_2-fixation and TP. Smith found a positive linear relationship up to a TP level of about 250 $\mu g\ l^{-1}$, above which a negative relationship occurred. My model agrees well with the positive linear portion of this relationship, but cannot test the unimodality of it because TP in the Grayling Arm never exceeded 200 $\mu g\ l^{-1}$. The negative relationship between DIN:SRP and nitrogenase activity supports my experimental results. Increased DIN:SRP (N addition) decreased nitrogenase activity,while decreased DIN:SRP (P addition) increased nitrogenase activity. Research done in Experimental Lakes Area of Canada lakes (Flett et al. 1980) concluded that N:P ratios (TN:TP) play a key role in determining whether or not N_2-fixation will occur in lakes.

Temperature was the most important variable (based on standardized partial regression coefficients) in both models. Torrey and Lee (1976) found significant positive correlation of nitrogenase activity with temperature and SRP in Lake Mendota. Priscu (1987) showed strong temperature dependence of nitrogenase activity in Canyon Ferry Reservoir, Montana, and concluded that increased nitrogenase activity provides Aphanizomenon with a distinct competitive advantage at higher temperatures. In chemostat experiments with Lake Superior phytoplankton, Tilman and Kiesling (1984) concluded that blue-green algal relative abundance should increase with temperature.

High water temperature in lakes often leads stratification which promotes water column stability which, in turn, is conducive to blue-green algal dominance. The contribution of temperature as a factor in determining blue-green algal dominance emphasizes the need to be aware of other factors besides nutrient levels when considering lake management options to reduce blue-green algae. As discussed in my introduction, and elsewhere in this thesis, many factors have been shown to influence blue-green algal dominance. Even though I have shown that nutrients are very important, other factors may be more important in a given situation. For example, blue-green algal biomass in four North Carolina reservoirs was frequently lower than would be predicted by published models because of high concentration

of non-algal turbidity (Smith 1990). Blue-green algal bouyancy, thought to be a very important characteristic in promoting their dominance, may be overcome by turbulence (Priscu 1987). I chose to study the influence of nutrients because our capability of controlling the input of nutrients to water bodies makes them likely candidates in developing plans to control blue-green algae.

Conclusion

I have shown that nutrient inputs are important in controlling phytoplankton productivity, standing crop, community structure, and nitrogenase activity in Hebgen Lake, Montana. It is imperative to understand the effects of changes in nutrient supply to undertake successfully any nutrient removal program to control eutrophication, or any nutrient addition program aimed at increasing lake or reservoir productivity. If a nutrient is in ample supply (deficiency cannot be detected by experimental bioassays) then enrichment with (or removal of) that nutrient may not increase (or decrease) the productivity of the system.

My experimental results indicate that control of Anabaena and Aphanizomenon in the Grayling Arm may be possible by fertilization with N. However, my model results indicate that N enrichment may also increase blue-green algal biomass and might intensify blue-green algal blooms there. Furthermore, N-enrichment may stimulate macrophyte growth in the Grayling Arm that can lead to nuisance

macrophyte levels while concomitantly stripping N from the water column, rendering N-enrichment useless in the control of planktonic blue-green algae.

In summary, my study revealed nutrient deficiencies of phytoplankton photosynthesis in all cases, although simple trends were not always evident. Nitrogen was found to be limiting photosynthetic C-uptake and biomass more often than phosphorus, but phosphorus was also important in several cases when added alone or in conjunction with nitrogen. The blue-green and non-blue-green components of the community showed different responses to nutrient enrichments. The non-blue-green component was N-deficient more often than the blue-green component whereas the latter was often stimulated by P addition, though the blue-green component was also stimulated by N enrichment in some cases. Organic carbon enrichment did not result in any consistent changes in productivity, biomass or community structure, but did stimulate nitrogenase activity in certain cases. Nitrogenase activity was depressed by N addition consistently and stimulated by P addition occasionally. N addition promoted changes in the phytoplankton community structure in the direction of non-blue-green dominance, and P addition increased blue-green algal dominance. However, because N-deficiency is important in controlling phytoplankton (including blue-green algal) productivity in the Grayling Arm, and because of other possible problems discussed above,

N-enrichment is not suggested. My data lead me to conclude that nuisance blue-green algal blooms in the Grayling Arm of Hebgen Lake could be reduced by removal of P from inflowing waters (instead of addition of N) to increase the N:P ratios to a level where the N_2-fixing blue-green algae lose their competitive advantage over the more beneficial eucaryotic phytoplankton.

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APPENDICES

APPENDIX A

LAKE STATION DATA

TABLE 7. KEY TO SYMBOLS USED TO PRESENT DATA.

SYMBOL	DEFENITION
SRP	SOLUBLE REACTIVE PHOSPHORUS
TDP	TOTAL DISSOLVED PHOSPHORUS
DOP	DISSOLVED ORGANIC PHOSPHORUS (DOP = TDP - SRP)
PART-P	PARTICULATE PHOSPHORUS
TOT-P	TOTAL PHOSPHORUS (TOT-P = TDP + PART-P)
NH4-N	AMMONIUM NITROGEN
NO3-N	NITRATE NITROGEN
DIN	DISSOLVED INORGANIC NITROGEN (DIN = NH4-N + NO3-N)
TDN	TOTAL DISSOLVED NITROGEN
DON	DISSOLVED ORGANIC NITROGEN (DON = TDN - DIN)
PART-N	PARTICULATE NITROGEN
TOT-N	TOTAL NITROGEN (TOT-N = TDN + PART-N)
DOC	DISSOLVED ORGANIC CARBON
PART-C	PARTICULATE CARBON
PPR	PRIMARY PRODUCTIVITY (PHOTOSYNTHETIC CARBON UPTAKE)
CHL a	CHLOROPHYLL a
PHYTBIO	PHYTOPLANKTON BIOMASS
B.G.BIO	BLUE-GREEN ALGAL BIOMASS
FIXING B.G.BIO	ATMOSPHERIC NITROGEN FIXING BLUE-GREEN ALGAL BIOMASS
nmol C2H4/ l*h	NITROGENASE ACTIVITY (ACETYLENE REDUCTION)
% B.G.	% OF TOTAL PHYTOPLANKTON BIOMASS COMPRISED OF BLUE-GREEN ALGAE
FIXING % B.G.	% OF TOTAL PHYTOPLANKTON BIOMASS COMPRISED OF N^2-FIXING BLUE-GREEN ALGAE

TABLE 8. GRAYLING ARM 1988 DATA.

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
13MAY-0m	11.3	1.0	5.2	4.2	15.3	20.6	1.1	2.5	3.6	0.17
-1m	11.1	1.0	5.2	4.2	16.0	21.2	1.9	2.3	4.2	0.17
-3m	11.0	1.0	5.2	4.2	21.1	26.4	1.1	2.4	3.5	0.16
-5m	8.5	.	.	.	.	.	.	.	.	.
20MAY-0m	12.2	3.6	10.4	6.8	14.3	24.7	3.4	3.6	7.0	0.13
-1m	10.5	2.8	10.4	7.6	16.4	26.7	3.4	2.6	6.0	0.15
-3m	10.0	3.6	10.4	6.8	17.5	27.9	4.9	3.0	7.8	0.20
-5m	9.5	3.6	6.9	3.3	17.6	24.6	57.2	3.5	60.7	0.14
02JUN-0m	11.0	6.1	11.8	5.6	12.4	24.2	11.3	1.8	13.1	0.25
-1m	11.1	7.9	10.0	2.1	12.7	22.7	1.1	2.2	3.3	0.15
-3m	10.9	6.1	10.0	3.9	13.2	23.3	1.9	2.2	4.1	0.22
-5m	10.9	6.1	10.0	3.9	12.5	22.5	0.4	2.2	2.5	0.13
16JUN-0m	17.0	0.5	11.8	11.3	14.7	26.4	5.6	1.8	7.3	0.16
-1m	16.9	1.4	10.0	8.6	16.2	26.2	4.7	2.5	7.2	0.19
-3m	16.6	3.3	11.8	8.5	14.9	26.6	6.4	3.3	9.6	0.21
-5m	14.2	6.0	6.6	0.5	8.2	14.8	6.4	2.1	8.5	0.12
30JUN-0m	18.9	2.3	30.3	28.0	23.0	53.3	16.3	3.2	19.5	0.23
-1m	18.8	2.3	47.7	45.4	23.2	70.9	7.2	3.2	10.4	0.33
-3m	18.6	3.3	49.5	46.2	25.8	75.3	6.4	3.6	10.0	0.20
-5m	18.2	2.3	53.0	50.7	32.1	85.0	14.7	9.1	23.8	0.23
14JUL-0m	18.5	5.5	41.1	35.6	26.5	67.6	15.1	16.9	32.0	0.27
-1m	18.6	3.7	23.8	20.2	26.5	50.3	16.0	10.7	26.7	0.25
-3m	18.5	3.7	18.7	15.0	24.0	42.7	17.7	12.4	30.1	0.26
-5m	18.5	1.8	13.5	11.7	20.6	34.1	12.6	12.5	25.1	0.21
28JUL-0m	20.0	1.8	22.1	20.3	24.1	46.2	16.8	3.3	20.1	0.20
-1m	20.0	0.9	18.7	17.8	24.9	43.6	4.1	3.2	7.4	0.25
-3m	19.9	1.8	23.8	22.0	26.3	50.1	5.0	3.6	8.6	0.23
-5m	19.5	2.7	23.8	21.1	22.2	46.0	5.8	4.0	9.9	0.24
17AUG-0m	17.5	9.9	32.6	22.7	166.8	199.4	10.1	3.0	13.1	0.53
-1m	17.8	9.0	129.8	120.8	68.4	198.2	5.0	3.0	8.0	0.38
-3m	17.8	10.8	96.8	86.0	74.1	170.9	16.8	3.0	19.8	0.43
-5m	17.5	32.9	91.6	58.7	24.3	115.9	48.0	38.1	86.2	0.47
09SEP-0m	15.2	55.0	73.7	18.7	12.5	86.2	34.5	85.3	119.8	0.40
-1m	15.5	60.4	73.7	13.4	11.8	85.5	30.3	80.8	111.1	0.42
-3m	15.5	58.6	79.0	20.4	11.4	90.4	34.5	92.0	126.5	0.41
-5m	15.5	58.6	89.6	31.0	12.3	101.9	32.8	92.3	125.1	0.51
010CT-0m	11.5	16.7	26.0	9.4	72.1	98.1	8.0	14.8	22.8	0.26
-1m	11.5	17.5	26.0	8.5	14.4	40.4	7.2	15.1	22.3	0.28
-3m	10.6	33.2	48.9	15.8	14.2	63.1	8.9	39.9	48.7	0.31
-5m	10.2	38.4	40.1	1.7	15.4	55.6	16.4	65.5	81.9	0.35
22OCT-0m	8.8	30.4	36.6	6.2	12.6	49.2	18.5	52.4	70.9	.
-1m	8.8	31.3	36.6	5.3	13.9	50.6	17.6	51.9	69.5	0.41
-3m	8.8	30.4	40.1	9.7	12.9	53.0	16.8	51.6	68.3	0.31
-5m	8.8	35.8	52.5	16.6	13.1	65.5	15.9	49.8	65.7	0.27
04NOV-0m	5.0	27.4	31.4	4.0	8.4	39.9	16.2	67.8	84.0	0.31
-1m	5.0	25.5	33.2	7.7	8.8	42.0	21.8	64.6	86.4	0.35
-3m	5.0	25.5	33.2	7.7	17.9	51.1	15.3	58.5	73.7	0.30
-5m	5.0	28.3	38.5	10.1	14.3	52.7	16.2	61.2	77.3	0.33

TABLE 8. GRAYLING ARM 1988 DATA (continued).

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
13MAY-0m	64.7	234.7	.	1251.2	4.10	2.6	.	.	.	0.0
-1m	36.1	206.1	.	799.6	4.00	2.5	.	.	.	0.0
-3m	74.2	234.2	.	1120.5	1.60	3.0	.	.	.	0.0
-5m	.	.	.	.	.	.	.	.	.	.
20MAY-0m	27.3	157.3	.	737.8	.	1.1	558.0	0.0	0.0	0.0
-1m	42.4	192.4	.	1095.0	.	1.5	.	.	.	0.0
-3m	48.6	248.6	.	1110.1	.	1.8	1655.0	0.0	0.0	0.0
-5m	40.5	180.5	.	1262.3	.	0.9	1976.4	30.7	30.7	0.0
02JUN-0m	74.6	324.6	2.8	584.7	6.33	6.3	2305.1	0.0	0.0	23.8
-1m	79.5	229.5	.	607.1	6.76	2.9	.	.	.	14.7
-3m	77.0	297.0	2.6	573.9	2.13	3.0	.	.	.	16.6
-5m	71.9	201.9	2.7	820.7	0.28	4.0	15969.4	360.6	360.6	12.8
16JUN-0m	183.9	343.9	2.8	1180.1	19.05	4.7	2579.9	0.0	0.0	540.6
-1m	141.7	331.7	.	1026.0	24.53	10.1	.	.	.	496.1
-3m	140.6	350.6	2.7	1017.1	1.61	7.2	3595.7	1357.7	1357.7	209.8
-5m	33.4	153.4	2.4	450.0	0.18	2.8	2702.1	1558.4	1558.4	679.0
30JUN-0m	405.6	635.6	2.8	2569.7	15.30	9.6	6632.6	6349.0	6349.0	257.5
-1m	373.6	703.6	.	2241.9	39.40	6.1	.	.	.	508.0
-3m	359.3	559.3	3.2	2114.3	7.50	7.8	6663.4	5424.5	5424.5	240.3
-5m	281.5	511.5	2.7	1821.1	0.20	7.2	3892.1	3300.3	3300.3	150.9
14JUL-0m	200.1	470.1	2.9	1309.0	12.00	5.9	9086.0	7142.0	4894.0	50.2
-1m	290.0	540.0	.	1565.5	23.10	11.2	.	.	.	54.1
-3m	215.7	475.7	2.7	1367.6	7.80	9.8	3511.5	1916.0	1594.8	56.4
-5m	202.7	412.7	2.7	1265.0	0.90	8.1	3353.1	2111.1	2111.1	12.3
28JUL-0m	214.9	414.9	3.1	1471.8	32.60	11.1	2448.4	797.9	797.9	225.2
-1m	219.1	469.1	.	1519.0	31.90	16.4	.	.	.	243.9
-3m	203.9	433.9	2.9	1462.5	6.70	14.8	2846.8	1311.8	1270.1	105.0
-5m	214.3	454.3	3.0	1429.6	1.30	15.5	4782.3	2392.5	2392.5	41.2
17AUG-0m	1484.1	2014.1	4.6	7902.4	101.20	116.8	3290.4	3275.9	3275.9	1159.9
-1m	809.4	1189.4	.	4373.4	28.20	86.7	.	.	.	632.2
-3m	751.5	1181.5	5.8	4241.8	1.40	85.1	3475.4	3382.7	3382.7	184.8
-5m	105.5	575.5	6.0	1234.7	0.00	8.8	514.5	451.1	451.1	0.2
09SEP-0m	70.9	470.9	6.4	921.2	12.60	3.7	1031.9	471.1	471.1	6.5
-1m	47.8	467.8	.	841.4	14.60	4.5	.	.	.	5.5
-3m	41.9	451.9	5.5	771.6	5.80	3.0	1154.1	224.0	224.0	3.3
-5m	32.6	542.6	6.5	728.5	0.40	2.7	319.7	85.0	85.0	0.2
01OCT-0m	1534.9	1794.9	2.3	9038.3	22.10	151.5	35492.1	33595.1	33595.1	560.8
-1m	39.4	319.4	.	962.8	16.50	13.9	.	.	.	35.8
-3m	22.4	332.4	2.5	680.0	4.40	3.9	1543.3	0.0	0.0	8.3
-5m	86.7	436.7	6.6	799.5	0.10	1.2	411.0	0.0	0.0	0.2
22OCT-0m	23.9	.	5.1	886.1	7.70	5.8	2108.3	0.0	0.0	42.4
-1m	35.1	445.1	.	1128.5	13.80	5.4	.	.	.	4.7
-3m	41.6	351.6	4.4	1078.3	2.10	5.6	3249.0	177.6	177.6	5.4
-5m	23.6	293.6	4.0	905.3	0.40	2.9	1210.2	0.0	0.0	9.5
04NOV-0m	54.5	364.5	2.6	811.0	.	3.9	902.6	278.0	278.0	.
-1m	40.5	390.5	.	699.3	.	3.3	.	.	.	.
-3m	75.7	375.7	2.9	1176.6	.	4.3	1035.9	0.0	0.0	.
-5m	32.3	362.3	3.1	820.8	.	3.2	.	.	.	.

TABLE 9. GRAYLING ARM 1988 DATA INTEGRATED 0-5 METERS.

DATE	TEMP AVG	SRP mg/m^2	TDP mg/m^2	DOP mg/m^2	PP mg/m^2	TOT-P mg/m^2	NH4-N mg/m^2	NO3-N mg/m^2	DIN mg/m^2	TDN g/m^2
13MAY88	11.11	3.03	15.66	12.63	52.73	68.39	4.52	7.10	11.62	0.50
20MAY88	10.37	16.80	48.46	31.67	84.38	132.84	73.69	15.19	88.88	0.83
02JUN88	10.97	33.21	50.96	17.76	64.13	115.09	11.51	10.66	22.17	0.92
16JUN88	16.14	14.87	50.96	36.09	69.57	120.52	29.06	13.20	42.26	0.91
30JUN88	18.60	13.46	238.66	225.20	129.97	368.63	46.42	22.72	69.14	1.24
14JUL88	18.53	17.35	107.14	89.79	121.63	228.77	79.52	61.90	141.41	1.24
28JUL88	19.84	8.68	110.59	101.91	124.11	234.70	30.42	17.77	48.19	1.18
17AUG88	17.68	73.02	496.23	423.22	358.55	854.79	94.21	50.13	144.34	2.17
09SEP88	.	293.79	395.02	101.24	58.99	454.01	164.63	440.02	604.65	2.16
01OCT88	10.88	139.39	190.09	50.71	101.44	291.53	48.86	175.39	224.25	1.52
22OCT88	8.80	158.79	205.94	47.15	66.07	272.01	85.13	256.86	341.99	1.71
04NOV88	5.00	131.34	170.30	38.96	67.40	237.70	87.46	308.83	396.28	1.61

DATE	PART-N mg/m^2	TOT-N mg/m^2	DOC g/m^2	PART-C g/m^2	PPR mgC/m^2	CHL a mg/m^2	PHYTBIO g/m^2	B.G.BIO g/m^2	FIXING B.G.BIO g/m^2	umol C2H4/ m^2*h
13MAY88	160.70	660.70	.	2.95	9.65	8.04	.	.	.	0.00
20MAY88	214.95	1044.95	.	5.49	.	7.24	6.95	0.03	0.03	0.00
02JUN88	382.45	1302.45	13.33	3.17	17.85	17.34	45.69	0.90	0.90	79.92
16JUN88	619.10	1524.10	13.30	4.61	49.72	34.77	15.56	4.95	4.95	2113.08
30JUN88	1763.30	3003.30	14.85	10.70	81.95	36.67	30.50	26.39	26.39	1522.20
14JUL88	1169.15	2409.15	13.73	7.00	57.15	47.36	25.76	17.61	13.44	231.35
28JUL88	1058.20	2233.20	14.83	7.37	78.85	75.25	15.57	6.87	6.76	729.64
17AUG88	3564.65	5729.65	27.37	20.23	95.70	367.55	14.14	13.82	13.82	1898.04
09SEP88	223.55	2383.55	29.85	3.99	40.20	17.38	4.75	1.35	1.35	18.30
01OCT88	958.05	2478.05	16.35	8.12	44.70	105.66	23.56	16.80	16.80	350.87
22OCT88	171.40	1886.95	22.78	5.20	29.15	25.10	12.50	0.44	0.44	48.63
04NOV88	271.70	1881.70	14.16	4.63	.	18.63	4.98	1.45	1.45	.

DATE	% B.G.	FIXING % B.G.	DIN:SRP	TN:TP	PN:PP	NO3:SRP
13MAY88	.	.	3.83	9.66	3.05	2.34
20MAY88	0.44	0.44	5.29	7.87	2.55	0.90
02JUN88	1.97	1.97	0.67	11.32	5.96	0.32
16JUN88	31.83	31.83	2.84	12.65	8.90	0.89
30JUN88	86.51	86.51	5.14	8.15	13.57	1.69
14JUL88	68.38	52.17	8.15	10.53	9.61	3.57
28JUL88	44.11	43.44	5.55	9.52	8.53	2.05
17AUG88	97.76	97.76	1.98	6.70	9.94	0.69
09SEP88	28.44	28.44	2.06	5.25	3.79	1.50
01OCT88	71.30	71.30	1.61	8.50	9.44	1.26
22OCT88	3.55	3.55	2.15	6.94	2.59	1.62
04NOV88	29.17	29.17	3.02	7.92	4.03	2.35

TABLE 10. MADISON ARM 1988 DATA.

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
20MAY -0	12.0	1.0	8.7	7.7	10.8	19.4	1.9	3.7	5.6	0.13
-1	12.0	1.9	8.7	6.8	11.7	20.4	2.6	2.9	5.6	0.36
-3	9.3	1.9	29.3	27.4	8.0	37.3	1.9	3.0	4.9	0.69
-5	9.0	1.0	8.7	7.7	8.5	17.2	2.6	3.2	5.8	0.51
-10	7.8	.	.	.	.	.	.	.	.	.
02JUN -0	11.1	7.9	13.5	5.6	7.1	20.6	0.4	1.8	2.2	0.19
-1	11.0	0.8	4.8	4.0	7.8	12.6	0.4	1.8	2.2	0.15
-3	11.0	2.6	6.6	4.0	10.0	16.5	1.9	2.0	3.9	0.25
-5	10.4	4.4	6.6	2.2	5.5	12.0	5.8	2.2	8.0	0.15
-10	9.0	.	.	.	.	.	.	.	.	.
16JUN -0	16.9	1.4	18.7	17.3	4.6	23.2	4.7	1.8	6.5	0.16
-1	16.0	1.4	15.2	13.8	4.9	20.2	5.6	1.8	7.4	0.13
-3	15.5	2.3	11.8	9.4	4.7	16.4	8.0	2.1	10.2	0.19
-5	14.6	3.3	10.0	6.8	5.9	15.9	45.2	2.1	47.3	0.13
-10	12.0	5.1	8.3	3.2	3.7	12.0	9.7	2.9	12.6	0.11
30JUN -0	18.0	1.4	42.5	41.1	5.5	48.0	.	2.1	.	0.19
-1	18.0	1.4	44.2	42.8	4.8	49.0	6.4	2.2	8.6	0.19
-3	17.6	1.4	26.8	25.4	4.7	31.5	10.4	2.5	12.9	0.13
-5	17.5	3.3	11.1	7.8	5.3	16.3	.	4.6	.	0.13
-10	15.6	7.9	11.1	3.2	5.8	16.9	.	5.8	.	0.12
14JUL -0	18.0	2.7	13.5	10.8	8.2	21.7	0.0	2.5	2.5	0.12
-1	18.0	0.9	15.2	14.3	8.1	23.4	1.6	2.6	4.2	0.18
-3	17.9	4.6	25.6	21.0	7.7	33.3	1.6	2.5	4.1	0.18
-5	17.8	1.8	8.3	6.5	8.0	16.3	2.4	2.5	4.9	0.15
-10	16.0	10.1	15.2	5.2	6.7	22.0	18.5	5.9	24.4	0.16
28JUL -0	20.0	1.8	22.1	20.3	7.8	29.9	2.4	2.1	4.6	0.15
-1	20.0	0.9	13.5	12.6	11.4	24.8	3.3	2.1	5.4	0.19
-3	20.0	0.0	39.4	39.4	10.7	50.0	1.6	2.2	3.8	0.15
-5	19.8	0.9	18.7	17.8	10.0	28.7	1.6	1.8	3.4	0.14
-10	18.0	10.1	20.4	10.3	11.9	32.3	28.7	5.8	34.5	0.13
17AUG -0	17.8	4.6	39.5	34.9	12.8	52.3	5.9	3.0	8.8	0.19
-1	17.8	6.4	43.0	36.7	12.4	55.5	8.4	3.4	11.8	0.21
-3	17.8	3.7	25.7	21.9	15.2	40.8	15.1	3.0	18.1	0.22
-5	17.8	4.6	25.7	21.1	12.6	38.3	6.7	3.0	9.7	0.23
-10	17.1	8.1	23.3	15.1	10.0	33.3	20.2	6.0	26.2	0.09
09SEP -0	15.8	5.5	19.1	13.6	15.6	34.6	16.0	4.1	20.1	0.19
-1	15.8	5.5	20.8	15.4	14.7	35.5	16.8	3.3	20.2	.
-3	15.8	5.5	20.8	15.4	14.5	35.3	16.0	5.2	21.2	0.18
-5	15.8	6.4	24.4	18.0	12.6	37.0	16.0	5.7	21.7	0.16
-10	15.2	5.5	27.9	22.4	17.7	45.6	14.3	4.5	18.8	0.17
01OCT -0	13.2	2.8	15.5	12.7	78.7	94.1	4.7	3.9	8.5	.
-1	12.8	3.6	15.5	11.9	14.3	29.8	4.7	3.6	8.3	.
-3	12.6	2.8	13.7	11.0	9.4	23.2	4.7	3.5	8.2	.
-5	12.5	1.9	11.9	10.1	8.1	20.0	5.5	3.2	8.7	.
-10	10.8	1.9	8.4	6.5	5.6	14.0	6.3	5.7	12.0	.
22OCT -0	10.0	13.2	10.2	0.0	8.1	18.2	9.0	9.5	18.5	0.17
-1	10.0	10.4	10.2	0.0	7.7	17.9	3.0	3.0	5.9	0.18
-3	10.0	11.3	15.5	4.1	7.7	23.2	3.0	3.7	6.7	0.16
-5	10.0	9.5	17.2	7.7	6.4	23.6	3.8	7.8	11.6	0.16
-10	10.0	11.3	20.8	9.4	8.0	28.7	3.0	4.8	7.7	0.22

TABLE 10. MADISON ARM 1988 DATA (continued).

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (mg/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
20MAY -0	18.7	130.0	.	1137.4	.	1.0	2423.6	61.8	61.8	0.0
-1	39.9	360.0	.	743.3	.	1.0	.	.	.	0.0
-3	15.1	690.0	.	975.9	.	1.2	999.1	0.0	0.0	0.0
-5	15.9	510.0	.	812.8	.	3.0	2440.2	0.0	0.0	0.0
-10	.	.	.	.	.	.	.	.	.	0.0
02JUN -0	49.2	190.0	.	422.0	.	2.9	858.2	0.0	0.0	0.0
-1	50.5	150.1	.	719.1	5.20	3.2	.	.	.	0.0
-3	40.9	250.0	.	604.7	2.50	2.3	1439.7	0.0	0.0	0.0
-5	21.0	150.0	.	425.9	0.60	1.8	484.2	0.0	0.0	0.0
-10	.	.	.	.	.	.	.	.	.	0.0
16JUN -0	39.1	160.0	.	531.6	2.32	0.5	259.8	0.0	0.0	0.0
-1	34.2	130.0	.	445.8	3.59	1.0	.	.	.	0.0
-3	34.9	190.0	.	421.8	4.56	1.2	2312.5	361.4	0.0	0.0
-5	38.2	130.0	.	472.2	4.09	0.4	2266.6	545.4	51.2	0.0
-10	21.9	110.0	.	463.2	0.18	1.0	.	.	.	0.0
30JUN -0	31.9	190.0	.	394.0	2.92	1.3	755.5	0.0	0.0	31.5
-1	45.9	190.0	.	395.8	4.83	1.5	.	.	.	5.3
-3	54.5	130.1	.	433.8	5.35	1.7	446.4	0.0	0.0	2.7
-5	61.1	130.1	.	489.2	4.58	2.4	2530.4	1686.3	0.0	0.0
-10	49.7	120.0	.	362.5	0.44	4.3	.	.	.	0.0
14JUL -0	105.4	120.1	.	974.9	.	6.6	720.7	500.9	19.1	.
-1	85.9	180.1	.	804.2	.	5.1	.	.	.	.
-3	95.2	180.1	.	914.7	.	5.4	3052.6	2380.6	148.3	.
-5	84.6	150.1	.	787.5	.	4.6	1442.3	1130.8	30.7	.
-10	32.0	160.0	.	481.2	.	.	.	.	.	.
28JUL -0	93.4	150.1	.	917.2	8.12	6.0	3059.8	2810.5	0.0	182.4
-1	101.5	190.1	.	952.6	10.18	7.6	.	.	.	170.0
-3	91.0	150.1	.	843.3	8.82	4.4	799.9	240.9	0.0	59.2
-5	89.4	140.1	.	872.7	3.40	5.1	4323.7	3731.2	0.0	181.6
-10	52.3	130.1	.	629.7	0.11	1.6	.	.	.	13.3
17AUG -0	63.4	190.1	.	724.8	11.40	6.3	1351.8	770.9	0.0	21.5
-1	113.2	210.1	.	840.6	18.06	13.4	.	.	.	0.2
-3	88.2	220.1	.	974.6	13.77	4.0	1357.1	240.9	0.0	15.7
-5	55.5	230.1	.	863.7	5.10	3.7	1353.1	0.0	0.0	16.5
-10	61.0	90.1	.	691.6	0.23	2.6	.	.	.	0.2
09SEP -0	142.6	190.1	.	1035.3	14.96	4.8	1093.3	880.4	880.4	11.0
-1	96.7	.	.	808.4	15.69	6.4	.	.	.	3.4
-3	62.1	180.1	.	711.9	12.51	6.1	.	.	.	4.4
-5	80.6	160.1	.	875.8	4.96	6.8	4729.2	2801.3	231.7	3.6
-10	126.5	170.1	.	1057.2	0.32	6.8	.	.	.	0.2
01OCT -0	2487.3	.	.	13725.0	38.86	203.7	38615.1	38615.1	38615.1	914.7
-1	123.5	.	.	1183.6	13.84	15.1	.	.	.	300.0
-3	134.6	.	.	992.6	8.61	7.7	1905.7	919.0	919.0	26.1
-5	63.0	.	.	645.7	1.80	3.6	12644.2	1451.9	1451.9	8.6
-10	33.3	.	.	670.5	0.51	7.7	.	.	.	3.3
22OCT -0	19.4	170.0	.	730.9	.	6.1	2296.4	0.0	0.0	.
-1	22.0	180.0	.	771.3	.	4.8	.	.	.	.
-3	37.6	160.0	.	984.5	.	5.3	1666.5	92.7	92.7	.
-5	31.5	160.0	.	883.4	.	7.9	5884.8	85.0	85.0	.
-10	54.9	220.1	.	874.5	.	6.4	.	.	.	.

TABLE 11. MADISON ARM 1988 DATA INTEGRATED 0-10 METERS.

DATE	TEMP AVG	SRP mg/m^2	TDP mg/m^2	DOP mg/m^2	PP mg/m^2	TOT-P mg/m^2	NH4-N mg/m^2	NO3-N mg/m^2	DIN mg/m^2	TDN g/m^2
20MAY88	9.41	8.09	84.62	76.53	47.50	132.12	11.28	15.40	26.67	2.50
02JUN88	10.27	14.67	33.63	18.96	40.59	74.22	10.34	9.79	20.13	0.97
16JUN88	14.45	31.59	111.47	79.88	48.90	160.36	209.35	22.45	231.80	1.39
30JUN88	17.11	36.70	207.53	170.83	52.14	259.66	.	39.74	.	1.40
14JUL88	17.37	43.41	147.89	104.48	76.43	224.31	60.47	33.43	93.90	1.62
28JUL88	19.39	30.59	226.36	195.77	106.85	333.20	86.68	29.47	116.15	1.48
17AUG88	17.61	55.75	283.66	227.91	124.54	408.20	119.70	38.09	157.79	1.88
09SEP88	15.64	57.98	237.46	179.48	147.08	384.54	156.84	48.70	205.53	1.72
01OCT88	12.16	23.59	121.20	97.62	121.88	243.08	53.64	39.74	93.38	.
22OCT88	10.00	106.61	163.48	58.74	73.28	236.76	35.53	55.73	91.26	1.79

DATE	PART-N mg/m^2	TOT-N mg/m^2	DOC g/m^2	PART-C g/m^2	PPR mgC/m^2	CHL a mg/m^2	PHYTBIO g/m^2	B.G.BIO g/m^2	FIXING B.G.BIO g/m^2	umol C2H4/ m^2*h
20MAY88	115.30	2610.30	.	4.45	.	7.40	8.57	0.09	0.09	0.00
02JUN88	203.15	1173.15	.	2.92	16.00	12.55	5.37	0.00	0.00	0.00
16JUN88	329.10	1714.10	.	4.59	30.43	7.93	8.44	1.45	0.05	0.00
30JUN88	531.90	1926.90	.	4.28	36.53	25.44	4.78	1.69	0.00	29.00
14JUL88	748.05	2363.05	.	7.48	.	.	10.15	7.83	0.43	.
28JUL88	824.60	2299.60	.	8.20	49.13	44.97	10.91	8.55	0.00	1133.60
17AUG88	724.65	2604.65	.	8.32	78.74	50.93	6.77	1.76	0.00	100.63
09SEP88	938.90	2687.50	.	8.86	74.18	65.21	14.56	9.20	2.78	32.65
01OCT88	2001.85	.	.	14.56	64.99	171.73	75.33	61.67	61.67	997.89
22OCT88	365.40	2150.40	.	8.77	.	64.42	13.50	0.32	0.32	.

DATE	% B.G.	FIXING % B.G.	DIN:SRP	TN:TP	PN:PP	NO3:SRP
20MAY88	1.08	1.08	3.30	19.76	2.43	1.90
02JUN88	0.00	0.00	1.37	15.81	5.00	0.67
16JUN88	17.17	0.61	7.34	10.69	6.73	0.71
30JUN88	35.28	0.00	.	7.42	10.20	1.08
14JUL88	77.14	4.24	2.16	10.53	9.79	0.77
28JUL88	78.34	0.00	3.80	6.90	7.72	0.96
17AUG88	25.96	0.00	2.83	6.38	5.82	0.68
09SEP88	63.23	19.10	3.54	6.99	6.38	0.84
01OCT88	81.87	81.87	3.96	.	16.43	1.68
22OCT88	2.37	2.37	0.86	9.08	4.99	0.52

TABLE 12. MID LAKE 1988 DATA.

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
20MAY -0	9.5	2.6	8.7	6.1	6.8	15.5	3.5	2.2	5.6	0.37
-1	9.2	2.6	10.4	7.8	7.2	17.6	19.9	3.2	23.1	0.80
-3	8.2	2.6	12.1	9.5	7.9	20.0	0.4	.	.	.
-5	8.2	4.4	.	.	6.4	.	0.4	.	.	.
-10	7.3	15.0	17.3	2.3	7.5	24.8	26.2	10.9	37.0	0.15
-15	5.3	4.4	10.4	6.0	7.7	18.1	1.1	8.7	9.8	0.10
02JUN -0	12.0	2.6	6.6	4.0	4.5	11.0	15.2	2.2	17.4	0.15
-1	12.0	2.6	10.0	7.4	4.4	14.4	10.5	1.8	12.3	0.16
-3	12.0	4.4	10.0	5.7	3.4	13.4	11.3	2.2	13.5	0.12
-5	12.0	4.4	10.0	5.7	4.8	14.8	12.1	2.2	14.2	0.19
-10	11.8	4.4	10.0	5.7	3.0	13.0	15.2	2.5	17.7	0.15
-15	9.2	9.7	11.8	2.1	4.6	16.4	29.3	5.8	35.0	0.18
16JUN -0	17.0	2.3	6.6	4.2	3.2	9.8	8.9	1.8	10.6	0.13
-1	16.5	1.4	6.6	5.2	4.7	11.2	13.8	1.8	15.6	0.13
-3	16.0	1.4	8.3	6.9	4.3	12.6	39.5	2.2	41.6	0.13
-5	14.9	2.3	8.3	6.0	6.2	14.4	8.0	1.8	9.8	.
-10	13.2	4.2	15.2	11.0	4.6	19.8	8.9	1.8	10.6	.
-15	9.8	9.7	23.9	14.1	4.6	28.5	69.2	6.9	76.1	0.13
-20	6.9	32.9	27.4	-5.6	4.6	31.9	165.9	10.2	176.1	0.18
30JUN -0	18.2	0.5	18.1	17.6	5.2	23.2	49.4	1.8	51.1	0.10
-1	19.4	1.4	33.8	32.4	5.4	39.2	3.9	1.8	5.7	0.12
-3	19.0	6.0	46.0	40.0	6.2	52.1	3.9	1.8	5.7	0.11
-5	18.8	2.3	40.8	38.4	6.4	47.2	4.7	1.8	6.5	0.14
-10	17.2	1.4	28.5	27.1	9.5	38.1	10.5	2.5	13.0	0.10
-15	10.5	37.6	40.8	3.2	14.6	55.3	215.5	10.9	226.3	.
-20	8.5	27.4	44.2	16.9	16.4	60.6	119.6	15.5	135.1	0.23
14JUL -0	19.2	3.7	10.0	6.4	10.3	20.4	3.3	2.5	5.8	0.17
-1	19.1	0.9	10.0	9.1	11.0	21.1	0.8	2.2	2.9	0.17
-3	18.9	2.7	11.8	9.0	11.5	23.3	2.4	2.6	5.0	0.25
-5	18.6	2.7	22.1	19.4	11.7	33.8	2.4	2.5	4.9	0.17
-10	18.2	3.7	15.2	11.6	7.6	22.8	4.1	2.5	6.6	0.18
-15	11.5	15.5	29.0	13.5	6.6	35.6	66.0	13.2	79.1	0.24
28JUL -0	20.5	0.9	13.5	12.6	10.3	23.8	2.4	1.8	4.3	0.14
-1	20.5	1.8	8.3	6.5	8.4	16.8	88.8	2.5	91.3	0.20
-3	20.0	0.9	16.9	16.0	12.4	29.3	4.1	2.9	7.0	0.20
-5	19.8	1.8	13.5	11.7	14.4	27.9	2.4	2.2	4.6	0.15
-10	17.9	1.8	18.7	16.8	5.7	24.4	8.4	2.5	10.9	0.09
-15	13.2	6.4	20.4	14.0	5.2	25.6	29.5	18.9	48.5	0.09
17AUG -0	18.9	2.0	15.3	13.3	13.3	28.5	4.2	3.7	7.9	0.13
-1	18.9	1.1	39.5	38.5	13.6	53.2	4.2	2.6	6.8	0.14
-3	18.6	1.1	27.4	26.3	11.4	38.8	3.3	2.7	6.0	.
-5	18.5	10.8	22.2	11.4	11.2	33.4	58.1	5.2	63.4	0.15
-10	18.5	28.5	41.3	12.8	10.5	51.8	123.9	5.3	129.2	0.17
-15	16.2	10.8	22.2	11.4	6.4	28.6	56.5	48.6	105.1	0.21
-18	12.7	26.7	39.5	12.8	9.2	48.7	128.1	3.7	131.8	0.76

TABLE 12. MID LAKE 1988 DATA (continued).

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
09SEP -0	16.5	5.5	15.6	10.1	11.4	26.9	8.4	2.6	11.0	0.23
-1	16.5	3.7	15.6	11.8	11.7	27.3	6.7	2.6	9.3	.
-3	16.5	4.6	15.6	11.0	11.1	26.6	6.7	2.6	9.3	0.15
-5	16.5	3.7	15.6	11.8	10.2	25.7	8.4	2.6	11.0	0.24
-10	16.5	4.6	15.6	11.0	9.2	24.8	10.9	2.7	13.6	0.28
-15	16.2	8.1	19.1	10.9	7.2	26.2	38.7	2.6	41.4	0.22
-18	13.5	123.2	170.7	47.5	74.0	244.7	587.7	2.6	590.3	0.32
01OCT -0	14.0	8.0	17.2	9.3	10.1	27.4	30.7	6.1	36.7	0.19
-1	13.2	8.0	17.2	9.3	10.7	27.9	24.8	6.0	30.8	0.19
-3	12.8	8.0	22.5	14.5	15.0	37.5	.	6.1	.	0.21
-5	12.6	8.8	19.0	10.1	10.4	29.4	31.5	6.3	37.9	0.21
-10	12.4	7.1	20.8	13.7	8.7	29.5	34.0	6.3	40.4	0.22
-15	12.2	6.2	20.8	14.5	7.9	28.6	30.7	6.4	37.1	0.21
22OCT -0	10.8	9.5	29.6	20.0	9.5	39.1	22.0	4.5	26.4	0.16
-1	10.8	12.3	19.0	6.7	11.6	30.6	20.2	4.4	24.7	0.22
-3	10.8	13.2	19.0	5.8	10.5	29.5	18.5	4.4	22.9	0.20
-5	10.8	6.4	11.9	5.6	8.5	20.4	22.7	5.9	28.6	0.20
-10	10.8	6.4	11.9	5.6	11.7	23.7	20.2	6.0	26.1	0.21
-15	10.8	7.3	11.9	4.7	7.8	19.7	20.2	6.1	26.3	0.19
04NOV -0	8.2	6.9	15.6	8.7	10.7	26.2	15.3	5.5	20.7	0.21
-1	8.2	5.9	19.1	13.2	12.9	32.0	16.2	8.8	25.0	0.19
-3	8.2	5.9	20.8	14.9	8.6	29.5	15.3	3.5	18.8	0.20
-5	8.2	4.1	20.8	16.8	10.8	31.7	15.3	3.2	18.5	0.20
-10	8.2	5.0	13.8	8.8	8.3	22.1	16.2	3.7	19.8	0.20
-15	8.2	5.9	12.0	6.1	9.0	21.0	15.3	2.8	18.1	0.20

TABLE 12. MID LAKE 1988 DATA (continued).

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
20MAY -0	46.3	416.3	.	722.0	.	1.7	373.6	0.0	0.0	0.0
-1	52.2	852.2	.	504.4	.	1.3	.	.	.	0.0
-3	46.5	.	.	920.1	.	1.9	1261.3	0.0	0.0	0.0
-5	49.3	.	.	640.7	.	1.7	1891.5	0.0	0.0	0.0
-10	48.1	198.1	.	693.4	.	2.9	950.9	0.0	0.0	0.0
-15	42.9	142.9	.	657.7	.	1.8	.	.	.	.
02JUN -0	15.9	165.9	1.8	434.2	2.04	1.2	.	.	.	0.0
-1	17.7	177.7	.	230.7	.	.	.	.	.	0.0
-3	20.4	140.4	1.8	296.0	2.09	1.2	554.8	0.0	0.0	0.0
-5	22.8	212.8	1.9	380.2	0.99	1.3	2511.1	0.0	0.0	0.0
-10	14.8	164.8	.	181.4	0.04	0.5	138.1	35.2	19.2	0.0
-15	28.5	208.5	.	414.9	0.01	.	.	.	.	0.0
16JUN -0	33.6	163.6	1.9	506.5	1.56	0.3	1855.6	388.0	117.7	0.0
-1	33.5	163.5	.	479.3	2.48	1.6	.	.	.	0.0
-3	35.4	165.4	1.9	411.5	3.27	1.4	1790.9	578.2	0.0	0.0
-5	44.7	.	1.9	450.5	3.44	3.1	1923.6	0.0	0.0	0.0
-10	36.0	.	.	373.5	0.46	2.1	2319.6	0.0	0.0	0.0
-15	11.8	141.8	.	521.3	0.04	0.8	.	.	.	0.0
-20	18.3	198.3	.	432.5	.	0.1	.	.	.	.
30JUN -0	66.0	166.0	1.9	529.7	3.65	2.9	1874.5	1204.5	0.0	42.1
-1	79.9	199.9	.	575.7	10.99	3.0	.	.	.	0.0
-3	96.0	206.0	1.9	792.9	12.75	2.6	798.7	0.0	0.0	90.5
-5	83.2	223.2	1.8	723.7	8.63	3.0	524.4	230.2	69.6	24.7
-10	65.0	165.0	2.0	511.9	0.74	2.6	763.4	12.8	12.8	0.0
-15	38.5	.	.	390.6	.	1.2	.	.	.	0.0
-20	111.0	341.0	.	905.9	.	2.0	.	.	.	.
14JUL -0	160.5	330.5	2.2	1436.1	3.47	1.4	927.9	724.2	81.8	5.7
-1	155.8	325.8	.	1409.7	10.76	11.1	.	.	.	23.4
-3	170.5	420.5	2.5	1505.7	14.25	7.7	1398.3	803.0	0.0	66.4
-5	171.1	341.1	2.2	1354.9	9.12	10.3	2228.9	1284.8	0.0	30.6
-10	70.7	250.7	.	733.4	0.36	12.8	1876.3	1846.9	0.0	0.0
-15	21.3	261.3	.	475.8	0.50	5.1	.	.	.	0.0
28JUL -0	106.9	246.9	2.3	929.0	9.23	9.8	2703.8	2584.9	1534.0	180.3
-1	85.4	285.4	.	854.8	13.37	5.7	.	.	.	595.0
-3	129.0	329.0	2.1	1255.3	8.01	8.2	3081.3	2625.8	0.0	120.4
-5	161.8	311.8	2.3	1461.8	4.62	14.4	2969.6	1930.8	0.0	120.6
-10	29.1	119.1	2.2	536.9	0.10	2.1	63.9	54.1	0.0	875.4
-15	23.0	113.0	.	461.0	0.16	1.0	.	.	.	.
17AUG -0	155.3	285.3	4.6	1366.1	16.17	26.0	6249.6	5861.8	0.0	31.1
-1	96.2	236.2	.	964.9	13.15	7.0	.	.	.	17.2
-3	117.1	.	5.8	1138.0	12.33	5.0	889.2	80.3	0.0	20.4
-5	96.4	246.4	6.0	971.3	8.15	7.3	1521.3	563.8	563.8	10.4
-10	89.9	259.9	.	947.7	0.54	5.0	1464.0	883.3	0.0	0.0
-15	31.7	241.7	.	432.1	0.03	3.1	.	.	.	0.0
-18	27.1	787.1	.	525.7	.	0.6	.	.	.	.

TABLE 12. MID LAKE 1988 DATA (continued).

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
09SEP -0	74.3	304.3	5.7	838.4	9.81	6.3	1857.9	775.4	216.2	3.8
-1	123.7	.	.	951.5	11.77	4.9	.	.	.	3.8
-3	69.6	219.6	5.1	790.6	12.31	6.2	1244.6	508.4	508.4	6.2
-5	59.1	299.1	3.8	721.7	5.75	4.9	4885.6	1885.3	287.4	5.5
-10	55.7	335.7	.	767.8	0.51	3.4	997.2	420.6	211.3	0.0
-15	13.2	233.2	.	551.8	0.15	1.7	.	.	.	0.0
-18	622.6	942.6	.	5018.4	.	.	.	.	.	.
01OCT -0	133.5	323.5	3.0	1081.8	4.86	7.2	3553.7	2983.0	2983.0	13.6
-1	96.6	286.6	.	785.8	7.72	6.1	.	.	.	10.5
-3	117.1	327.1	2.1	943.0	10.95	7.9	2687.8	1989.4	1989.4	0.0
-5	76.4	286.4	4.1	818.3	2.69	6.3	3202.5	1601.1	1601.1	16.9
-10	53.5	273.5	.	711.5	0.34	2.9	364.5	169.9	169.9	0.0
-15	45.8	255.8	.	590.2	0.20	2.0	.	.	.	0.0
22OCT -0	49.0	209.0	4.0	856.0	9.83	8.1	13184.9	0.0	0.0	27.3
-1	45.0	265.0	.	759.2	10.35	7.3	.	.	.	13.6
-3	56.2	256.2	3.3	761.9	6.83	8.8	14317.3	1119.8	1119.8	8.0
-5	50.9	250.9	4.1	1109.1	3.11	5.5	2113.5	316.6	316.6	6.9
-10	18.5	228.5	.	549.7	0.32	4.7	4961.4	1869.0	1869.0	4.7
-15	28.5	218.5	.	654.3	0.04	5.6	.	.	.	3.9
04NOV -0	60.6	270.6	2.6	756.9	.	13.3	2300.6	216.2	216.2	.
-1	66.6	256.6	.	1023.9	.	6.7	.	.	.	.
-3	77.9	277.9	3.8	858.9	.	6.3	6972.3	795.5	795.5	.
-5	75.4	275.4	2.2	704.0	.	8.0	4182.8	641.0	641.0	.
-10	67.3	267.3	.	807.5	.	10.6	6999.1	1730.0	1730.0	.
-15	52.8	252.8	.	721.8	.	5.3	.	.	.	.

TABLE 13. MID LAKE 1988 DATA INTEGRATED 0-10 METERS.

DATE	TEMP AVG	SRP mg/m^2	TDP mg/m^2	DOP mg/m^2	PP mg/m^2	TOT-P mg/m^2	NH4-N mg/m^2	NO3-N mg/m^2	DIN mg/m^2	TDN g/m^2
20MAY88	8.21	62.92	134.84	65.75	71.27	211.02	98.87	66.31	285.17	4.86
02JUN88	11.95	39.96	98.46	58.50	39.95	138.42	126.23	22.05	148.27	1.60
16JUN88	15.05	24.63	96.74	72.12	50.32	147.07	154.40	18.43	172.82	1.30
30JUN88	18.43	26.02	365.60	339.58	69.22	434.82	81.26	19.47	100.73	1.19
14JUL88	18.67	27.39	159.09	131.71	104.64	263.73	26.54	24.52	51.06	1.89
28JUL88	19.48	16.00	147.00	131.00	107.40	254.39	172.18	24.26	196.44	1.52
17AUG88	18.61	113.71	302.60	188.89	115.55	418.15	528.21	42.55	570.75	1.52
09SEP88	16.50	42.05	155.50	113.46	104.07	259.57	84.31	26.22	110.53	2.26
01OCT88	12.79	80.57	197.82	117.25	109.22	307.04	304.26	62.36	366.74	2.09
22OCT88	10.80	87.62	152.89	65.26	102.22	255.11	208.28	53.31	261.59	2.04
04NOV88	8.20	50.74	185.48	134.74	100.52	286.00	156.22	43.35	199.57	1.99

DATE	PART-N mg/m^2	TOT-N mg/m^2	DOC g/m^2	PART-C g/m^2	PPR mgC/m^2	CHL a mg/m^2	PHYTBIO g/m^2	B.G.BIO g/m^2	FIXING B.G.BIO g/m^2	umol C2H4/ m^2*h
20MAY88	487.25	5360.60	.	6.93	.	19.81	12.71	0.00	0.00	0.00
02JUN88	192.10	1787.10	18.65	2.94	11.84	10.57	11.35	0.09	0.05	0.00
16JUN88	384.30	1650.25	19.28	4.31	24.20	21.46	19.79	2.03	0.18	0.00
30JUN88	798.55	1988.55	18.47	6.53	75.88	27.76	8.55	2.64	0.28	288.40
14JUL88	1430.55	3315.55	20.54	12.42	79.21	100.58	16.22	11.44	0.08	278.03
28JUL88	1078.60	2598.60	22.04	10.72	57.11	85.48	22.31	17.33	2.30	3833.85
17AUG88	1018.30	2491.70	57.34	10.18	82.33	71.10	20.58	13.17	1.97	118.68
09SEP88	708.00	2891.55	44.26	7.87	68.55	48.72	25.49	10.08	3.13	39.36
01OCT88	847.00	2932.00	34.19	8.25	46.17	57.71	24.17	15.48	15.48	81.74
22OCT88	428.80	2463.80	39.00	8.35	45.76	63.58	75.37	8.58	8.58	85.65
04NOV88	718.15	2708.15	26.81	8.11	.	83.93	53.02	8.88	8.88	.

DATE	% B.G.	FIXING % B.G.	DIN:SRP	TN:TP	PN:PP	NO3:SRP
20MAY88	0.00	0.00	4.53	25.40	6.84	1.05
02JUN88	0.78	0.42	3.71	12.91	4.81	0.55
16JUN88	10.24	0.89	7.02	11.22	7.64	0.75
30JUN88	30.92	3.22	3.87	4.57	11.54	0.75
14JUL88	70.57	0.50	1.86	12.57	13.67	0.90
28JUL88	77.69	10.31	12.28	10.22	10.04	1.52
17AUG88	64.01	9.59	5.02	5.96	8.81	0.37
09SEP88	39.56	12.28	2.63	11.14	6.80	0.62
01OCT88	64.03	64.03	4.55	9.55	7.76	0.77
22OCT88	11.38	11.38	2.99	9.66	4.19	0.61
04NOV88	16.75	16.75	3.93	9.47	7.14	0.85

TABLE 14. DAM STATION 1988 DATA.

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
20MAY -0	8.3	4.4	10.4	6.0	6.3	16.7	0.4	2.2	2.5	0.13
-1	8.1	6.1	15.6	9.4	7.0	22.6	1.1	2.2	3.3	0.13
-3	7.8	4.4	12.1	7.8	8.1	20.2	2.7	2.5	5.2	0.22
-5	7.2	6.1	12.1	6.0	8.2	20.3	2.7	.	.	.
-10	6.9	4.4	12.1	7.8	8.8	20.9	19.1	2.5	21.6	0.18
-15	6.0	7.9	13.8	6.0	8.3	22.2	30.1	6.9	37.0	0.15
02JUN -0	12.8	2.6	8.3	5.7	4.4	12.7	7.4	1.8	9.2	.
-1	12.8	2.6	6.6	4.0	4.0	10.5	5.8	1.8	7.6	0.19
-3	12.8	4.4	6.6	2.2	5.2	11.8	7.4	1.8	9.2	0.14
-5	12.8	4.4	8.3	3.9	4.2	12.5	6.6	1.8	8.4	0.19
-10	12.2	2.6	17.0	14.4	2.8	19.8	12.1	2.2	14.3	0.21
-15	6.8	9.7	17.0	7.3	5.4	22.3	24.6	7.2	31.8	0.19
-20	6.0	13.2	13.5	0.3	5.8	19.3	35.5	10.1	45.6	0.17
16JUN -0	17.0	1.4	11.1	9.7	4.5	15.5	12.2	1.8	13.9	0.11
-1	16.8	2.3	18.1	15.7	5.9	24.0	.	2.2	.	0.12
-3	16.0	4.2	21.5	17.4	5.3	26.9	.	2.1	.	0.14
-5	15.9	4.2	32.0	27.8	10.5	42.5	4.7	3.5	8.3	0.16
-10	13.2	2.3	32.0	29.7	4.9	36.9	5.6	2.2	7.7	0.12
-15	9.6	13.5	32.0	18.6	4.0	36.0	20.4	8.1	28.5	0.13
-20	7.9	31.1	26.8	0.0	4.8	31.6	74.2	12.3	86.5	0.20
30JUN -0	19.9	9.7	26.8	17.0	7.1	33.9	6.4	2.1	8.5	0.10
-1	19.8	4.2	14.6	10.4	7.1	21.7	71.7	2.2	73.9	0.17
-3	19.2	1.4	21.5	20.1	7.1	28.6	3.9	2.5	6.4	0.11
-5	19.1	3.3	32.0	28.8	6.0	38.0	36.1	2.1	38.3	0.12
-10	17.0	9.7	39.0	29.3	5.7	44.7	27.1	2.2	29.2	0.11
-15	10.8	10.7	39.0	28.3	6.5	45.5	35.3	8.8	44.1	0.13
-20	9.0	17.2	46.0	28.8	8.3	54.3	54.3	13.4	67.7	0.17
14JUL -0	.	.	.	.	.	.	.	.	.	.
-1	.	.	.	.	.	.	.	.	.	.
-3	.	.	.	.	.	.	.	.	.	.
-5	.	.	.	.	.	.	.	.	.	.
-10	.	.	.	.	.	.	.	.	.	.
-15	.	.	.	.	.	.	.	.	.	.
28JUL -0	19.2	1.8	15.2	13.4	11.5	26.8	2.4	2.1	4.6	0.13
-1	19.2	2.7	15.2	12.5	10.0	25.2	2.4	1.8	4.2	0.12
-3	19.1	3.7	10.0	6.4	12.7	22.8	6.7	1.8	8.5	0.18
-5	19.1	1.8	8.3	6.5	15.5	23.8	9.2	1.8	11.0	0.15
-10	17.9	1.8	8.3	6.5	6.7	15.1	6.7	2.5	9.2	0.15
-15	13.9	4.6	10.0	5.5	6.9	16.9	18.5	13.0	31.6	0.15
-20	10.2	9.1	16.9	7.8	15.1	32.1	53.3	24.6	77.9	0.19
17AUG -0	19.0	2.0	8.3	6.4	12.3	20.6	2.5	2.6	5.1	0.20
-1	19.0	2.0	10.0	8.1	10.4	20.4	2.5	3.0	5.5	0.27
-3	19.0	2.0	10.0	8.1	13.8	23.8	3.3	2.6	5.9	0.18
-5	19.0	2.0	11.8	9.8	10.2	22.0	4.2	2.6	6.8	0.19
-10	18.9	2.0	11.8	9.8	8.8	20.6	3.3	2.6	5.9	0.22
-15	15.8	17.0	23.9	6.9	6.6	30.5	95.2	2.6	97.8	0.19
-19	12.8	42.7	79.5	36.8	12.3	91.7	216.7	15.6	232.3	0.68

TABLE 14. DAM STATION 1988 DATA (continued).

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
09SEP -0	16.2	7.3	15.6	8.3	11.6	27.2	20.2	3.4	23.6	0.20
-1	16.2	6.4	17.3	10.9	11.2	28.5	21.9	3.3	25.2	0.19
-3	16.2	5.5	158.3	152.8	10.9	169.2	18.5	3.4	21.9	0.17
-5	16.2	5.5	20.8	15.3	9.4	30.3	20.2	3.4	23.6	0.15
-10	16.2	6.4	24.4	18.0	9.5	33.9	20.2	3.0	23.2	0.17
-15	16.1	7.3	20.8	13.6	8.7	29.6	22.7	2.6	25.3	0.16
-18	15.5	81.6	73.7	0.0	14.3	88.0	409.7	2.6	412.4	0.27
01OCT -0	13.2	15.8	33.1	17.3	7.6	40.7	93.7	8.2	101.8	0.28
-1	13.1	15.8	27.8	12.0	7.7	35.5	96.2	7.8	104.0	0.28
-3	12.8	15.8	.	.	7.3	.	91.1	8.3	99.4	.
-5	12.6	15.8	27.8	12.0	8.1	35.9	90.3	8.1	98.4	0.36
-10	12.5	15.8	27.8	12.0	8.0	35.8	92.0	8.1	100.1	0.26
-15	12.5	15.8	24.3	8.5	7.7	32.0	96.2	8.2	104.4	0.31
22OCT -0	10.6	7.9	17.1	9.2	9.9	27.0	22.7	6.6	29.3	0.23
-1	10.6	7.9	20.5	12.6	9.9	30.4	22.7	4.9	27.6	0.22
-3	10.6	7.0	15.4	8.4	9.2	24.6	22.7	4.6	27.3	0.20
-5	10.6	7.9	18.8	10.9	9.0	27.8	21.8	6.0	27.8	0.21
-10	10.6	7.9	20.5	12.6	8.5	29.0	19.3	4.6	23.9	0.36
-15	10.6	7.9	25.6	17.7	9.9	35.4	22.7	5.8	28.4	0.21
04NOV -0	8.5	6.9	20.8	14.0	9.3	30.1	30.2	6.5	36.7	0.28
-1	8.5	5.9	22.6	16.7	9.6	32.2	28.3	5.5	33.8	0.28
-3	8.5	5.9	22.6	16.7	9.3	31.8	30.2	5.3	35.5	0.27
-5	8.5	6.9	22.6	15.7	9.1	31.7	32.1	4.7	36.7	0.22
-10	8.5	6.9	19.1	12.2	9.4	28.5	28.3	5.1	33.4	0.23
-15	8.5	5.9	17.3	11.4	8.8	26.1	28.3	4.2	32.5	0.21

TABLE 14. DAM STATION 1988 DATA (continued).

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
20MAY -0	42.1	172.1	.	469.3	.	1.8	.	.	.	.
-1	46.6	176.6	.	488.4	.	3.0	.	.	.	.
-3	63.1	283.1	.	677.6	.	2.3	.	.	.	.
-5	50.0	.	.	646.5	.	2.6	.	.	.	.
-10	65.5	245.5	.	499.9	.	1.2	.	.	.	.
-15	51.3	201.3	.	763.2	.	.	.	.	.	.
02JUN -0	28.8	.	.	563.1	3.43	2.6	149.0	42.6	0.0	0.0
-1	8.7	198.7	.	411.8	3.77	2.5	.	.	.	0.0
-3	51.7	191.7	.	579.2	1.68	2.5	144.4	0.0	0.0	0.0
-5	99.4	289.4	.	654.1	0.66	1.9	.	.	.	0.0
-10	32.8	242.8	.	614.4	0.06	0.8	119.9	0.0	0.0	0.0
-15	36.2	226.2	.	481.8	.	1.1	.	.	.	0.0
-20	44.2	214.2	.	535.4	.	1.0	.	.	.	.
16JUN -0	45.5	155.5	.	415.1	.	2.2	355.2	43.5	43.5	.
-1	39.9	159.9	.	630.5	.	2.0	.	.	.	.
-3	41.4	181.4	.	566.3	.	1.6	1168.7	449.8	56.4	.
-5	42.0	202.0	.	454.4	.	1.4	973.8	344.9	344.9	.
-10	22.0	142.0	.	383.5	.	0.8	2391.2	0.0	0.0	.
-15	16.4	146.4	.	266.0	.	0.4	.	.	.	.
-20	16.9	216.9	.	266.6	.	0.6	.	.	.	.
30JUN -0	79.0	179.0	.	677.4	7.37	0.9	1747.1	8.7	8.7	0.0
-1	89.4	259.4	.	662.6	11.21	2.4	.	.	.	3.1
-3	87.8	197.8	.	766.9	11.19	3.2	1219.4	790.2	388.7	14.7
-5	78.9	198.9	.	708.3	7.85	3.6	381.2	30.7	30.7	0.0
-10	69.3	179.3	.	525.4	0.90	1.5	1333.5	5.1	5.1	0.0
-15	53.1	183.1	.	441.0	.	1.3	.	.	.	0.0
-20	66.8	236.8	.	585.6	.	2.2	.	.	.	.
14JUL -0	.	.	.	.	.	.	.	.	.	.
-1	.	.	.	.	.	.	.	.	.	.
-3	.	.	.	.	.	.	.	.	.	.
-5	.	.	.	.	.	.	.	.	.	.
-10	.	.	.	.	.	.	.	.	.	.
-15	.	.	.	.	.	.	.	.	.	.
28JUL -0	201.6	331.6	.	1208.2	.	8.0	2907.2	2678.8	69.1	.
-1	169.4	289.4	.	1323.9	.	12.8	.	.	.	.
-3	185.5	365.5	.	1453.9	.	9.3	2991.8	2971.1	0.0	.
-5	181.8	331.8	.	1476.5	.	12.9	3008.6	2955.0	0.0	.
-10	81.3	231.3	.	735.2	.	3.5	205.3	0.0	0.0	.
-15	45.6	195.6	.	417.0	.	2.5	.	.	.	.
-20	108.1	298.1	.	1084.3	.	3.2	.	.	.	.
17AUG -0	83.7	283.7	.	939.4	8.43	2.5	2051.4	1124.7	447.9	4.4
-1	98.7	368.7	.	1023.5	13.47	3.7	.	.	.	20.2
-3	125.7	305.7	.	1131.6	12.93	4.6	815.9	200.8	0.0	13.0
-5	68.3	258.3	.	872.7	6.75	1.9	570.2	54.1	54.1	0.0
-10	79.5	299.5	.	1386.6	0.87	4.5	1023.5	803.0	0.0	0.0
-15	.	.	.	609.8	.	0.8	.	.	.	0.0
-19	51.0	731.0	.	729.4	.	1.7	.	.	.	.

TABLE 14. DAM STATION 1988 DATA (continued).

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
09SEP -0	21.4	221.4	.	672.4	.	4.7	2732.0	123.6	123.6	.
-1	33.6	223.6	.	828.0	.	4.2	.	.	.	.
-3	44.1	214.1	.	868.2	.	4.0	2550.9	1204.5	0.0	.
-5	55.2	205.2	.	813.5	.	4.3	1296.7	849.5	0.0	.
-10	38.5	208.5	.	630.7	.	4.5	1650.9	216.2	216.2	.
-15	55.4	215.4	.	677.9	.	4.5	.	.	.	.
-18	41.4	311.4	.	602.4	.	1.1	.	.	.	.
01OCT -0	45.6	325.6	.	734.1	.	3.1	818.3	0.0	0.0	.
-1	46.2	326.2	.	492.2	.	3.0	.	.	.	.
-3	41.2	.	.	656.5	.	3.1	1479.2	293.5	293.5	.
-5	24.2	384.2	.	569.4	.	2.4	542.7	502.0	502.0	.
-10	36.6	296.6	.	598.6	.	2.1	1112.9	1081.0	278.0	.
-15	16.7	326.7	.	599.5	.	2.6	.	.	.	.
22OCT -0	61.7	291.7	.	755.0	15.50	7.0	3178.1	0.0	0.0	12.7
-1	44.4	264.4	.	715.3	6.93	5.4	.	.	.	7.9
-3	22.8	222.8	.	520.2	5.33	5.2	1658.4	285.8	285.8	11.0
-5	17.5	227.5	.	520.3	1.29	6.5	1936.9	278.0	278.0	29.9
-10	21.1	381.1	.	660.9	0.09	6.1	2793.4	0.0	0.0	19.8
-15	13.2	223.2	.	572.5	0.23	6.4	.	.	.	12.9
04NOV -0	56.3	336.3	.	646.6	.	5.6	6555.8	656.5	0.0	.
-1	63.2	343.2	.	762.7	.	5.9	.	.	.	.
-3	52.4	322.4	.	709.0	.	6.8	4283.8	139.0	139.0	.
-5	49.9	269.9	.	620.9	.	5.8	11757.5	38.6	38.6	.
-10	64.3	294.3	.	771.2	.	5.6	2368.8	0.0	0.0	.
-15	55.3	265.3	.	861.6	.	6.4	.	.	.	.

TABLE 15. DAM STATION 1988 DATA INTEGRATED 0-10 METERS.

DATE	TEMP AVG	SRP mg/m^2	TDP mg/m^2	DOP mg/m^2	PP mg/m^2	TOT-P mg/m^2	NH4-N mg/m^2	NO3-N mg/m^2	DIN mg/m^2	TDN g/m^2
20MAY88	7.45	52.30	125.40	73.10	80.39	205.79	64.44	24.53	105.39	1.88
02JUN88	12.64	35.54	98.46	62.93	40.32	138.78	80.48	18.98	99.46	1.85
16JUN88	15.40	32.97	267.81	234.84	70.65	338.45	.	26.12	.	1.38
30JUN88	18.71	49.67	287.88	238.22	63.72	351.60	312.65	22.06	334.71	1.22
14JUL88	.	.	.	.	.	.	.	.	.	.
28JUL88	18.80	23.31	100.44	77.14	117.17	217.61	67.21	20.01	87.22	1.51
17AUG88	18.97	19.50	109.97	90.47	107.00	216.97	34.54	26.85	61.39	2.08
09SEP88	16.20	59.31	484.19	424.88	101.22	585.40	201.08	32.87	233.94	1.68
010CT88	12.73	157.90	280.64	122.74	77.98	359.83	919.28	80.97	1000.25	3.11
220CT88	10.60	77.38	187.33	109.95	90.70	278.03	215.34	52.12	267.46	2.48
04NOV88	8.50	65.21	216.02	150.81	92.98	309.00	300.97	51.15	352.11	2.45

DATE	PART-N mg/m^2	TOT-N mg/m^2	DOC g/m^2	PART-C mg/m^2	PPR mgC/m^2	CHL a mg/m^2	PHYTBIO g/m^2	B.G.BIO g/m^2	FIXING B.G.BIO g/m^2	umol C2H4/ m^2*h
20MAY88	555.90	2484.15	.	5834.95	.	22.07	.	.	.	.
02JUN88	560.75	2400.70	.	5883.00	13.17	18.85	1.37	0.06	0.00	0.00
16JUN88	367.40	1742.40	.	4835.05	.	14.06	12.84	2.40	1.41	.
30JUN88	798.60	2018.60	.	6658.95	72.62	26.76	10.34	2.11	1.11	33.99
14JUL88	.	.	.	.	.	.	.	.	.	.
28JUL88	1565.45	3070.45	.	12503.50	.	95.63	22.88	21.79	0.10	.
17AUG88	879.10	2959.10	.	10789.10	76.06	33.80	9.67	4.39	0.86	58.38
09SEP88	438.75	2113.75	.	7738.60	.	43.01	19.14	6.71	0.73	.
010CT88	350.70	3448.70	.	5907.75	.	26.13	9.61	5.19	3.19	.
220CT88	257.05	2737.05	.	5964.15	33.56	60.16	22.68	1.69	1.69	194.07
04NOV88	563.15	3008.15	.	6986.50	.	59.56	67.62	1.47	0.48	.

DATE	% B.G.	FIXING % B.G.	DIN:SRP	TN:TP	PN:PP	NO3:SRP
20MAY88	.	.	2.02	12.07	6.92	0.47
02JUN88	4.68	0.00	2.80	17.30	13.91	0.53
16JUN88	18.67	11.01	.	5.15	5.20	0.79
30JUN88	20.40	10.69	6.74	5.74	12.53	0.44
14JUL88	.	.	.	.	.	.
28JUL88	95.21	0.45	3.74	14.11	13.36	0.86
17AUG88	45.35	8.90	3.15	13.64	8.22	1.38
09SEP88	35.06	3.79	3.94	3.61	4.33	0.55
010CT88	54.06	33.16	6.33	9.58	4.50	0.51
220CT88	7.44	7.44	3.46	9.84	2.83	0.67
04NOV88	2.17	0.71	5.40	9.74	6.06	0.78

TABLE 16. GRAYLING ARM 1989 DATA.

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
21MAY -0	9.2	11.2	26.5	15.3	22.2	48.6	5.0	6.7	11.7	0.23
-1	9.1	9.5	28.4	18.9	22.5	50.9	5.0	6.7	11.7	0.17
-3	8.9	8.6	28.4	19.8	23.2	51.6	3.3	6.7	10.0	0.22
-5	7.7	12.9	28.4	15.5	30.6	59.0	9.9	12.3	22.2	0.18
04JUN -0	11.6	9.5	24.5	15.1	17.5	42.1	4.2	6.7	10.8	0.24
-1	10.8	7.7	24.5	16.8	17.1	41.6	1.7	21.3	23.0	0.18
-3	10.0	8.6	24.5	15.9	15.7	40.2	1.7	6.7	8.4	0.15
-5	9.4	12.0	28.4	16.3	11.9	40.3	1.7	25.8	27.5	0.10
13JUN -0	15.2	7.7	26.5	18.7	7.7	34.1	1.7	5.6	7.3	0.25
-1	14.6	7.7	22.6	14.9	7.2	29.8	3.3	48.2	51.5	0.14
-3	14.0	8.6	22.6	14.0	7.7	30.3	4.2	6.7	10.8	0.27
-5	10.1	11.2	26.5	15.3	12.7	39.1	3.3	12.3	15.7	0.16
29JUN -0	15.4	5.1	24.5	19.4	61.5	86.0	3.3	6.7	10.0	0.19
-1	15.2	5.1	24.5	19.4	14.1	38.6	2.5	6.7	9.3	0.20
-3	15.2	5.1	24.5	19.4	13.7	38.3	4.2	.	.	0.13
-5	15.2	6.9	22.6	15.7	11.2	33.8	4.2	35.6	39.8	0.12
19JUL -0	20.6	3.4	30.3	26.9	14.0	44.3	2.5	30.3	32.8	0.16
-1	19.2	3.4	30.3	26.9	8.5	38.8	2.5	6.7	9.2	0.14
-3	18.6	4.3	26.5	22.2	7.0	33.5	5.0	6.7	11.7	0.17
-5	18.1	6.9	24.5	17.7	6.3	30.8	6.6	22.6	29.2	0.25
03AUG -0	19.2	8.6	30.3	21.7	21.0	51.3	5.0	.	.	0.16
-1	19.2	7.7	30.3	22.6	20.7	51.0	4.2	73.5	77.6	0.15
-3	19.2	7.7	30.3	22.6	19.3	49.6	5.0	21.3	26.3	0.21
-5	19.1	7.7	30.3	22.6	21.2	51.5	5.0	17.8	22.8	0.14
23AUG -0	16.8	10.3	38.0	27.7	28.6	66.5	8.2	35.9	44.1	0.18
-1	16.8	9.5	38.0	28.5	27.4	65.4	8.2	33.4	41.6	0.33
-3	16.7	9.5	38.0	28.5	23.6	61.6	11.5	29.1	40.6	0.34
-5	16.6	11.2	39.9	28.7	18.7	58.6	15.6	36.7	52.3	0.32
07SEP -0	15.0	7.7	30.3	22.6	40.3	70.6	5.8	35.9	41.7	0.32
-1	14.8	6.9	28.4	21.5	39.5	67.9	5.8	64.5	70.3	0.33
-3	13.8	6.9	28.4	21.5	31.4	59.8	5.8	30.3	36.0	0.26
-5	13.3	6.9	32.2	25.4	29.5	61.7	8.2	28.9	37.2	0.24
20SEP -0	.	13.8	41.8	28.1	23.0	64.8	22.9	48.2	71.1	0.35
-1	.	14.6	43.7	29.1	19.6	63.4	19.6	51.2	70.8	0.30
-3	.	13.8	28.1	41.8	18.4	46.4	19.6	50.4	70.1	0.27
-5	.	16.4	41.8	25.5	20.4	62.2	23.7	53.4	77.1	0.37
08OCT -0	10.1	21.6	51.4	29.9	131.1	182.5	24.5	80.7	105.2	0.44
-1	9.0	24.1	57.2	33.1	21.4	78.6	32.7	91.3	123.9	0.34
-3	8.8	25.9	57.2	31.3	11.2	68.4	35.9	93.0	128.9	0.31
-5	8.6	27.6	61.0	33.5	14.9	75.9	32.7	93.5	126.2	0.28
10NOV -0	1.0	12.0	36.1	24.0	23.1	59.2	3.3	15.7	19.0	0.19
-1	0.9	12.9	39.9	27.0	24.6	64.5	5.8	10.0	15.8	0.11
-3	0.9	12.9	39.9	27.0	23.0	62.9	6.6	10.1	16.7	0.20
-5	0.9	12.0	39.9	27.9	22.3	62.2	5.0	10.0	15.0	0.21

TABLE 16. GRAYLING ARM 1989 DATA (continued).

DATE DEPTH	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR (ugC/l*h)	CHL a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
21MAY -0	164.3	394.1	4.0	1167.4	.	5.4	3240.3	0.0	0.0	0.0
-1	173.2	340.0	3.4	1072.0	.	5.0	3086.5	0.0	0.0	0.0
-3	150.6	369.9	2.8	927.0	.	4.4	920.2	0.0	0.0	0.0
-5	156.1	334.1	3.9	1014.0	.	5.2	903.7	0.0	0.0	0.0
04JUN -0	153.5	388.5	3.3	698.0	6.00	2.8	3452.8	0.0	0.0	1.2
-1	127.4	303.5	4.2	764.0	10.08	3.2	2626.8	0.0	0.0	3.3
-3	131.5	281.2	3.9	816.0	5.23	3.3	1045.0	0.0	0.0	4.1
-5	120.2	218.2	2.8	522.0	0.59	2.3	627.4	0.0	0.0	1.8
13JUN -0	54.0	299.4	4.0	600.0	4.71	2.8	2632.4	129.3	129.3	9.7
-1	68.7	203.9	4.9	620.0	7.33	2.9	338.4	22.3	22.3	16.5
-3	75.7	349.0	4.0	595.0	5.68	2.5	391.1	44.7	44.7	17.8
-5	71.3	227.0	3.8	625.0	2.19	2.9	431.7	0.0	0.0	0.8
29JUN -0	992.6	1182.3	3.3	5203.0	134.75	94.5	46127.8	45560.2	45560.2	2582.8
-1	268.3	468.6	2.9	1366.0	53.59	15.5	4050.1	2444.8	2444.8	510.3
-3	167.2	293.1	3.2	1137.0	16.94	8.4	8138.0	5278.0	5278.0	256.4
-5	117.3	237.4	3.9	649.0	1.61	4.5	2789.3	860.2	860.2	45.6
19JUL -0	195.6	351.3	3.6	1098.0	20.48	8.7	12060.4	11852.9	3997.7	60.2
-1	120.0	264.5	2.7	699.0	16.98	3.5	3596.6	2956.9	2171.4	69.5
-3	67.3	239.7	3.5	451.0	14.01	2.0	2763.8	1671.7	1671.7	19.3
-5	35.3	280.7	3.1	496.0	3.89	2.1	4615.3	4528.8	77.5	3.4
03AUG -0	181.6	344.7	6.4	1330.0	23.85	11.9	13561.5	12999.2	10119.0	209.7
-1	161.9	308.1	6.2	1125.0	35.27	13.9	11441.6	5430.7	5430.7	207.9
-3	218.0	431.3	6.4	1257.0	12.01	11.8	8125.4	7956.0	3452.4	144.5
-5	162.2	299.7	10.4	1219.0	1.27	15.1	6460.6	5490.1	5490.1	85.5
23AUG -0	354.1	533.9	9.1	1941.0	21.77	26.2	14182.4	13964.7	13964.7	.
-1	275.0	605.7	8.3	1617.0	67.07	19.3	12562.1	11389.0	11389.0	.
-3	265.8	603.6	7.4	1440.0	7.02	19.3	14865.2	13611.7	12040.7	.
-5	224.8	543.3	8.3	1112.0	0.24	12.8	8101.9	7215.1	7215.1	.
07SEP -0	513.4	828.9	6.9	2612.0	14.61	33.4	12900.8	12273.4	12273.4	200.9
-1	404.3	735.0	9.5	2143.0	2.56	36.2	16984.2	16473.2	16473.2	130.8
-3	406.7	664.6	10.5	2147.0	0.73	27.6	11532.7	11171.8	11171.8	45.6
-5	305.2	541.9	8.9	1672.0	0.13	22.6	16707.3	16468.0	16468.0	25.4
20SEP -0	171.7	520.9	11.4	1099.0	3.98	5.7	3968.5	3633.4	3633.4	36.8
-1	181.8	484.7	9.7	1049.0	17.24	8.0	2841.8	2505.9	2505.9	29.2
-3	170.9	436.2	10.4	881.0	1.75	4.6	6884.4	2958.5	2958.5	24.2
-5	108.3	475.6	7.3	798.0	0.05	2.8	1140.5	850.8	850.8	0.0
08OCT -0	284.0	725.9	58.8	15285.0	129.88	275.2	98800.9	98373.7	98373.7	1144.7
-1	93.0	428.9	73.4	826.0	12.85	5.8	6931.0	1365.4	1365.4	27.3
-3	72.0	380.1	27.8	550.0	1.17	2.3	226.0	0.0	0.0	14.4
-5	82.3	360.4	9.3	671.0	0.18	1.8	190.7	0.0	0.0	0.0
10NOV -0	162.4	353.3	10.4	1087.0	4.57	13.4	1818.6	0.0	0.0	0.0
-1	173.5	280.0	24.5	1217.0	17.44	12.3	2319.1	0.0	0.0	0.0
-3	165.3	361.9	9.6	1182.0	2.50	11.3	2187.5	0.0	0.0	0.0
-5	169.0	381.6	13.1	1224.0	0.30	10.7	1777.8	0.0	0.0	0.0

TABLE 17. GRAYLING ARM 1989 DATA INTEGRATED 0-5 METERS.

DATE	TEMP AVG	SRP mg/m^2	TDP mg/m^2	DOP mg/m^2	PP mg/m^2	TOT-P mg/m^2	NH4-N mg/m^2	NO3-N mg/m^2	DIN mg/m^2	TDN g/m^2
21MAY89	8.7	49.86	140.89	91.04	121.78	262.67	26.48	39.11	65.59	0.98
04JUN89	10.3	45.53	126.49	80.95	77.66	204.15	9.78	74.41	84.18	0.78
13JUN89	13.4	43.80	118.78	74.99	42.62	161.39	17.53	100.74	118.27	1.03
29JUN89	15.2	27.38	120.72	93.30	90.50	211.22	17.95	91.36	107.68	0.77
19JUL89	19.0	22.20	138.01	115.81	40.08	178.09	21.60	61.21	82.81	0.88
03AUG89	19.2	39.04	151.45	112.42	101.38	252.83	23.63	207.29	230.52	0.86
23AUG89	16.7	49.42	191.82	142.41	121.31	313.13	55.01	163.00	218.01	1.58
07SEP89	14.1	34.73	146.65	111.94	171.80	318.45	31.39	204.17	235.56	1.41
20SEP89	.	72.75	184.44	166.79	98.05	282.49	103.91	255.14	359.05	1.53
08OCT89	9.0	126.32	286.96	160.65	134.86	421.81	165.85	456.70	622.54	1.62
10NOV89	0.9	63.25	197.58	134.33	116.70	314.28	28.53	53.06	81.58	0.86

DATE	PART-N mg/m^2	TOT-N mg/m^2	DOC g/m^2	PART-C g/m^2	PPR mgC/m^2	CHL a mg/m^2	PHYTBIO g/m^2	B.G.BIO g/m^2	FIXING B.G.BIO g/m^2	umol C2H4/ m^2*h
21MAY89	799.25	1780.95	16.63	5.06	.	24.22	8.99	0.00	0.00	0.00
04JUN89	651.05	1430.10	18.41	3.65	29.17	15.06	8.38	0.00	0.00	15.55
13JUN89	352.75	1380.55	21.13	3.05	26.90	13.57	3.04	0.19	0.19	65.85
29JUN89	1350.45	2117.65	16.39	7.57	183.25	91.84	48.20	37.86	37.86	2615.16
19JUL89	447.70	1332.50	15.87	3.00	67.62	15.63	21.57	18.23	8.68	176.33
03AUG89	931.85	1796.80	35.66	6.09	90.12	65.47	46.65	36.05	25.60	791.29
23AUG89	1345.95	2926.00	40.06	7.39	125.77	93.24	63.77	58.50	55.36	.
07SEP89	1981.75	3388.05	47.66	10.49	12.74	148.83	71.70	69.66	69.66	413.25
20SEP89	808.65	2335.50	48.37	4.68	31.40	26.83	21.16	12.34	12.34	110.50
08OCT89	507.80	2126.90	204.31	10.65	86.74	152.82	60.44	51.23	51.23	642.03
10NOV89	841.05	1702.05	74.32	5.96	33.75	58.46	10.54	0.00	0.00	0.00

DATE	% B.G.	% FIX B.G.	DIN:SRP	TN:TP	PN:PP	NO3:SRP
21MAY89	0.00	0.00	1.32	6.78	6.56	0.78
04JUN89	0.00	0.00	1.85	7.01	8.38	1.63
13JUN89	6.17	6.17	2.70	8.55	8.28	2.30
29JUN89	78.55	78.55	3.93	10.03	14.92	3.34
19JUL89	84.54	40.23	3.73	7.48	11.17	2.76
03AUG89	77.27	54.87	5.91	7.11	9.19	5.31
23AUG89	91.75	86.82	4.41	9.34	11.10	3.30
07SEP89	97.15	97.15	6.78	10.64	11.54	5.88
20SEP89	58.34	58.34	4.94	8.27	8.25	3.51
08OCT89	84.77	84.77	4.93	5.04	3.77	3.62
10NOV89	0.00	0.00	1.29	5.42	7.21	0.84

TABLE 18. MID LAKE 1989 DATA.

DATE -DEPTH(m)	TEMP (deg C)	SRP (ug/l)	TDP (ug/l)	DOP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (mg/l)
08JUN -0	17.0	4.3	28.4	24.1	30.3	58.7	2.5	10.1	12.6	0.09
-1	15.0	4.3	26.5	22.2	7.2	33.7	5.0	6.7	11.7	0.11
-3	13.1	10.3	24.5	14.2	9.5	34.0	0.9	6.7	7.6	0.09
-5	10.0	4.3	26.5	22.2	11.0	37.5	0.1	6.7	6.8	0.18
-10	9.0	4.3	24.5	20.3	6.9	31.4	5.0	6.7	11.7	0.09
-15	8.0	8.6	28.4	19.8	5.8	34.2	40.0	8.9	48.9	0.12
19JUL -0	22.6	3.4	26.5	23.1	11.5	38.0	0.1	14.6	14.7	0.12
-1	19.1	3.4	26.5	23.1	10.9	37.4	2.5	6.7	9.2	0.07
-3	18.4	3.4	24.5	21.1	17.8	42.3	0.1	6.7	6.8	0.07
-5	18.1	2.5	26.5	23.9	17.1	43.6	0.1	10.0	10.1	0.16
-10	14.8	6.9	32.2	25.4	22.6	54.8	9.1	10.1	19.1	0.09
-15	11.6	17.2	41.8	24.6	34.5	76.3	54.7	21.1	75.8	0.15
08OCT -0	11.0	6.9	32.2	25.4	50.2	82.4	18.8	9.0	27.8	0.25
-1	11.0	7.7	30.3	22.6	15.2	45.5	19.6	10.0	29.7	0.16
-3	10.9	8.6	32.2	23.6	9.6	41.8	21.3	9.0	30.2	0.12
-5	10.9	7.7	32.2	24.5	9.8	42.0	22.1	10.0	32.1	0.12
-10	10.9	6.9	32.2	25.4	13.2	45.4	21.3	9.0	30.2	0.10
-15	10.9	7.7	34.1	26.4	9.0	43.1	20.5	1.0	21.5	0.11

DATE -DEPTH(m)	PART-N (ug/l)	TOT-N (ug/l)	DOC (mg/l)	PART-C (ug/l)	PPR ugC/l*h	Chl a (ug/l)	PHYTBIO (ug/l)	B.G.BIO (ug/l)	FIXING B.G.BIO (ug/l)	nmol C2H4/ l*h
08JUN -0	37.6	127.6	3.3	488.5	4.45	1.3	296.3	0.0	0.0	3.1
-1	33.7	140.7	3.1	491.1	3.49	1.1	378.4	170.7	170.7	6.3
-3	58.3	146.3	3.4	487.6	2.94	1.6	412.5	0.0	0.0	3.3
-5	65.3	242.3	2.7	536.7	3.45	3.1	308.5	0.0	0.0	2.0
-10	52.1	138.1	5.8	499.8	0.30	2.7	777.7	0.0	0.0	0.0
-15	151.1	272.1	2.1	1422.9	0.14	1.8	2684.7	0.0	0.0	0.0
19JUL -0	552.0	673.0	3.3	3334.7	44.70	28.1	13423.1	13347.8	5056.2	257.5
-1	86.3	155.3	2.3	1056.6	13.41	4.3	3035.6	2657.2	38.8	21.1
-3	131.9	204.9	2.3	1209.5	20.30	7.8	5252.5	4763.0	835.4	23.1
-5	114.1	272.1	2.9	1004.3	12.63	9.5	2211.9	1809.1	499.9	10.5
-10	17.5	109.5	3.2	338.4	0.40	1.1	632.1	372.4	372.4	5.5
-15	13.9	166.9	2.1	333.1	0.21	0.3	336.6	186.2	186.2	0.0
08OCT -0	771.3	1019.3	90.3	3792.3	13.70	75.7	23213.3	22064.3	22064.3	112.5
-1	68.2	229.2	116.1	569.6	7.42	5.4	1864.5	1683.5	1683.5	29.3
-3	64.4	179.4	58.5	470.7	6.83	3.2	709.2	574.1	574.1	4.8
-5	91.1	214.1	9.9	607.9	4.22	8.1	2107.3	1675.8	1675.8	21.8
-10	102.5	206.5	10.8	581.0	0.46	6.8	7232.0	6790.3	2024.8	0.0
-15	85.8	195.8	19.9	601.9	0.21	.	1231.9	1039.6	1039.6	9.7

TABLE 19. MID LAKE 1989 DATA INTEGRATED 0-10 METERS.

DATE	TEMP AVG	SRP mg/m^2	TDP mg/m^2	DOP mg/m^2	PP mg/m^2	TOT-P mg/m^2	NH4-N mg/m^2	NO3-N mg/m^2	DIN mg/m^2	TDN g/m^2
08JUN89	11.61	54.80	256.82	202.02	100.70	357.52	23.22	68.68	91.91	1.22
19JUL89	17.80	39.64	275.06	235.42	174.05	449.11	26.90	91.02	117.92	1.09
08OCT89	10.92	76.36	319.22	242.86	134.40	453.62	211.91	94.90	306.81	1.29

DATE	PART-N mg/m^2	TOT-N mg/m^2	DOC g/m^2	PART-C g/m^2	PPR mgC/m^2	CHL a mg/m^2	PHYTBIO g/m^2	B.G.BIO g/m^2	FIXING B.G.BIO g/m^2	umol C2H4/ m^2*h
08JUN89	544.75	1760.75	37.25	5.08	26.17	22.99	4.56	0.26	0.26	24.65
19JUL89	1112.35	2205.35	27.78	10.03	128.27	72.05	31.09	27.45	6.94	256.92
08OCT89	1191.85	2477.85	398.09	7.27	47.56	97.85	41.28	37.55	25.63	185.82

DATE	% B.G.	FIXING % B.G.	DIN:SRP	TN:TP	PN:PP	NO3:SRP
08JUN89	5.61	5.61	1.68	4.92	5.41	1.25
19JUL89	88.28	22.31	2.97	4.91	6.39	2.30
08OCT89	90.96	62.10	4.02	5.46	8.87	1.24

APPENDIX B

INFLOW AND OUTFLOW DATA

TABLE 20. HEBGEN LAKE 1988 AND 1989 INFLOW AND OUTFLOW DATA.

DATE LOCATION	TEMP (deg C)	COND (umho/cm)	SRP (ug/l)	TDP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (ug/l)	PART-N (ug/l)	TOT-N (ug/l)	PART-C (ug/l)	DOC (mg/l)
13MAY88														
OUTFLOW	NA	NA	6.2	13.8	14.6	28.4	10.9	NA	NA	140	21.5	161.5	718.9	
GRAYCREEK	NA	NA	8.0	8.7	31.8	40.5	5.6	NA	NA	180	42.8	222.8	1283.1	
DUCKCREEK	NA	NA	14.9	17.3	11.3	28.6	6.4	NA	NA	300	4.6	304.6	825.1	
COUGARCR	NA	NA	7.1	6.9	24.5	31.5	7.9	NA	NA	170	50.8	220.8	1288.8	
MADISONR	NA	NA	4.5	8.7	26.9	35.5	6.4	NA	NA	330	44.0	374.0	1590.6	
SO.FK.MAD	NA	NA	8.0	10.4	18.0	28.4	4.9	NA	NA	160	34.6	194.6	1099.4	
20MAY88														
OUTFLOW	4	304.0	5.4	12.1	8.6	20.7	13.8	11.0	24.9	150	4.0	154.0	662.9	
GRAYCREEK	8	74.6	7.1	8.7	13.0	21.7	4.1	34.3	38.4	170	27.6	197.6	777.0	
DUCKCREEK	11	58.7	14.1	13.8	12.8	26.7	4.1	15.0	19.1	180	31.3	211.3	914.3	
COUGARCR	9	42.4	3.6	6.9	16.0	22.9	8.6	15.2	23.8	100	49.1	149.1	1677.8	
MADISONR	14.5	269.0	2.8	6.9	10.4	17.4	4.9	26.0	30.8	170	39.5	209.5	878.9	
SO.FK.MAD	12	92.0	6.2	6.9	7.5	14.5	4.1	21.6	25.7	390	27.1	417.1	507.8	
02JUN88														
OUTFLOW	10	235.0	6.1	6.6	4.4	11.0	19.1	6.5	25.6	260	46.6	306.6	427.6	1.53
GRAYCREEK	8	72.6	7.9	20.4	4.4	24.8	5.0		5.0	160	43.6	203.6	582.7	2.68
DUCKCREEK	11	53.5	16.7	6.6	7.3	13.9	4.3	9.4	13.6	220	53.0	273.0	665.1	2.92
COUGARCR	9	40.2	4.4	42.9	7.9	50.9	4.3	19.5	23.7	60	42.8	102.8	846.5	1.57
MADISONR	16	271.0	4.4	10.0	3.7	13.7	3.5	12.0	15.4	100	49.2	149.2	806.6	2.43
SO.FK.MAD	12	96.3	7.9	6.6	4.2	10.8	3.5	8.3	11.8	150	26.0	176.0	457.4	1.03
16JUN88														
OUTFLOW	12	253.0	8.8	19.8	3.4	23.2	17.1	10.1	27.3	110	31.7	141.7	286.2	1.64
GRAYCREEK	7.9	57.2	5.1	18.1	4.9	23.0	3.9	9.5	13.4	60	27.2	87.2	646.7	2.79
DUCKCREEK	18	77.8	23.7	18.1	8.1	26.2	5.6	9.5	15.1	150	39.2	189.2	582.2	
COUGARCR	16	89.7	4.2	14.6	5.1	19.6	26.2	5.1	31.3	60	27.8	87.8	492.9	
MADISONR	21.8	360.0	10.7	25.0	3.4	28.4	66.7	7.0	73.8	110	37.0	147.0	571.0	1.78

TABLE 20. HEBGEN LAKE 1988 AND 1989 INFLOW AND OUTFLOW DATA (continued).

DATE LOCATION	TEMP (deg C)	COND (umho/cm)	SRP (ug/l)	TDP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (ug/l)	PART-N (ug/l)	TOT-N (ug/l)	PART-C (ug/l)	DOC (mg/l)
30JUN88														
OUTFLOW	17	235.0	12.5	40.8	6.1	46.8	38.6	17.7	56.3	160	61.6	221.6	474.4	1.29
GRAYCREEK	14	108.0	6.0	25.0	2.5	27.6	14.7	3.5	18.2	60	34.9	94.9	388.2	1.05
DUCKCREEK	21	90.1	39.4	39.0	18.8	57.8	10.5	19.0	29.6	150	157.7	307.7	1938.0	
COUGARCR	19.5	62.0	10.7	26.8	3.8	30.5	8.0	5.8	13.8	50	13.7	63.7	514.4	
MADISONR	23	342.0	8.8	16.3	3.8	20.1	4.7	7.0	11.8	90	30.2	120.2	555.9	1.69
14JUL88														
OUTFLOW	15.5	258.0	5.5	16.9	7.4	24.4	17.7	10.4	28.0	280	61.7	341.7	678.4	1.98
GRAYCREEK	18	122.0	4.6	10.0	3.5	13.5	4.1	4.0	8.1	160	18.7	178.7	487.2	1.26
DUCKCREEK	21	104.5	4.6	16.9	7.9	24.9	5.0	5.5	10.5	260	32.4	292.4	582.1	
COUGARCR	19.6	82.0	9.1	10.0	5.0	15.0	3.3	5.6	8.9	90	46.1	136.1	457.8	
MADISONR	21.9	416.0	5.5	11.8	4.8	16.6	14.3	7.9	22.2	230	55.0	285.0	676.1	1.66
28JUL88														
OUTFLOW	NA	NA	3.7	13.5	6.4	19.9	13.5	11.6	25.1	120	45.1	165.1	494.5	1.96
GRAYCREEK	15	111.0	4.6	11.8	2.3	14.0	5.0	5.7	10.7	80	3.1	83.1	403.7	1.02
DUCKCREEK	19	106.0	10.1	20.4	5.5	25.9	3.3	5.1	8.4	150	18.4	168.4	525.0	
COUGARCR	17.5	86.0	7.3	16.9	4.8	21.8	-0.0	4.3	4.3	80	17.4	97.4	506.2	
MADISONR	21.5	375.0	1.8	13.5	17.5	31.0	1.6	4.0	5.6	90	28.3	118.3	450.0	1.18
17AUG88														
OUTFLOW	13	237.0	8.1	8.3	10.7	19.0	46.3	11.1	57.4	210	78.9	288.9	693.9	2.75
GRAYCREEK	15	115.0	2.8	18.7	NA		10.1	4.1	14.2	90	0.0	90.0	419.4	1.69
DUCKCREEK	18	110.0	6.4	22.2	7.7	29.9	2.5	3.0	5.5	160	10.3	170.3	741.8	
COUGARCR	18	97.0	8.1	20.5	5.6	26.1	1.6	4.1	5.8	100	9.5	109.5	387.2	
MADISONR	21	390.0	1.1	50.0	2.6	52.5	5.0	3.7	8.7	90	0.0	90.0	315.9	1.51
09SEP88														
OUTFLOW	15	249.0	8.1	15.6	9.9	25.5	23.6	7.8	31.3	210	41.3	251.3	741.4	3.10
GRAYCREEK	12	106.0	3.7	6.7	3.5	10.2	3.3	2.6	5.9	70	0.0	70.0	462.0	2.50
DUCKCREEK	12.8	101.0	4.6	19.1	7.6	26.7	2.5	4.6	7.1	140	5.4	145.4	485.1	
COUGARCR	14.3	85.0	9.0	19.1	7.3	26.4	139.9	3.7	143.7	60	0.0	60.0	353.5	
MADISONR	15.2	378.0	3.7	10.3	4.4	14.6	5.0	4.1	9.1	90	0.0	90.0	413.5	4.95

TABLE 20. HEBGEN LAKE 1988 AND 1989 INFLOW AND OUTFLOW DATA (continued).

DATE LOCATION	TEMP (deg C)	COND (umho/cm)	SRP (ug/l)	TDP (ug/l)	PART-P (ug/l)	TOT-P (ug/l)	NH4-N (ug/l)	NO3-N (ug/l)	DIN (ug/l)	TDN (ug/l)	PART-N (ug/l)	TOT-N (ug/l)	PART-C (ug/l)	DOC (mg/l)
01OCT88														
OUTFLOW	13	244.0	14.9	22.5	7.9	30.4	91.1	11.4	102.6	290	17.6	307.6	668.8	3.77
GRAYCREEK	9.8	105.0	1.9	8.4	1.8	10.2	3.0	3.2	6.2	50	0.0	50.0	389.0	1.30
DUCKCREEK	12	101.0	8.8	17.2	20.2	37.4	4.7	5.0	9.7	110	0.0	110.0	437.3	
COUGARCR	13	85.0	3.6	15.5	8.3	23.8	6.3	6.7	13.0	150	99.7	249.7	1643.1	
MADISONR	17	351.0	1.0	13.7	4.3	18.0	3.8	7.7	11.6	100	0.0	100.0	479.9	3.34
22OCT88														
OUTFLOW	10.5	205.0	8.8	11.9	9.0	20.9	23.5	10.4	33.9	310	17.9	327.9	564.8	3.61
GRAYCREEK	5.5	86.0	3.4	4.9	2.1	7.0	1.3	5.6	6.9	110	0.0	110.0	408.4	1.27
DUCKCREEK	7.5	88.0	7.0	8.4	8.1	16.6	3.0	3.9	6.9	110	0.0	110.0	538.3	
COUGARCR	8.5	75.0	13.4	10.2	6.4	16.6	5.6	9.5	15.1	80	0.0	80.0	433.5	
MADISONR	12	340.0	2.4	6.7	3.2	9.8	2.2	5.6	7.8	80	25.1	105.1	512.5	2.04
16MAY89														
DUCKCREEK			41.5	40.4			6.6	59.0	65.6	173				
26JUL89														
DUCKCREEK			23.8	65.4			10.6	9.7	20.3	98	13.2	110.9	494.4	
COUGARCR			25.7	39.6			34.9	55.7	90.6	94	81.3	175.3	1170.1	
												0.0		
03AUG89												0.0		
GRAYCREEK			5.1	27.7			3.4	8.1	11.5	62	24.1	86.1	518.2	
DUCKCREEK			19.1	43.6			4.3	8.2	12.5	83	29.6	112.6	516.5	
COUGARCR			21.0	33.7			16.9	63.0	79.9	69	64.5	133.5	967.0	
												0.0		
20SEP89												0.0		
GRAYCREEK			5.1	29.7			7.0	6.5	13.6	50	18.5	68.5	413.2	
DUCKCREEK			9.8	19.8			7.9	8.1	16.0	96	43.5	139.5	683.0	
COUGARCR			13.5	31.7			7.9	13.1	21.0	18	20.3	38.3	323.9	
												0.0		
08OCT89												0.0		
GRAYCREEK			1.3	19.8	5.3	25.1	4.3	4.8	9.1		23.1	23.1	256.3	
DUCKCREEK			7.0	19.8	9.0	28.8	5.2	6.5	11.7		45.0	45.0	476.6	
COUGARCR			10.7	17.8	5.6	23.4	10.6	12.9	23.5		27.0	27.0	258.8	