EFFECTS OF NON-POINT NUTRIENT LOADING ON PLANKTONIC COMMUNITY STRUCTURE AND FUNCTION IN A GREAT LAKES COASTAL WETLAND

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Master of Science in Biology

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by
Brian M. Binion
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Director of Thesis

Master's Committee: Chair

Howard J. Sitsen

25 July 95

Date

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Brian M. Binion, M.S.
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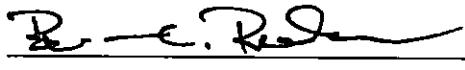
Director of Thesis: 

ABSTRACT

Old Woman Creek National Estuarine Research Reserve and State Natural Area and Preserve, is a shallow, hypereutrophic Great Lakes coastal wetland on the western basin of Lake Erie, Ohio, U.S.A. Primary production was measured by several methods from 1987-1993 at Old Woman Creek. We assessed many commonly used techniques to determine primary production including diel oxygen changes, light and dark bottle incubations, chlorophyll a concentrations, and daily pH change. Using algal volume as an independent variable, analysis revealed that the best estimator of primary production was diurnal oxygen changes (r^2=0.940(NPP): r^2=0.661(GPP)). Because many of the normally used methods failed to provide reasonable estimates of primary production in this shallow hypereutrophic system, wetland scientists should be cautious when selecting a method of estimating water column primary production. This wetland also receives much non-point pollution, largely from agricultural runoff. These nutrients, specifically phosphorus and nitrogen, tend to increase primary

production and phytoplankton and periphyton volume where the creek enters the wetland. The effect of these nutrients is not as profound on primary production and algal communities at the output near Lake Erie. The presence of macrophytes, dominated by *Nelumbo lutea*, tend to be more important in changing relative species abundances in the phytoplankton communities, shifting the community structure from a euglenophyte to a diatom dominated community. The algal communities tend not to show successional species replacements throughout the year, but remain in an early successional stage, due to sediment perturbation and non-point nutrient inputs.

Accepted by: _____, Chair

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CHAPTER I:

Comparison of Methods of Measuring Water Column Production in a Great Lakes Coastal Wetland

1.1. Introduction

Although a number of studies have been done on primary production of the vascular flora wetlands, relatively few studies have been done on water column production. Wetland ecologists usually measure primary production using methods designed for use in terrestrial or deep water ecosystems. No studies have been conducted to determine if techniques commonly used to measure water column production in lakes and oceans are applicable to productive wetlands, although there are indications they may not (c.f. Hall and Moll 1975; Kemp and Boynton 1980). As ecotones, wetlands are recognized as having characteristics of aquatic and terrestrial systems; however, they also have unique biotic communities and hydrologies (Mitsch and Gosselink 1994). Aquatic flora in shallow water are often not under the same environmental constraints found in most deeper water systems. For example, many freshwater wetlands harbor extensive populations of epiphyton and periphyton, and nutrients are often plentiful. As a result, epiphytic and planktonic production in many freshwater wetlands may be orders of magnitude greater than in most lakes and the ocean. Consequently, it is possible that reliance on techniques designed for use in

lakes and oceans -- where production, respiration rates, algal volume and community structure are profoundly different -- may not provide reliable estimates to wetland scientists.

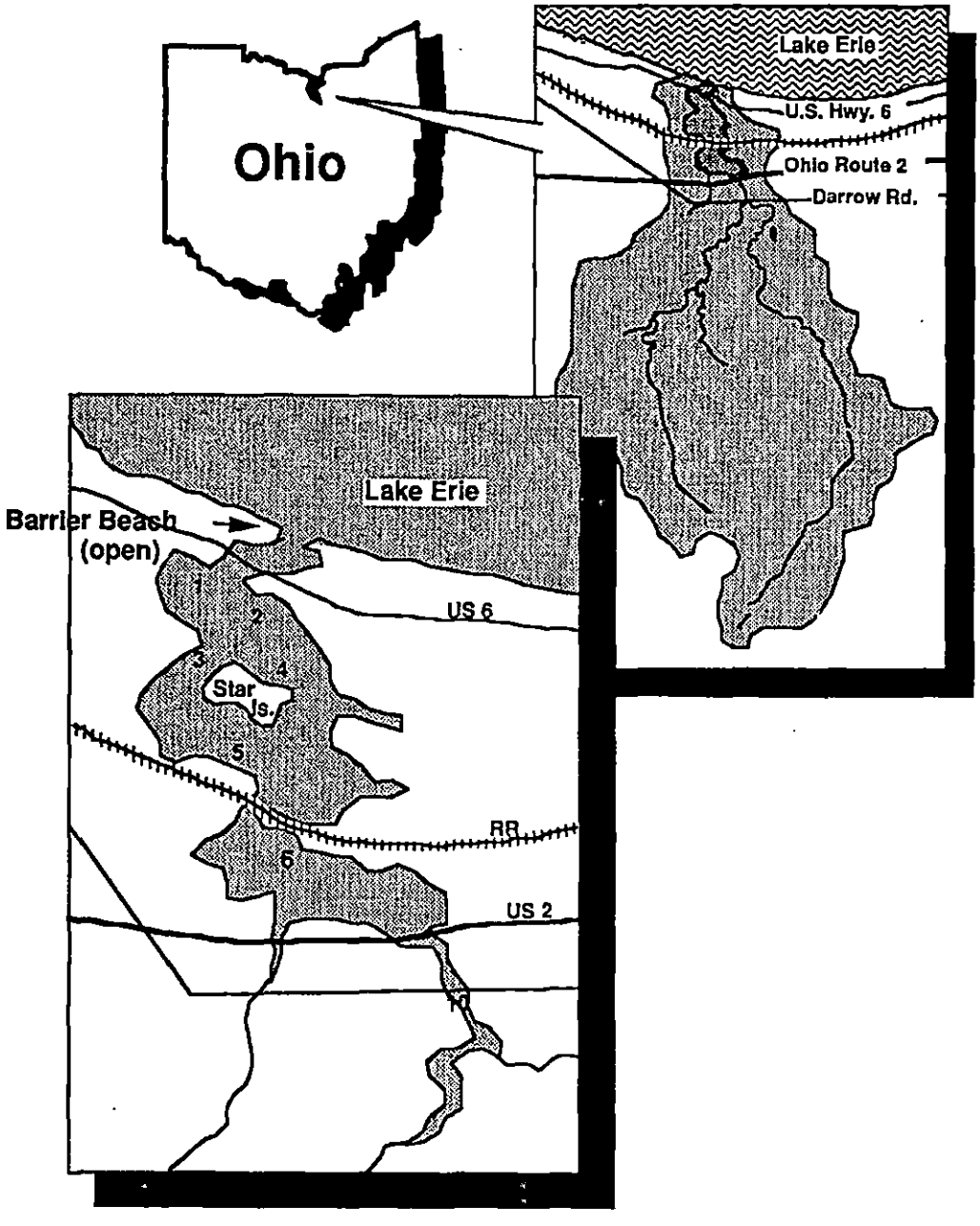
Because the products of photosynthesis determine the structure and production of all higher trophic levels, it is essential for wetland scientists to obtain reliable estimates of primary production. This is particularly critical in wetland biogeochemistry studies -- where "source, sink, transformer questions" are being examined. In such studies, estimates of *in situ* primary production can be helpful in elucidating ecosystem functions (Meyer and Edwards 1990; Reeder 1994). This study compares a number of commonly accepted methods of measuring *in situ* water column production in a shallow hypereutrophic freshwater wetland to determine which estimates most accurately reflect the status of the algal community.

1.2. Methods

1.2.1. Site Description

Old Woman Creek National Estuarine Research Reserve and State Natural Area and Preserve (Old Woman Creek) is a 56 ha wetland on the edge of western Lake Erie near Huron, Ohio, U.S.A. (Fig. 1). Depths in the wetland average about 0.5 m or less, but this can change dramatically (up to 1 m) throughout the year not only because of storm pulses from the watershed, but also because of adjacent lake level

Figure 1: Map of Old Woman Creek demonstrating sampling sites. Note railroad separating estuary, creating two distinct embayments. Barrier beach is semipermanent, typically open to Lake Erie in winter and closed during summer.



fluctuations and the activity of a barrier beach (which may be opened or closed by hydrologic events). The wetland remains closed to the lake throughout most of the growing season. Normally, less than 30% of the wetland is covered by the dominant macrophyte, *Nelumbo lutea*; therefore, this system is often dominated by open water primary producers, rather than macrophytes (despite its shallow conditions). The planktonic community is dominated by nanoplanktonic flagellates, euglenophytes, and small centric diatoms (Klarer and Millie 1994). Detailed site descriptions of the study area are available in Klarer and Millie (1989, 1992) and Mitsch and Reeder (1991, 1992).

1.2.2. Field and Laboratory Methods

Measurements of water column production were taken at various sites in the wetland during the 1987, 1988, 1992, and 1993 growing seasons. Water column production was estimated using six common techniques: 1) hourly diel oxygen changes 2) dawn-dusk-dawn oxygen changes; 3) diel pH changes; 4) bottle incubations; 5) chlorophyll *a* concentrations; and 6) algal volumes. Not all techniques were used in all years.

Because daily changes in products of metabolism are traditionally recognized as profound in hypereutrophic systems (Hall and Moll 1975), emphasis was given to diurnal oxygen change techniques to calculate production. When D.O. changes were used, corrections for diffusion were measured by using a floating dome (Copeland and

Duffer 1962). These rates were not sufficient to create any significant error in metabolism calculation; therefore D.O. change numbers are presented uncorrected for diffusion.

Production was calculated using rates of change every one to four hours (following the calculations of Fontaine and Ewel 1981), as well as using only dawn-dusk-dawn changes (following the calculations of Odum and Hoskin 1958). During 1987 and 1988 oxygen was measured using Winkler titrations at dawn and dusk, and in-between with a YSI 54A dissolved oxygen meter (calibrated against the Winkler D.O. measurements) at six sites (Fig. 1.). During 1992 and 1993 dissolved oxygen concentrations were measured using a Hydrolab DataSonde 3. The Hydrolab oxygen probe was air calibrated less than an hour before being deployed, then rechecked when the instrument was retrieved to correct for flux--which was always less than 0.2 mg l^{-1}.

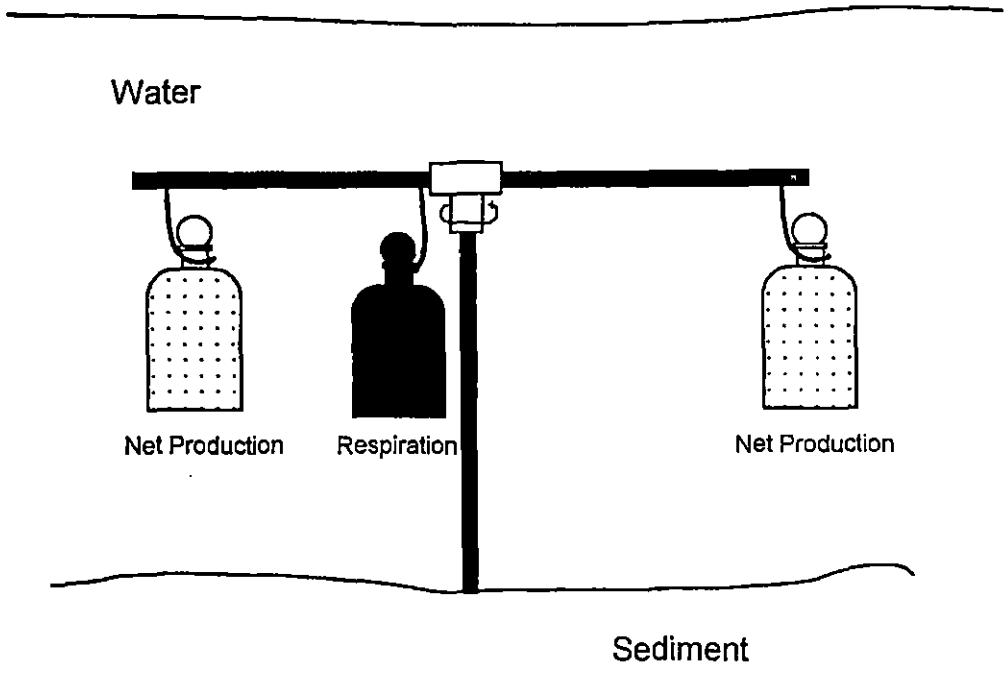
Diel pH changes were measured at dawn and dusk at six sites in 1988 and 1992, and at four sites in 1993. Fluctuations in pH provide an estimate of CO_2 metabolism in productive aquatic systems (Beyers and Odum 1959; Beyers 1964). During 1988, a Hach field pH meter was placed in the middle of the water column at each site at dawn and dusk. The instrument was calibrated at 4.00, 7.00, and 10.00 less than an hour before measurements. During 1992 and 1993 a Fisher Accumet 1003 field pH meter was used similarly. Additionally, during 1992 and 1993, hourly pH measurements were taken at two sites using the Hydrolab DataSonde 3. The probe was calibrated at 7.00 and the reference electrode checked less than one hour

before deployment. The pH probe accuracy was rechecked upon retrieval. Deviations in the standardization were never more than 0.2 pH units.

During 1992 and 1993 light bottle-dark bottle incubations were done between 10:00 a.m. and 4:00 p.m. (following the methodology of Wetzel and Likens 1991). Incubation times ranged from 2 to 5 hours. We chose to measure oxygen rather than ^{14}C uptake because the sensitivity provided by ^{14}C was unnecessary in such a highly productive system. Similarly, problems with ^{14}C uptake and subsequent respiration -- inaccuracies inherent in uptake measurements, are amplified in productive systems (Hall and Moll 1975). Because water turbulence usually stimulates production (Westlake 1967; Mann et al. 1972; Odum 1988; Campbell et al. 1991) bottles were attached to a rope which allowed some movement with wind and ambient water movement (Fig. 2).

Chlorophyll *a* concentrations were determined by filtering 100-300 ml of water through a 0.45 micron membrane filter and analyzing the pigments extracted in 90% alkalized acetone spectrophotometrically using a 4 cm path length cell. Filters were kept at $< 0°C$ in the dark and analyzed within 24 hours of collecting the sample. Chlorophyll concentrations were determined using Lorenzen's (1967) equation.

Figure 2: Light and dark bottle incubation apparatus. allowing the bottles to move freely with wind and water currents, which may help to stimulate production estimates, and reduce some of the bottle effects associated with this method of estimating open water primary production.



Algae were concentrated from 500 ml water samples and settled using Lugol's iodine. Algae were identified and enumerated using a Nikon light microscope equipped with Hoffman Modulation Contrast, at 400X and 630X. Measurements were made on at least 12 representative samples of each species, when possible, and volumes were calculated based on geometric shape equivalents (Wetzel and Likens 1991).

Statistics were run using StatView 4.02 software for the Apple Macintosh. For regressions, we used algal volume as an independent variable, because we felt it would be the best static indicator of water column production. All production measurements and concentrations are presented per unit volume in order to make comparisons less susceptible to depth factors. Each variable is compared to the algal volume determined at the same site on the same day.

1.3. Results

During 1987 and 1988 the average depth in the wetland was greater than in 1992 and 1993, despite a drought, because the barrier beach remained closed. During 1992 there was a high amount of rainfall, and the barrier beach was open to the wetland most of the growing season. Submerged aquatic vascular vegetation (SAV) was much greater in extent and diversity during the lower water levels in 1992-93 versus 1987-88.

Table 1: Mean (+/- sd) mid-summer primary production measurements at Old Woman Creek wetland, Ohio. GPP = Gross Primary Production, NPP = Net Primary Production

Method Year	Diel NPP	Diel GPP	DDD NPP	DDD GPP	Daily Δ pH	LBDB NPP	LBDB GPP	Chl. a	Algal Vol.
1987-88	7.9 (3.3)	24.4 (10.7)	7.2 (1.6)	26.0 (8.0)	1.3 (0.3)	---	---	156 (76)	---
1992*	6.9 (6.4)	17.0 (12.8)	3.2 (3.2)	9.2 (9.9)	0.9 (0.5)	7.6 (5.5)	15.1 (9.1	76 (42)	8.9 (5.3)
1993*	5.1 (3.2)	15.1 (9.3)	1.1 (1.5)	2.9 (3.5)	0.8 (0.4)	9.3 (8.2)	11.0 (8.2)	116 (73)	7.4 (3.8)

* Diurnals were only done at site 4, all other values are means for all sites.

Productivity in this wetland was very high during both high and low water years. Oxygen levels were more prone to go towards anoxia (<3 mg l^{-1}) during the high water (low inflow) years when compared to the lower water level (higher inflow, more Lake Erie interaction) years. Oxygen levels in the water often were below 2 mg l^{-1} for a few hours before dawn. On extremely productive days (>20 mg O_2 m^3 d^{-1}) oxygen levels could range from 33% saturation near sun-up to 137% before dusk. July and August appear to be the most productive months (having the highest algal volumes). Table 1 indicates that water column production has decreased with water level increases and invasion of SAV's.

Light and dark bottle incubations provided lower gross primary production estimates than diurnal measurements (mean = 11.1 mg O_2 m^3 d^{-1}). Dark bottles occasionally became nearly anoxic, and incubation times were shortened accordingly. The light and dark bottle incubations produced the highest estimates of production in June and July (Fig. 3); however, LBDB production estimates were typically not as high as those recorded by diurnal methods.

The daily change in pH produced values ranging from 6.7 -7.8. The average pH change was 0.98 units per day. This is a very large change considering this is a well buffered ecosystem. The largest pH changes (*ca.* 2) were recorded during the drought year (1988). The daily changes in pH tended to be the highest during June and July.

Figure 3: Mean monthly water column primary production estimates (+/-) for 1992-93 growing seasons at Old Woman Creek, Ohio. GPP = Gross Primary Production, NPP = Net Primary Production.

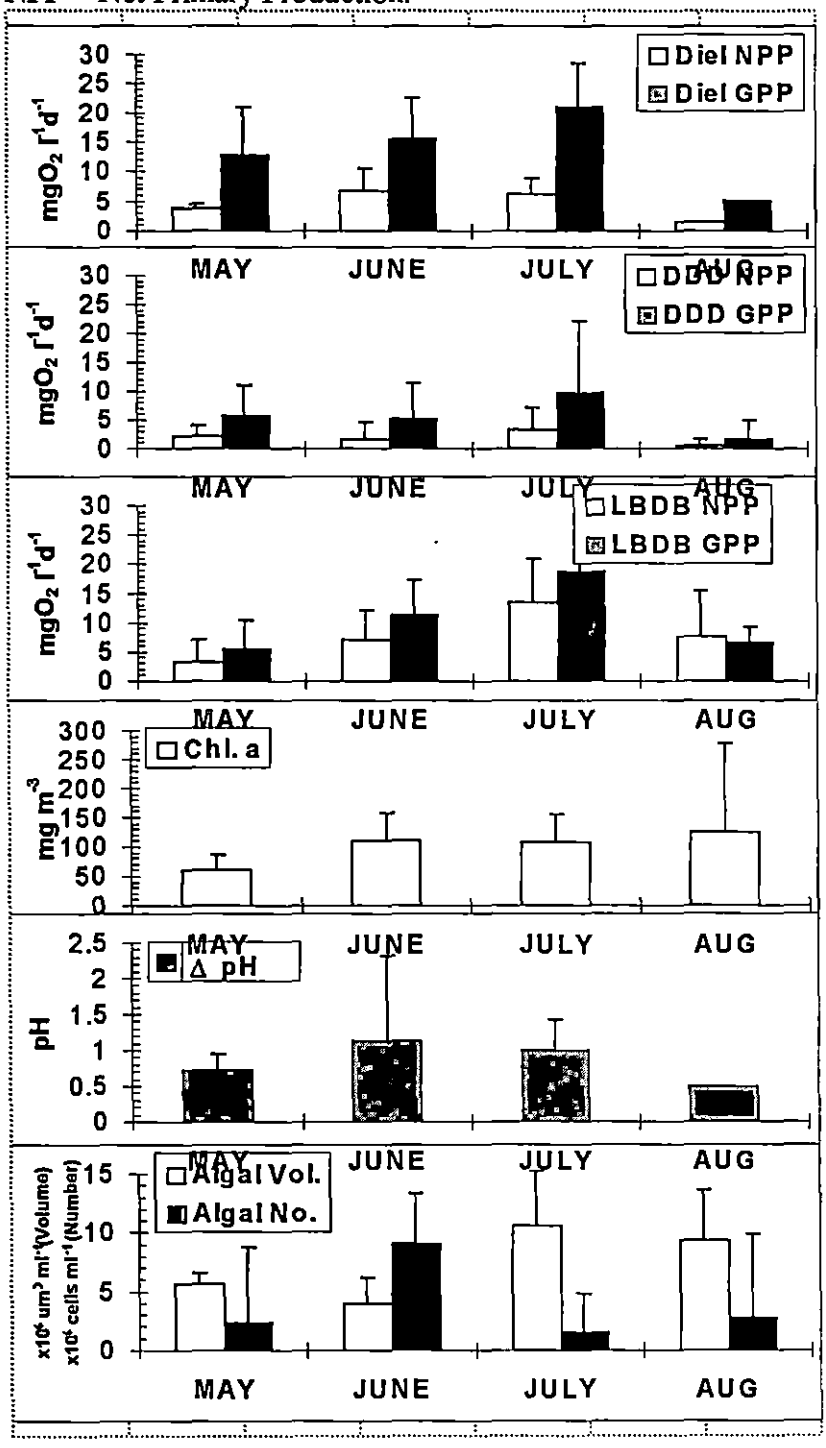


Table 2: Results of regression analysis indicating the relationship between the production estimate method and algal volume, showing that the diel estimates of production are the best estimates of primary production in this wetland.

Production Estimate	Regression Equation	R^2
Diel NPP	Diel NPP = -0.366 + 0.559 * Algal Volume	$r^2 = 0.940$
Diel GPP	Diel GPP = 0.286 + 1.694 * Algal Volume	$r^2 = 0.661$
Dawn-dusk NPP	DDD NPP = 0.718 + 0.111 * Algal Volume	$r^2 = 0.049$
Dawn-dusk GPP	DDD GPP= 1.148 + 0.391 * Algal Volume	$r^2 = 0.068$
Daily Δ pH	Daily Δ pH = 0.449 + 0.052 * Algal Volume	$r^2 = 0.394$
LBDB NPP	LBDB NPP = 7.20 + 0.167 * Algal Volume	$r^2 = 0.013$
LBDB GPP	LBDB GPP = 8.935 + 0.443 * Algal Volume	$r^2 = 0.067$
Chlorophyll a	Chl. *a* = 69.443 + 3.754 * Algal Volume	$r^2 = 0.073$

Chlorophyll *a* values are extraordinarily high when compared to other types of aquatic systems. Table 1 indicates that chlorophyll *a* values were highest during the drought year (1988). It was not unusual to have levels greater than 100 mg m^{-3} during the most productive periods. Algal volumes tended to be the highest in July and August and lowest during June in both the 1992 and 1993 growing seasons. The maximum algal volume was 15.9×10^6 μm^3 ml^{-1} in July of 1992 (mean = 7.09×10^6 μm^3 ml^{-1}). Algal populations were dominated by diatoms, euglenophytes, and small chlorophytes (even though the latter did not contribute as much to volume) during growing season. The small chlorophytes achieved their peak biomass in July and August at all sites. Diatoms and euglenophytes dominated the volume at nearly all sites throughout the growing season. Algal volumes were not recorded for the 1987 and 1988 growing seasons.

Regression analysis implies that the most commonly used indicator of production, chlorophyll *a*, is one of the least sensitive indicators of algal volume (Table 2). Similarly, bottle incubations were also very poor indicators of algal volume; however when respiration estimates were calculated in, the probability of predicting algal volume decreased. Second to diel oxygen production in predicting algal volume were dawn to dusk changes in pH. Dawn to dusk changes in dissolved oxygen did not provide good estimates of algal volume. Although only eight dates are included in the regressions for diurnal production, the other methods were not significant ($\alpha = 0.05$) when analyzed for the same eight sampling dates.

1.4. Discussion

1.4.1. Diel Changes

Diurnal oxygen was often the highest estimator of production and correlated well with algal volume. It is evident that oxygen concentrations must be measured every 2-4 hours, since dawn to dusk differences were not adequate to predict daily gross primary production. This is mostly due to the high production directly after daybreak, and respiration exceeding production later in the day. Cronk and Mitsch (1994), in recently constructed wetlands on the Des Plaines River, found that oxygen minimum and maximum provided the same estimate of production as full diurnals. At Old Woman Creek, dusk measurements were sometimes not much different than dawn measurements, even though significant changes occurred over the course of the daylight hours. Often the dawn and dusk measurements did not represent daily extremes. Full diels also allow the effects of differential light patterns (e.g. cloud cover or turbidity changes) to be taken into account.

Diurnal estimates of gross primary production in the water column produced values ranging from 4.3 - 48.3 mg $O_2 l^{-1}$ (mean = 20.3 mg $O_2 l^{-1}$). These values indicate this to be a very productive system. In another diel study of wetland production, Cronk and Mitsch (1994) found ranges of <1.0 mg $O_2 l^{-1}$ to 12.8 mg $O_2 l^{-1}$ in newly constructed freshwater wetlands in Illinois. Adjacent Lake Erie has productivity values from 100 - 15,867 mg $O_2 m^{-2} y^{-1}$ (Vollenweider et al. 1974) whereas

Old Woman Creek has much higher values of 2,150 - 24,150 mg $O_2m^{-2}y^{-1}$ (mean = 10,150 mg $O_2m^{-2}y^{-1}$). Although our values seem high when compared to other published rates of algal production in wetlands (for example Vymazal's (1995) comparisons of measured productions report the highest production in a hatchery pond: 150 - 10,000 mg $O_2m^{-2}d^{-1}$), we caution that the diurnal estimates may be much higher than measurements obtained with incubation techniques, or by using chlorophyll as a surrogate for production.

Because the diel oxygen method was measuring epiphytic, planktonic, and vascular plant metabolism, it may be overestimating water column production. However, when years with low aquatic plant growth are compared to the relatively high year of 1993, there is little significant difference. It may be that epiphytes are not as important as phytoplankton, in O_2 / CO_2 changes in this wetland.

When production levels were highest (1987-88) dawn-dusk-dawn calculations provided an estimate of daily production similar to hourly measurements. As vascular plant invasion increased, and water column production decreased, dawn to dusk changes failed to reflect diurnal changes. This could be because we have a greater variability with sunlight and production throughout the day or because turbidity created greater variations in daily production (Reeder 1990; Heath 1992).

We found little relationship between insolation and algal production. This is not unusual, Fennessey et al. (1994) did not find a correlation between insolation and algal production (as measured by oxygen flux) in the Des Plaines River constructed

wetlands. Berger (1989), in a blue-green algae dominated shallow lake in the Netherlands, also found no relationship between production and either insolation or temperature. This suggests that standard models of algal production (e.g. Bannister 1974; Vollenweider 1974) may not be applicable to wetland studies.

Measurable changes in pH in a well buffered system, such as Old Woman Creek, show that it is a good general estimate of production. Changes in pH show the same trend of decreasing with production in different years. Based on stable isotope data in a Lake Superior estuary, Jan Keough (in review) has shown that submerged aquatic vegetation recycles respired carbon. This could be increased by utilizing HCO_3^- as a carbon source. Similar evidence has been seen for macrophyte uptake of bicarbonate in Old Woman Creek (David Francko, pers. comm.).

1.4.2. Bottle Incubations

Kemp and Boynton (1980) noted that isolating some wetland systems in containers would give inaccurate measures of primary production. We found that bottle incubation production rates were similar to measurements obtained using diurnal oxygen, but respiration rates were often lower. It would be convenient to assume that chlorophyll *a* and light and dark bottle incubations were measuring production of planktonic algae, and that the extra production measured with whole system oxygen measurements represents epiphytic, macrophytic, and benthic metabolism. However, in Old Woman Creek, benthic algae can be resuspended into the water column during

storms and due to wind (Krieger and Klarer 1991). If it is assumed that the higher measurements obtained using diel oxygen techniques represented the contribution of both bottled and non-bottled components to oxygen change, we could also expect that bottle incubations of algae would correlate with open water algal volumes and/or chlorophyll. Since they do not , we suggest that the dynamic water action created in shallow water by winds (Krieger and Klarer 1991; Heath 1992; Klarer and Millie 1992) and biota (King and Hunt 1967; Heath 1992) must remain intact to allow the algae to get natural light and nutrient concentrations. Bottles eliminate both of these production enhancing conditions.

Because the rates of photosynthesis showed considerable daily variation, we would surmise that if bottle incubations are to be used in wetland studies, multiple incubations should be employed over the course of the day -- so that production can be evaluated over the entire daylight period. In this wetland, light bottles may reach over 100% O_2 saturation after incubating a couple of hours; consequently, performing multiple incubations over the course of a Summer day could be labor intensive. Another problem with bottle incubations may be daily variability in production; changes in turbidity and insolation cannot be accounted for in the short time the bottles can be left out.

1.4.3. Chlorophyll *a* Measurements

Chlorophyll *a* measurements, one of the most common estimates of biomass and correlated to primary production, did not seem to coincide with estimates of production in this wetland. Therefore, the assumption is often that since chlorophyll *a* is the ultimate acceptor of energy from electrons excited by sunlight, it should correlate with production and carbon uptake. However, when chlorophyll *a* is not used to normalize the data, it has not correlated with other measures of production in wetland studies (Hall and Moll 1975; Bott et al. 1978; Berger 1989; Fennessy et al. 1994), and we would caution against its use as an estimate of primary production in wetland studies.

The reasons for this lack of correlation are numerous. For example, algae represent a taxonomically and biochemically diverse group, which have a long evolutionary history. Little is known about the metabolism of many common species. In this study, we recorded over 70 algal species, which may not be unusual in a wetland. Due to the energy capturing variability with the various accessory pigments, it seems reasonable to assume that chlorophyll *a* may not be the dominant pigment in highly productive ecosystems.

Chlorophyll *a* is probably also not a good estimate of biomass in wetlands. For example, many shallow water bodies have high turbidity due to algae and other suspended material, and algae can also be shaded by macrophytes or other algae. It could be that light limited algae respond to low light conditions by increasing

chlorophyll production, only to reduce it when light levels are high again. Cells adapted to high light levels have less chlorophyll per cell, than do those grown at low light conditions (Wassink 1959). In *Chlorella pyrenoidosa* a doubling of light intensity reduced the amount of chlorophyll per cell an order of magnitude, with a negligible increase in production (Steemann Nielsen and Jorgensen (1968), as cited in Wetzel (1983)). Photosynthetic efficiency also increases in dim light conditions. This could be due to photoinhibition during high light conditions, or the inability to capture all the available energy. The dominant algal taxa in this study (by volume) used chlorophyll *a* as the major pigment. However, given the phenomenal concentrations of algae (compared to lakes and the ocean), even if only 25% of the pigment concentration was other pigments, it could result in a significant underestimate of production.

1.4.4. Unique Ecology of Old Woman Creek

The factors specifically limiting the phytoplankton production in Old Woman Creek is enigmatic. Nutrients, specifically nitrogen and phosphorus (Shindler 1980), are often limiting to production in aquatic systems. Heath (1992) showed that phosphorus is most likely not the limiting nutrient at OWC. All other nutrients appear to be plentiful as well. In fact, Klarer and Millie (1992) found storm events resulted in a rapid growth of the phytoplankton population. The storms may enhance production by increasing nutrients and flow (Klarer and Millie 1992), reducing zooplankton

(Krieger and Klarer 1991) and the lack of flushing with increased flow due to the unique hydrology (Klarer and Millie 1994). Also, agricultural runoff may lead to increased levels of pesticides in Old Woman Creek, which may hamper primary production. The main factor limiting to phytoplankton production at Old Woman Creek appears to be sunlight, due to the high turbidity levels measured (typically 60-80 NTU (Heath 1992)). Therefore, the factors limiting phytoplankton production in Old Woman Creek are complicated and may vary throughout the year.

The effect of zooplankton grazing must be considered as a method to regulate phytoplankton production. Zooplankton grazing appears to be less important early in the year, when zooplankton populations are kept in check by agricultural storm runoff (Krieger and Klarer 1991). In turbid waters, such as Old Woman Creek, zooplankton may have more difficulty foraging on phytoplankton due to decreased successful capture per unit effort, resulting in a decrease in zooplankton and a corresponding increase in phytoplankton biomass. If the zooplankton are limited in their ability to harvest phytoplankton, a corresponding reduction in fish standing crop should result (Carpenter et al. 1987). Havens (1993) measured both top-down, (fish removal) and bottom-up effects (sediment perturbation) on Old Woman Creek phytoplankton biomass. He demonstrated that fish can increase the algal biomass, measured by chlorophyll *a*, by reducing the number of planktivores. Havens ascribes the increase in chlorophyll *a* to cascading trophic interactions, and benthic nutrient recycling; however, the possibility that the phytoplankton concentrate the amount of chlorophyll

per cell in highly turbid, light limiting conditions, was not considered. The treatments with a net covering the sediments resulted in much less of an increase in chlorophyll *a*. This fact may be considered largely influenced by the absence of benthic nutrient recycling, as indicated by Havens (1993), however, concentration of chlorophyll in phytoplankton may be significant.

1.5. Conclusion

Measuring primary production in wetlands is of utmost importance in assessing the value of wetlands as nutrient sources, sinks, or transformers; as well as understanding gross ecosystem function. Accurately measuring primary production in wetlands presents problems not encountered in lakes or terrestrial ecosystems. In summary, mean values suggest that all methods of measuring production provide similar estimates. Although there is a great deal of variability in all the measurements, the data suggests open water dissolved oxygen changes provide the best estimate of open water primary production. Further, we would caution against the use of bottle incubations or chlorophyll *a* to estimate open water primary production in wetlands.

CHAPTER II

Effect of Non-Point Pollution on Planktonic Community Structure in Old Woman Creek

2.1. Introduction

Coastal wetlands along the Great Lakes have been subjected to a number of perturbations -- including diking, drainage, introduction of exotic species, and increased pollution loading -- especially non-point runoff. Along western Lake Erie, non-point pollution is a concern both to the lake and adjacent coastal wetlands. There has been much focus on the eutrophication of Lake Erie, and many algal studies have been performed on the lake (Tiffany 1934, Chandler 1940, 1942, 1944, and Munawar and Munawar 1976); however, there have been relatively few on coastal wetland phytoplankton. There is a paucity of accurate information on the effects of non-point pollution on functional biodiversity and ecology of these estuarine systems.

Research has been conducted on spatial variability in nutrient concentrations in Old Woman Creek National Estuarine Research Reserve and State Natural Area and Preserve (Old Woman Creek). The sites nearer the inflow have nutrient concentrations (Nitrogen and Phosphorus) greater than those found at the outflow into Lake Erie (Heath 1987; Richards and Baker 1985; Mitsch et al. 1989; Reeder 1990). Klarer (1988) found nutrient retention to be particularly apparent during storm events,

which are also known to export plankton (Kreiger and Klarer 1991). None of these studies examined the effect of the increased nutrients on biodiversity within the estuary.

There are many factors that may effect phytoplankton and periphyton community structure in wetlands. Klarer and Millie (1994) found the effect of storms on phytoplankton communities at Old Woman Creek. They showed that storm events tend to export plankton to Lake Erie, and that the upper estuary (nearer the input) recovers more slowly than the lower estuary (near Lake Erie) due to more scouring and fewer refugia in the upper estuary.

Havens (1991) showed that fish may be important in resuspending nutrients from the sediments, maintaining the algal communitites in an immature state, with relatively small algal species. Havens (1991) also showed that if sediment nutrients were denied to the algal communities larger algal species became dominant. Other factors, such as non-point nutrient loading may also be important in determining algal community structure.

Evidence suggests that high nutrient loads affect species composition. It has been shown in lakes that increasing the trophic status of the lakes changes the algal community structure (Wetzel 1983). Nitrogen to phosphorus ratios have been shown to be important regulators of phytoplankton communities (Smith 1983). High N:P ratios have been shown to favor green algae, whereas low N:P ratios tend to favor blue-green algae for their nitrogen fixing abilities (Schindler 1977, Smith 1983,

Reynolds 1978b in Reynolds 1984). Nitrogen is also found in high concentrations at Old Woman Creek resulting in high N:P ratios exemplified by the dominance of green algae and the scarcity of blue-green species (Klarer 1985). However, if the nonpoint runoff brings in copious amounts of herbicides and pesticides, we may see declines in community volumes, especially at sites nearer the "source" of the nonpoint pollution.

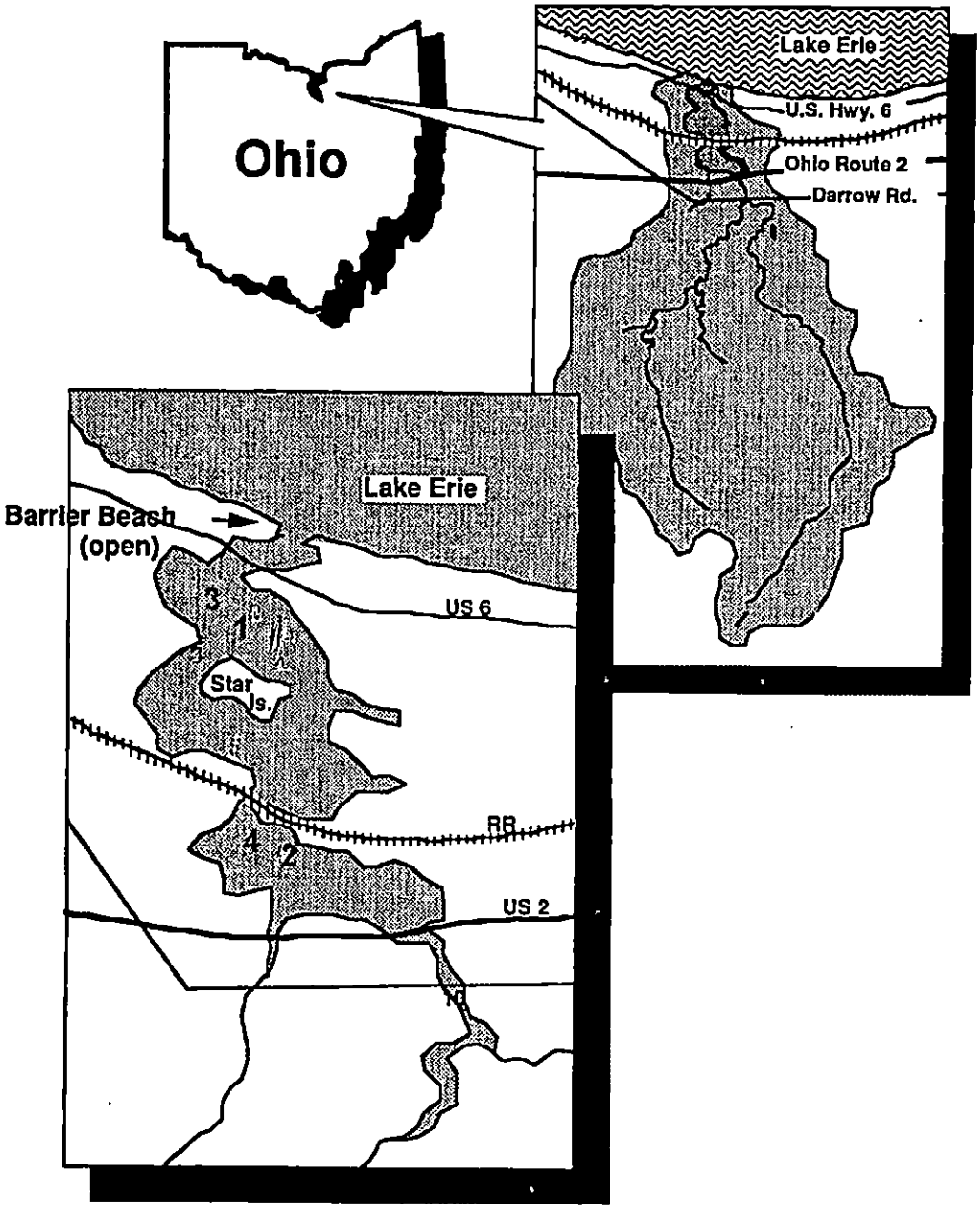
The goal of this research is to quantify the effect of non-point pollution on diversity of the Old Woman Creek Estuary, and to determine the effects on community structure in phytoplankton and periphyton.

2.2. Methods

2.2.1. Site Description

Old Woman Creek National Estuarine Research Reserve and State Natural Area and Preserve (Old Woman Creek) is a 56 ha wetland on the edge of western Lake Erie near Huron, Ohio, U.S.A. (Fig. 4.). Depths in the wetland average about 0.5 m or less, but this can change dramatically (up to 1 m) throughout the year not only because of storm pulses from the watershed, but also because of adjacent lake level fluctuations and a barrier beach which may be opened or closed by hydrologic events. Normally, less than 30% of the wetland is covered by the dominant macrophyte, *Nelumbo lutea*; therefore, this system is often dominated by open water primary producers, rather than macrophytes (despite its shallow conditions). Detailed

Figure 4: Map of Old Woman Creek, showing sampling sites 1 and 3 in the lower estuary and sites 2 and 4 in the upper estuary. Sites 2 and 3 are in macrophyte beds, whereas sites 1 and 3 are in open water.



site descriptions of the study area are available in Klarer and Millie (1989, 1992) and Mitsch and Reeder (1991, 1992).

To study the effect of non-point pollution on the community structure of the phytoplankton, we selected sites in the front and rear of the wetland. The rear sites are separated from the front of the wetland by a railroad bed, effectively dividing the wetland into two distinct basins. The back sites receive nonpoint pollution from the creek. The railroad bridge acts as a restriction to hold water and suspended sediments in the upper estuary. The front sites are near the wetland barrier beach in the lower estuary at the output into Lake Erie. Careful attention was paid to select sites of the same depth, to eliminate depth effects. At each site, samples were taken in and out of the macrophyte beds, to determine if there is a difference in community structure.

2.2.2. Field and Laboratory Methods

Sampling was performed from 12 May 1993 to 11 August 1993 at each of the four sites. To sample the phytoplankton at each site, 500 ml of Old Woman Creek water, collected with a 5 liter Van Dorn sampler, was fixed with Lugol's iodine and allowed to settle in 500 ml Nalgene bottles. The algae-free water from the bottles was evacuated by siphoning from the top, being cautious not to disturb the settled algae. The volume of this algal slurry (about 60 ml) was homogenized and 2 subsamples of known volume were mounted on slides. Algae were identified and enumerated using a Nikon light microscope with Hoffman Modulation Contrast, generally at 630X.

Species determinations were made using Prescott (1982), Tiffany and Britton (1952), and Tiffany (1934). To estimate algal volume, measurements were made on at least 12 representative taxa, when possible, and compared to equivalent geometric shapes to calculate the average species volume (Wetzel and Likens 1991).

Periphyton samples were collected on artificial substrate at the front and back sites. Floating periphyton samplers suspended microscope slides in the water column for at least 3 weeks before collection of the slides for examination. One slide was randomly removed from a sampler at each sampling date and immediately placed in 10% ethyl alcohol. The periphyton were removed with a razor blade and a slurry of a known volume was prepared for microscopic analysis as indicated above (APHA 1985).

Nutrient measurements included total phosphorus (TP) and soluble reactive phosphorus (SRP), nitrate (NO_3), nitrite(NO_2), and ammonia (NH_3). SRP was determined as molybdate reactive phosphorus (Murphy and Riley 1962). TP was determined as orthophosphate released after digestion with ammonium persulfate (APHA 1985). Ammonia was analyzed using the phenate method (Weatherburn 1967). Nitrate + nitrite nitrogen species were determined by passing the samples through a cadmium reduction column. Nitrate concentrations were determined by subtracting the nitrite concentrations from the combined nitrogen concentrations after all nitrogen species were reduced to nitrite and measured spectrophotometrically.

Total inorganic nitrogen (TIN) was determined by combining nitrate, nitrite, and ammonia concentrations.

To assess any community differences in diversity, several diversity indices were calculated, including number of species per site (species richness), Margalef, Inverse Simpson's, and Shannon diversities.

2.3. Results

Nutrients in the wetland were typically higher in the back sites than the front sites due to non-point loading. Total phosphorus was highly variable throughout the growing season ranging from 35-178 μgl^{-1}, however all sites were high in August (Fig. 5). The back sites (111.9 ± 35.4 μgl^{-1}) were significantly higher in TP concentrations than the front sites (91.5 ± 39.0 μgl^{-1}). Temporally, SRP ranged from 9-64 μgl^{-1} throughout the growing season, with the highest concentration in June (Fig. 6). SRP was higher at the back sites (mean = 27.6 ± 15.9 μgl^{-1}) than the front sites (mean = 25.5 ± 11.3 μgl^{-1}); however there were no significant differences in SRP in versus out of the macrophyte beds. Nitrite showed that the back sites (mean = 43.1 ± 45.5 μgl^{-1}) were significantly higher than the front sites (mean = 18.5 ± 18.4 μgl^{-1}), and were the highest at all sites during June (Fig. 7). The mean of the back site nitrate measurements (103.4 ± 179.0 μgl^{-1}) are greater than twice that of the front sites (mean = 37.8 ± 33.0 μgl^{-1}), however, due to a large variability, there is no significant

Figure 5: Total Phosphorus (TP) at Old Woman Creek, 1993.

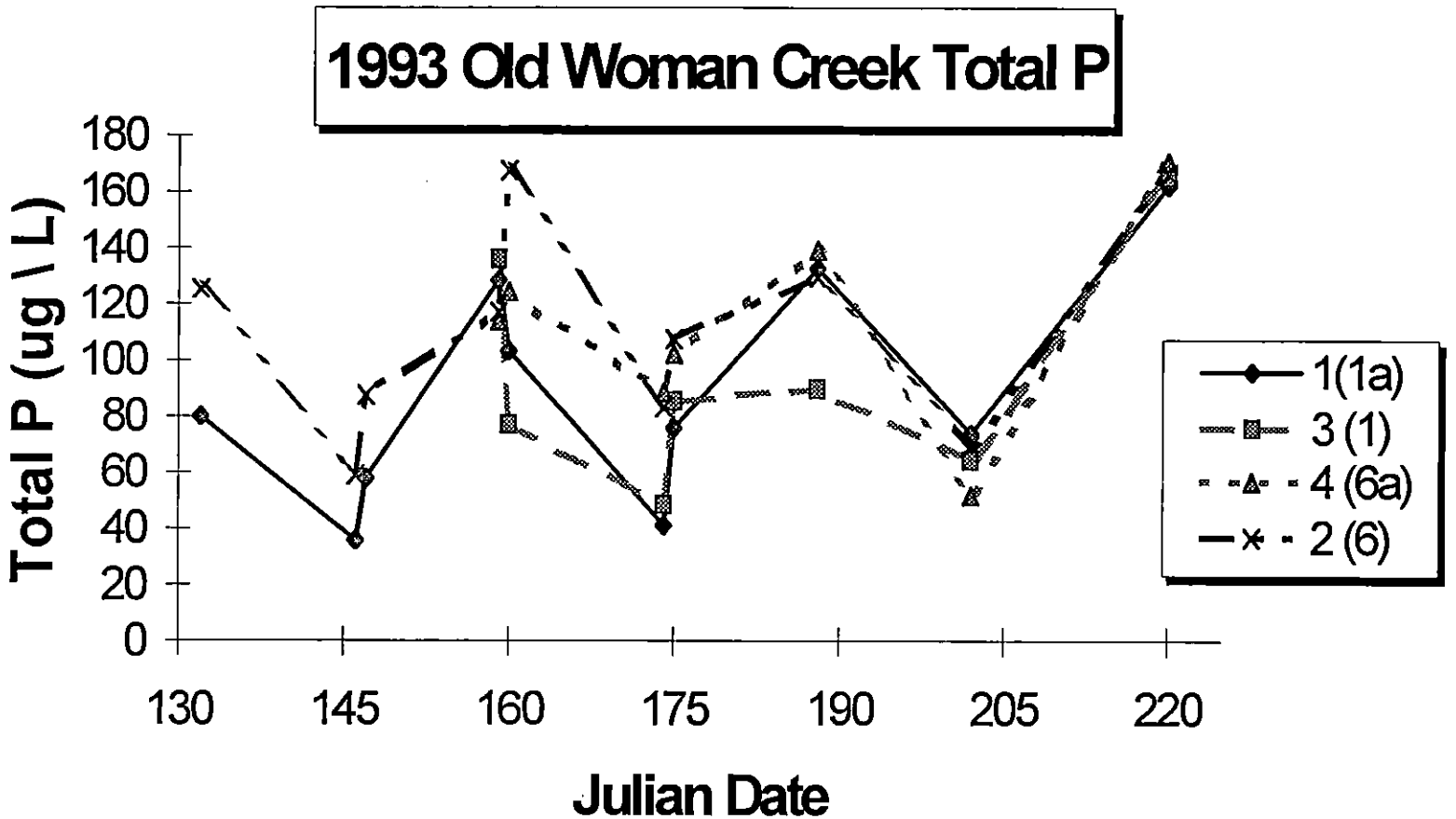


Figure 6: Ortho-phosphate (SRP) at Old Woman Creek, 1993.

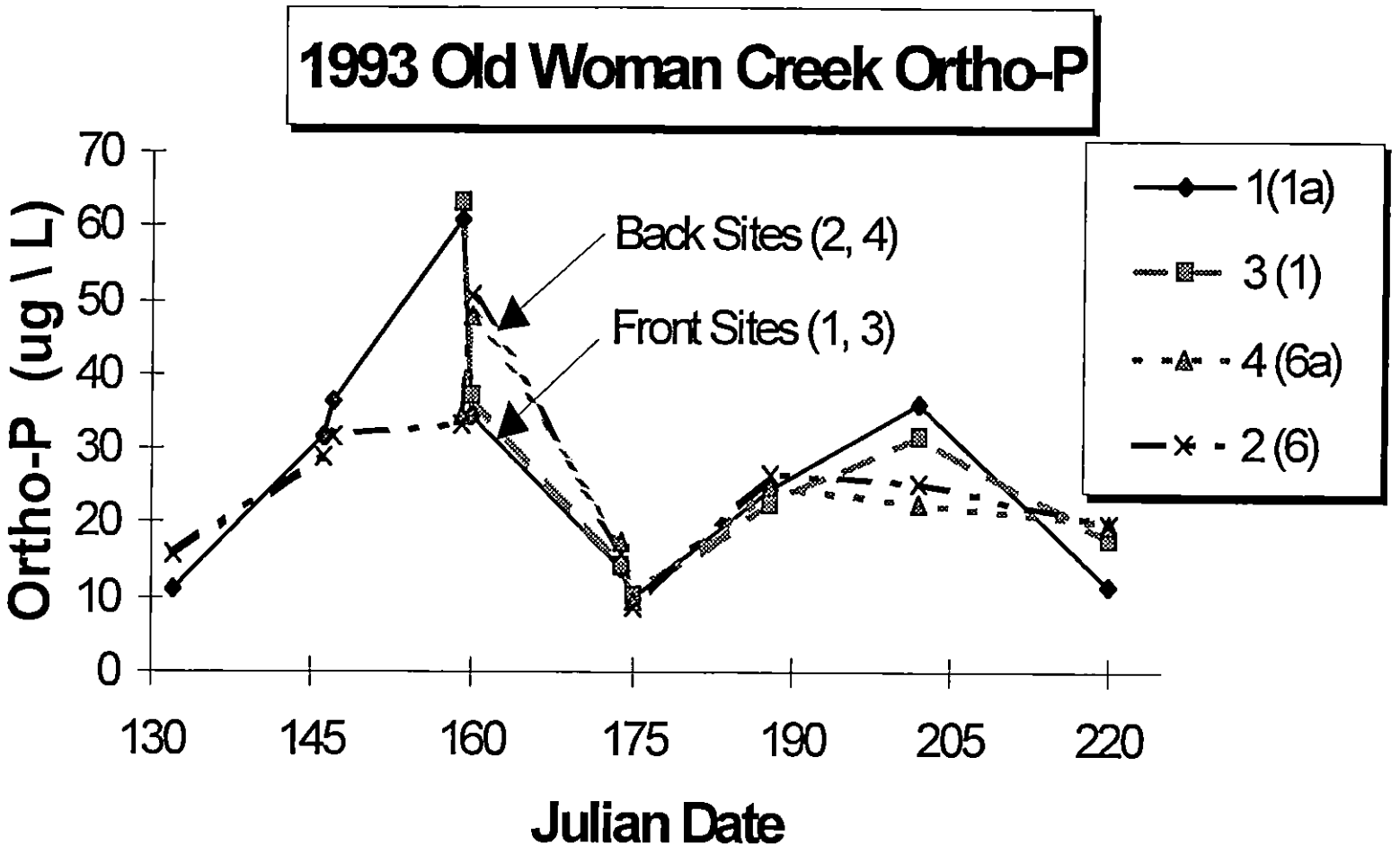
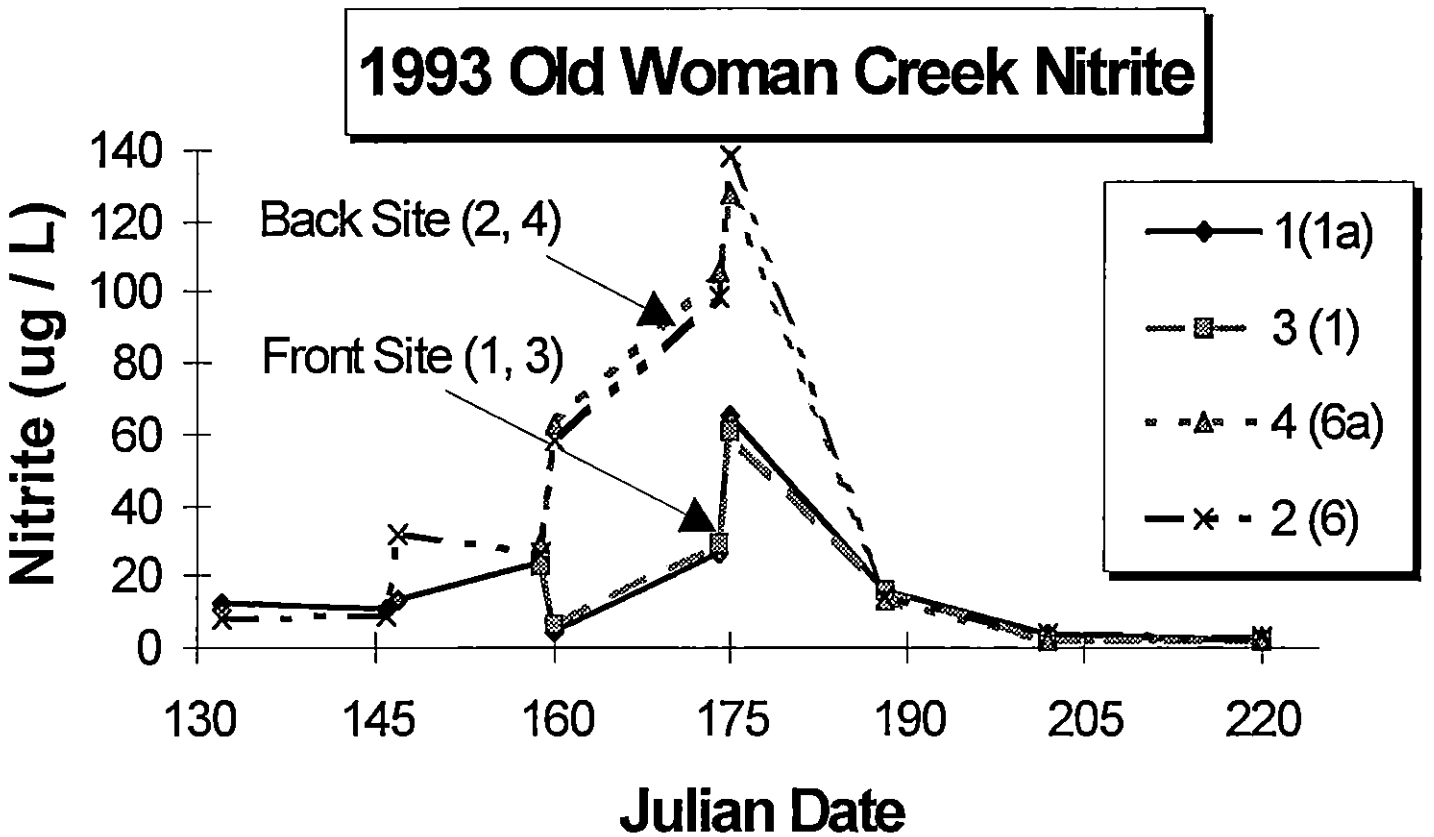


Figure 7: Nitrite (NO_2) at Old Woman Creek, 1993.



difference in the means (Fig. 8). Nitrate concentrations were relatively steady throughout the growing season (mean = 70.6 μgl^{-1}), except for a huge increase of nitrate at the back sites during early June that was not present at the front sites. Total inorganic nitrogen exhibits a similar pattern to that of the nitrates (Fig. 9), that is, the back sites (mean = 276.0 ± 248.1 μgl^{-1}) are much higher than the front sites (mean = 163.4 ± 69.0 μgl^{-1}), however there is no significant difference in the means, and it showed the same temporal trend as nitrate. Ammonia exhibited no statistically significant spatial variability; however it was the greatest at all sites in late June and early July, and lower in May and August (Fig. 10).

The phytoplankton volume was the greatest during August, when production was generally lower than in June and July (see figures 11-14). The algal volumes of the back sites (9.013 x 10^6 $\mu m^3 l^{-1}$) were significantly higher than the front sites (5.916 x 10^6 $\mu m^3 l^{-1}$), however there were no significant differences in versus out of the macrophyte beds. Table 3 shows the occurrence of phytoplankton taxa during the sampling period. Many species appear to be present at nearly all sites throughout the sampling period. Common chlorophytes included *Ankistrodesmus* sp., *Lagerheimia* sp., and *Scenedesmus* sp. Other common species included *Cryptomonas erosa*; diatoms, such as *Cyclotella menegheniana*, *Diploneis* sp., *Melosira* (=*Aulacoseira*) sp., *Navicula* sp, and *Nitzschia* sp. Some species were typically located at the front sites, such as *Treubaria setigera*, however, patterns were not well-

Figure 8: Nitrate (NO_3) at Old Woman Creek, 1993.

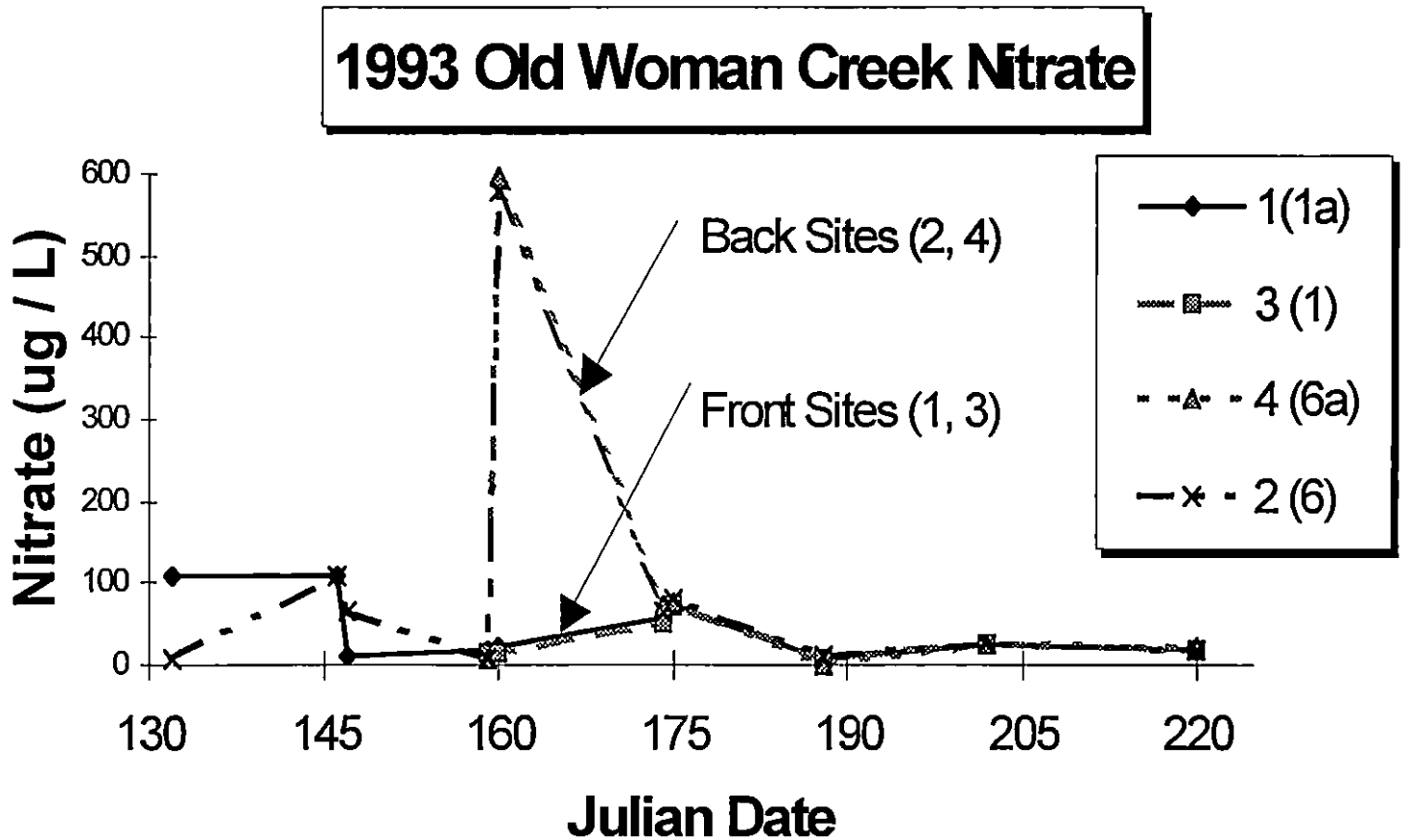


Figure 9: Total Inorganic Nitrogen (TIN) at Old Woman Creek, 1993

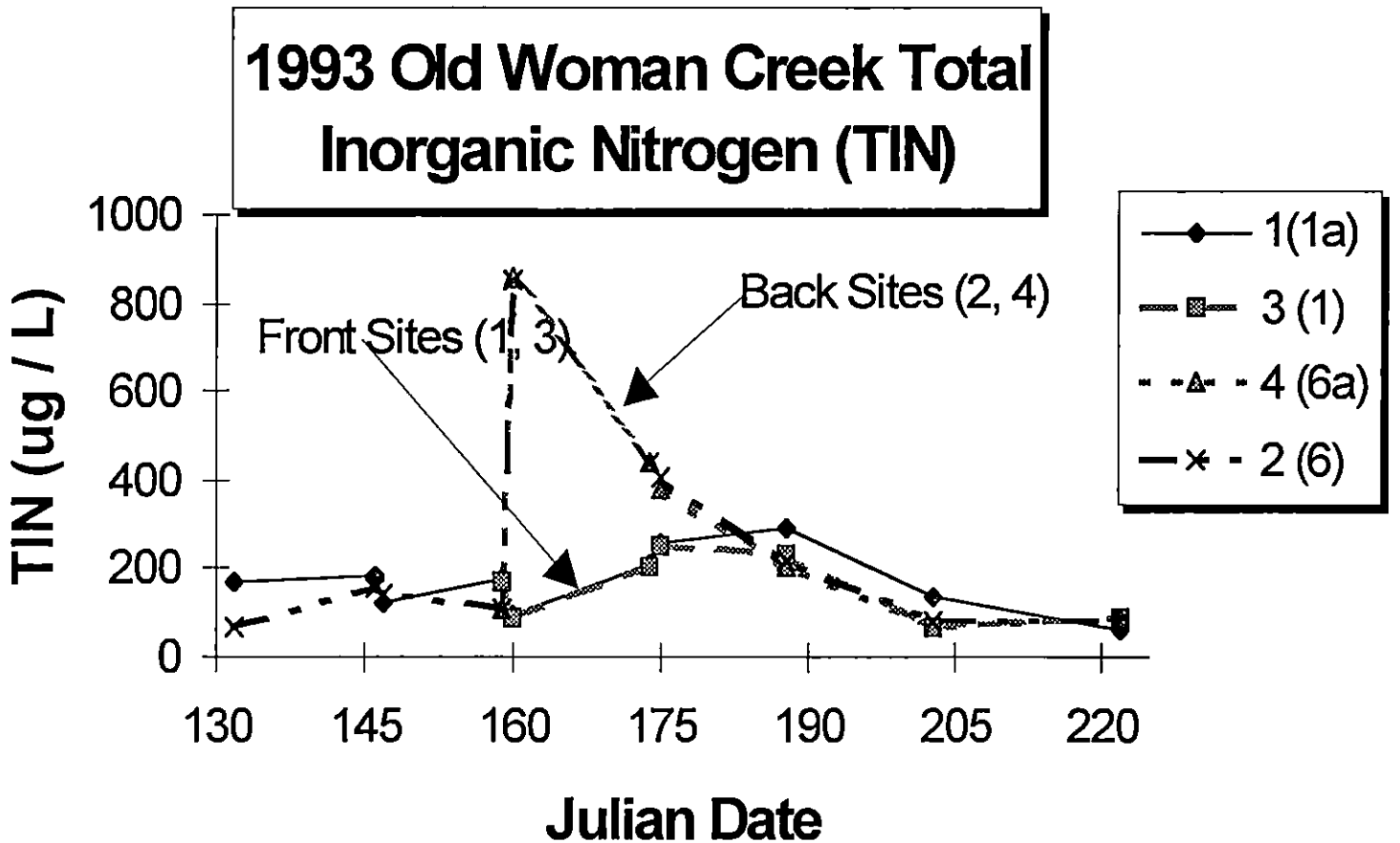


Figure 10: Ammonia (NH_3) at Old Woman Creek, 1993.

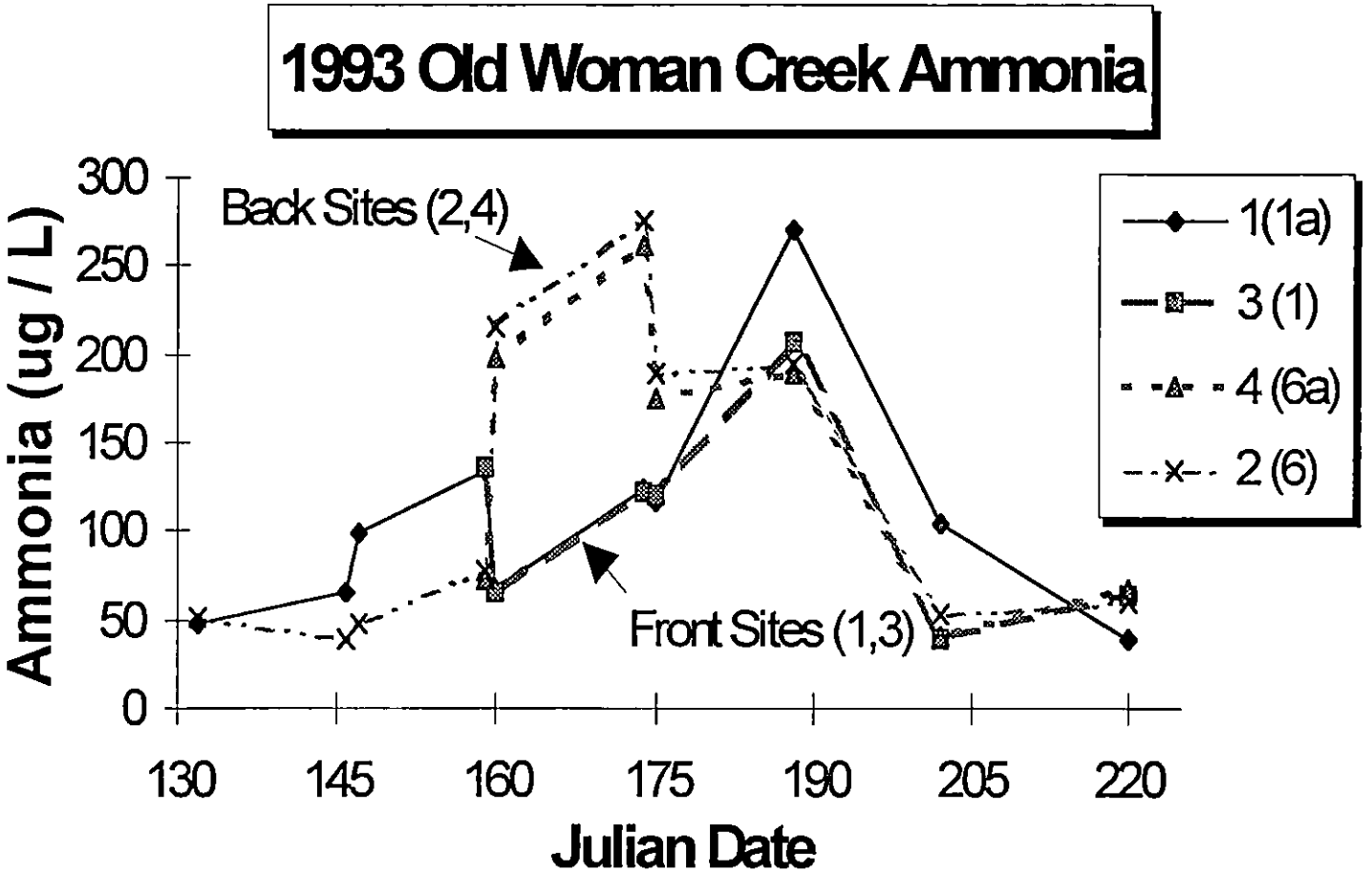


Figure 11: Phytoplankton volumes at Old Woman Creek, 1993 -- Site 1.

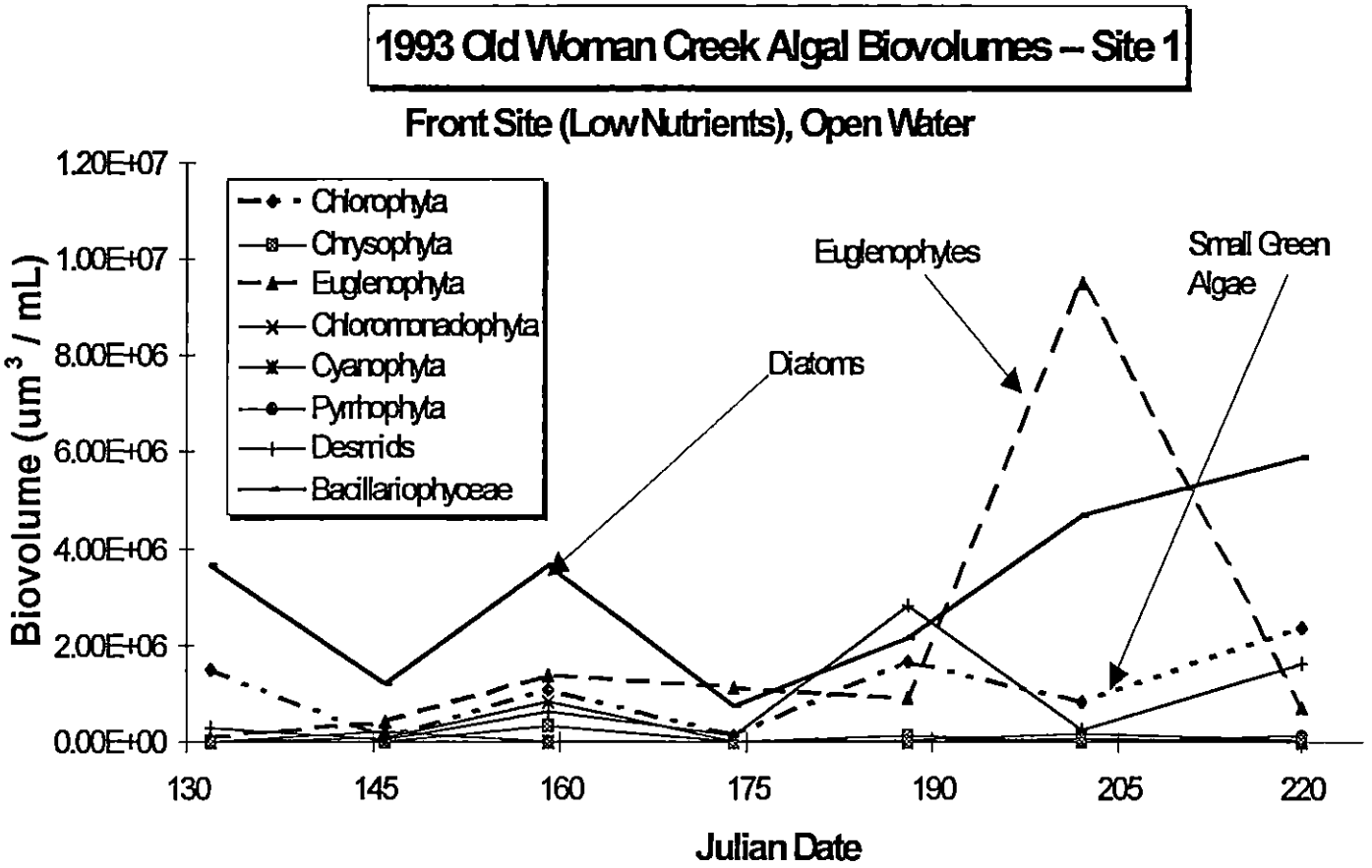


Figure 12: Phytoplankton volumes at Old Woman Creek, 1993 -- Site 2.

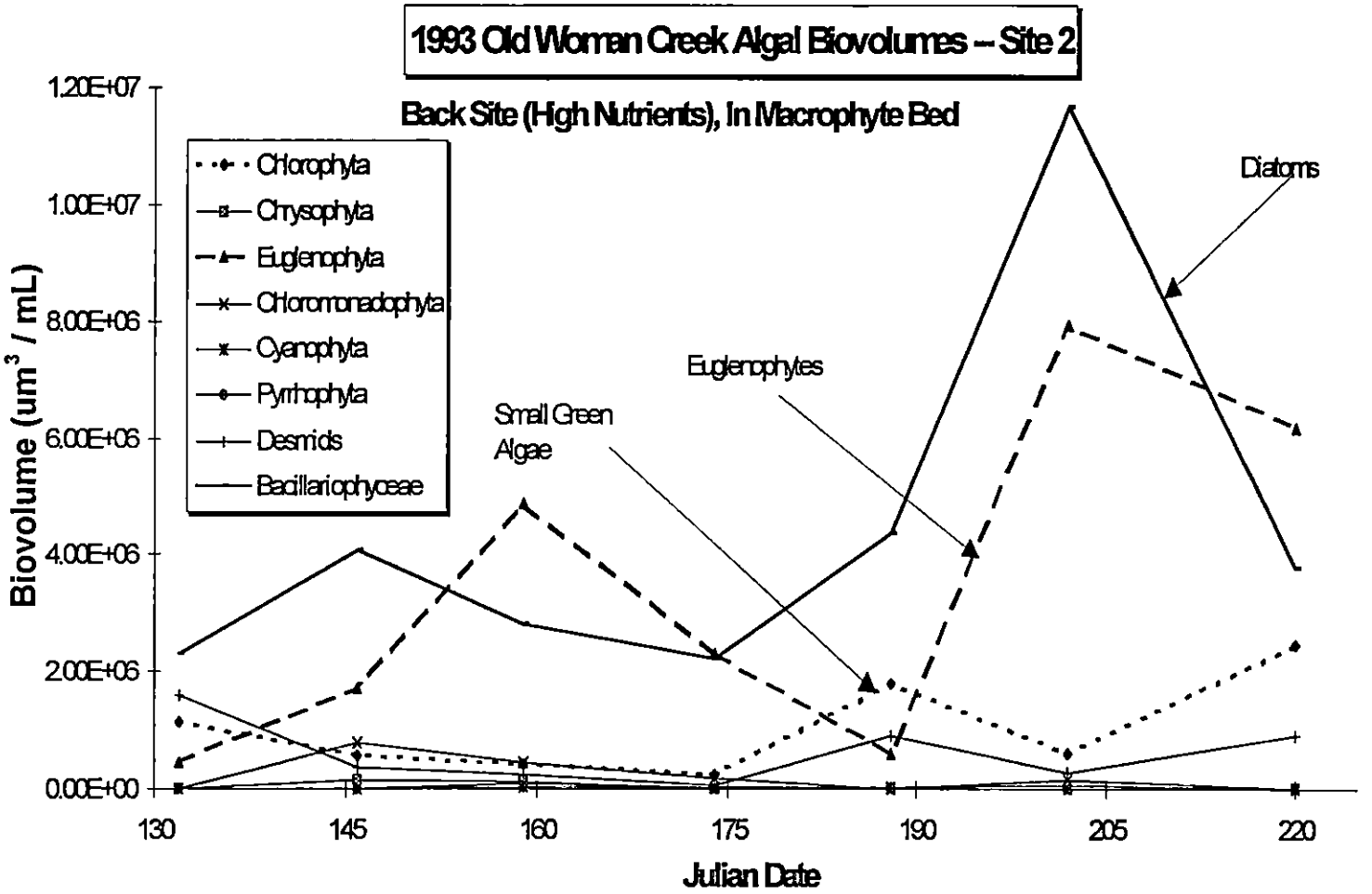


Figure 13: Algal Volumes at Old Woman Creek, 1993 -- Site 3.

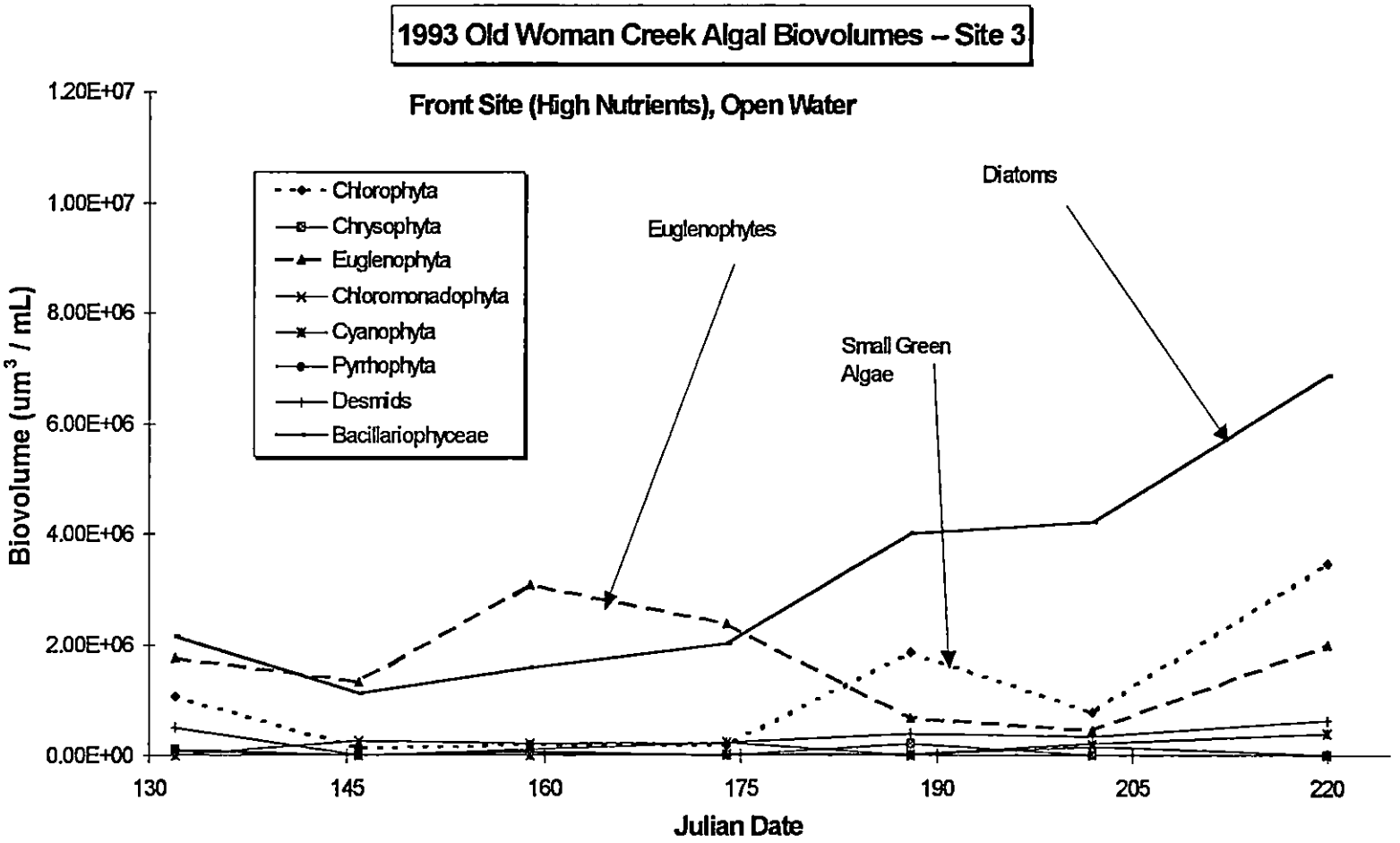


Figure 14: Algal Volumes at Old Woman Creek, 1993 -- Site 4.

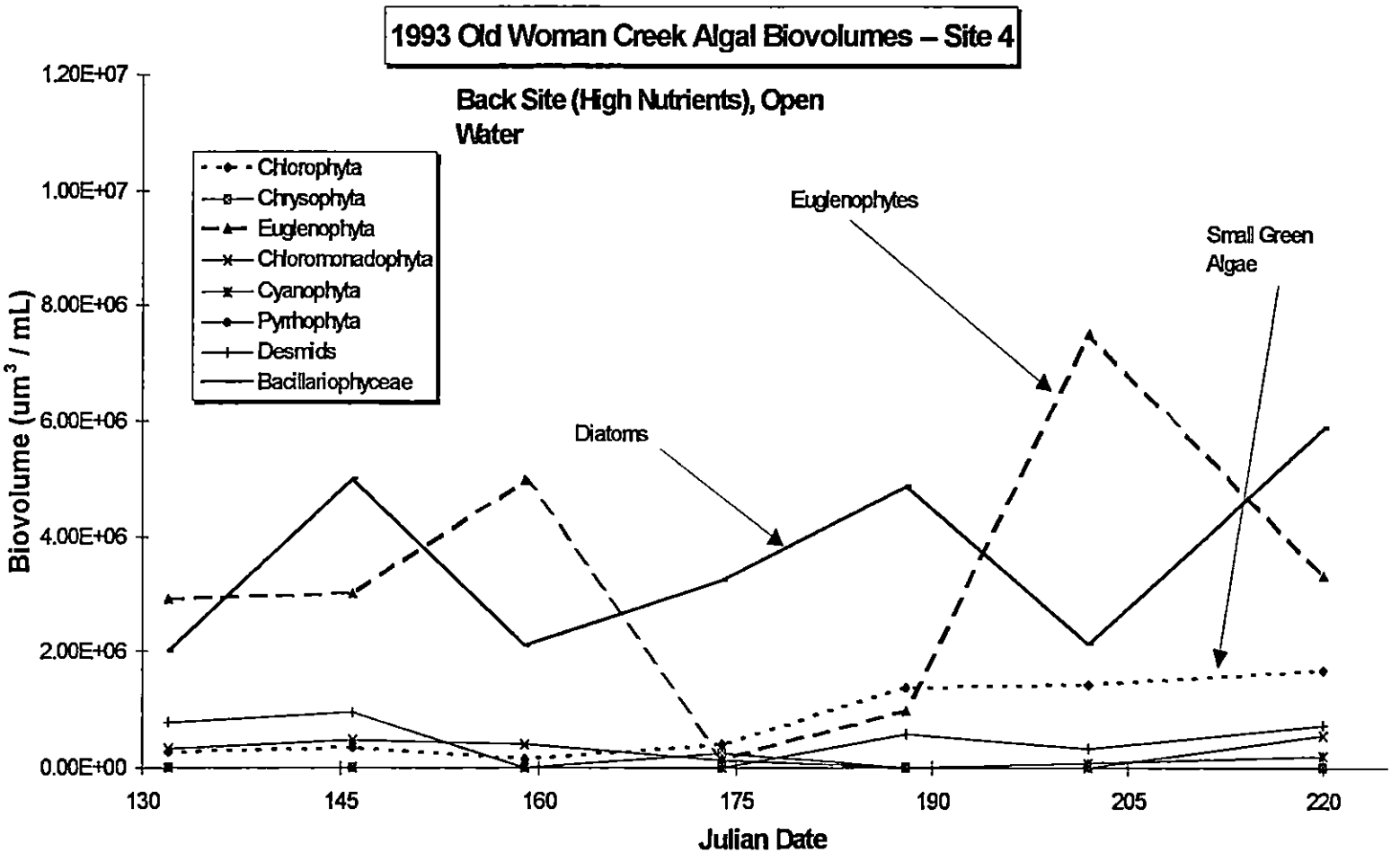


Table 3: Occurrence of algal species in whole water samples between 12 May and 8 August 1993 at Old Woman Creek, indicating location of sampling site in the estuary.

	12-May				26-May				8-Jun				23-Jun				7-Jul				21-Jul				8-Aug			
Estuary Position	Front		Back		Front		Back		Front		Back		Front		Back		Front		Back		Front		Back		Front		Back	
Macrophyte Bed	Out	In	In	Out	Out	In	In	Out	Out	In	In	Out	Out	In	In	Out	Out	In	In	Out	Out	In	In	Out	Out	In	In	Out
Site	1	3	2	4	1	3	2	4	1	3	2	4	1	3	2	4	1	3	2	4	1	3	2	4	1	3	2	4
Chloromonadophyta																												
Cryptomonas erosa				X	X	X	X	X	X	X	X	X		X	X	X					X	X	X					X
Chlorophyta																												
- Chlorococcales																												
Actinastrum hantzschii	X	X									X						X	X	X		X	X	X	X	X	X	X	X
Ankistrodesmus convulutus	X	X	X	X		X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Ankistrodesmus falcatus	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characium ambiguum	X		X	X													X											
Chlorella vulgaris	X	X	X	X		X	X		X																			
Crucigenia fenestrata						X	X		X		X						X											
Crucigenia quadrata	X						X										X	X	X	X								
Crucigenia tetrapedia															X	X	X	X	X			X			X	X	X	X
Franceia droescheri										X						X	X		X									
Kirchneriella subsolitaria							X		X					X	X	X						X	X	X	X	X	X	X
Lagerheimia quadriseta	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X			X	X		X		X
Lagerheimia wratislaviensis			X	X	X		X	X	X	X	X					X							X			X		X
Micractinium pusillum	X						X	X	X				X				X								X	X	X	
Pediastrum duplex	X	X	X															X	X	X	X			X		X		X
Pediastrum tetras																		X								X		X
Scenedesmus bijuga	X						X							X	X	X	X	X	X	X					X		X	
Scenedesmus denticulatus																			X									X
Scenedesmus dimorphus	X																X	X	X	X						X		X
Scenedesmus opoliensis																	X	X	X	X	X							
Scenedesmus quadricauda	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Schroederia setigera		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tetraedron quadratum																									X			
Tetraedron regulare	X	X												X	X				X	X	X	X	X	X	X	X	X	X
Tetrastrum glabrum		X	X				X	X	X		X						X	X	X	X					X	X	X	X
Tetrastrum heteracanthum																		X		X						X		
Treubaria setigerum										X								X			X	X				X		X

Table 3: Occurrence of algal species in whole water samples between 12 May and 8 August 1993 at Old Woman Creek, indicating location of sampling site in the estuary.

	12-May				26-May				8-Jun				23-Jun				7-Jul				21-Jul				8-Aug			
Estuary Position	**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**	
Macrophyte Bed	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**
Site	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**
- Tetrasporales																												
Gloeocystis ampla																			X		X	X	X	X	X	X	X	X
- Volvocales																												
Chlamydomonas globosa	X			X	X	X	X	X	X	X	X	X	X		X		X				X			X				
- Zygnematales																												
Closterium acerosum	X	X	X	X	X			X	X	X	X		X		X			X	X	X	X	X			X		X	X
Cosmarium biretum	X		X	X			X	X					X	X			X	X	X	X	X	X	X	X	X	X	X	X
Chrysophyta																												
-- Chrysophyceae																												
Dinobryon divergens		X					X		X	X	X					X	X	X										
-- Bacillariophyceae																												
Cyclotella menegheniana	X		X	X	X	X	X	X	X	X	X			X		X	X	X	X	X	X	X	X	X	X	X	X	X
Diploneis puella	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gomphonema sp.	X		X	X			X	X				X			X			X	X		X			X	X			
Melosira distans	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Melosira granulata								X				X					X			X	X	X		X		X		
Navicula mutica		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nitzschia acicularis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhoicosphenia sp.															X						X		X					
Cyanophyta																												
Aphanocapsa rivularis																					X	X	X	X		X		X
Merismopedia tenuissima	X	X		X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X
Phormidium tenue		X	X	X	X		X				X				X										X	X		
Spirulina nordstedtii				X		X			X	X	X								X		X							

Table 3: Occurrence of algal species in whole water samples between 12 May and 8 August 1993 at Old Woman Creek, indicating location of sampling site in the estuary.

	12-May				26-May				8-Jun				23-Jun				7-Jul				21-Jul				8-Aug			
Estuary Position	**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**		**Front**		**Back**	
Macrophyte Bed	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**	**Out**	**In**	**In**	**Out**
Site	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**	**1**	**3**	**2**	**4**
Euglenophyta																												
Euglena acus		X		X			X	X		X	X	X	X	X	X		X			X	X		X	X			X	X
Euglena convoluta		X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X	X
Euglena gracilis		X	X	X	X	X	X	X	X		X			X	X	X		X				X	X	X				
Euglena minuta						X	X	X	X												X		X	X				
Phacus caudatus	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X		X
Phacus longicauda								X		X	X	X		X							X	X	X	X		X		
Trachelomonas armata		X		X															X		X			X				X
Trachelomonas playfairii																					X		X	X				
Trachelomonas volvocina	X	X	X	X	X		X																X		X	X		X
Pyrrhophyta																												
Glenodinium pulvisculus		X								X	X														X			

defined. To compare community diversity, several biotic indices were calculated. All of the diversity indices showed that phytoplankton community diversity was highest in the back sites, and the sites in the macrophyte beds (Table 4); however, there was no significant difference in the means of the diversity indices by site. The front sites were dominated by diatoms nearly exclusively; however, euglenophytes and small green algae are also important contributors to the community volume. The back sites are dominated mutually by diatoms and euglenophytes, with other algal groups making less of a contribution to total community volume. Sites located within a macrophyte bed tend to be dominated by euglenophytes in early June and by diatoms at the other times in the growing season, whereas those in open water are dominated by diatoms early in the year and euglenophytes in late July.

All periphyton communities were dominated by diatoms (see figures 15-16) -- which composed 48% of the community volume, with euglenophytes (18%) and green algae (30%) also making large contributions to the community volume. The back sites, with typically higher nutrients than the front sites, were dominated by diatoms (42%) and green algae (37%). The front sites were dominated by diatoms (55%) with green algae (23%) and euglenophytes (19%) making less of a contribution to community volume.

Diatoms, such as *Cyclotella menegheniana*, *Fragillaria* sp., *Navicula* sp. , and *Nitzschia* sp., were common members of the periphyton throughout the study period (Table 5). Chlorophytes such as *Ankistrodesmus* sp. and *Scenedesmus* sp. were

Table 4: Phytoplankton diversity indices with algal volume and number for each sampling date and site at Old Woman Creek, from 12 May to 8 August 1993.

Date	12-May				26-May				8-Jun			
Estuary Position	Front		Back		Front		Back		Front		Back	
Macrophyte Bed	Out	In	In	Out	Out	In	In	Out	Out	In	In	Out
Site	1	3	2	4	1	3	2	4	1	3	2	4
PHYTOPLANKTON												
Number of Species	25	25	23	27	16	18	31	25	26	24	26	17
Algal Number (cells l^{-1})	1.12E+07	1.19E+07	1.81E+09	7.88E+06	1.05E+07	1.31E+07	1.31E+07	1.53E+07	1.57E+07	4.89E+06	1.12E+07	7.38E+06
Algal Volume ($\mu m^3 ml^{-1}$)	5.50E+06	5.63E+06	5.49E+06	6.32E+06	2.04E+06	2.82E+06	7.63E+06	9.79E+06	7.96E+06	5.27E+06	9.00E+06	7.61E+06
Margalef Diversity	10.92	10.76	9.32	11.42	6.43	9.28	12.5	11.15	11.44	11.22	11.6	8.43
Inv. Simpson's Diversity	12.17	13.15	13.27	16.87	2.02	16.39	13.14	10.86	17.62	14.42	12.34	12.37
Shannon Diversity	2.75	2.79	2.77	3	1.35	2.72	2.91	2.68	2.96	2.8	2.83	2.58

Date	23-Jun				7-Jul			
Estuary Position	Front		Back		Front		Back	
Macrophyte Bed	Out	In	In	Out	Out	In	In	Out
Site	1	3	2	4	1	3	2	4
PHYTOPLANKTON								
Number of Species	14	21	22	20	28	28	29	24
Algal Number (cells l^{-1})	3.06E+06	8.63E+06	8.60E+06	1.33E+07	1.77E+07	1.58E+07	2.08E+07	1.54E+07
Algal Volume ($\mu m^3 l^{-1}$)	2.09E+06	5.04E+06	5.03E+06	4.20E+06	5.16E+06	7.15E+06	7.68E+06	7.82E+06
Margalef Diversity	7.73	9.84	9.7	8.63	11.37	11.29	11.16	10.25
Inv. Simpson's Diversity	7.89	12.19	11.95	9.57	11.91	10.08	11.01	9.5
Shannon Diversity	2.21	2.68	2.7	2.48	2.79	2.66	2.72	2.58

Date	21-Jul				8-Aug			
Estuary Position	Front		Back		Front		Back	
Macrophyte Bed	Out	In	In	Out	Out	In	In	Out
Site	1	3	2	4	1	3	2	4
PHYTOPLANKTON								
Number of Species	32	25	28	28	26	33	21	32
Algal Number (cells l^{-1})	1.65E+07	1.31E+07	1.08E+07	1.13E+07	2.93E+07	3.63E+07	1.92E+07	2.54E+07
Algal Volume ($\mu m^3 l^{-1}$)	1.55E+07	6.13E+06	1.17E+07	1.15E+07	1.07E+07	1.33E+07	1.33E+07	1.23E+07
Margalef Diversity	12.79	10.05	13.03	11.85	9.91	12.11	8.38	12.21
Inv. Simpson's Diversity	15.94	13.23	19.84	20.61	9.86	10.03	15.13	13.7
Shannon Diversity	3	2.8	3.04	3.1	2.72	2.83	2.82	2.94

Figure 15: Periphyton volumes at Old Woman Creek, 1993.

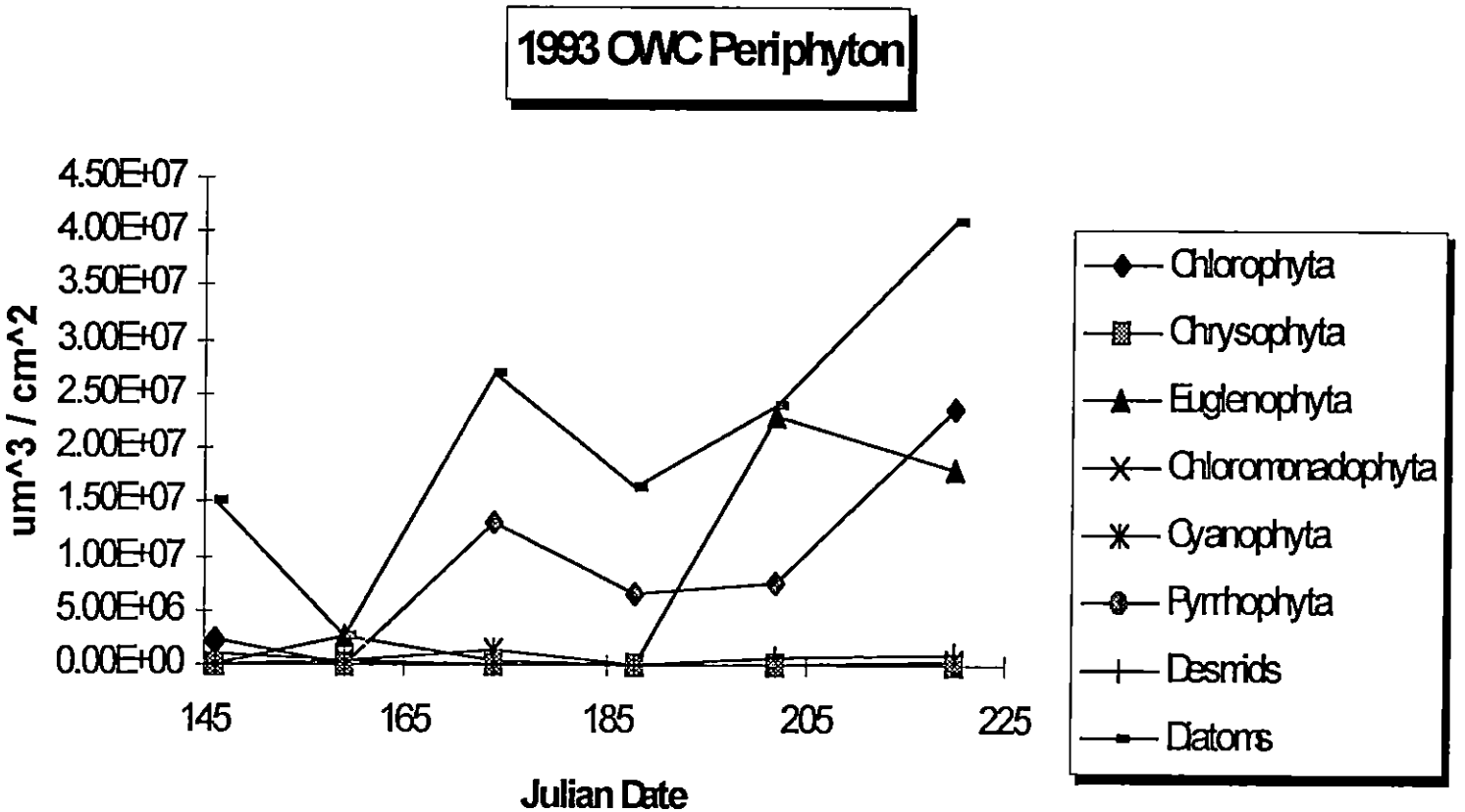


Figure 16: Periphyton Volumes at Old Woman Creek, 1993.

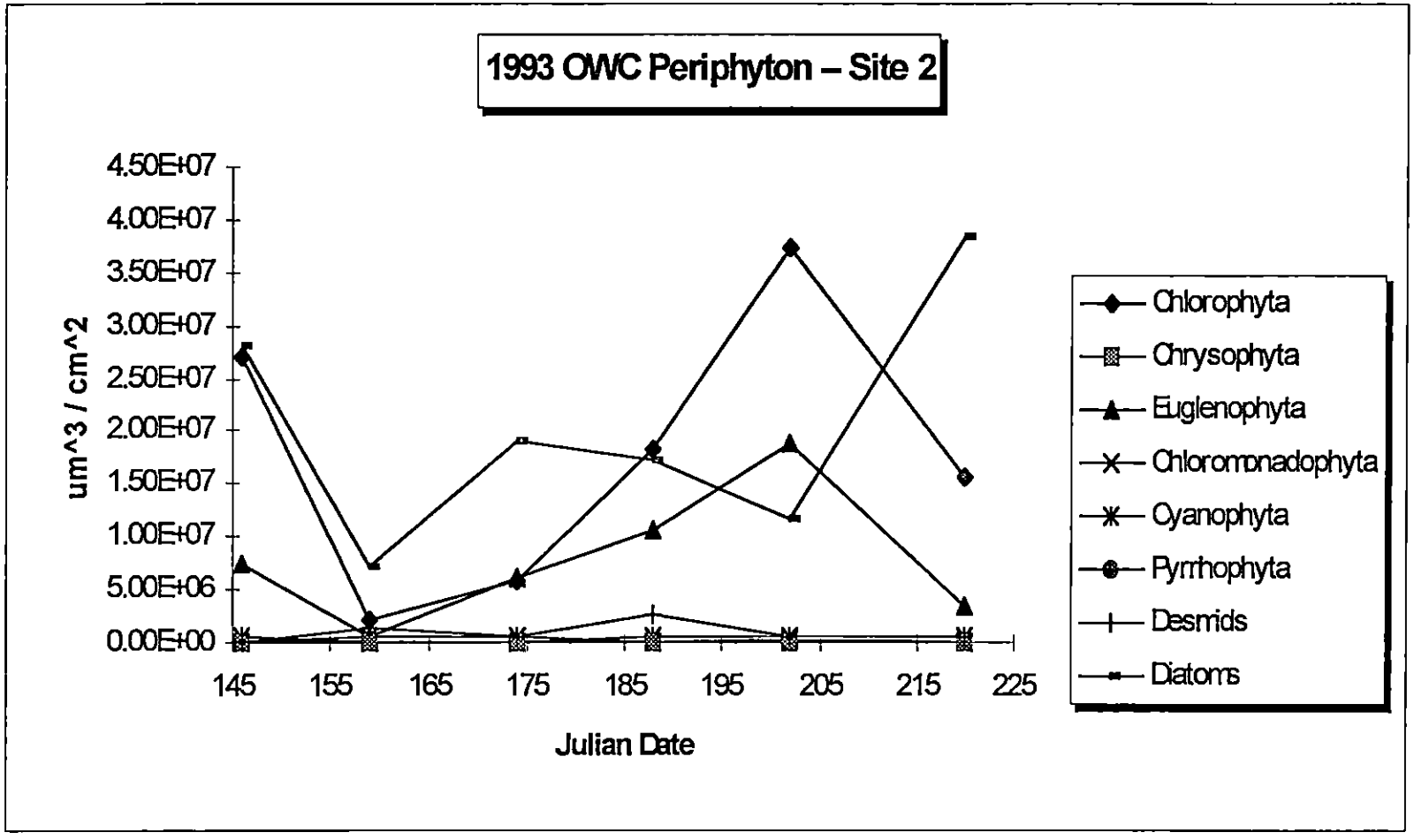


Table 5: Occurrence of species in periphyton between 8 May and 11 August 1993 at Old Woman Creek, indicating location of samplers in the estuary.

	26-May		8-Jun		23-Jun		7-Jul		21-Jul		11-Aug	
Estuary Position	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**
Chloromonadophyta												
Cryptomonas erosa				X		X				X		
Chlorophyta												
- Chlorococcales												
Ankistrodesmus falcatus		X	X	X	X	X	X	X	X	X	X	X
Crucigenia tetrapedia				X					X	X		X
Kirchneriella subsolitaria					X		X					X
Lagerheimia quadriseta			X	X								
Micractinium pusillum	X			X	X	X	X	X			X	X
Pediastrum duplex								X				X
Scenedesmus abundans	X											
Scenedesmus bijuga			X		X							
Scenedesmus denticulatus							X					
Scenedesmus dimorphus				X	X			X	X			
Scenedesmus opoliensis									X			
Scenedesmus quadricauda	X	X	X		X	X	X	X	X	X	X	X
Schroederia setigera			X	X	X							
Tetraedron quadratum									X			
Tetrastrum glabrum								X				
- Oedogoniales												
Oedogonium sp.	X	X								X	X	X
- Tetrasporales												
Gloeocystis ampla					X							
- Volvocales												
Chlamydomonas globosa			X		X							
- Zygnematales												
Closterium acerosum				X				X				
Cosmarium biretum			X	X		X		X	X	X	X	X

Table 5: Occurrence of species in periphyton between 8 May and 11 August 1993 at Old Woman Creek, indicating location of samplers in the estuary.

	26-May		8-Jun		23-Jun		7-Jul		21-Jul		11-Aug	
Estuary Position	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**
Chrysophyta												
-- Bacillariophyceae												
Achnanthes sp.					X		X		X			
Cyclotella meneghenlana	X	X	X	X	X	X	X	X	X	X	X	X
Cymbella sp.	X	X	X	X		X					X	
Diploneis puella		X	X	X	X	X	X	X	X	X		
Fragillaria sp.	X	X	X	X	X	X	X	X	X	X	X	X
Gomphonema sp.	X		X	X	X	X		X		X	X	X
Melosira distans		X	X	X	X	X	X	X	X	X	X	X
Melosira granulata	X			X	X			X	X			X
Meridion sp.	X	X					X					X
Navicula mutica	X	X	X	X	X	X	X	X	X	X	X	X
Nitzschia acicularis	X	X	X	X	X	X	X	X	X	X	X	X
Rhoicosphenia sp.		X	X	X	X	X	X	X	X	X		X
Stauroneis sp.						X	X					
Terpsinoe sp.					X							
Cyanophyta												
Merismopedia tenuissima					X	X				X		
Oscillatoria sp.	X	X	X	X	X	X	X	X	X	X	X	X
Phormidium tenue	X	X	X		X					X		X
Euglenophyta												
Euglena acus						X			X			
Euglena convoluta									X			
Euglena gracilis		X	X			X			X			
Euglena minuta			X					X	X			
Phacus caudatus				X		X						
Phacus pleuronectes		X	X			X		X	X	X	X	X
Trachelomonas armata				X								
Trachelomonas volvocina					X							

common throughout the sampling period. Some were present only at the front site, which may be less tolerant of non-point nutrient loading, such as *Gloeocystis ampla*, *Chlamydomonas globosa*, *Achnanthes* sp. and *Trachelomonas volvocina*. Others, however, were present only at the back sites, such as *Phacus caudatus* and *Trachelomonas armata*. Periphyton diversity was the highest during June when the periphyton density was also the greatest. All diversity indices indicated that diversity was highest at the back sites, and lower at the front sites (Table 6).

2.4. Discussion

One factor that may affect production and phytoplankton community structure is nutrient loading. Although not statistically significantly different during the study period, the back sites usually had much higher nutrient concentrations than the front sites. This may not be uncommon at Old Woman Creek or other wetlands which are driven by sporadic hydrologic events, creating spatial variability in nutrient loading. Klarer (1994) noted that storm events can increase the nutrients and turbidity rapidly. As the nutrient front moves through the wetland, the nutrient concentrations may decrease, however, our sampling regimen did not allow that fine of a temporal resolution. As storm water runs off of agricultural fields it collects nutrients, and brings them into the wetland. The back sites receive this nutrient input first where settling, from decreased water velocity, and biotic uptake remove some nutrients before the water reaches the front sites. This leads to lower nutrients at the front sites;

Table 6: Periphyton volumes and diversity indices by date and site at Old Woman Creek from 26 May to 11 August 1993.

Date	26-May		8-Jun		23-Jun		7-Jul		21-Jul		11-Aug	
Estuary Position	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back	Front	Back
PERIPHYTON												
Number of Species	14	17	22	23	25	22	17	21	23	19	15	21
Periphyton Volume ($\mu m^3 cm^{-2}$)	1.86E+07	6.32E+07	6.10E+06	1.19E+07	4.14E+07	3.20E+07	2.31E+07	4.93E+07	5.54E+07	6.89E+07	8.40E+07	5.84E+07
Margalef Diversity	4.74	5.97	7.88	9.7	9.05	8.39	6.61	7.48	8.63	6.5	5.04	7.36
Inv. Simpson's Diversity	3.83	6.76	2.89	11.17	4.92	7.93	7.31	3.5	10.97	4.41	5.79	9.99
Shannon Diversity	1.76	2.17	1.62	2.71	2.2	2.4	2.29	1.9	2.63	1.97	2.04	2.52

however, due to the high variability created by storm pulses at both sites, statistically there is no significant difference in the nutrient means. This explanation is particularly pertinent for nitrate -- for which the mean of the back sites was greater than twice the mean of the front sites. Phosphorus was not spatially variable, which is not surprising, since phosphorus is rapidly sunk into the sediments through both biotic and physical action. However, phosphorus resuspension is significant in the entire wetland due to its shallow depth.

Nutrient concentrations are not significantly different in and out of the macrophyte beds. This is not surprising due to the closeness of the sites, and the mixing of the water in the wetland due to wind action. The community differences appear not to affect the nutrients at each site significantly in a top-down manner (Carpenter and Kitchell 1987, Havens 1991). This is not to say that biotically induced nutrient release from the sediments is not important or does not occur, it is just not the most significant factor regulating nutrient concentrations between sites in versus out of macrophyte beds. Nitrite concentrations were unusually high for a freshwater system. This may be in part due to low oxygen concentrations in the water (Reynolds 1984).

The back sites had higher periphyton volumes in the back sites than the front sites, indicating that periphyton would be more important contributors to primary production in higher nutrient conditions, as indicated by our production estimates. In the back sites, the green algae composed a larger percentage of the community of periphyton than at the front sites. Due to the higher nutrient loading, especially

nitrogen, we would expect such a relationship to exist. This also explains the higher chlorophyll a measurements at the back sites, due to the higher percentage of green algae, which possess higher concentrations of chlorophyll *a* relative to other pigments.

Algal communities at Old Woman Creek have been shown to have a bimodal seasonality (Klarer and Millie 1992). This trend exhibits a vernal peak in May and an autumnal peak in July or August, and is common in phytoplankton dynamics of temperate wetlands (Vymazal 1995). In 1993, algal numbers exhibit this same trend, however, the peak in early May is quite large. The early May peak has 1.81×10^9 phytoplankton l^{-1}, which is larger than the May peaks reported by Millie and Klarer (1992). This high volume during the vernal peak was largely due to a bloom of euglenophytes. The autumnal peak, which actually begins in late July and early August, is of similar magnitude to that reported by Millie and Klarer (1992), having 2.8×10^7 phytoplankton l^{-1}. Algal volumes, however, do not show the same bimodal seasonality. They have a small peak in May, followed by a much larger peak in Late July and early August. This is somewhat related to algal numbers, however, we see temporal differences in communities. The early peak is dominated by small euglenophytes; whereas the late summer peak is dominated by much larger diatoms producing higher total community algal volumes. Algal volumes appear to relate more closely to production estimates than do algal numbers.

Algal volumes indicate that the back sites are significantly higher than the front sites. Whether the community is located in the front or back of the wetland appears

not to be as important to community structure as the presence of macrophytes. The nutrient loading at the back sites appears to affect phytoplankton community algal volume more than community structure. The macrophytes tend to change the community structure, possibly due to shading. The dominant macrophyte, *Nelumbo lutea*, probably has little effect on the community structure due to shading until at least the middle of June, when the aerial leaves appear. At this time we see the sites in the macrophyte beds shift from a euglenophyte to diatom dominated community. This is not a common trend. Algal communities in eutrophic and hypereutrophic systems tend to shift from diatom dominated systems to some other group, such as green or blue-green algae (Reynolds 1984). The macrophyte beds appear to have the opposite temporal pattern, shifting from euglenophyte to diatom dominated communities. The open water communities, at nearly the same time, shift from a diatom to a euglenophyte dominated community as would be considered a typical seasonal community succession (Reynolds 1984). The *Nelumbo* appears to provide some competitive advantage for the diatoms over the euglenophytes, be it shading, or substrate for attachment. However, this raises the question, why don't euglenophytes dominate the open water early in the year. It may be that the young underwater shoots of *Nelumbo* provide good habitat for the euglenophytes, more food or possibly provide less turbid water. The largest answer may lie in the nutrient concentrations from nonpoint pollution. High nutrient levels early in the growing season may

promote an increase in the trophic status, allowing diatoms to be more efficient competitors.

There are few well-defined successional species replacements in the phytoplankton communities at Old Woman Creek. This may be due to sediment perturbation, either by wind and water, or biotic action. The phytoplankton community may remain in an early successional stage due to this perturbation. This is supported by Havens (1991) who demonstrated that biotically-induced sediment resuspension created this kind of early successional stage community, composed largely of r-strategists.

The wetland may be somewhat nutrient limited at times, however, this may not be the most important limitation. The peak nutrient input is in late May and early June. This is not when production is at its greatest. Production reaches its peak in July, when nutrients are similar at nearly all sites, and much lower than the maximum values. However, we do see that the algal volume is significantly higher at the back sites, with higher nutrient loading. It appears that sunlight may also be an important limiting factor and shading may be responsible for community structure shifts.

2.5. Conclusion

Non-point pollution is a current problem facing or aquatic resources. Few studies have focused on the effect of non-point nutrient loading on the algal communities in wetlands, which are important in nutrient removal. In summary, we

found that while the closer the community is to the non-point "source" the greater the community volume, it had no significant effect on community structure. The presence of macrophytes appeared to be more important in altering community structure than did non-point nutrient loading.

Chapter III.

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APPENDICES

APPENDIX A

PRIMARY PRODUCTION DATA

Site 1	Julian	LBDB		Diurnal		DDD		Chl. a	Δ	Algal
Date	Date	NPP	GPP	NPP	GPP	NPP	GPP		pH	Volume
		mgO_2l^{-1}	mgO_2l^{-2}	mgO_2l^{-3}	mgO_2l^{-4}	mgO_2l^{-5}	mgO_2l^{-6}	$mg\ m^{-3}$		$x10^6\ \mu m^3ml^{-1}$
12-May-93	132	1.54	3.88	3.68	20.5			46	0.6	5.52
13-May-93	133	1.6	2.21	2.86	4.3	0.93	2.42	52	0.6	5.00
26-May-93	146	0.8	1.19			1.37	3.41	13	0.5	2.04
27-May-93	147	1.11	2.52					111	0.7	
8-Jun-93	159	1.31	5.46					148		7.96
9-Jun-93	160	5.58	7.7			-0.78	-1.94	148		
23-Jun-93	174	1.64	2.69					22	0.5	2.09
24-Jun-93	175	8.16	14.95	8.74	20.48	4.4	11	22	0.8	
7-Jul-93	188	21.85	26.2			1.57	3.94	141	1.1	5.16
21-Jul-93	202		17.41	18.55		0.19	0.46	141		1.55
22-Jul-93	203						0.44	1.09		
11-Aug-93	223	5.41	2.88			-0.15	-0.37	229		10.7
Site 2	Julian	LBDB		Diurnal		DDD		Chl. a	Δ	Algal
Date	Date	NPP	GPP	NPP	GPP	NPP	GPP		pH	Volume
		mgO_2l^{-1}	mgO_2l^{-2}	mgO_2l^{-3}	mgO_2l^{-4}	mgO_2l^{-5}	mgO_2l^{-6}	$mg\ m^{-3}$		$x10^6\ \mu m^3ml^{-1}$
12-May-93	132	1.78	4.94					11	0.8	5.49
13-May-93	133	1.12	1.9			0.85	2.7	56	0.5	
26-May-93	146	3.86	5.96			1.08	2.7	111	0.8	7.63
27-May-93	147	2.64	4.26					111	0.7	
8-Jun-93	159	3.35	13.81					204		9
9-Jun-93	160	0.57	1.93			-2.1	-0.87	204		
23-Jun-93	174	11.61	12.04					78	0.3	5.03
24-Jun-93	175	19.61	21.93			4.4	10.98	78	1.7	
7-Jul-93	188	22.19	27.02			2.71	6.8	87	1	7.68
21-Jul-93	202	13.87	13.7	5.32	18.72	0.64	1.61	204	0.71	16.6
22-Jul-93	203			4.21	14.92	1.06	2.63		0.64	
11-Aug-93	223	7.69	7.87			-0.35	-0.88	245		13.3

Site 3	Julian	LBDB		Diurnal		DDD		Chl. a	Δ	Algal
Date	Date	NPP	GPP	NPP	GPP	NPP	GPP		pH	Volume
		mgO_2l^{-1}	mgO_2l^{-2}	mgO_2l^{-3}	mgO_2l^{-4}	mgO_2l^{-5}	mgO_2l^{-6}	$mg\ m^{-3}$		$x10^6\ \mu m^3ml^{-1}$
12-May-93	132									
13-May-93	133									
26-May-93	146									
27-May-93	147									
8-Jun-93	159							140		5.27
9-Jun-93	160									
23-Jun-93	174							94	0.3	5.03
24-Jun-93	175									
7-Jul-93	188	9.34	12.51			3.13	8.06	130	1.4	7.15
21-Jul-93	202	16.09	14.66			1.1	2.73	129		6.13
22-Jul-93	203					1.3	3.23			
11-Aug-93	223	5.41	2.88			-0.15	-0.37	229		10.7
Site 4	Julian	LBDB		Diurnal		DDD		Chl. a	Δ	Algal
Date	Date	NPP	GPP	NPP	GPP	NPP	GPP		pH	Volume
		mgO_2l^{-1}	mgO_2l^{-2}	mgO_2l^{-3}	mgO_2l^{-4}	mgO_2l^{-5}	mgO_2l^{-6}	$mg\ m^{-3}$		$x10^6\ \mu m^3ml^{-1}$
12-May-93	132									
13-May-93	133									
26-May-93	146									
27-May-93	147									
8-Jun-93	159							32		7.61
9-Jun-93	160									
23-Jun-93	174							137		4.2
24-Jun-93	175									
7-Jul-93	188	18.12	20.92			1.75	4.38	57	1.1	7.82
21-Jul-93	202	23.66	24.21			1.17	2.92	155		11.5
22-Jul-93	203					1.3	3.23			
11-Aug-93	223	23.4	18.58			-0.04	-0.1	248		12.3

APPENDIX B

NUTRIENT DATA

Site 1 Date	Julian Date	Total Phosphorus	Soluble Reactive P	Ammonia	Nitrite	Nitrate	Total Inorganic N
		μgl^{-1}	μgl^{-1}	μgl^{-1}	μgl^{-1}	μgl^{-1}	μgl^{-1}
12-May-93	132	79.5	11.2	48.5	12.1	109.8	170.4
13-May-93	133						
26-May-93	146	35.6	31.8	65.6	10.7	106.7	183
27-May-93	147	58.1	36.2	98.4	13.3	9.4	121.1
8-Jun-93	159	128	61.1	134.5	23.8	18.8	177.1
9-Jun-93	160	103.2	34.2	67.4	4.3	20.4	92.1
23-Jun-93	174	41.2	13.8	123.8	26.5	56.5	206.8
24-Jun-93	175	76.2	10.1	115.9	65.6	73.4	255.2
7-Jul-93	188	132.5	24.4	269.5	16	6.3	291.8
21-Jul-93	202						
22-Jul-93	203	73.9	36	104.9	3.4	25.1	133.3
11-Aug-93	223						
Site 2 Date	Julian Date	Total Phosphorus	Soluble Reactive P	Ammonia	Nitrite	Nitrate	Total Inorganic N
		μgl^{-1}	μgl^{-1}	μgl^{-1}	μgl^{-1}	μgl^{-1}	μgl^{-1}
12-May-93	132	125.8	15.8	51.1	8.2	6.3	65.6
13-May-93	133						
26-May-93	146	59.3	29	39.6	9	106.7	155.2
27-May-93	147	87.4	31.8	47	31.8	64.3	143.1
8-Jun-93	159	116.7	33.1	76.8	26.2	6.2	109.4
9-Jun-93	160	167.4	50.5	215.4	58.5	577.3	851.2
23-Jun-93	174	82.9	16	276	98.6	65.9	440.6
24-Jun-93	175	107.7	8.8	189.7	138.5	80	408.2
7-Jul-93	188	129.1	26.3	193.3	13.8	9.4	216.5
21-Jul-93	202						
22-Jul-93	203	69.4	25.2	52.6	3.1	25.1	80.8
11-Aug-93	223						

Site 3 Date	Julian Date	Total Phosphorus	Soluble Reactive P	Ammonia	Nitrite	Nitrate	Total Inorganic N
		$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$
12-May-93	132						
13-May-93	133						
26-May-93	146						
27-May-93	147						
8-Jun-93	159	135.9	62.3	135.1	22.6	14.1	171.7
9-Jun-93	160	77.3	37.3	65.6	6	14.1	85.8
23-Jun-93	174	48	14.2	121.8	28.9	50.2	200.9
24-Jun-93	175	85.2	10.3	119.7	60.5	70.1	250.8
7-Jul-93	188	89.7	22.4	206.6	15.5	6.3	228.4
21-Jul-93	202						
22-Jul-93	203	63.8	31.6	39.3	1.9	25.1	66.3
11-Aug-93	223						

Site 4 Date	Julian Date	Total Phosphorus	Soluble Reactive P	Ammonia	Nitrite	Nitrate	Total Inorganic N
		$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$	$\mu g l^{-1}$
12-May-93	132						
13-May-93	133						
26-May-93	146						
27-May-93	147						
8-Jun-93	159	113.4	34.2	72.1	28.9	6.3	107.3
9-Jun-93	160	124.6	47.9	197.1	62.2	597.6	856.9
23-Jun-93	174	88.6	17.5	261.5	105.4	73.7	440.7
24-Jun-93	175	102.1	9.6	174.1	128	75.3	377.4
7-Jul-93	188	139.3	25	188.6	13.3	0.02	202
21-Jul-93	202						
22-Jul-93	203	51.4	22.4	40.2	1.7	23.5	65.4
11-Aug-93	223						

APPENDIX C

PHYTOPLANKTON VOLUMES

Date	12-May-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton ($\mu m^3 l^{-1}$)								
CHLOROPHYTA	1.49E+06	1.87E+05	1.13E+06	1.12E+05	1.06E+06	3.61E+04	2.71E+05	7.66E+03
CHRYSOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+05	1.07E+05	0.00E+00	0.00E+00
EUGLENOPHYTA	7.17E+04	4.60E+04	4.64E+05	1.70E+05	1.75E+06	1.31E+04	2.92E+06	3.53E+05
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.28E+05	4.69E+04
CYANOPHYTA	8.69E+03	4.23E+03	6.56E+03	6.56E+03	1.15E+04	1.74E+03	9.88E+03	9.65E+02
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.34E+04	8.34E+04	0.00E+00	0.00E+00
DESMIDS	2.81E+05	1.60E+05	1.60E+06	3.53E+05	4.86E+05	2.08E+05	7.90E+05	4.47E+04
BACILLARIOPHYCEAE	3.65E+06	2.41E+05	2.30E+06	7.98E+04	2.13E+06	5.79E+04	2.01E+06	4.71E+04
TOTAL VOLUME ($\mu m^3 l^{-1}$)	**5.50E+06**	**1.64E+05**	**5.49E+06**	**3.81E+05**	**5.63E+06**	**7.99E+03**	**6.32E+06**	**3.17E+05**
Date	26-May-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton ($\mu m^3 ml^{-1}$)								
CHLOROPHYTA	7.87E+04	6.69E+02	5.78E+05	1.66E+04	1.18E+05	5.03E+04	3.51E+05	3.73E+04
CHRYSOPHYTA	0.00E+00	0.00E+00	1.57E+05	3.21E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EUGLENOPHYTA	4.10E+05	3.98E+04	1.71E+06	4.74E+04	1.32E+06	6.55E+04	3.02E+06	6.88E+04
CHLOROMONADOPHYTA	8.31E+04	8.31E+04	7.67E+05	1.38E+05	2.64E+05	8.80E+04	4.80E+05	1.69E+05
CYANOPHYTA	2.19E+05	3.04E+04	6.92E+03	1.15E+02	7.33E+03	8.80E+02	0.00E+00	0.00E+00
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	5.54E+04	5.54E+04	3.53E+05	5.75E+04	0.00E+00	0.00E+00	9.42E+05	9.08E+04
BACILLARIOPHYCEAE	1.19E+06	1.43E+05	4.06E+06	1.38E+04	1.11E+06	9.86E+04	4.99E+06	1.67E+05
TOTAL VOLUME ($\mu m^3 ml^{-1}$)	**2.04E+06**	**6.48E+04**	**7.63E+06**	**1.24E+02**	**2.82E+06**	**6.99E+04**	**9.79E+06**	**2.13E+05**

Date	8-Jun-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton ($\mu m^3 ml^{-1}$)								
CHLOROPHYTA	1.08E+06	7.05E+03	4.08E+05	1.28E+05	1.79E+05	1.96E+04	1.41E+05	4.32E+04
CHRYSOPHYTA	3.29E+05	1.37E+04	1.21E+05	1.21E+05	7.63E+04	7.63E+04	0.00E+00	0.00E+00
EUGLENOPHYTA	1.38E+06	6.35E+04	4.88E+06	1.14E+06	3.07E+06	3.36E+04	4.96E+06	1.60E+06
CHLOROMONADOPHYTA	8.10E+05	1.94E+05	4.55E+05	2.53E+05	2.14E+05	8.44E+04	4.09E+05	1.28E+05
CYANOPHYTA	1.31E+04	5.33E+03	2.55E+04	1.96E+03	4.25E+03	1.22E+03	3.13E+03	3.13E+03
PYRRHOPHYTA	0.00E+00	0.00E+00	9.43E+04	9.43E+04	5.19E+04	5.19E+04	0.00E+00	0.00E+00
DESMIDS	6.34E+05	1.87E+05	2.24E+05	8.98E+04	9.30E+04	6.49E+03	0.00E+00	0.00E+00
BACILLARIOPHYCEAE	3.72E+06	7.30E+04	2.80E+06	6.97E+04	1.58E+06	1.72E+05	2.10E+06	6.76E+04
TOTAL VOLUME ($\mu m^3 ml^{-1}$)	7.96E+06	1.28E+05	9.00E+06	1.90E+06	5.27E+06	2.74E+05	7.61E+06	1.84E+06
Date	23-Jun-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton ($\mu m^3 ml^{-1}$)								
CHLOROPHYTA	1.23E+05	2.33E+04	2.37E+05	3.14E+04	1.88E+05	3.76E+04	4.10E+05	4.45E+03
CHRYSOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E+05	6.41E+03
EUGLENOPHYTA	1.11E+06	2.62E+05	2.31E+06	9.62E+05	2.38E+06	4.63E+05	1.54E+05	8.64E+04
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	1.73E+05	4.21E+03	2.29E+05	1.09E+04	1.25E+05	1.25E+05
CYANOPHYTA	0.00E+00	0.00E+00	2.54E+04	5.79E+03	1.32E+04	2.03E+03	1.21E+04	6.29E+03
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	1.24E+05	3.88E+03	5.89E+04	5.89E+04	2.28E+05	8.54E+04	0.00E+00	0.00E+00
BACILLARIOPHYCEAE	7.33E+05	1.09E+05	2.23E+06	8.88E+04	2.00E+06	1.31E+05	3.24E+06	6.61E+04
TOTAL VOLUME ($\mu m^3 ml^{-1}$)	2.09E+06	1.26E+05	5.03E+06	9.73E+05	5.04E+06	2.00E+05	4.20E+06	4.43E+04

Date	8-Aug-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton ($\mu m^3 ml^{-1}$)								
CHLOROPHYTA	2.37E+06	3.70E+05	2.46E+06	1.33E+05	3.46E+06	2.94E+05	1.68E+06	1.20E+05
CHRYSOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EUGLENOPHYTA	7.03E+05	1.73E+05	6.17E+06	1.56E+05	1.99E+06	1.08E+04	3.32E+06	4.73E+05
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E+05	1.10E+05
CYANOPHYTA	4.42E+04	1.08E+04	0.00E+00	0.00E+00	3.93E+05	3.54E+04	1.99E+05	8.54E+04
PYRRHOPHYTA	1.05E+05	1.05E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	1.64E+06	8.42E+04	8.89E+05	1.92E+05	6.18E+05	3.09E+04	7.20E+05	1.47E+03
BACILLARIOPHYCEAE	5.89E+06	8.53E+04	3.77E+06	5.03E+05	6.87E+06	3.23E+05	5.87E+06	1.42E+05
TOTAL VOLUME ($\mu m^3 ml^{-1}$)	1.07E+07	2.93E+05	1.33E+07	7.18E+05	1.33E+07	6.72E+05	1.23E+07	4.07E+05

APPENDIX D

PHYTOPLANKTON NUMBERS

Date	12-May-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	5.61E+06	1.26E+06	5.57E+06	4.64E+05	6.95E+06	5.89E+05	2.04E+06	5.90E+04
CHRYSOPHYTA	0.00E+00	0.00E+00	8.38E+07	1.19E+08	6.95E+04	9.82E+04	0.00E+00	0.00E+00
EUGLENOPHYTA	1.91E+05	9.01E+04	1.72E+09	2.43E+09	5.56E+05	0.00E+00	1.58E+06	4.72E+05
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.09E+05	5.90E+04
CYANOPHYTA	2.55E+05	1.80E+05	2.19E+05	3.09E+05	3.47E+05	9.82E+04	3.34E+05	0.00E+00
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E+04	9.82E+04	0.00E+00	0.00E+00
DESMIDS	2.55E+05	1.80E+05	1.59E+06	5.41E+05	4.86E+05	2.95E+05	7.51E+05	0.00E+00
BACILLARIOPHYCEAE	4.91E+06	2.70E+05	3.99E+06	6.96E+05	3.40E+06	4.91E+05	2.96E+06	1.77E+05
TOTAL NUMBER (Cells l^{-1})	1.12E+07	1.98E+06	1.81E+09	2.55E+09	1.19E+07	1.67E+06	7.88E+06	7.67E+05
Date	26-May-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	5.54E+05	1.57E+05	3.72E+06	2.22E+05	3.72E+06	2.22E+05	3.02E+06	6.11E+05
CHRYSOPHYTA	0.00E+00	0.00E+00	1.05E+05	0.00E+00	1.05E+05	0.00E+00	0.00E+00	0.00E+00
EUGLENOPHYTA	1.11E+06	3.13E+05	1.73E+06	2.22E+05	1.73E+06	2.22E+05	3.02E+06	3.06E+05
CHLOROMONADOPHYTA	5.54E+04	7.83E+04	5.24E+05	1.48E+05	5.24E+05	1.48E+05	3.24E+05	1.53E+05
CYANOPHYTA	7.04E+06	1.80E+06	2.10E+05	0.00E+00	2.10E+05	0.00E+00	0.00E+00	0.00E+00
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	5.54E+04	7.83E+04	3.67E+05	7.41E+04	3.67E+05	7.41E+04	9.72E+05	1.53E+05
BACILLARIOPHYCEAE	1.72E+06	2.35E+05	6.50E+06	2.96E+05	6.50E+06	2.96E+05	7.99E+06	0.00E+00
TOTAL NUMBER (Cells l^{-1})	1.05E+07	2.66E+06	1.31E+07	9.63E+05	1.31E+07	9.63E+05	1.53E+07	1.22E+06

Date	8-Jun-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	6.98E+06	2.90E+05	2.51E+06	0.00E+00	1.25E+06	3.06E+05	1.68E+06	2.64E+05
CHRYSOPHYTA	2.05E+05	0.00E+00	7.86E+04	1.11E+05	4.33E+04	6.12E+04	0.00E+00	0.00E+00
EUGLENOPHYTA	1.13E+06	4.36E+05	2.12E+06	1.11E+05	8.22E+05	1.84E+05	1.68E+06	5.28E+05
CHLOROMONADOPHYTA	5.13E+05	1.45E+05	3.14E+05	2.22E+05	1.30E+05	6.12E+04	2.80E+05	1.32E+05
CYANOPHYTA	4.11E+05	2.90E+05	8.64E+05	1.11E+05	1.30E+05	6.12E+04	9.34E+04	1.32E+05
PYRRHOPHYTA	0.00E+00	0.00E+00	7.86E+04	1.11E+05	4.33E+04	6.12E+04	0.00E+00	0.00E+00
DESMIDS	6.16E+05	2.90E+05	2.36E+05	1.11E+05	8.65E+04	0.00E+00	0.00E+00	0.00E+00
BACILLARIOPHYCEAE	5.85E+06	7.26E+05	5.03E+06	2.22E+05	2.38E+06	1.84E+05	3.64E+06	3.96E+05
TOTAL NUMBER (Cells l^{-1})	1.57E+07	2.18E+06	1.12E+07	1.00E+06	4.89E+06	9.18E+05	7.38E+06	1.45E+06
Date	23-Jun-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	1.02E+06	3.61E+05	2.24E+06	3.33E+05	2.56E+06	6.78E+05	5.18E+06	0.00E+00
CHRYSOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.67E+05	0.00E+00
EUGLENOPHYTA	1.91E+05	9.02E+04	7.66E+05	8.33E+04	8.79E+05	3.39E+05	5.85E+05	3.55E+05
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	1.18E+05	0.00E+00	1.60E+05	0.00E+00	8.36E+04	1.18E+05
CYANOPHYTA	0.00E+00	0.00E+00	7.66E+05	2.50E+05	3.99E+05	1.13E+05	3.34E+05	2.36E+05
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	1.28E+05	0.00E+00	5.89E+04	8.33E+04	2.40E+05	1.13E+05	0.00E+00	0.00E+00
BACILLARIOPHYCEAE	1.72E+06	2.71E+05	4.66E+06	9.17E+05	4.39E+06	1.13E+05	6.94E+06	1.06E+06
TOTAL NUMBER (Cells l^{-1})	3.06E+06	7.21E+05	8.60E+06	1.67E+06	8.63E+06	1.36E+06	1.33E+07	1.77E+06

Date	7-Jul-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	1.02E+07	8.44E+05	9.06E+06	1.73E-01	6.35E+06	1.18E+06	4.32E+06	1.62E+06
CHRYSOPHYTA	7.46E+04	1.06E+05	0.00E+00	0.00E+00	1.28E+05	0.00E+00	0.00E+00	0.00E+00
EUGLENOPHYTA	5.22E+05	1.06E+05	2.59E+05	0.00E+00	3.85E+05	0.00E+00	1.76E+05	0.00E+00
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CYANOPHYTA	1.19E+06	0.00E+00	6.47E+05	1.83E+05	9.62E+05	4.54E+05	2.65E+05	1.25E+05
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	2.99E+05	2.11E+05	9.71E+05	9.15E+04	3.85E+05	0.00E+00	6.18E+05	1.25E+05
BACILLARIOPHYCEAE	5.45E+06	1.06E+05	9.90E+06	9.15E+04	7.57E+06	1.81E+05	1.01E+07	2.50E+05
TOTAL NUMBER (Cells l^{-1})	1.77E+07	1.37E+06	2.08E+07	3.66E+05	1.58E+07	1.81E+06	1.54E+07	2.12E+06
Date	21-Jul-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)	MEAN	(+/- SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	3.74E+06	3.53E+05	3.21E+06	6.48E+05	4.50E+06	7.58E+05	4.39E+06	5.03E+05
CHRYSOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EUGLENOPHYTA	2.93E+06	7.94E+05	3.02E+06	1.30E+05	3.75E+05	2.28E+05	2.73E+06	1.68E+05
CHLOROMONADOPHYTA	6.24E+04	8.82E+04	9.17E+04	1.30E+05	1.07E+05	0.00E+00	0.00E+00	0.00E+00
CYANOPHYTA	1.56E+06	2.65E+05	3.67E+05	2.59E+05	7.51E+05	0.00E+00	4.15E+05	8.38E+04
PYRRHOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	2.49E+05	0.00E+00	2.75E+05	1.30E+05	3.22E+05	5.39E-03	3.56E+05	1.68E+05
BACILLARIOPHYCEAE	7.98E+06	3.53E+05	3.85E+06	2.59E+05	7.08E+06	1.52E+05	3.38E+06	8.38E+04
TOTAL NUMBER (Cells l^{-1})	1.65E+07	1.85E+06	1.08E+07	1.56E+06	1.31E+07	1.14E+06	1.13E+07	1.01E+06

Date	8-Aug-93							
Site	1		2		3		4	
Mean (+/- sd)	MEAN	(+/-SD)	MEAN	(+/-SD)	MEAN	(+/-SD)	MEAN	(+/-SD)
Phytoplankton Cells (Cells l^{-1})								
CHLOROPHYTA	1.21E+07	7.44E+05	1.03E+07	1.22E+06	1.38E+07	1.05E+06	1.02E+07	5.19E+05
CHRYSOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EUGLENOPHYTA	1.05E+06	4.96E+05	1.10E+06	0.00E+00	1.49E+06	0.00E+00	1.32E+06	2.07E+05
CHLOROMONADOPHYTA	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.67E+05	1.04E+05
CYANOPHYTA	1.49E+06	6.20E+05	0.00E+00	0.00E+00	4.22E+06	8.19E+05	9.53E+05	1.04E+05
PYRRHOPHYTA	8.77E+04	1.24E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DESMIDS	1.75E+06	2.48E+05	9.43E+05	2.22E+05	6.62E+05	0.00E+00	7.33E+05	0.00E+00
BACILLARIOPHYCEAE	1.28E+07	2.48E+05	6.84E+06	1.11E+05	1.61E+07	1.17E+05	1.18E+07	3.11E+05
TOTAL NUMBER (Cells l^{-1})	2.93E+07	2.48E+06	1.92E+07	1.56E+06	3.63E+07	1.99E+06	2.54E+07	1.24E+06

APPENDIX E

PERIPHYTON VOLUMES

Date	26-May-93		8-Jun-93		23-Jun-93	
Site	1	2	1	2	1	2
Periphyton Volume (μm^3 cm^{-2})						
Chlorophyta	2.23E+06	2.70E+07	1.49E+05	2.20E+06	1.31E+07	5.94E+06
Chrysophyta	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	7.50E+06	2.52E+06	5.49E+05	2.52E+05	5.99E+06
Chloromonadophyta	0.00E+00	0.00E+00	1.06E+05	6.48E+05	0.00E+00	4.32E+05
Cyanophyta	1.11E+06	5.73E+05	3.86E+05	4.03E+04	1.21E+06	6.71E+04
Pyrrhophyta	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Desmids	0.00E+00	0.00E+00	2.08E+05	1.36E+06	0.00E+00	4.23E+05
Diatoms	1.52E+07	2.81E+07	2.73E+06	7.13E+06	2.68E+07	1.91E+07
TOTAL	**1.86E+07**	**6.32E+07**	**6.10E+06**	**1.19E+07**	**4.14E+07**	**3.20E+07**
Date	**7-Jul-93**		**21-Jul-93**		**11-Aug-93**	
Site	**1**	**2**	**1**	**2**	**1**	**2**
Periphyton Volume (μm^3 cm^{-2})						
Chlorophyta	6.47E+06	1.83E+07	7.53E+06	3.73E+07	2.37E+07	1.55E+07
Chrysophyta	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	1.05E+07	2.30E+07	1.87E+07	1.81E+07	3.40E+06
Chloromonadophyta	0.00E+00	0.00E+00	0.00E+00	3.12E+05	0.00E+00	0.00E+00
Cyanophyta	1.05E+05	5.99E+05	6.82E+04	5.82E+05	3.11E+05	4.02E+05
Pyrrhophyta	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Desmids	0.00E+00	2.63E+06	8.15E+05	4.07E+05	9.65E+05	6.11E+05
Diatoms	1.65E+07	1.72E+07	2.40E+07	1.16E+07	4.10E+07	3.85E+07
TOTAL	**2.31E+07**	**4.93E+07**	**5.54E+07**	**6.89E+07**	**8.40E+07**	**5.84E+07**

APPENDIX F

TAXONOMIC LIST OF PHYTOPLANKTON SPECIES

Taxonomic List of Phytoplankton species at Old Woman Creek, 1993

Chloromonadophyta
Cryptomonas erosa

Chlorophyta
- Chlorococcales
Ankistrodesmus falcatus
Crucigenia tetrapedia
Kirchneriella subsolitaria
Lagerheimia quadriseta
Micractinium pusillum
Pediastrum duplex
Scenedesmus abundans
Scenedesmus bijuga
Scenedesmus denticulatus
Scenedesmus dimorphus
Scenedesmus opoliensis
Scenedesmus quadricauda
Schroederia setigera
Tetraedron quadratum
Tetrastrum glabrum
- Oedogoniales
Oedogonium sp.
- Tetrasporales
Gloeocystis ampla
- Volvocales
Chlamydomonas globosa
- Zygnematales
Closterium acerosum
Cosmarium biretum

Chrysophyta
– Bacillariophyceae
Achnanthes sp.
Cyclotella menegheniana
Cymbella sp.

Taxonomic List of Phytoplankton Species at Old Woman Creek, 1993.

Diploneis puella
Fragillaria sp.
Gomphonema sp.
Melosira distans
Melosira granulata
Meridion sp.
Navicula mutica
Nitzschia acicularis
Rhoicosphenia sp.
Stauroneis sp.
Terpsinoe sp.

Cyanophyta
Merismopedia tenuissima
Oscillatoria sp.
Phormidium tenue

Euglenophyta
Euglena acus
Euglena convoluta
Euglena gracilis
Euglena minuta
Phacus caudatus
Phacus pleuronectes
Trachelomonas armata
Trachelomonas volvocina

APPENDIX G

TAXONOMIC LIST OF PERIPHYTON SPECIES

Taxonomic List of Periphyton species at Old Woman Creek, 1993

Chloromonadophyta
Cryptomonas erosa

Chlorophyta
- Chlorococcales
Ankistrodesmus falcatus
Crucigenia tetrapedia
Kirchneriella subsolitaria
Lagerheimia quadriseta
Micractinium pusillum
Pediastrum duplex
Scenedesmus abundans
Scenedesmus bijuga
Scenedesmus denticulatus
Scenedesmus dimorphus
Scenedesmus opoliensis
Scenedesmus quadricauda
Schroederia setigera
Tetraedron quadratum
Tetrastrum glabrum
- Oedogoniales
Oedogonium sp.
- Tetrasporales
Gloeocystis ampla
- Volvocales
Chlamydomonas globosa
- Zygnematales
Closterium acerosum
Cosmarium biretum

Chrysophyta
-- Bacillariophyceae
Achnanthes sp.
Cyclotella menegheniana
Cymbella sp.
Diploneis puella

Taxonomic List of Periphyton species at Old Woman Creek, 1993

Fragillaria sp.
Gomphonema sp.
Melosira distans
Melosira granulata
Meridion sp.
Navicula mutica
Nitzschia acicularis
Rhoicosphenia sp.
Stauroneis sp.
Terpsinoe sp.

Cyanophyta
Merismopedia tenuissima
Oscillatoria sp.
Phormidium tenue

Euglenophyta
Euglena acus
Euglena convoluta
Euglena gracilis
Euglena minuta
Phacus caudatus
Phacus pleuronectes
Trachelomonas armata
Trachelomonas volvocina