

## Elevated Nutrient Levels from Agriculturally Dominated Watersheds Stimulate Metaphyton Growth

Joseph C. Makarewicz<sup>1,\*</sup>, Peter E. D’Aiuto<sup>1</sup>, and Isidro Bosch<sup>2</sup>

<sup>1</sup>*Department of Environmental Science and Biology  
SUNY Brockport  
Brockport, New York 14420*

<sup>2</sup>*Department of Biology  
SUNY Geneseo  
Geneseo, New York 14454*

**ABSTRACT.** *The linkage between land use in a catchment basin and downstream aquatic ecosystems, especially effects on algae attached to substrata or loosely aggregated in the littoral zone, represents a void in our understanding of lake systems. The occurrence of beds of metaphyton at some stream mouths and not others in Conesus Lake, NY (USA) provided an opportunity to consider the relationship between land use and phosphorus and nitrogen losses on the development of shoreline metaphyton blooms. Experiments were performed in the littoral zone of a large temperate lake to test the hypothesis that effluent high in phosphorus and nitrate from tributaries draining agricultural watersheds had a stimulatory effect on the growth of littoral metaphyton, while effluent from a forested watershed did not. The study encompassed six watersheds of varying agricultural use (60–80%) and a forested watershed (12% agriculture). For each experiment, two quadruplicate sets of plexiglass incubation chambers (height = 50 cm, interior diameter = 9.5 cm) containing native assemblages of metaphyton received lake or tributary water continuously over a 3-day lake incubation period. Growth of metaphyton incubated in lake water and in tributary water was compared and differences appeared to be related to nutrient concentrations. A statistically significant stimulatory effect was measured for the six tributaries draining agricultural watersheds but not for the forested watershed. Tributary loadings appear to stimulate metaphyton at sites where the hydrology and hydrodynamics are suitable. A significant positive linear relationship existed between percent metaphyton cover in the littoral zone and the percent of land use in agriculture. Metaphyton abundance is impacted by land use practices and subsequent loss of nutrients from the catchment.*

**INDEX WORDS:** *Littoral zone, metaphyton, watershed, phosphorus, land use, agriculture.*

### INTRODUCTION

The littoral community of a lake, the interface between the land of the drainage basin and the open water of lakes (Wetzel 1983), is a metabolically active region playing a role in a lake’s phosphorus cycle (Wetzel 1979, 1996; Howard-Williams 1981). In particular, the linkage between land use in a catchment basin and downstream aquatic ecosystems, especially the littoral zone, deserves more attention. Metaphyton, a portion of the littoral community of a lake, is the loosely aggregated algae and cyanobacteria community that is neither strictly attached to substrata nor truly suspended

(Wetzel 2001). Located near tributaries, littoral communities can remove and store soluble nutrients from the flowing water, reducing total nutrient loading to the open waters of a lake (Howard-Williams 1981, Wetzel 1979) by transformation of nutrient into particulates (Havens *et al.* 1999). With enhanced nutrient inputs, littoral areas in Lake Tahoe, U.S.A. (Goldman 1981) and Lake Taupo, New Zealand (Hawes and Smith 1993) experienced an increase in metaphyton biomass and productivity. In subtropical Lake Okeechobee, Havens *et al.* (1999) demonstrated that phytoplankton did not become dominant at high nutrient loadings while a dramatic change in nearshore community structure occurred with increased dominance by epiphytes. Experiments in wetlands of the Florida Everglades

\*Corresponding author. E-mail: Jmakarew@brockport.edu

have demonstrated similar cause-and effect linkages between nutrient inputs and periphyton, metaphyton, and planktonic and benthic algae (McCormick and O'Dell 1996, McDougal *et al.* 1997). Although in the Everglades, phosphorus enrichment often caused a succession of species with green algae replacing abundant filamentous cyanobacteria (Dong *et al.* 2002) and calcareous species replacing non-calcareous periphyton communities (McCormick and O'Dell 1996). However, factors other than nutrients may play a role in controlling phytoplankton levels in the littoral zone and shallow lakes. In a small shallow lake lacking submerged plants, phytoplankton populations were relatively low, despite large populations of filamentous green algae and adequate nutrient availability due to intense grazing of phytoplankton by cladocerans (Irfanullah and Moss 2005).

In catchment basins dominated by agricultural land use, tributaries often have elevated levels of nutrients compared to the open waters of a lake. Many of the bays, rivers, and drowned river mouths, as well as the coastal zone of the south shore of Lake Ontario, are suffering from high turbidity, sedimentation, nutrient enrichment, and algae blooms that are often associated with agricultural land use (Makarewicz 2000). In Conesus Lake, one of the Finger Lakes of New York State, USA, average concentrations of total phosphorus in six streams during baseline flow draining agriculturally dominated catchments (60 to 80% of the land use) ranged from 41.9 to 245.3  $\mu\text{g P/L}$  (Makarewicz *et al.* 2001). In contrast, summer epilimnetic lake total phosphorus concentrations ranged from 15.0 to 38.3  $\mu\text{g P/L}$ . During hydrometeorological events, levels of tributary total phosphorus ranged a magnitude higher (258 to 1,313  $\mu\text{g P/L}$ ) than during non-events as materials were washed off the landscape and carried downstream. The mass loss from the watershed, that is, the loading into the lake from the watershed of nitrate (up to 1,800 g N/ha/day) and total phosphorus (up to 34 g P/ha/day) during hydrometeorological events was high (Makarewicz *et al.* 2001). A concentration gradient, high to low, existed from the tributary to the littoral zone and on into the offshore region of the lake. In Conesus Lake, littoral areas near tributaries sustained a luxuriant growth of plants (Fig. 1), characterized by large beds of the vascular macrophyte *Myriophyllum spicatum* and extensive cover of metaphyton, primarily comprised of species of *Zygnema* and *Spirogyra*. Annual standing crops of the macrophytes were significantly related

to nutrient loading from nearby streams (Bosch *et al.* 2000, 2001, 2002). The macrophytes, in turn, provide a three dimensional substrate allowing the accumulation of metaphyton biomass and effectively extend the suitable surface habitat for metaphyton well off shore. However, a cause and effect relationship between metaphyton biomass and nutrient loading from nearby tributaries has not been established.

The occurrence of abundant levels of metaphyton, often filamentous green algae, in the littoral areas of many freshwater and marine ecosystems is not unusual (Howell *et al.* 1990; France and Welbourn 1992; Thybo-Christesen *et al.* 1993; Pillsbury and Lowe 1994; Planas *et al.* 1996; Pihl *et al.* 1996, 1999). With shelter (often provided by macrophytes), abundant irradiance, a stable water column, and ample nutrients, metaphyton and epiphyton can develop to nuisance levels (Stevenson *et al.* 1996). The occurrence of beds of metaphyton at some stream mouths and not others in Conesus Lake provided an opportunity to consider the relationship between land use and phosphorus and nitrogen losses on the development of metaphyton blooms. To further evaluate the relationship between tributary nutrient loading and growth of metaphyton, the hypothesis that tributary effluent high in phosphorus and nitrate from agriculturally dominated watersheds had a stimulatory effect on Conesus Lake metaphyton biomass was tested *in situ* in continuous flow incubation chambers. Lastly, we evaluated the relationship between littoral zone plant structure, nutrient loss from catchments and land use.

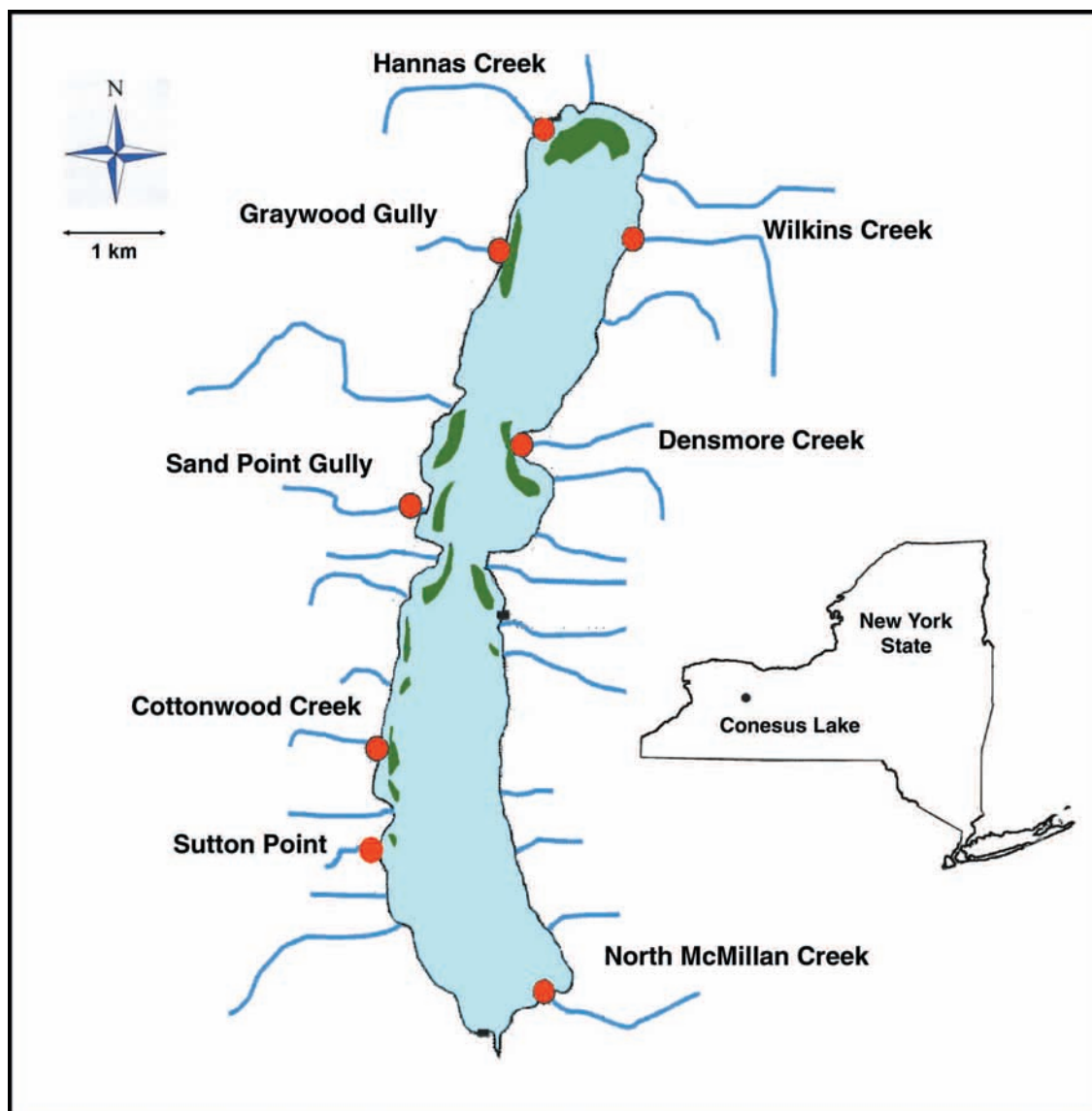
## METHODS

### Land Use

Land use percentages in the watershed were calculated by analyzing the 1998 Real Property Tax Services (RPS) acreage data, comparing it to Natural Resource Conservation Services (NCRS) Digital Orthophoto Quadrangles and field verification of results (SOCL 2001). Agricultural lands included land use in pasture, corn, and row crops.

### Discharge

The discharge of from tributaries was determined 12 times [six hydrometeorological events (snow melt and rainfall) and six non-events] over a 9-month period (April through December) at culverts or cement bridges located at the base of each catch-



**FIG. 1.** Macrophyte beds in Conesus Lake (N 42° 46.784', W 77° 43.068') NY, USA. Circles represent experimental sites. Irregular areas near streams are GPS identified macrophyte beds. Macrophyte beds existed at Wilken's Creek but were not mapped. At Sutton Point, percent metaphyton cover was estimated but no growth experiments were performed.

ment. The use of established metal culverts and cement bridges with fixed bases substantially reduces errors associated with shifts in the morphometry of stream basins in open channel monitoring of discharge (Rantz *et al.* 1982, Chow 1964). Previously developed rating curves (velocity-area method Rantz *et al.* 1982) for each tributary (Makarewicz *et al.* 2001) were confirmed by velocities measured weekly at equally spaced locations with a Gurley

flow meter at different stage heights (Chow 1964, Rantz *et al.* 1982). Tributary cross-sectional areas were measured within each culvert or bridge and verified monthly for streambed movement. A crude estimate of nutrient loss (kg/ha/d) from each sub-watershed was estimated by multiplying discharge (m<sup>3</sup>/sec) on the day of the sample by the concentration of the nutrient (mg/L) from the appropriate water sample. Although we have not calculated

error in our discharge measurements, the standard error of individual discharge measurements can be as good as 2% under ideal conditions and as high as 20% when conditions are poor. In our case, where a recently calibrated current meter was employed, the basin was a stable substrate, measurements of culverts were accurately done, and there were no issues with ice, we probably fall in the standard error range of 3 to 6% commonly observed (Sauer and Meyer 1992).

### Chemistry

Grab surface samples of water were taken on each sampling day in each stream near the base of the catchment but clearly above the influence of the lake and in the littoral zone where the chambers were placed. Analyses were performed at SUNY Brockport's National Environmental Laboratory Accreditation Conference (NELAC) certified "Water Chemistry" lab (NY ID #11439). Quality Control and Quality Assurance procedures follow NELAC. Sample water for dissolved nutrient analysis (phosphate and nitrate + nitrite) was filtered immediately on site with 0.45- $\mu\text{m}$  MCI Magma Nylon 66 membrane filters and held at 4°C until analysis. Dissolved nitrate + nitrite nitrogen, dissolved phosphate and total phosphorus analyses were performed by the automated cadmium reduction method (APHA 1998) and the colorimetric ascorbic acid method (APHA 1998), respectively, with a Technicon Autoanalyser II. The persulfate digestion procedure was employed for total phosphorus. Ammonium analysis followed APHA (1998) method #4500-NH<sub>3</sub> (Orion Probe). Lake and stream pH and water temperature were measured with a calibrated mercury thermometer and an Accumet portable pH meter.

### Metaphyton

#### Percent Cover

Percent metaphyton cover was determined in macrophyte beds (Fig. 1) of Conesus Lake associated with Cottonwood, Graywood, Sand Point, Sutton Point, and North McMillan creeks using a 0.25-m<sup>2</sup> surface PVC/plexiglass fitted with a square grid made of monofilament line. Floats were attached to the sides of the PVC to make it neutrally buoyant during deployment. The percentage of the surface that was covered by metaphyton was determined by counting the number of individual grids in which metaphyton was visible.

At least ten replicate measurements were made at each depth (1, 2, and 3 m) randomly sampled by SCUBA along two or three offshore transects for each macrophyte bed. In some cases three transects were analyzed at a given depth spanning a shore distance of 30–45 m (10–15 m between transects). When metaphyton was not detectable visually at the sampling site, a "zero percent cover" was assigned. Surveys were conducted during the weeks of July and August when maximum algal cover was observed at the respective sites.

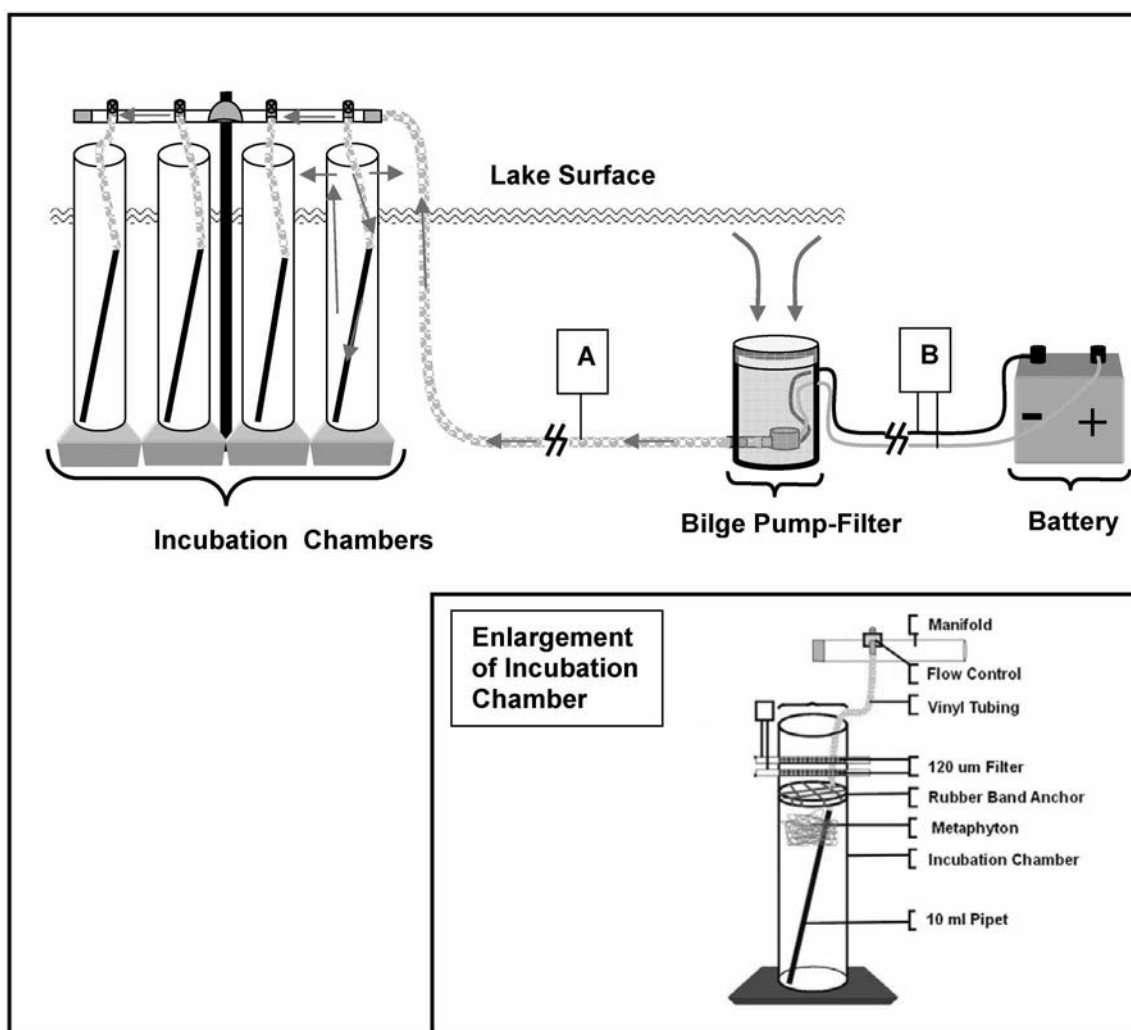
#### Wet weight

Metaphyton wet weight from experimental sites was obtained by placing the algae in a "salad spinner" lined with unbleached paper towels to remove surficial water from algal filaments before weighing. Microscopic inspection of spun filaments did not reveal any water droplets adhering to the filaments. Regression analysis indicated that the relationship between "spun" wet weight and dry weight (60°C for 48 hours) was excellent ( $r = 0.997$ ,  $n = 26$ ) allowing the use of wet weights for calculations of percent growth.

### Experimental Chambers

The system consisted of a plexiglass incubation chamber (50 cm long  $\times$  10 cm wide), a bilge pump-filter apparatus, and an automobile battery (Fig. 2). Water, either from a tributary or the lake, was pumped by a bilge pump through clear vinyl tubing (I.D. = 1.6 cm, O.D. = 1.9 cm) into a manifold (Fig. 2) and into the incubation chamber. The manifold had four outlets, each with a brass flow control knob, with 1 m of vinyl tubing (I.D. = 0.43 cm, O.D. = 0.63 cm) attached to each outlet. The small end of a 10 mL polystyrene pipet was connected to the tubing and the assembly was lowered into a chamber. This design allowed water to enter each cylinder from the bottom and drain from the top, resulting in continuous mixing throughout the chamber. The rate of water flow into each chamber was measured with a graduated cylinder and stopwatch. The flow control knobs were adjusted so that each chamber received approximately 500 mL/min. This rate was maintained for about 85% of the incubation period. Toward the end of the third day, the rate tapered off to approximately 350 mL/min due to diminished battery voltage (D'Aiuto *et al.* 2006).

The introduction of sediment and other unwanted elements into the chambers was prevented by the



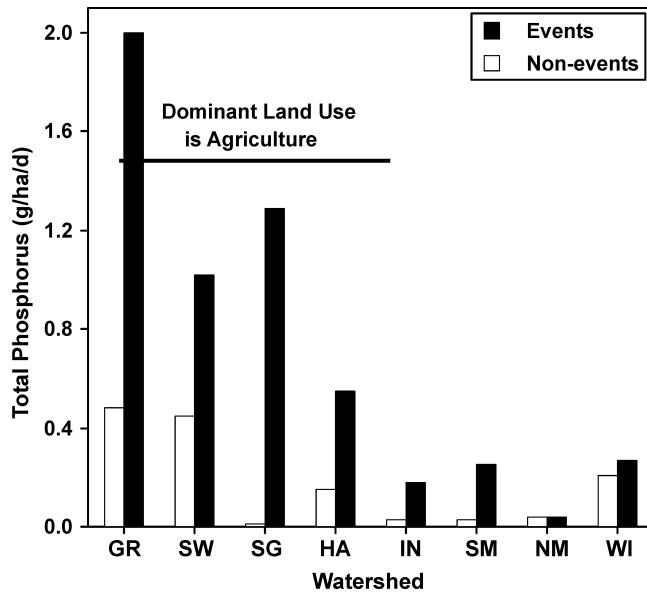
**FIG. 2.** Design of experimental chamber. Arrows indicating flow of lake ( $n = 4$  chambers) or tributary water ( $n = 4$  chambers) through the system. The incubation chambers are placed in shallow lake water allowing the top 20 cm of the chambers to extend above the water. A. Vinyl tubing, B. Electrical Wire.

use of a bilge pump-filter apparatus (Fig. 2). To prevent algal cells from rising to the surface, a lattice of rubber bands served as an anchor for the filamentous algae and two rolled squares of 120- $\mu$ m mesh were inserted into the outlets to serve as a filter (see insert, Fig. 2).

#### Effects of Tributary Water

Loss of phosphorus from sub-watersheds (g/ha/d) was quite variable within the Conesus Lake watershed (Fig. 3). Reflecting land use, seven sub-watersheds (Hanna's Creek, Graywood Gully, Sand Point Gully, Cottonwood Creek, Densmore Gully, North

McMillan Creek, and Wilkins Creek) were selected for testing the hypothesis that sub-watershed stream water was stimulating the growth of metaphyton in the littoral zone of Conesus Lake. With the exception of the predominantly forested North McMillan sub-watershed (12% of land use in agriculture), land use of the other six sub-watersheds was dominated by agriculture (48 to 83% of land use). Eight metaphyton experimental chamber experiments (72 hour incubation period) were conducted in the littoral zone of Conesus Lake at the mouths of seven creeks. With the exception of North McMillan Creek, weighed quantities from each site (range: 0.23–1.5 g wet weight) of the dominant Conesus



**FIG. 3.** Losses of total phosphorus (g P/ha/d) during hydrometeorologic (rain and snow melt) events (dark bars) and during non-event conditions (white bars) from selected sub-catchments of Conesus Lake. GR = Graywood Creek (> 70% of land in agriculture), SW = Southwest (53%), SG = South Gully (52%), HA = Hanna Creek (81%), IN = Inlet (35%), SM = South McMillan Creek (29%), NM = North McMillan Creek (12%), WI = Wilkens Creek (48%).

Lake metaphyton assemblage, *Zygnema* (~75% of abundance) and *Spirogyra* (25%), were placed in eight experimental chambers (Fig. 2) in the littoral zone, and either tributary effluent ( $n = 4$ ) or lake water ( $n = 4$ ) was continuously pumped from the tributary of interest or from the littoral zone of the lake south of each tributary. This position ensured, because of prevailing lake currents, that lake chambers would not be affected by tributary effluent (Y. Li, Personal Communication, Rochester Institute of Technology, 2007). At North McMillan Creek, where metaphyton were not naturally abundant, metaphyton were transferred from Graywood Creek for the experiment. Each site was examined for shading potential and chambers were positioned in such a manner that little or no shading occurred throughout the day. After a period of three days, metaphyton was removed, weighed, and the percent growth of metaphyton [ $((\text{Final weight} - \text{initial weight}) / \text{initial weight}) * 100$ ] was calculated.

Since each experimental chamber within the system had a slightly different amount of metaphyton

present and flow to each chamber was individually controlled, each chamber was considered a separate entity or replicate. Comparisons were made within a site only. That is, data were not pooled among creek sites. Pooling the variance of all experiments (all tributary fed chambers versus all lake fed chambers) was not appropriate as metaphyton were exposed to different physical, chemical, and ecological conditions throughout the growing season and at various locations. Thus a one-tailed t-test ( $\alpha = 0.05$ ) was employed to compare the average percent growth of metaphyton and average nutrient concentration in chambers receiving tributary effluent from those receiving lake water at a given site. Two assumptions were made when applying t-tests: The populations were normally distributed and that the populations had equal variance. Because the number of replicates was small ( $n = 4$ ), it was not appropriate to apply any test of normality. Zar (1999) stated that numerous studies have demonstrated that the t-test is robust enough to stand considerable departure from theoretical assumptions, especially if sample sizes are equal as ours. Even so, the assumption concerning variance was tested. For sets of data that did not have equal variances, a t-test was employed assuming unequal variance.

### Nutrient Limitation Experiment

Replicated experiments were completed in a period of 6 days to determine whether nitrogen, phosphorus, or both simultaneously were limiting to metaphyton growth (See Table 2 for design). Additional nutrients were added to the experimental chambers via a Harvard Apparatus Peristaltic pump at a rate of 1 mL/min. Target nutrient levels in the experimental chambers reflected historical maximum nitrate-nitrogen (1 mg N/L) and phosphate (12  $\mu\text{g P/L}$ ) concentrations in the lake. Actual concentrations were reasonably close to target values (Table 1). As before, metaphyton continually received lake water dosed with nutrients for 3 days. Water in the incubation chambers was analyzed daily, while nutrient stock solutions were made from  $\text{NaNO}_3$  and  $\text{Na}_2\text{HPO}_4$  placed in distilled water. A two-factor analysis of variance was used to analyze the effect of nitrate and dissolved phosphate on metaphyton biomass (SPSS, version 10.0.5) (Zar 1999). Data were pooled from two 3-day experiments to provide four replicates per treatment. Pooling the samples was deemed acceptable because both experiments were conducted at the

**TABLE 1.** Results of metaphyton experiments from sub-watersheds of Conesus Lake. Values are averages ( $N = 3$ )  $\pm$  1 SE. Dates represent the start date of an experiment. Samples for nutrient analysis were taken from the tributary and the littoral at each site on each day of the 3-day experiments. Under metaphyton,  $p$ -values are for a one tail  $t$ -test comparing metaphyton growth in tributary effluent versus lake water. \* $P < 0.05$  (one tail  $t$ -test).  $T$  = Temperature.

Site	Land Use % Agriculture (watershed area, ha)	Metaphyton % Growth/ 3 days	Trib vs Lake P-value	NO <sub>3</sub> -N (mg/L)	PO <sub>4</sub> -P ( $\mu$ g/L)	pH	Temp (°C)
Graywood (13/6/02)							
Tributary	63(38.1)	260 $\pm$ 17.38	P = 0.009	*17.15 $\pm$ .61	*147 $\pm$ 27.57	*7.5 $\pm$ 0.05	19.0 $\pm$ 1.00
Lake		174 $\pm$ 20		0.08 $\pm$ .01	6.1 $\pm$ 2.10	7.9 $\pm$ 0.12	20.7 $\pm$ 0.33
Sand Point (27/6/02)							
Tributary	83(188.0)	399 $\pm$ 2.03	P = 0.002	*0.81 $\pm$ .23	*16.0 $\pm$ 1.83	8.0 $\pm$ 0.50	22.1 $\pm$ 1.64
Lake		209 $\pm$ 23		0.06 $\pm$ .02	5.4 $\pm$ 1.21	8.5 $\pm$ 0.15	23.6 $\pm$ 1.50
Cottonwood (30/6/02)							
Tributary	75(98.8)	413 $\pm$ 32	P = 0.003	*1.04 $\pm$ .07	*26.6 $\pm$ 4.58	8.3 $\pm$ 0.17	25.6 $\pm$ 0.71
Lake		271 $\pm$ 15		0.04 $\pm$ .01	6.5 $\pm$ 1.99	8.6 $\pm$ 0.00	26.3 $\pm$ 0.71
Densmore (7/7/02)							
Tributary	58(647.5)	415 $\pm$ 55	P = 0.003	0.02 $\pm$ .00	*3.0 $\pm$ 0.18	7.1 $\pm$ 0.24	26.5 $\pm$ 1.15
Lake		168 $\pm$ 25		0.02 $\pm$ .01	*1.6 $\pm$ 0.52	6.9 $\pm$ 0.18	25.9 $\pm$ 1.19
North McMillan (14/7/02)							
Tributary	12(1,778.2)	105 $\pm$ 20	P = 0.469	*0.10 $\pm$ .01	4.3 $\pm$ 0.90	6.4 $\pm$ 0.26	21.8 $\pm$ 1.69
Lake		103 $\pm$ 19		0.05 $\pm$ .02	3.3 $\pm$ 0.95	7.1 $\pm$ 0.03	24.3 $\pm$ 0.67
Wilkins (21/7/02)							
Tributary	48(690.0)	344 $\pm$ 36	P = 0.004	*0.50 $\pm$ .30	*26.4 $\pm$ 7.5	7.4 $\pm$ 0.20	26.3 $\pm$ 1.8
Lake		207 $\pm$ 16		0.04 $\pm$ .01	2.9 $\pm$ 0.32	7.7 $\pm$ 0.26	25.0 $\pm$ 1.5
Wilkins (29/7/02)							
Tributary	48(690.0)	434 $\pm$ 26	P = 0.019	*0.16 $\pm$ .02	*6.7 $\pm$ 0.66	7.0 $\pm$ 0.29	28.0 $\pm$ 1.5
Lake		337 $\pm$ 26		0.01 $\pm$ .00	3.5 $\pm$ 1.3	7.6 $\pm$ 0.31	27.7 $\pm$ 1.4
Hanna's (1/8/02)							
Tributary	81(717.5)	69 $\pm$ 5	P = 0.021	0.01 $\pm$ .00	6.4 $\pm$ 0.57	8.2 $\pm$ 0.17	28.0 $\pm$ 0.58
Lake		46 $\pm$ 4		0.01 $\pm$ .00	5.7 $\pm$ 0.15	8.3 $\pm$ 0.09	29.2 $\pm$ 0.44

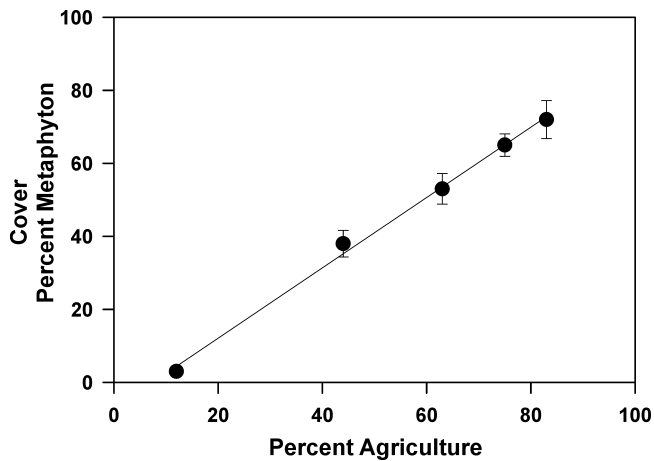
same location, within a short time period (6 days), and under similar physical and chemical conditions.

## RESULTS

Losses of phosphorus (g P/ha/d) were greatest from watersheds with land use in agriculture (Fig. 3). For example, agricultural land use in the Graywood Creek watershed exceeded 60% and total phosphorus loss during hydrometeorological events from this catchment to the lake was 2.00 g P/ha/d. This value was comparable to phosphorus losses from agricultural land in the Mississippi drainage basin (0.27 to 2.68 g P/ha/d,  $N = 30$ ) (Turner and Rabalais 2004). In contrast, in the mostly forested (< 12% in agriculture) North McMillan catchment, phosphorus loss rates averaged only 0.04 g P/ha/d. A surprisingly strong positive relationship ( $r^2 = 0.9965$ ) existed between percent cover of metaphy-

ton in macrophyte beds in Conesus Lake with the percent land use in agriculture (Fig. 4).

Except for North McMillan Creek ( $P = 0.47$ ), significantly higher metaphyton percent growth occurred in the tributary-fed chambers ( $P < 0.02$ ) compared to the chambers receiving lake water (Table 1). Tributary phosphate concentrations were significantly higher than lake phosphate concentrations ( $P < 0.05$ ) with the exception of Hanna's Creek ( $P = 0.25$ ) and North McMillan Creek ( $P = 0.24$ ) (Table 1). Tributary nitrate concentrations were significantly higher than lake concentrations at six experimental sites. Although experimental chambers received tributary and lake water that had similar nitrate concentrations, metaphyton biomass increased in the tributary-fed chambers of Densmore Creek and Hanna's Creek. North McMillan Creek had significantly higher concentrations of nitrate than lake water ( $P = 0.01$ ), but no significant



**FIG. 4.** Average percent metaphyton cover ( $\pm$ SE) versus percent of watershed used for agricultural practices. Values are the site average ( $n = 59$  to  $62$  per site) for 2001 except for North McMillan Creek. At this location, metaphyton was observed only once. This number is plotted.

difference in metaphyton growth between the tributary and lake-fed experimental chambers was evident. Average temperature and pH between tributary and lake-fed chambers were not statistically significant with one exception. Graywood Creek had significantly lower pH values ( $P = 0.04$ ) than adjacent lake water (Table 1). Ammonium was not measured during the experiment but average weekly concentrations during the 2002–2004 period ranged from 0.2 to 0.4 mg N/L in tributaries and 0.1 mg/L in the littoral of the lake.

Experimental enhancement of lake water with phosphate and phosphate+nitrate resulted in metaphyton growth (mean = 130 percent) that was significantly higher ( $P = 0.002$ , two-way ANOVA) than in chambers that received nitrate only or no nutrients (control) above ambient levels (mean = 60 percent growth, Table 2). Metaphyton growth in chambers enriched with nitrate did not differ significantly ( $P = 0.54$ , two-way ANOVA) from growth in chambers that received no additional nitrate above ambient levels. Furthermore, interaction effects were insignificant ( $P = 0.99$ , two-way ANOVA) indicating that the effect of phosphate on metaphyton percent growth was not influenced by the presence of nitrate (Table 2).

## DISCUSSION

The metaphyton chamber experiments demonstrated that tributary effluent may promote meta-

**TABLE 2.** Results of the (A) nutrient enrichment experiments ( $n = 2$ ) and (B) two-way ANOVA. Phosphate and nitrate are averages for the 3-day incubation. Percent growth represents the average increase in metaphyton biomass during the 3-day experiment. The experimental chambers were conducted in August of 2002 in the littoral at the north end of Conesus Lake.

A. Addition	PO <sub>4</sub> ( $\mu$ g/L)	NO <sub>3</sub> (mg/L)	% Growth
N+P	12.63	1.33	124
P	12.20	0.07	135
N	1.98	1.09	55
Ambient	1.86	0.06	66

B. Factor	Sum of Squares	df	f	p
P	19113.1	1	15.325	0.002
N	495.1	1	0.397	0.540
P X N	6.250E-02	1	0.000	0.994

phyton (*Spirogyra* and *Zygnema*) growth in the littoral zone of Conesus Lake. Metaphyton growth in chambers that received tributary effluent high in phosphorus was significantly higher than metaphyton growth in chambers that received lake water low in phosphorus (Table 1). Since the littoral zone of a lake, especially one dominated by macrophyte beds, is not unlike a wetland, it is reasonable to compare our results to those from wetlands. For example, Murkin *et al.* (1991) found that the biomass of phytoplankton and epiphyton in a normally oligotrophic wetland receiving cattle waste was significantly higher than that in an adjacent wetland. In the Florida Everglades, the cyanobacteria assemblage was replaced by a periphyton assemblage dominated by filamentous green algae including *Spirogyra* and *Mougeotia* when total phosphorus increased. However, above 48 to 134  $\mu$ g P/L, an increase in filamentous green algae did not occur (McCormick and O'Dell 1996). Increased amounts of allochthonous nutrients on wetland algae included increased phytoplankton biomass and proliferation of epiphyton, and in some cases thick metaphyton mats had developed after enrichment. Other studies have shown no response (reviewed by McDougal *et al.* 1997). Differences in the outcome of various studies undoubtedly reflect quantity and frequency of addition of nutrients, the relative residence time of nutrients in the water column, and site specific and geographic differences (McDougal *et al.* 1997). However, the prolific growth of metaphyton appeared to be a common response to exper-

imental nitrogen and phosphorus enrichments of wetlands (McDougal *et al.* 1997). Similarly, abundant metaphyton is a common occurrence in shallow aquatic ecosystems enriched by nutrients (Hann and Goldsborough 1997, Hillebrand 1983, Dodds 1991, Fong and Zedler 1993, Murkin *et al.* 1994). Our results from the littoral zone of a lake are consistent with the findings from wetlands and from lakes.

Because we compared stream to nearshore lake water in our chamber experiments, we present the worst case for the impact of the stream, rather than allowing for the effects of dilution. The distribution of nutrient-enriched water from streams will be determined by the nature of the entry plumes of streams and lake circulation (Trexler *et al.* 2006). In Conesus Lake, a three-dimensional, macrophyte drag hydrodynamic model has demonstrated that nutrient-laden stream water is focused into a macrophyte bed where metaphyton are prevalent (Y. Li, Personal Communication, Rochester Institute of Technology).

Not all tributary water from the sub-watersheds of Conesus Lake stimulated metaphyton growth in the littoral zone. North McMillan Creek is a catchment dominated by forest-covered land (< 12% in agriculture). Naturally occurring beds of macrophyte beds and metaphyton mats generally do not exist at this location in Conesus Lake. As expected, growth of metaphyton in tributary water was not significantly different ( $P = 0.47$ ) from the growth in chambers receiving lake water. Concentrations of phosphate in both stream and lake water were also not significantly different ( $P = 0.24$ ). Similarly, at Hanna's Creek, a watershed high in agricultural use (81%) with major losses of phosphorus from the sub-watershed during hydrometeorological events (Fig. 4), only a modest but significant ( $P = 0.021$ ) increase in percent metaphyton growth occurred in tributary water (mean = 69%) compared to lake water (mean = 46%). With 81% of the sub-watershed in agriculture, a much larger stimulatory effect on metaphyton growth was expected at Hanna's Creek. However, as with North McMillan Creek, the average phosphate concentration in Hanna's Creek during the experiment was 13.0% higher than the lake, but this difference was not significant ( $P = 0.25$ ). The lack of a large stimulatory response at Hanna's Creek was likely the consequence of the experiment being performed during a period of low losses of phosphorus from the watershed. Similarly, the low N:P ratio (under 23) (Table 3) suggests phosphorous may not have been limiting at this site

**TABLE 3.** *N:P ratios (molar) and sodium concentrations for Conesus Lake and selected streams. Values in parentheses represent the number of measurements.*

Stream / Lake	N:P
Graywood	62.2 (4)
Sand Point	67.4 (4)
Cottonwood	58.9 (4)
Densmore	40.6 (8)
North McMillan	56.5 (4)
Wilkins	29.7 (6)
Hanna	20.6 (2)
Conesus Lake nearshore	28.9 (4)

during the experiment. Another possibility that cannot be dismissed is that Hanna's Creek supported an ecologically different metaphyton community in Conesus Lake—a massive bloom of *Hydrodictyon*, rather than *Spirogyra* and *Zygnema* as at other sites. Confounding factors may also influence composition and growth of the metaphyton community in Hanna's Creek. Historically, this watershed and the water draining from it have been impacted by large losses of de-icing salt from storage piles and from application to roads to remove ice and snow common in this region (Makarewicz and Lewis 1993). Unfortunately, sodium data are not available for the experimental period. In summary in Conesus Lake, where dramatic differences in growth of metaphyton occurred among subwatersheds, tributary-fed experimental chambers receiving water from agriculturally dominated watersheds had significantly higher concentrations of phosphate than those receiving lake water.

Since pH and temperature of tributary and lake water were not significantly different during experiments, we propose that nutrients, specifically phosphorus rather than nitrate, was the cause of enhanced metaphyton growth observed in the littoral zone of Conesus Lake. Whenever tributary phosphorus concentrations exceeded lake phosphorus concentrations, metaphyton growth was stimulated. Also, metaphyton growth was often stimulated when nitrate concentrations were not significantly different between lake and tributary runoff or even when lake nitrate concentration was higher than tributary nitrate levels. For example, metaphyton growth was significantly higher in the tributary-fed chambers of Densmore Creek and Hanna's Creek even though nitrate concentrations between the effluent of these streams and corre-

sponding lake water were not significantly different. Also, no significant difference in metaphyton growth occurred between the North McMillan tributary- and lake-fed chambers, even though significantly ( $P = 0.005$ ) higher concentrations of nitrate, but not significantly higher phosphorus concentrations, were observed in the tributary water compared to the lake water.

Further corroboration of this hypothesis was provided by the N:P ratios and nutrient enrichment experiments in which both nitrate and phosphorus levels were experimentally manipulated. With N:P ratios for both lake water and stream water generally above 23 (Table 3) and ammonium, a possible preferred source of N for metaphyton, in the 0.2 to 0.4 mg N/L range, phosphorus rather than nitrogen appears to be limiting (Wetzel 2001). In the nutrient limiting experiment, metaphyton growth was significantly lower in chambers receiving only nitrate than in those receiving phosphorus at the north end of the lake. Furthermore, interaction effects were insignificant ( $P = 0.99$ , two-way ANOVA), suggesting that the effect of phosphate on metaphyton percent growth was not influenced by the presence of nitrate. Invariably, in the *in situ* incubation experiments, all chambers that yielded higher percent metaphyton growth received stream effluent containing higher phosphate concentrations. Our data set suggests that metaphyton biomass in Conesus Lake was influenced by phosphate levels. Other studies of fresh water bodies have demonstrated that filamentous green algae have flourished upon enrichment with phosphorus (e.g., Dodds and Gudder 1992). McCormick *et al.* (2001) demonstrated that filamentous green algae, that is metaphyton, accumulated phosphorus rapidly and in proportion to the loading rate and suggested that P-limitation plays an important role in shaping the periphyton assemblage.

### Land Use and Metaphyton

Moving water from lake currents and catchment discharges interact in complex ways to create and position areas of high and low periphyton productivity (Iwaniec *et al.* 2006, Trexler *et al.* 2006). Within Conesus Lake, local scale variation in littoral plant (macrophyte/metaphyton) communities apparently related to the local inputs of nutrients from tributaries dominated by agriculture (Fig. 1). Land use in the Conesus Lake catchment basin is dominated by agriculture with some sub-watersheds having as much as 80% of the land in farming

(SOCL 2001). Sub-watersheds in agriculture generally contribute more phosphorus to the lake than those that are not, especially during hydrometeorological events (Fig. 3). Furthermore, *in situ* experiments demonstrated that phosphorus was stimulating the growth of metaphyton within the littoral system and was a likely proximal cause of the masses of metaphyton beds associated with Eurasian milfoil (*Myriophyllum spicatum*) and tributary mouths. Lastly, percent cover of metaphyton in macrophyte beds in Conesus Lake increased with the percent land use in agriculture (Fig. 4). Interpretation of this graph has to be viewed with caution as there are few data points representing sub-watersheds with 15 to ~40% of the land use in agriculture. However, within the Conesus Lake ecosystem, this is a plausible relationship since Conesus Lake sub-watersheds in agriculture are generally delivering phosphorus to the littoral zone at a greater rate than sub-watersheds not in agriculture (Fig. 3). Similarly, hydrologic drivers (phosphorus loads) were regulating periphyton net production and respiration at oligotrophic Everglades sites (Iwaniec *et al.* 2006).

Within the Conesus Lake watershed, metaphyton cover in the littoral zone is a function of the percent of watershed in agriculture. The relationship provided in Figure 4 suggests a possible solution. A reduction in the percent of agriculture in the various sub-watersheds or the reduction of phosphorus loss through improved farming practices that reduced phosphorus loss may both lead to a decrease in metaphyton nuisance growth. Several of these sub-watersheds are receiving best management practices, such as reductions in fertilization rates, better handling of barn yard wastes, buffer strips, etc. in an attempt to reduce the loss of nutrients and soils from agriculture activity and improve downstream water quality. Similarly, the water quality of the coastal zone of Lake Ontario is determined in part by the magnitude of the components in the discharges from watersheds. Best management practices, if properly initiated, should lead to a reduction of nutrient and soil loss from the watershed and to a decline in nutrient and suspended solids concentrations and algal populations in the embayments, rivers and the nearshore of the Great Lakes.

The large metaphyton presence in the littoral region of Conesus Lake associated with macrophytes is considered a nuisance and aesthetically unappealing by lakeside homeowners. Typically in shallow water systems, macrophytes and phytoplankton are

often viewed as two potential lake “states” with the macrophyte state typically being preferred since turbidity is low (Moss *et al.* 1997). The overgrowth of metaphyton on a macrophyte substrate in the littoral of Conesus Lake provides a different perspective and suggests further research on restoration goals on this aspect of lake management. In summary, the experimental work and the field relationships suggest that phosphorus loss, but not nitrate from sub-watersheds due to agriculture activities, is the likely cause of the metaphyton blooms observed near tributary mouths in Conesus Lake.

### ACKNOWLEDGMENTS

We thank C. Hudon, C. Norment, and T. Lewis for their thoughtful suggestions and comments on an earlier draft. Funding was provided by the Cooperative State Research, Education, and Extension Service of the USDA.

### REFERENCES

- APHA. 1998. *Standard Methods for the Examination of Waste and Wastewater*. 19<sup>th</sup> ed. American Public Health Association. Washington, D.C., USA.
- Bosch, I., Makarewicz, J.C., Duncan, J., Thorn, P., and Martin, M. 2000. *Distribution and standing crops of submersed macrophytes in Conesus Lake, N.Y.* Livingston County Planning Department, Geneseo, NY.
- , Makarewicz, J.C., Emblidge, J.P., Johnson, D.A., and Valentino, M.D. 2001. *Population studies of Eurasian watermilfoil (Myriophyllum spicatum) and zebra mussels (Dreissena polymorpha) in Conesus Lake, N.Y.* Livingston County Planning Department, Geneseo, NY.
- , Makarewicz, J.C., Mis, E., Johnson, D., and Wagner, M. 2002. *Distribution and biomass of macrophytes in six large beds adjacent to streams with high nutrient loading, Conesus Lake*. Livingston County Planning Department, Geneseo, NY.
- Chow, Ven Te. 1964. *Handbook of Applied Hydrology*. New York: McGraw-Hill Book Company.
- D’Aiuto, P., Makarewicz, J.C., and Bosch, I. 2006. The impact of stream nutrient loading on macrophytes and metaphyton in Conesus Lake, USA. *Verh. Internat. Verein. Limnol.* 29:1373–1376.
- Dodds, W.K. 1991. Factors associated with dominance of the filamentous green alga *Cladophora glomerata*. *Water Resources* 25:1325–1332.
- , and Gudder, D.A. 1992. The ecology of *Cladophora*. *Journal of Phycology*. 28:415–427.
- Dong, Q., McCormick, P.V., Sklar, F.H., and DeAngelis, D.L. 2002. Structural instability, multiple stable states, and hysteresis in periphyton driven by phosphorus enrichment in the Everglades. *Theoretical Population Biology* 61:1–13.
- Fong, P., and Zedler, J.B. 1993. Temperature and light effects on the seasonal succession of algal communities in shallow coastal lagoons. *Journal of Experimental Marine Ecology* 171:259–272.
- France, F.L., and Welbourn, P.M. 1992. Influence of lake pH and macrograzers on the distribution and abundance of nuisance metaphytic algae in Ontario, Canada. *Can. J. Fish. Aquat. Sci.* 49:185–195.
- Goldman, C.R. 1981. Lake Tahoe: two decades of change in a nitrogen deficient oligotrophic lake. *Verhandlungen der Internationale Vereinigung für theoretische und angewandte Limnologie* 21:45–70.
- Hann, B.J., and Goldsborough, L.G. 1997. Responses of a prairie wetland to press and pulse additions of inorganic nitrogen and phosphorus: Invertebrate community structure. *Archiv für Hydrobiologie* 140:169–194.
- Havens, K.E., East, T.E., Hwang, S.J., Rodusky, A.J., Sharpstein, B., and Steinman, A.D. 1999. Algal responses to experimental nutrient addition in the littoral community of a subtropical lake. *Freshwater Biology* 42:329–344.
- Hawes, I., and Smith, R. 1993. Effect of localized nutrient enrichment on the shallow epilithic periphyton of oligotrophic Lake Taupo, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 27:365–372.
- Hillebrand, H. 1983. Development and dynamics of floating clusters of filamentous algae. In *Periphyton of Freshwater Ecosystems*, R.G. Wetzel, ed., pp. 31–39. Dr. W. Junk Publishers.
- Howard-Williams, C. 1981. Studies on the ability of a *Potamogeton pectinatus* community to remove dissolved nitrogen and phosphorus compounds from lake water. *J. Applied Ecol.* 43:343–350.
- Howell, E.T., Turner, M.A., France, R.L., Jackson, M.B., and Stokes, P.M. 1990. Comparison of Zygnematacean (Chlorophyta) algae in the metaphyton of two acidic lakes. *Can. J. Fish. Aquat. Sci.* 47:1085–1092.
- Irfanullah, H.M., and Moss, B. 2005. A filamentous green algae-dominated temperate shallow lake: Variations on the theme of clear-water stable states. *Arch. Hydrobiol.* 163:25–47.
- Iwaniec, D.M., Childers, D.L., Rondeau, D., Madden, C.J., and Saunders, C. 2006. Effects of hydrologic and water quality drivers on periphyton dynamics in the southern Everglades. *Hydrobiologia* 569:223–235.
- Makarewicz, J.C. 2000. *New York’s North Coast: A troubled Coastline. Lake Ontario Embayment Initiative*. Finger-Lakes-Lake Ontario Watershed Protection Alliance. Available from the Center of Environmental Information, Rochester, NY.
- , and Lewis, T.W. 1993. *Stress stream analysis of two sub-watersheds of Conesus Lake—Hanna’s and*

- Wilkins Creeks*. Technical report to the Livingston County Planning Department, Mount Morris, NY. Available from Drake Memorial Library, SUNY Brockport, Brockport, NY, USA.
- , Bosch, I., and Lewis, T.W. 2001. *Soil and nutrient loss from selected subwatersheds of Conesus Lake*. Livingston County Planning Department, Mount Morris, N.Y. Available from Drake Memorial Library, SUNY Brockport, Brockport, NY, USA.
- McCormick, P.V., and O'Dell, M.B. 1996. Quantifying periphyton responses to phosphorus in the Florida Everglades: A synoptic-experimental approach. *J. North Am. Benth. Soc.* 15:450–468.
- , O'Dell, M.B., Shuford III, R.B.E., Backus, J.G., and Kennedy, W.C. 2001. Periphyton responses to experimental phosphorus enrichment in a subtropical wetland. *Aquatic Botany* 7:119–139.
- McDougal, R.L., Goldsborough, G.L., and Hann B.J. 1997. Responses of a prairie wetland to press and pulse additions of inorganic nitrogen and phosphorus: production by planktonic and benthic algae. *Archiv für Hydrobiologie* 140:145–167.
- Moss, B., Madgwick, J., and Phillips, G. 1997. *A Guide to the Restoration of Nutrient-Enriched Shallow Lakes*. W.W. Hawes, U.K.
- Murkin, H.R., Pollard, J.B., Stainton, M.P., Boughen, J.A., Pollard, J.B., and Titman, R.D. 1991. Nutrient status of wetlands in the Interlake Region of Manitoba, Canada. *Wetlands* 11:105–122.
- , Pollard, J.B., Stainton, M.P., Boughen, J.A., and Titman, R.D. 1994. Nutrient additions to wetlands in the inter-lake region of Manitoba, Canada: Effects of periodic additions throughout the growing season. *Hydrobiologia* 280:1980–1994.
- Pihl, L., Magnusson, G., Isaksson, I., and Wallentinus, I. 1996. Distribution and growth dynamics of ephemeral macroalgae in shallow bays on the Swedish west coast. *J. Sea Res.* 35:169–180.
- , Svenson, A., Moksnes, P., and Wennhage, H. 1999. Distribution of green algal mats shallow soft bottoms of the Swedish Skagerrak Archipelago in relation to nutrients sources and wave exposure. *J. Sea Res.* 41:281–294.
- Pillsbury, R.W., and Lowe, R.L. 1994. The impact of zebra mussels on benthic alga communities in Saginaw Bay, Lake Huron. In *Proc. 4<sup>th</sup> International Zebra Mussel Conference*. Madison, Wisconsin.
- Planas, D., Maberly, S.C., and Parker, J.E. 1996. Phosphorus and nitrogen relationships of *Cladophora glomerata* in two lake basins of different trophic status. *Freshwater Biology* 35:609–622.
- Rantz, S.E. et al. (18 authors) 1982. *Measurement and computation of stream flow*. Geological Survey Water Supply Paper 2175. U.S. Government Printing Office. Washington, D.C.
- Sauer, V.B., and Meyer, R.W. 1992. *Determination of error in individual discharge measurements*. U.S. Geological Survey. Norcross, GA. Open-File Report 92-144.
- SOCL. 2001. *State of the Conesus Lake watershed*. Livingston County Planning Department, Geneseo, NY.
- Stevenson, R.J., Bothwell, M.L., and Lowe, R.L. 1996. *Algae Ecology: Freshwater Benthic Ecosystems*. Academic Press.
- Thybo-Christesen, M., Rasmussen, M.B., and Blackburn, T.H. 1993. Nutrient fluxes and growth of *Cladophora sericea* in a shallow Danish bay. *Marine Ecology Progress Series* 100:273–278.
- Turner, R.E., and Rabalais, N.N. 2004. Suspended sediment, C, N, P, and Si yields from the Mississippi River basin. *Hydrobiologia* 511:79–89.
- Trexler, J., Gaiser, E.E., and Childers, D. 2006. Interaction of hydrology and nutrients in controlling ecosystem function in oligotrophic coastal environments of South Florida. *Hydrobiologia* 569:1–2.
- Wetzel, R.G. 1979. The role of the littoral zone and detritus in lake metabolism, *Archiv für Hydrobiologie. Advances in Limnology* 13:145–161.
- . 1983. *Limnology*. 2<sup>nd</sup> ed. Saunders Publishing.
- . 1996. Benthic algae and nutrient cycling in lentic freshwater systems. In *Algal Ecology*, R.J. Stephenson, M.L. Bothwell, and R.L. Lowe, eds., pp. 641–753. Academic Press.
- . 2001. *Limnology*. 3<sup>rd</sup> ed. Academic Press.
- Zar, J.H. 1999. *Biostatistical Analysis*. 4<sup>th</sup> ed. Prentice Hall.

Submitted: 26 August 2006

Accepted: 13 February 2007

Editorial handling: Christiane Hudon