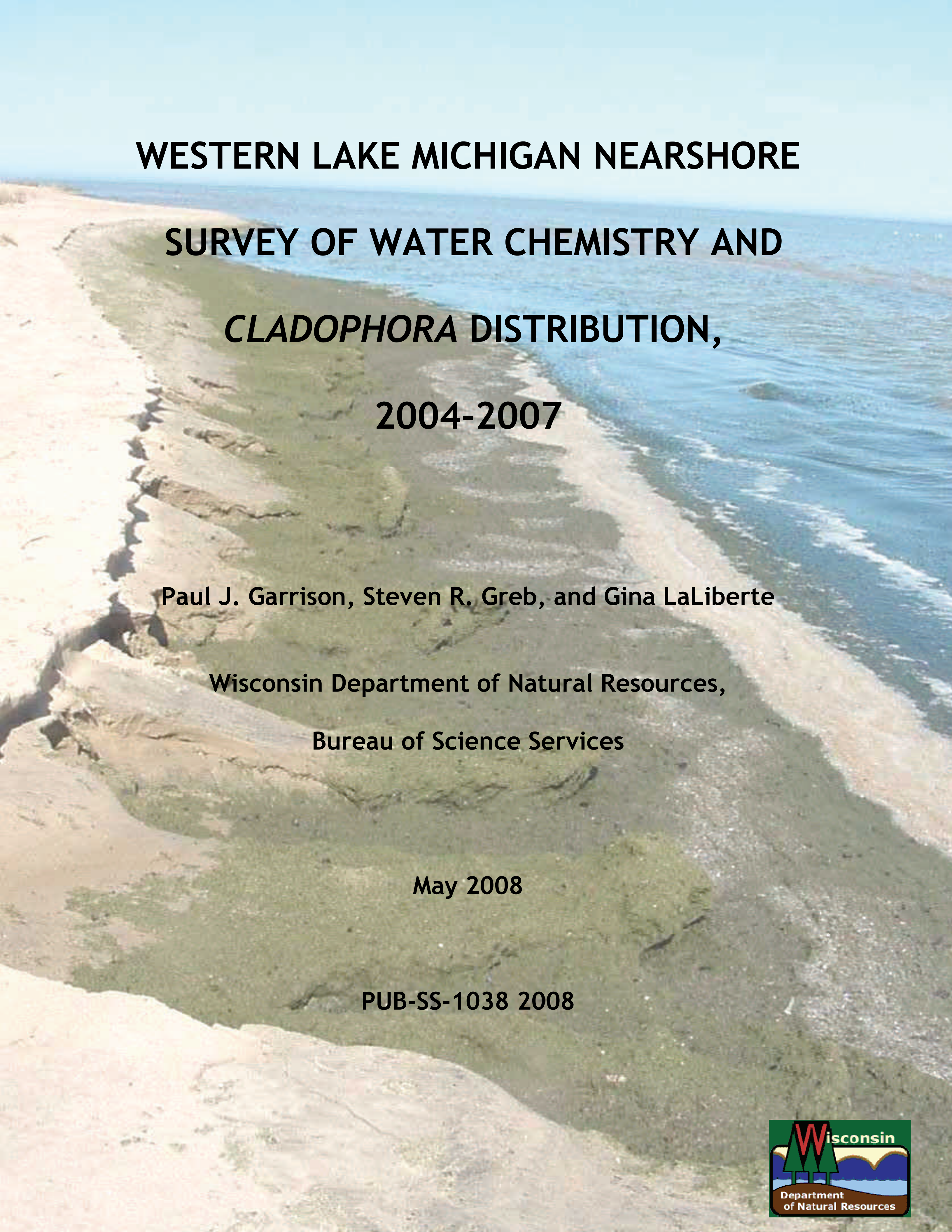

WESTERN LAKE MICHIGAN NEARSHORE SURVEY OF WATER CHEMISTRY AND *CLADOPHORA* DISTRIBUTION, 2004-2007

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Introduction

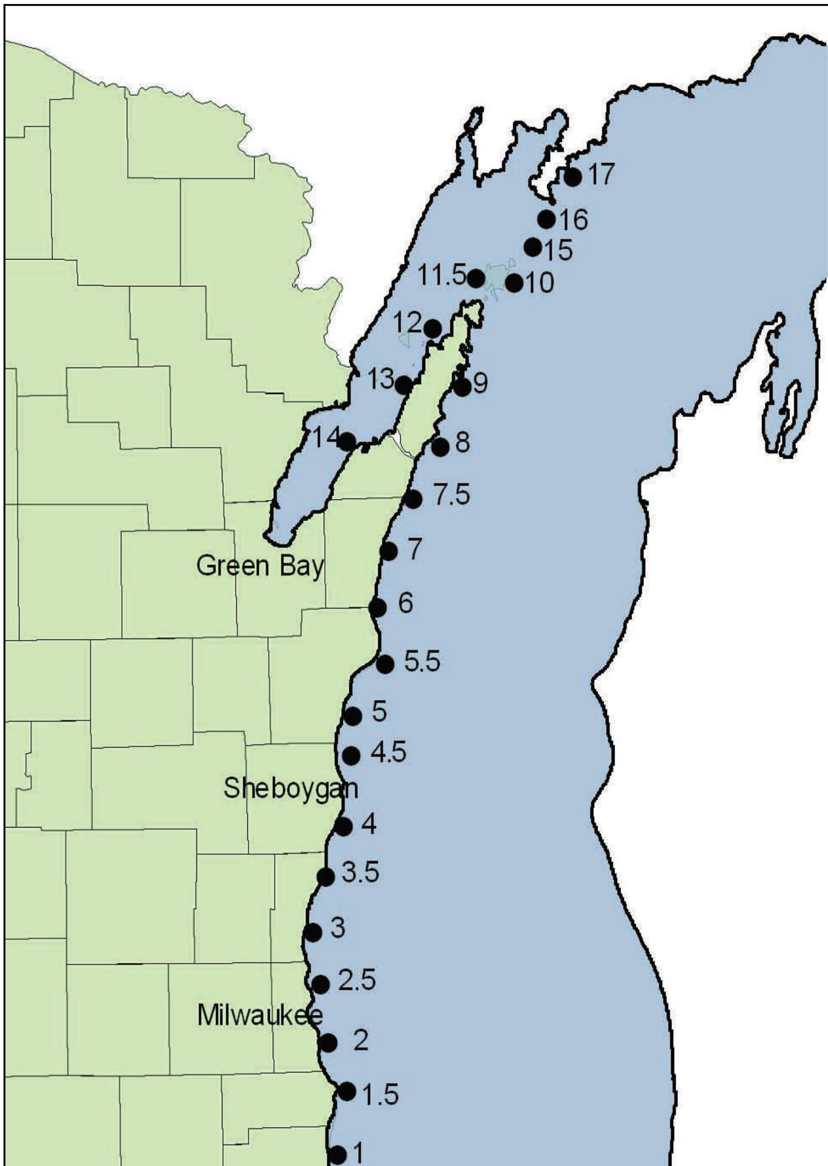
In recent years, algae of the genus *Cladophora* (referred to here simply as *Cladophora*) has increased along the Lake Michigan shore and has been deposited in large quantities along Lake Michigan beaches. The presence of decomposing *Cladophora* on beaches presents aesthetic and odor problems that impair recreational use of Lake Michigan. Conditions in the rotting algae may be ideal for bacterial growth. The presence of mollusks deposited on the beach with the may attract large flocks of gulls. Large quantities of fecal material from these birds can result in increased bacteria (*E. coli*) concentrations in nearby beach waters.

In spring 2004, the Wisconsin DNR initiated a *Cladophora* Working Group to address the nuisance algal problem on Lake Michigan. The working group includes representatives from the DNR's Northeast Region, Southeast Region, Bureau of Science Services, and Central Office Water Division. The group's objectives include researching environmental factors causing the algal blooms to assist with developing long-term management plans, identifying short-term beach clean-up and odor mitigation options, and addressing public information needs. The *Cladophora* Working Group collaborates with others, including the University of Wisconsin-Extension, University of Wisconsin-Milwaukee's WATER Institute, UW Sea Grant, county health departments, and Centerville Cares, a Manitowoc County citizen's organization.

A portion of the *Cladophora* Working Group (Central Office and Science Services) developed and implemented a monitoring program, which began in the summer of 2004. The purpose of this program was to observe the density, distribution, and associated water quality of *Cladophora* along Wisconsin's Lake Michigan shoreline. This report presents the results of the monitoring and research program for the years 2004-07.

Methods

Figure 1 depicts the locations of our 24 sampling sites and Table 1 identifies locations of these same sites. Figure 2 identifies months when samples were collected during the study period. During the first year, the survey ranged from Kenosha to Rowley's Bay in Door County. In subsequent years, the survey expanded north to the Fayette Peninsula in Michigan's Upper Peninsula. Within a given year, we attempted to sample each site twice. The timing of these surveys depended on weather conditions and logistic considerations. In addition, the timing of the sampling reflected multiple project objectives (e.g., potential nutrient pool in spring, summer *Cladophora* growth rates). At some sites, only one sampling run was attainable during a given year. The selection of sites also changed from year to year as more was learned about the growth and distribution of *Cladophora*. To a large extent, this change was towards fewer sites with greater spatial coverage and reflected available sampling



Station no.	Location
1	Kenosha
1.5	Racine
2	Milwaukee S
2.5	Shorewood
3	Cedarburg
3.5	Port Washington
4	Oostburg
4.5	Whistling Straits
5	Centerville
5.5	Manitowoc
6	Two Creeks
7	Rostock
7.5	Kewaunee
8	Lily Bay
9	Bailey's Bay
9.5	Rowleys Bay
10	Wash. Is. E
11.5	Wash. I. W.
12	Sister Bay
13	Horseshoe Bay
14	Henderson Point
15	St. Martin Is.
16	Summer Is.
17	Kregg Bay

Figure 1. Sampling locations (stations) during 2004-07. Not all locations were sampled in all years. See Figure 2 for sampling frequencies.

and analysis funds. During the first year, samples were collected at two locations at each site, one location where the total water depth was 2 meters (m) and the other where the total water depth was 10 m.

At the 2-m locations, samples were collected at the surface. At the 10-m locations, samples were collected at both the surface and bottom. In addition, water column profiles of temperature, DO, and conductivity were recorded at all 10-m sites. Water quality parameters analyzed in all samples included: total Kjeldahl nitrogen (TKN), nitrate+nitrite (NO_3+NO_2, generally expressed as NO_3), total phosphorus (TP), total dissolved phosphorus (TDP), dissolved reactive phosphorus (DRP), and

Table 1. Sampling locations (stations) during 2004-2007. Not all locations were sampled in all years. See Figure 2 for sampling frequencies.				
Station no.	Location	Latitude	Longitude	Lat. Mile #
1	Kenosha	42 34.619	87 48.793	0.0
1.5	Racine	42 45.257	87 46.748	10.6
2	Milwaukee, South	42 55.852	87 50.699	21.2
2.5	Shorewood	43 06.230	87 52.842	31.6
3	Cedarburg	43 16.860	87 54.136	42.2
3.5	Port Washington	43 27.730	87 48.197	53.1
4	Oostburg	43 37.794	87 44.380	63.2
4.5	Whistling Straits	43 51.598	87 43.841	77.0
5	Centerville	43 58.745	87 41.652	84.1
5.5	Manitowoc	44 09.285	87 32.623	94.7
6	Two Creeks	44 19.728	87 32.533	105.1
7	Rostock	44 30.052	87 28.815	115.4
7.5	Kewaunee	44 40.508	87 22.307	125.9
8	Lily Bay	44 50.456	87 14.994	135.8
9	Bailey's	45 01.059	87 07.585	146.4
9.5	Rowleys Bay	45 11.78	87 01.37	157.2
10	Wash. Is. E	45 22.75	86 49.85	168.1
11.5	Wash. Is. W.	45 22.03	86 57.21	167.4
12	Sister Bay	45 12.00	87 07.56	157.4
13	Horseshoe Bay	45 1.43	87 20.988	146.8
14	Henderson Point	44 51.30	87 34.31	136.7
15	St. Martin Is.	45 28.73	86 44.91	174.1
16	Summer Is.	45 33.70	86 36.91	179.1
17	Kregg Bay	45 41.92	86 33.91	187.3

Chlorophyll-a (Chl-a). Additional parameters, which were not collected during all years, included total suspended solids (TSS), ammonia (NH3-N), chloride (Cl) and dissolved silica (Si). Table 2 lists the total number of samples analyzed for each parameter by year.

When available, we lowered a camera to the bottom and estimated the amount of the bottom that was covered with vegetation. We also collected the vegetation with an Ekman dredge to identify the vegetation. We also described the substrate.

We measured *Cladophora* productivity during the cruises in 2006-07. This was done by collecting *Cladophora* with an Ekman dredge. The samples were immediately placed in low light and nonalgal material was separated from the *Cladophora*. In subdued light, the algal complex was placed in

Station	Year												
	2004			2005				2006			2007		
	June	July	Aug-Sept	Apr-May	June	July	Aug-Sept	June-July	Aug	Sept-Oct	June-July		July-Aug
1	■		■	■			■	■		■	■		■
1.5	■		■										
2	■		■	■			■	■		■			■
2.5	■		■										
3	■		■	■			■	■		■	■		■
3.5	■		■										
4	■		■	■			■						
4.5	■		■										
5	■		■	■			■	■		■	■		■
5.5	■		■										
6	■		■	■			■	■		■	■		■
6.5													
7	■		■	■			■	■		■	■		■
7.5	■		■										
8	■		■	■			■	■		■	■		■
9	■							■		■	■		■
9.5	■			■			■						
10				■			■	■		■			■
11.5				■			■						
12				■			■	■		■	■		■
13				■			■	■		■			■
14				■			■						
15				■			■	■		■			■
16				■			■	■		■			■
17				■			■	■		■			■

300 ml clear BOD glass bottles within a few minutes of collection. Starting temperature and DO levels were measured and the samples were incubated for about 1 hour. The samples were incubated at ambient lake surface water temperatures and the light intensity was 195.5 watts m^{-2}. For each site, we attempted to have 3 light bottles and 1 dark bottle. The dark bottle estimated community respiration. The mean of the light bottles represented gross productivity, while the oxygen change in the light bottle minus the oxygen change in the dark bottle reflected net productivity. Following incubation the algae was removed, blotted, and placed in small plastic bags. Samples were kept in the dark

Table 2. Total number of samples analyzed for each water quality parameter by year.

Parameter	2004	2005	2006	2007
TSS-Top	30	34	28	0
TSS-Bottom	30	34	28	0
TKN-Top	29	34	28	24
TKN-Bottom	29	34	28	16
NO3-N Top	29	34	28	24
NO3-N Bottom	29	34	28	16
TP-Top	29	34	28	24
TP-Bottom	29	34	28	16
TDP-Top	29	34	28	24
TDP-Bottom	29	34	28	16
SRP-Top	29	33	28	24
SRP-Bottom	29	34	28	16
Cl-Top	0	34	26	16
Cl-Bottom	0	34	26	15
Chl-a	28	34	28	23
NH3-N Top	29	0	0	0
NH3-N Bottom	29	0	0	0
Si-Top	0	0	28	8
Si-Bottom	0	0	28	1

and on ice until they were returned to the lab. In the lab, the samples were again blotted and the weight of the fresh and ashed (500° C for 1 hour) were measured. The samples were then placed in acid washed plastic vials and frozen. The samples were later analyzed for carbon, phosphorus, and chlorophyll content at the lab of Dr. Harvey Bootsma at the University of Wisconsin-Milwaukee's Great Lakes WATER Institute.

In 2006, samples were collected at four locations to estimate *Cladophora* biomass: Hika Bay, Lily Bay, and the east sides of Washington and St. Martin islands. Samples were collected at 10-m depths via SCUBA by harvesting 0.1 m^2 quadrates. Four or five replicates were collected at each site. Upon returning to the lab, the algae was separated from non-algal material (rocks and dressinid mussels). Samples were collected monthly in June, July, and August. In 2007, samples were only collected from Lily Bay about biweekly from June through mid-August.

Results and Discussion

Summary statistics (minimum, maximum, and median) of all chemistry results are given in Table 3. In general, low concentrations of all parameters were observed at all stations. To a large extent, constituents such as TSS, NH3-N, and DRP were found at or below detection limits. Phosphorus and chlorophyll-a concentrations generally classify the water at these sites as oligotrophic, although the interior Green Bay sites (stations 12-14) tend towards mesotrophic conditions.

Chloride concentrations were uniform throughout the lake, although again, sites within Green Bay averaged a 2-3 mg/L higher than the other sites. Silica (Si) was only sampled during the last two years. Si concentrations varied from approximately 0.4 mg/L to almost 2 mg/L. Interestingly, the higher Si concentrations were found on the lakeside region of Door County and islands to the north (stations 8, 10, 15, and 17).

Comparison of 2-meter and 10-meter Depths/Sites

During the first year (2004), samples were taken at both a 2-m and 10-m locations. A paired t-test was employed to test differences between the surface waters of these two locations. Because of the large amount of nondetected values reported for the other constituents (for example, TSS had >80 percent non-detectable concentrations), t-tests were not performed on TSS, NH3, TDP, or SRP. In the constituents tested, namely TKN, NO3, Chl-a, and TP, there was a significant difference between the 2-m and 10-m locations at the p <0.05 level. In general, these differences were a result of higher constituent concentrations at the 2-m sites, which probably is a consequence of wave action and turbulence at these sites. The 2-m locations were commonly found within a few hundred meters of the shoreline, whereas the 10-m sites were generally located 1 kilometer or more from the shore. Nitrate, the only dissolved constituent compared, showed slightly lower concentrations (6.7 percent) at the 2-m sites (Figure 3). This lower concentration in the shallow waters may be a result of nearshore benthic productivity.

Comparison of Surface and Bottom Water Chemistry at 10-m Sites

Unlike the 2-m vs. 10-m comparison, little difference was seen in water chemistry between the surface and bottom samples at 10-m sites. Using data collected in all four years, paired t-tests found no significant difference (p<0.05) between top and bottom concentrations of TP, TDP, NO3, and TN. An example of this top-bottom similarity is illustrated in Figure 4. Note the equal spread around the 1:1 line, both suggesting similar top-bottom concentrations. This is true of both dissolved (e.g., NO_3) and particulate associated (e.g., TP) constituents; hence, the lake appears to generally stay well mixed at this 10-m region of the lake. This observation is further corroborated by the temperature and DO profiles recorded at these sites. Generally 2-5^{o} C decreases were observed from top to bottom, but little evidence of stratification. Oxygen concentrations were fairly uniform and approached saturation from top to bottom. Some sites exhibited slight increases in oxygen in close proximity to the bottom, reflecting the primary productivity of the *Cladophora* and other benthic algal growth.

Latitudinal Changes in Water Chemistry

Nutrient concentrations generally decreased along the 187 mile south to north survey transect. Figure 5a illustrates TP surface concentrations at the 10-m sites along the transect with a significant linear decrease in both TP (P = 0.001) and TN (P < 0.001) with linear distance north of Kenosha. The slope coefficients were -0.017 µg/L per mile for TP and -0.725 µg/L per mile for TN. Or, rescaling to change per 100 miles, TP decreased by 1.7 µg/L for every 100 miles north of Kenosha and TN decreased by 72 µg/L for every 100 miles north of Kenosha. This pattern was also observed in the

Table 3. Summary statistics for water quality analyses.

		TSS (mg/L)		TKN (mg/L)		NO2+NO3 (mg/L)		TP (mg/L)		TDP (mg/L)		SRP (mg/L)		Chloride (mg/L)		Chl-a (µg/L)	NH3 (mg/L)		Si. (mg/L)	
		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Top	Bottom	Top	Bottom
Spring	MIN	<2	<2	<0.14	<0.14	0.191	0.244	<0.005	<0.005	0.005	<0.005	<0.002	<0.002			0.28	<0.015	<0.015		
2004	MAX	<2	<2	0.37	0.97	0.346	0.355	0.013	0.014	0.009	0.008	0.004	0.003			3.03	0.017	0.025		
n=16	MED	<2	<2	0.22	0.24	0.274	0.280	0.009	0.008	0.006	<0.005	<0.002	<0.002			0.46	<0.015	0.019		
Fall	MIN	<2	<2	<0.14	0.15	0.225	0.231	<0.005	<0.005	<0.005	<0.005	<0.002	<0.002			0.28	<0.015	<0.015		
2004	MAX	5	3	0.19	0.24	0.327	0.297	0.010	0.017	0.005	<0.005	0.005	0.002			1.25	0.021	0.024		
n=14	MED	<2	<2	0.16	0.17	0.243	0.263	0.006	0.006	<0.005	<0.005	<0.002	<0.002			0.52	<0.015	<0.015		
Spring	MIN	<2	2	<0.14	<0.14	0.14	0.144	0.0028	0.003	0.0021	0.0021	<0.002	<0.002	10.00	9.90	0.26				
2005	MAX	4	4	<0.14	<0.14	0.32	0.316	0.0219	0.019	0.010	0.0097	0.0654	0.004	16.30	15.30	7.85				
n=17	MED	<2	2	<0.14	<0.14	0.23	0.239	0.006	0.006	0.003	0.0031	<0.002	<0.002	11.00	10.90	0.42				
Fall	MIN	<2	<2	<0.14	<0.14	0.004	0.057	0.0044	0.003	<0.002	0.002	<0.002	<0.002	10.6	10.3	0.26				
2005	MAX	4	6	0.44	0.49	0.312	0.306	0.019	0.035	0.008	0.0103	0.0041	0.0053	12.8	12.3	7.37				
n=17	MED	<2	<2	<0.14	<0.14	0.162	0.167	0.005	0.006	0.004	0.0045	<0.002	<0.002	10.8	10.7	0.5				
Spring	MIN	<2	<2	0.17	<0.14	0.06	0.099	0.0027	0.003	0.0021	0.0021	0.003	0.003	10.70	10.70	0.26			0.389	0.422
2006	MAX	<2	<2	0.37	0.42	0.34	0.311	0.0101	0.017	0.010	0.0132	0.036	0.009	12.50	12.80	2.62			1.97	2.09
n=14	MED	<2	<2	0.28	0.29	0.19	0.202	0.0045	0.004	0.0039	0.00305	0.003	0.004	11.15	11.10	0.265			1.125	1.3
Fall	MIN	<2	<2	0.16	<0.14	0.02	0.024	0.0027	0.0028	0.0020	0.0030	<0.002	<0.002	10.60	10.70	0.26			0.12	0.522
2006	MAX	4	<2	0.43	0.42	0.33	0.319	0.0137	0.016	0.010	0.0076	0.007	0.006	12.20	12.20	5.9			1.56	1.63
n=14	MED	<2	<2	0.25	0.215	0.18	0.182	0.0046	0.004	0.0030	0.0030	0.006	0.005	10.90	10.90	0.26			1.235	1.305
Spring				0.18		0.073		0.0047		0.0026		<0.002				<0.26			0.751	
2007				0.39		0.304		0.0103		0.0077		<0.002				1.65			1.47	
n=9				0.21		0.249		0.0055		0.0038		<0.002				<0.26			1.265	
Fall				0.14	0.200	0.032	0.039	0.002	0.002	0.002	<0.002	<0.0004	<0.002			<0.26			0.575	0.471
2007				0.37	0.347	0.598	0.263	0.0227	0.0192	0.0163	0.0057	0.015	0.002			1.45			1.75	1.56
N=15				0.27	0.27	0.228	0.198	0.0043	0.0038	0.0026	0.0025	<0.002	<0.002			<0.26			1.04	1.24

parameters TDP and NO_3. This decrease in nutrient concentrations, as one moves south to north, is likely attributed to watershed influences. Land use transitions from a largely agricultural and urban dominated landscape in the south to a forestry dominated landscape in the far north. There is also some indication of localized watershed influence in these nearshore waters. TP concentrations at Site 3 (Cedarburg) are lower than adjacent sites and may reflect the fact that no riverine inputs are located in this section of the coast.

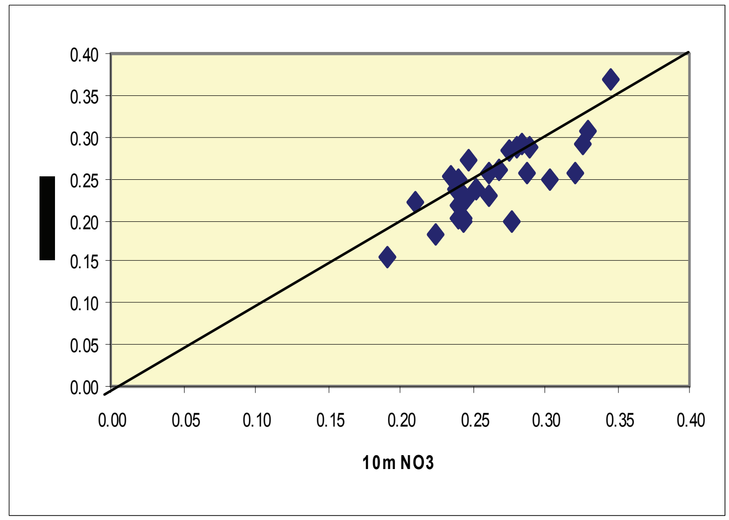


Figure 3. Comparison of 2-m and 10-m surface NO3 concentrations.

Another indication that allochthonous inputs are influencing ambient nearshore nutrient concentrations come from examining how well year-to-year variability of river inputs is reflected in in-lake nutrient concentrations. Figure 6 illustrates the relationship between annual river volume inputs (a rough surrogate for runoff and nutrient inputs) and in-lake nutrient concentrations. Even though we collected only 4 years of nutrient data in this study, a strong relationship was observed between mean annual daily flow (based on USGS water years Oct. through Sept.) and in-lake TP concentration (mean of all 10-m sites for each year). This relationship was observed for both the Milwaukee (r^2=0.78) and Sheboygan (r^2=0.97) rivers and illustrates the strong influence that land use and climate potentially exert on lake nutrient concentrations.

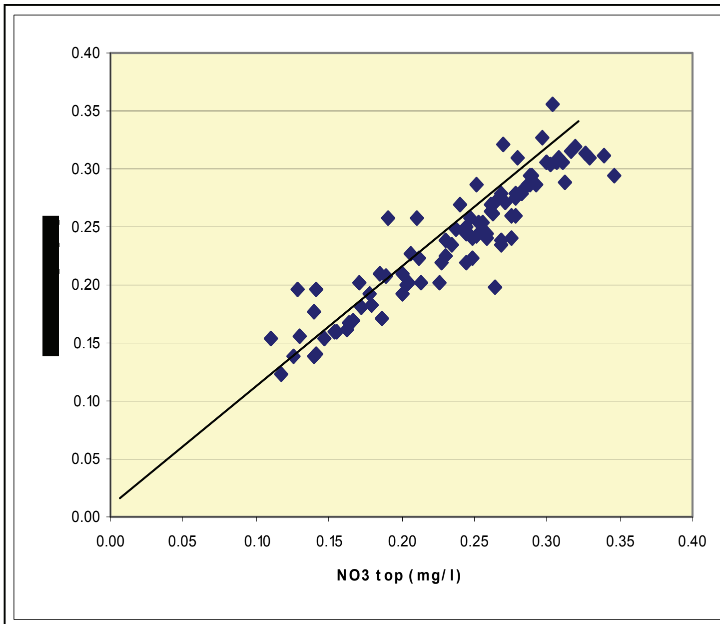


Figure 4. Comparison of top and bottom NO3 concentrations at 10-m locations.

Also plotted on the right side of Figures 5 a, c, d are the Lake Michigan open water concentrations measured by EPA's spring cruises [TKN was not reported by EPA and therefore total nitrogen

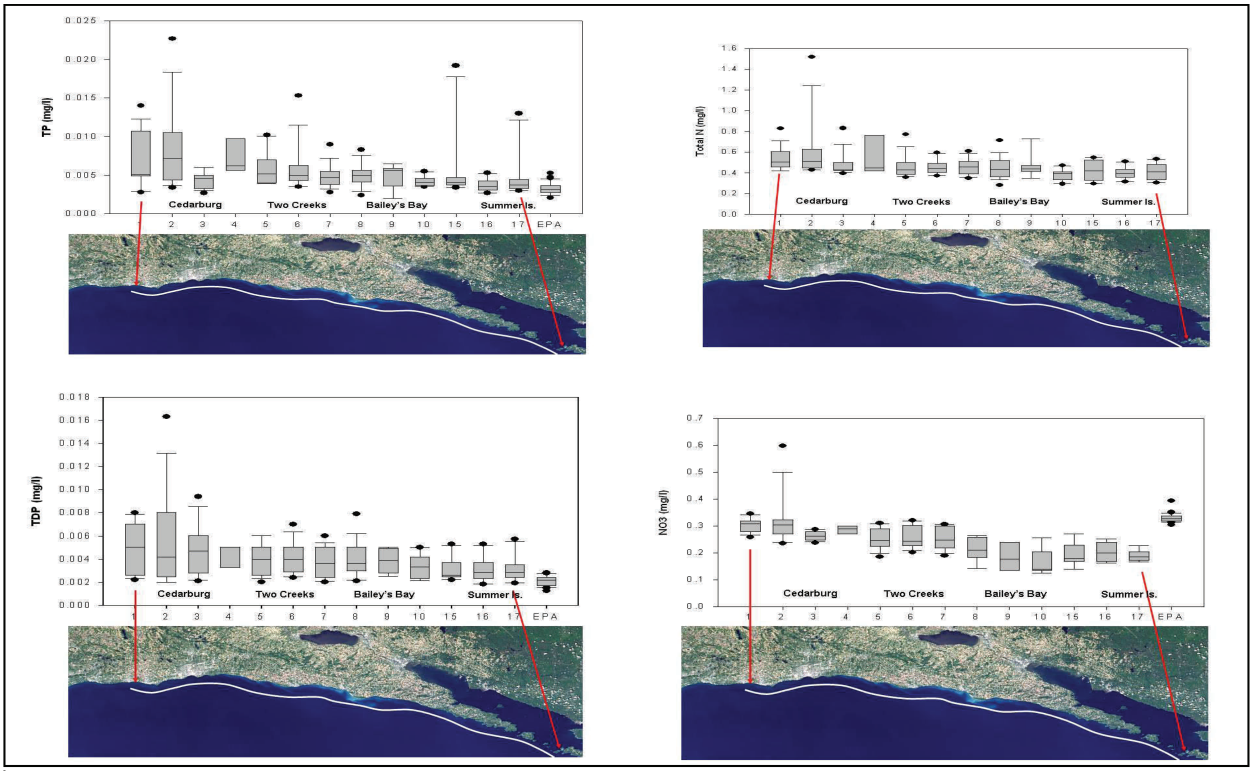


Figure 5a-d. Latitudinal plots of TP (a), TN (b), TDP (c), and NO3 (d) concentrations.

could not be shown]. These box plots (labeled EPA) represent the mean of surface mid-lake concentrations for the same 2004-2007 time period. Total phosphorus and total dissolved phosphorus concentrations were lower at the mid-lake sampling stations; these sites are the least affected by near-shore or riverine inputs. Nitrate followed an opposite pattern, with open water concentrations being greater than near-shore concentrations. Both the phosphorus and nitrate patterns are consistent with the changes in concentrations observed between the 2-m and 10-m sites, and further demonstrate the

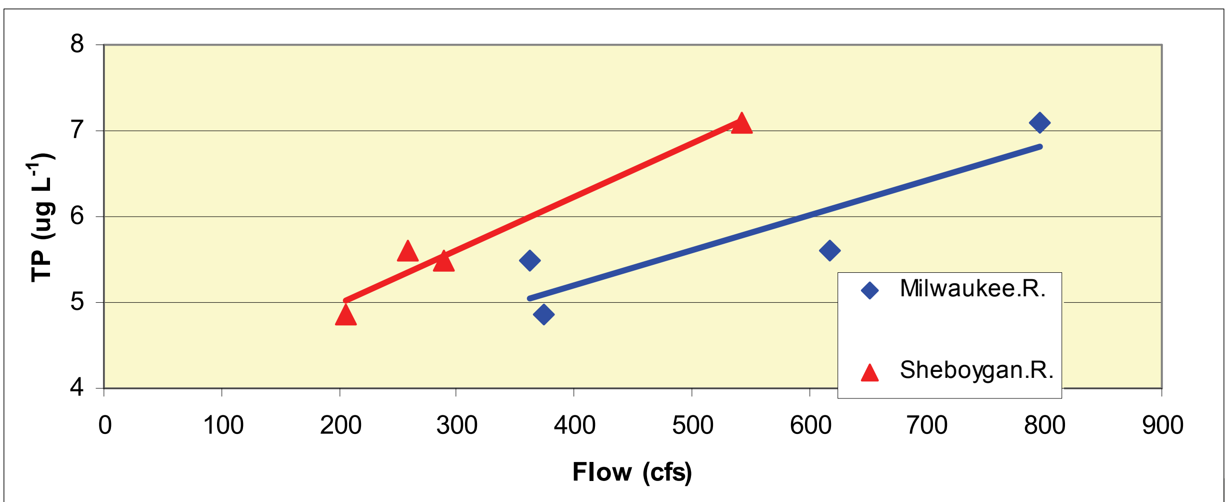


Figure 6. Relationship of in-lake TP concentration and annual inflow for selected rivers.

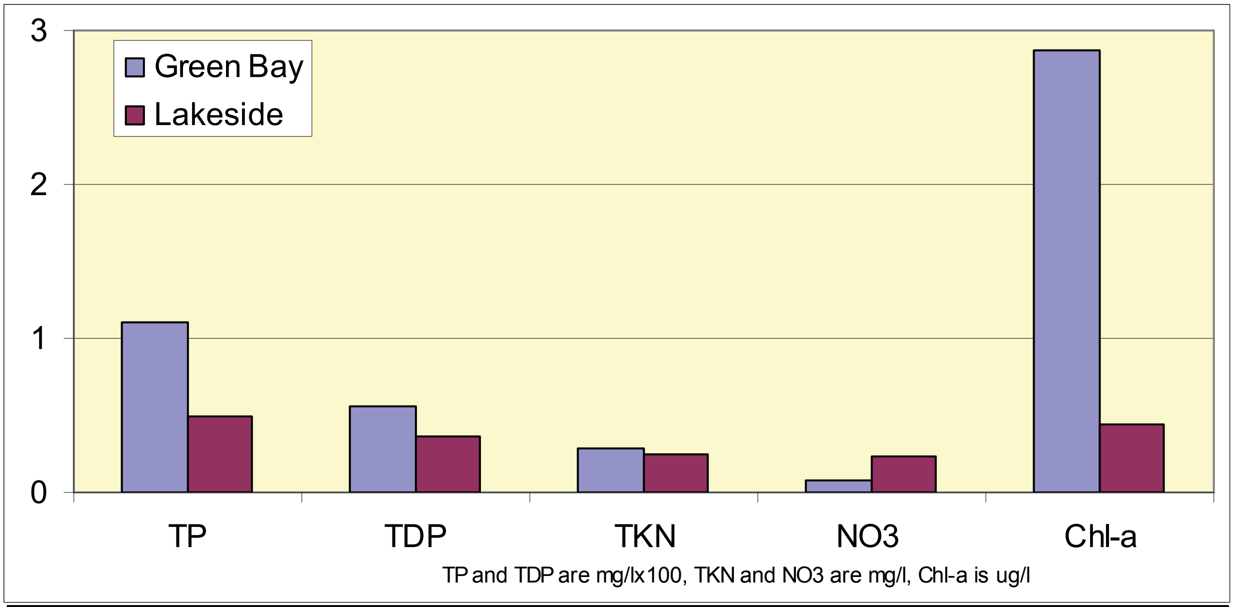


Figure 7. Comparison of lakeside stations with bayside stations.

general observation of phosphorus decrease and nitrate increase in a gradient from the shoreline to open waters.

Stations found within the bay of Green Bay displayed somewhat different nutrient characteristics due to the geophysical setting and the large riverine nutrient inputs from the Fox River. The Door County peninsula portion of the Niagara Escarpment prevents the river input from readily mixing with Lake Michigan as a whole. This geologic feature, along with the fact that the Fox River is the largest external source of nutrients to Lake Michigan, results in greater nutrient concentrations and productivity in the bay. Figure 7 compares average nutrient and Chl-a concentrations of the lakeside sites with those within the bay (Stations 12, 13, and 14). Note that TP concentrations were more than double in the bay than on the lakeside and approximately half of this phosphorus is in the particulate form (the other half being TDP). The bay nutrient concentrations are not evenly distributed, but decrease as one goes from the Fox River's mouth to Washington Island. The increased ambient phosphorus concentrations in Green Bay results in greater Chl-a concentrations. The increased productivity of the bay subsequently results in diminished NO_3 concentrations.

Modeling Efforts

Simple empirical models were constructed in an effort to better understand the *Cladophora* growth response to environmental factors. These models were developed by a series of step-wise regression analysis. Knowing *Cladophora* growth response to temperature, light and nutrients, various combinations of these explanatory variables (or surrogates), which were measured during the lake surveys, were used to develop a simple multiple regression equation to predict *Cladophora* cell phosphorus (cell-P) concentrations. If cell-P concentrations can be satisfactorily modeled, established relationships between cell-P concentrations and growth rates can be utilized to simulated growth rates.

The input variables used included TP, TDP, NO3, Secchi disk, light extinction coefficient and bottom-water temperature. The two best equations (highest r^2 with fewest variables) were:

$$\text{Cell P} = 89.2(\text{TP}) + 0.061\ (\text{Water Temp}) - 0.642 \qquad r^2 = 0.77 \qquad (1)$$

and

$$\text{Cell P} = 57.04(\text{TDP}) + 0.0437(\text{Water Temp}) - 0.109\ \text{Secchi} + 0.869 \qquad r^2 = 0.79 \qquad (2)$$

The predicted *vs.* measured cell P for both equations is plotted in Figure 8. Both models closely track the measured variability observed in cell P concentrations. Though these models may be considered empirical, they are nonetheless based on factors known to influence phosphorus uptake. Given their simplicity and minimal input requirements, they may be a useful tool in predicting in-lake *Cladophora* growth. Of the two models presented, the TP model is simpler, requiring fewer inputs, but would be considered somewhat less mechanistically correct, knowing that *Cladophora* doesn't directly respond to TP. The TDP model requires more inputs, but may prove more robust with changing lake conditions. Future plans are to compare this output presented here with the output generated by the more mechanistic modeling effort underway at the UW-M WATER Institute.

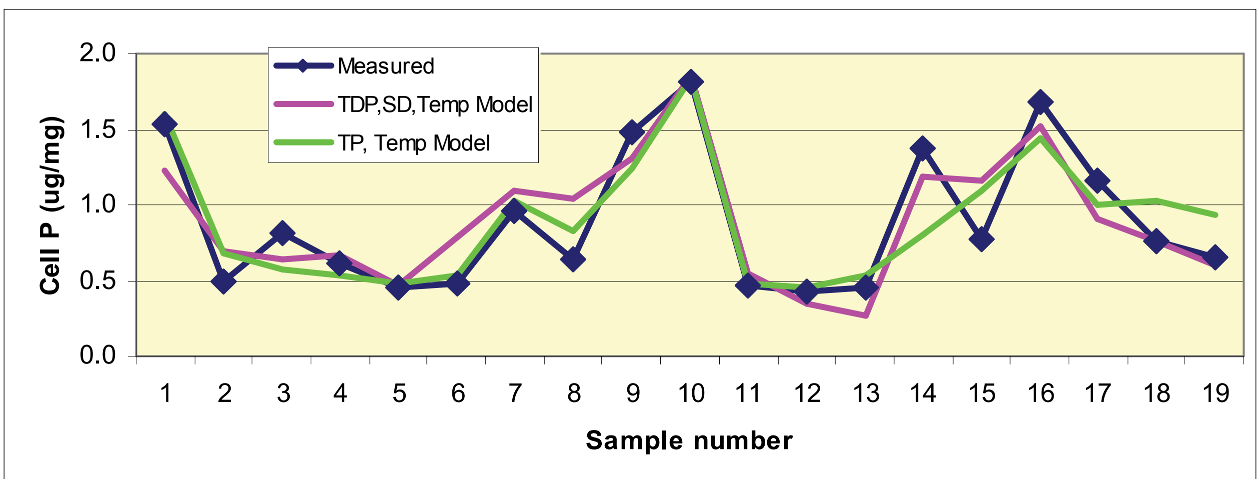


Figure 8. Predicted and measured cell P concentrations for 2006 *Cladophora* tissue samples. The num-

Cladophora Biomass

In nearly all cases when hard substrate was present, it was covered with *Cladophora*. When sand was the dominant substrate, there was little if any algae. Substrate suitability for *Cladophora* growth is summarized in Figure 9. Some of the best substrate is dressinid mussel colonies. At 2 to 15 m depths where mussels are present they are almost always covered with the algae. Often algae growing on the mussels appears greener and thus more healthy than *Cladophora* growing on bare rock.

- **Coverage dependent upon substrate**
  - ***Best is rock*--**coverage generally 80-100%
  - ***Second best* is a mixture of cobble and sand--**coverage generally 50%
  - ***Sand*** is the least desirable--coverage generally less than 10%

Figure 9. Summary of on what substrate *Cladophora* grows best.

Where appropriate substrate was present, nearly all of the sites had significant *Cladophora* growth. The one exception was the southern most site, off shore from Kenosha. The filamentous algae growing there was the green alga *Tolypella*. The density of growth was considered high from Racine all the way to St. Martin's Island, MI (Figure 10). While the two most northern sites had *Cladophora* growth, it did not appear as dense as the other sites.

In northern Green Bay, there appeared to be much less *Cladophora* growth than on the lake side of the Door County peninsula. Growth that did occur was in water shallower than 10 m. This was because of the reduced water clarity in Green Bay. When *Cladophora* was collected at the Green Bay sites it was found in 5 m water depth. At the two southern Green Bay sites visited, Henderson Point and Dykesville, very little *Cladophora* was observed.

Cladophora biomass was measured at 4 sites in 2006: Hika Bay, Lily Bay, and the lakeside of Washington and St. Martin islands. The sites were visited monthly from May through Sept and biomass was measured at most sites in June through August. Visual observations were made during other visits.

Biomass was relatively low in May at all of the sites, although biomass was only measured at Washington Island and Hika Bay (Figure 11). By mid-June, only the Washington Island site showed significant accumulation of *Cladophora*. The peak periods of growth occurred in July until about mid-August. In mid-August, sloughing occurred. Measurements were not taken at the St. Martin Island site at that time because of adverse weather conditions. Sloughing had recently occurred at Washington Island and was beginning at the other sites. Visual observations from the water surface confirmed that

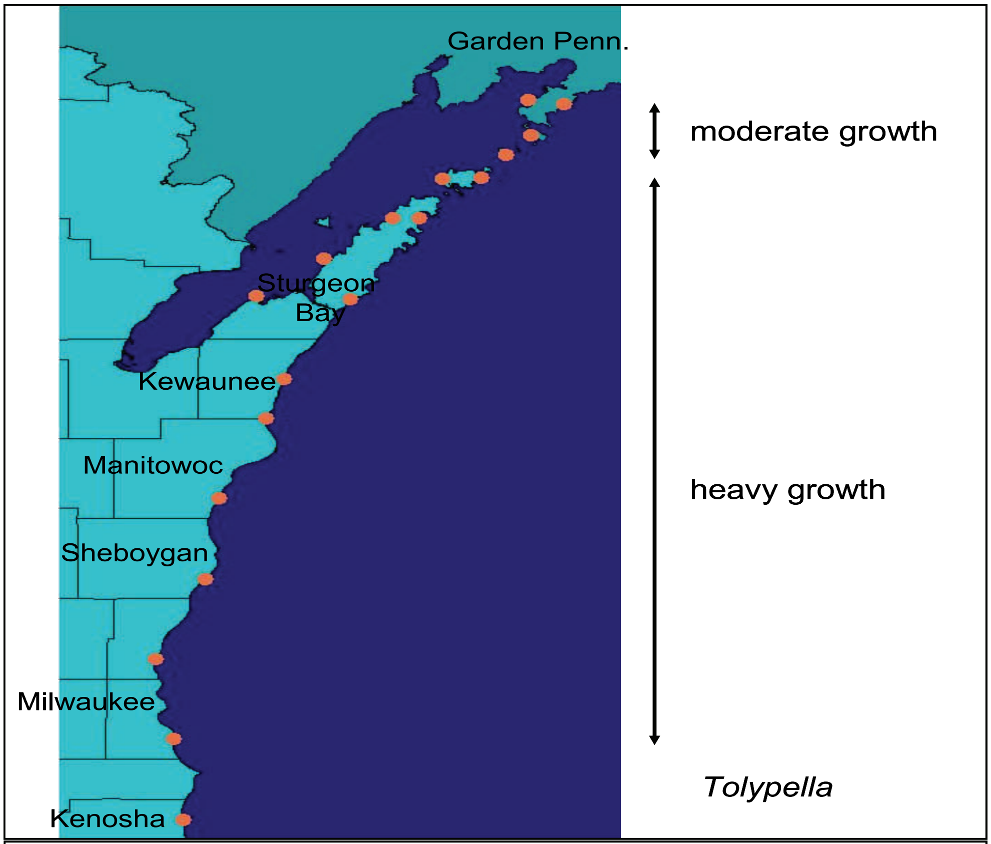


Figure 10. Distribution of *Cladophora* along Wisconsin's lake Michigan coast. Growth appeared uniformly dense from Racine northward to St. Martin's Island, MI. The growth at the two northernmost sites was less but still significant.

sloughing was complete by mid-September.

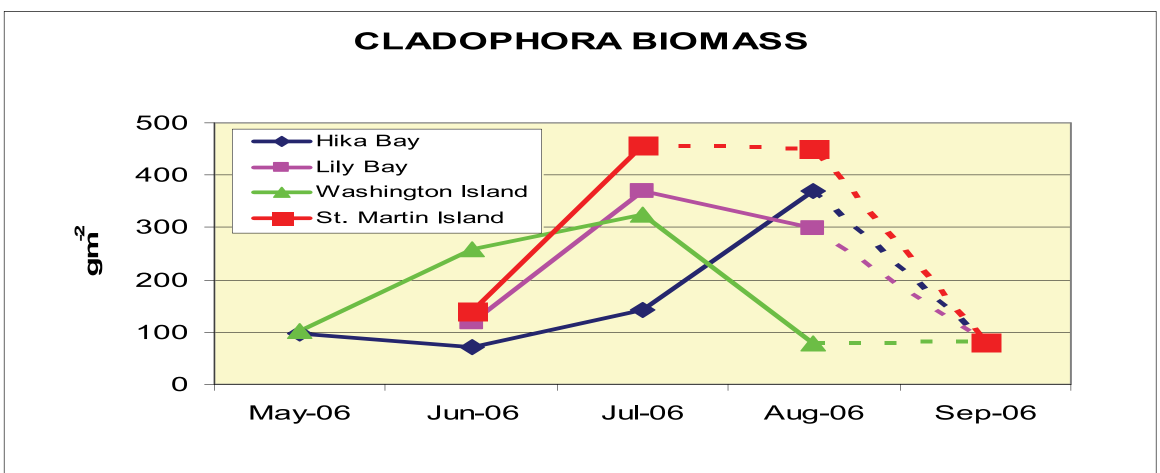


Figure 11. *Cladophora* biomass measurements at four northern sites in 2006. By mid-August sloughing had occurred or was in the process at all of the sites. St. Martin's Island was not sampled in August because of adverse weather conditions.

Productivity

In 2006, productivity was measured during the June and September cruises. The June cruise occurred when the *Cladophora* community was increasing its biomass while the September cruise was after the late summer sloughing. In 2007, productivity was measured in July, which was near the peak summer biomass period.

Figure 12 depicts a plot of productivity at all of the sites where we measured biomass. The productivities from the June 2007 cruise are not shown. Most values at that time were negative. It is not clear whether these values represent actual conditions or if there was a problem with the measurements. We suspect there may have been problems with the measurements so do not show the results.

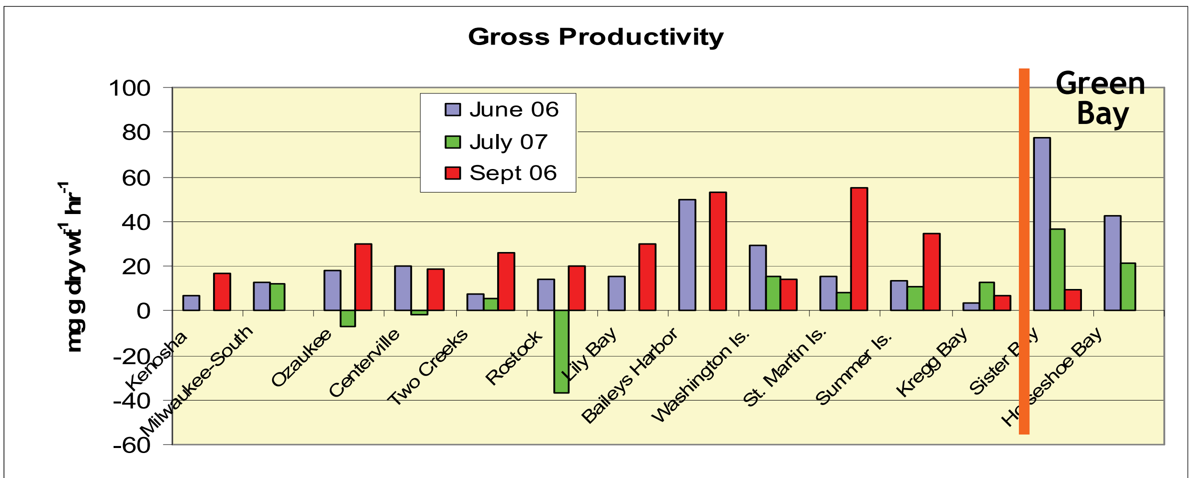


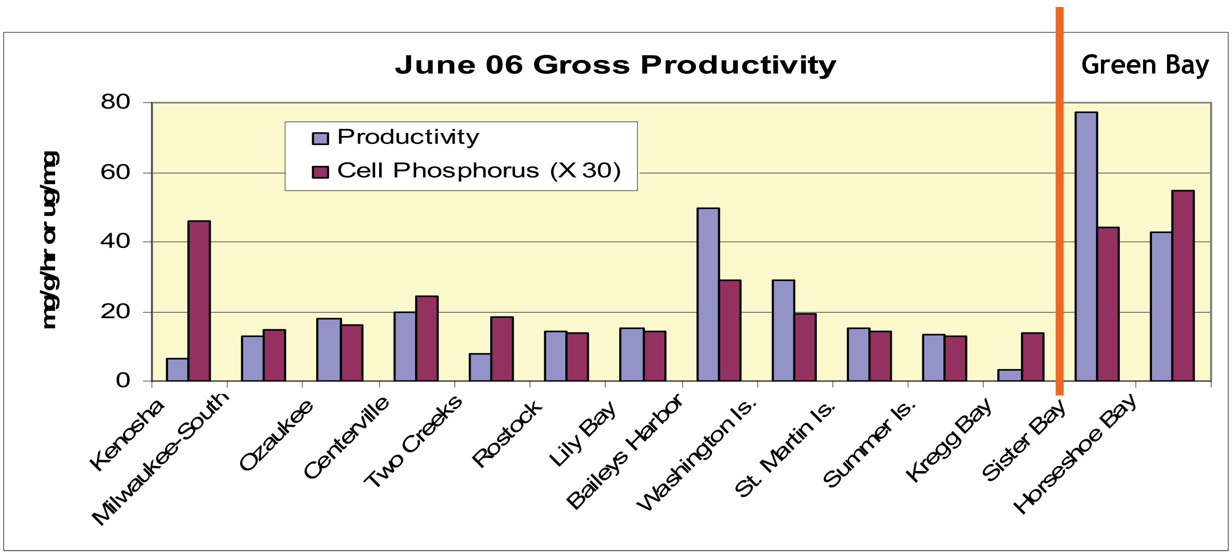
Figure 12. Productivities measured at three dates during the growing season. June and September cruises were in 2006 while the July cruise was in 2007.

Productivities are presented as gross values because the net growth was frequently measured as negative. This negative growth was largely due to high dark bottle values and may be caused by high respiration rates by non-algal material. We felt the gross values did portray an accurate picture of the growth of the *Cladophora* community.

In Figure 12, the productivities are arranged seasonally because it is assumed they did not vary significantly between 2006 and 2007. The plots are arranged to show how the values change within a year. Although biomass is accumulating in June and July, productivities were not necessarily at their highest rates during these months. In fact, at most sites, the highest productivities occurred in September following the late summer sloughing.

Productivity rates were generally similar from the southern to the northern sites, but there were a few sites that showed higher or lower productivity than the others. One site of note was Bailey's Bay (the site is actually outside the bay). This site's productivity was nearly as high as the sites in Green Bay, even though the latter sites have higher phosphorus values. In September 2006, productivity was high at two of the three Michigan sites (St. Martin Is., Summer Is.). In July 2007, the Rostock site had negative productivity. The sites in Green Bay were generally higher than the sites on the lake side of the Wisconsin shoreline. Unlike the lakeside sites, the highest productivity rates in the Green Bay sites occurred in June 2006. Values were considerably less in July and September.

Other studies have shown a good relationship between cellular P and productivity (Auer 2004). In general, this was observed in the June/July samples but not in the September cruise (Figure 13).



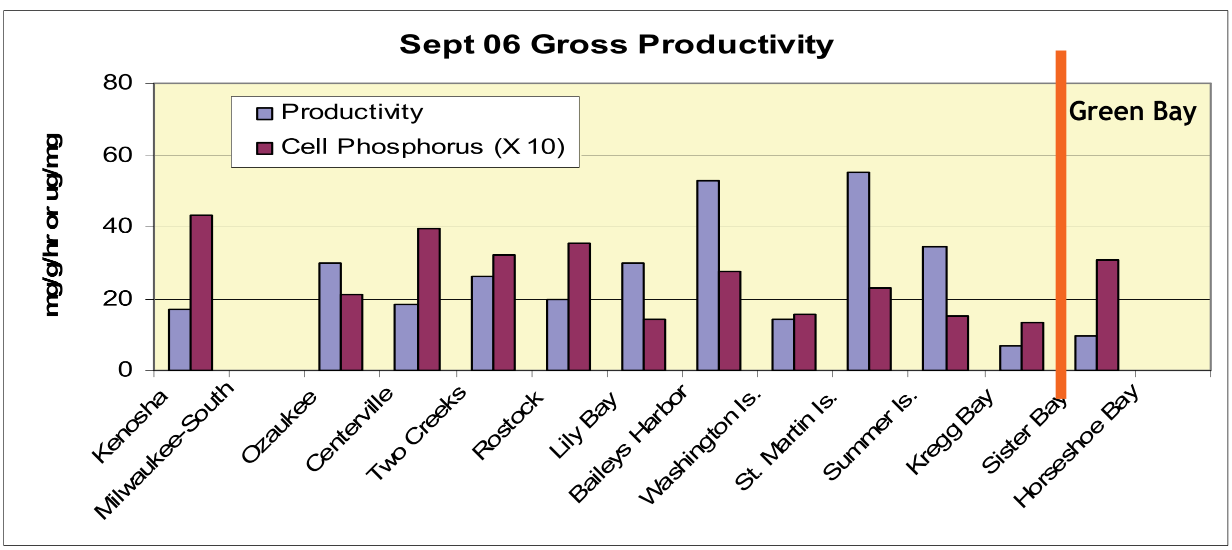
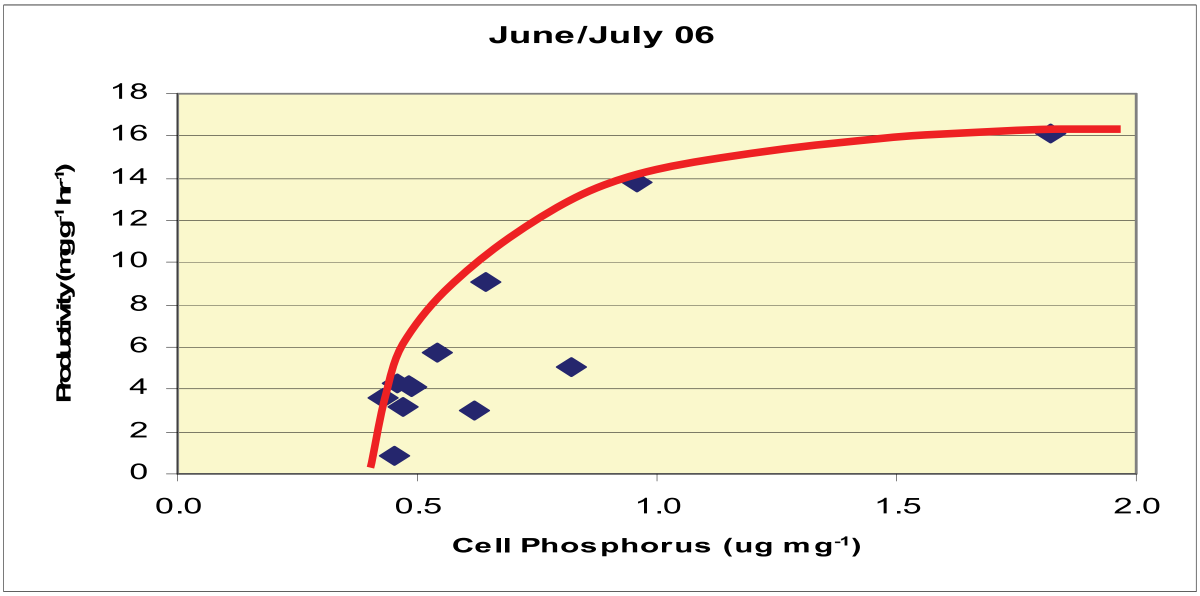


Figure 13. *Cladophora* productivity and cellular P content at the sites in June and September 2006. In general, higher productivity occurs where there is higher cellular P. The sites to the right of the orange vertical line are in Green Bay.

This is more apparent in Figure 14. It has been shown in the lab that productivity is linearly related to cellular P concentrations until a saturation point is reached. When the *Cladophora* is actively growing during the June/July , we observed such a relationship (Figure 14a). Following the mid-August sloughing, this relationship was not observed (Figure 14b). Algal biomass is much less in September and apparently cellular P concentration is not an important variable in determining the productivity rate.

(a)



(b)

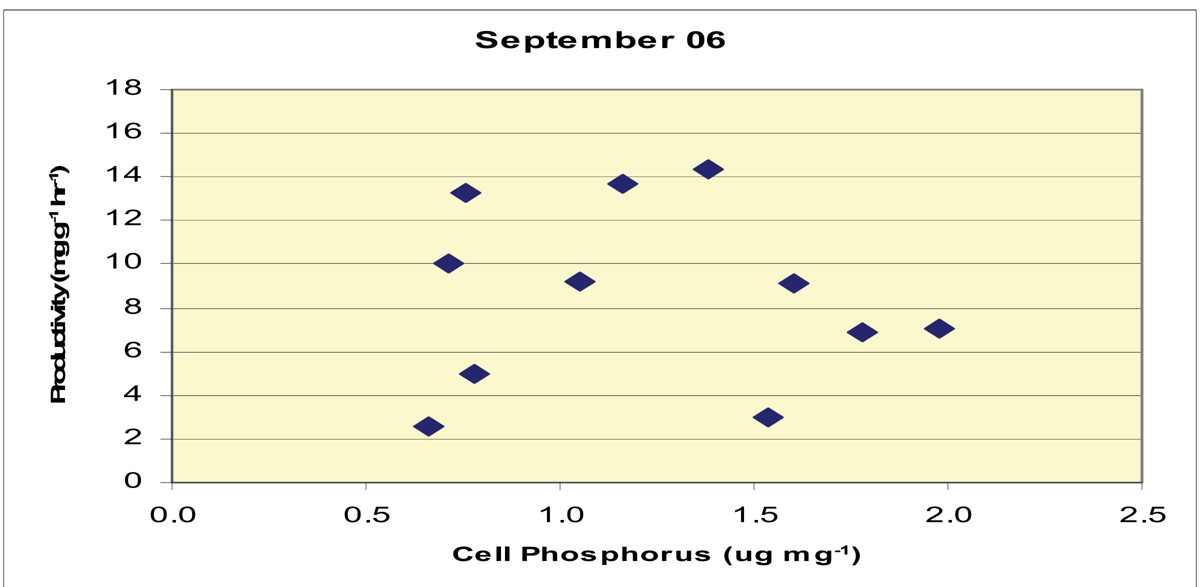


Figure 14. Relationship between productivity and cellular P content. The relationship (a) is as measured in the lab in June/July when *Cladophora* is activity growing. Following sloughing (b) this relationship does not occur.

Comparison of Growth in Green Bay and along Lake Michigan Shoreline

In Lake Michigan, the *Cladophora* is actually a community of *Cladophora* and associated diatoms. The diatoms make up a significant part of the community. This is not true in lakes Erie and Ontario. This is also not true in Green Bay. This can be seen in photos taken of the *Cladophora* community from the lakeside of the Door Peninsula and the Green Bay side (Figure 15). While there is some diatom growth in the Green Bay side it is much less than on the lake side. This is largely because of the reduced silica levels in the Bay (Figure 16). Silica is an essential nutrient for diatoms since their shells are largely composed of silica. While the *Cladophora* provides a substrate for the diatoms, *Cladophora* also supplies nutrients through cell leakage. The presence of the large diatom community likely reduces the amount of light that reaches the *Cladophora* cells and thus may restrict its productivity. When productivity and biomass are measured for the *Cladophora*, the diatom productivity is also a significant part of the measurement.

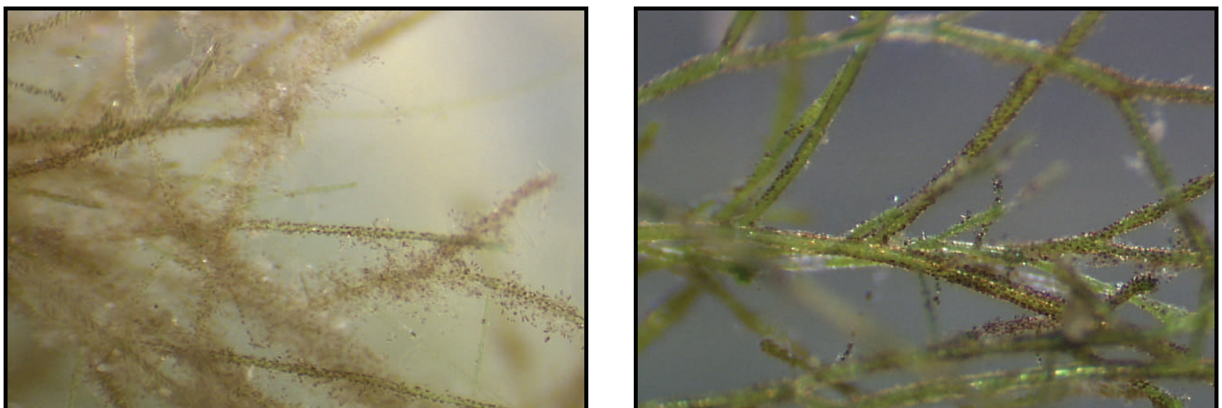


Figure 15. Microphotographs of *Cladophora* with associated diatom community. The left photo is of algae collected from Summer Island while the right photo is of algae collected in Green Bay in Nicolet Bay. Both samples were collected in July 2006. The Summer Island algal community is colored brown because the abundant diatoms mask the green color of the *Cladophora*. There is also a significant amount of gelatinous diatom growth. In contrast, the Nicolet Bay *Cladophora* community contains fewer diatoms and consequently the green color is not masked. (Photos by Gina LaLiberte).

Cladophora Overwintering Status

One of the questions we answered in 2005 was in what form *Cladophora* overwinters. It was not known if *Cladophora* grew slowly during the winter months or started growing from an encysting stage. The first cruise in 2005 occurred in late April to early May. It was apparent that the *Cladophora* significantly dies back during the winter but that growth in the spring does not occur as an encystment stage but instead from an overwintering filament. The overwintering filament *Cladophora* becomes heavily encrusted with diatoms to the point that the *Cladophora* filament is not visible. In the

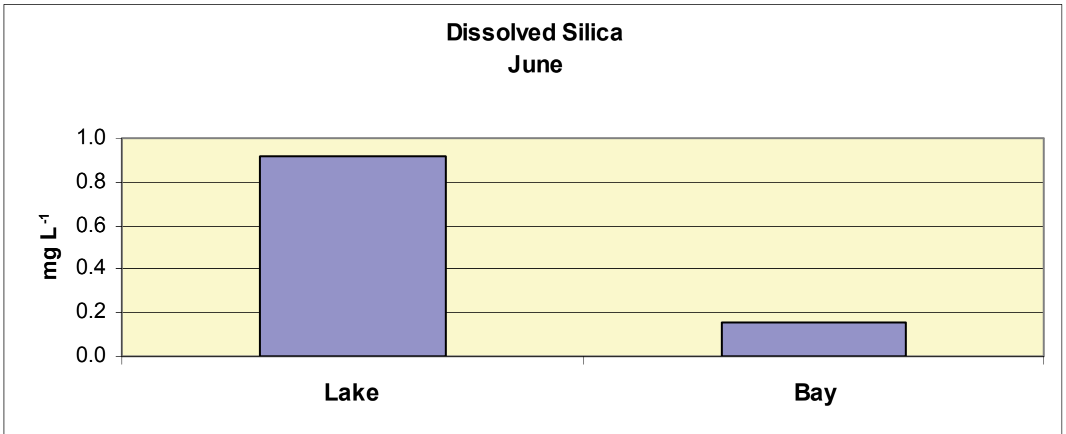


Figure 16. Dissolved silica concentrations collected from the lake- and baysides of the Door Peninsula. There is much less Si in Green Bay because the higher P levels result in greater growth of planktonic diatoms.

spring, growth starts as an extension of the filament. This new growth only possesses flat growing diatoms thus much less shading of light occurs (Figure 17).

During the cruise it was observed that growth occurred sooner at the southern sites compared with the northern sites. As seen in Figure 17, some growth was occurring in the central sites. No new

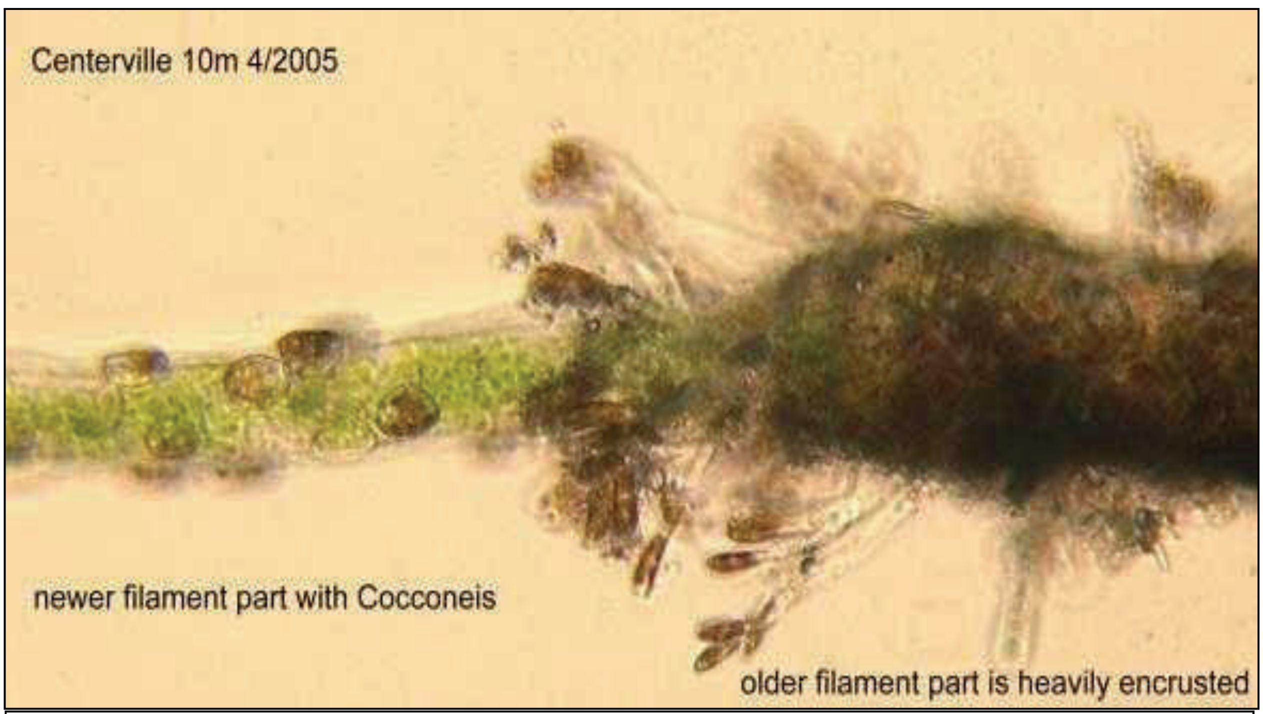


Figure 17. Microphotograph of *Cladophora* filament and associated diatom community. The portion of the filament in the right side of the picture was present during the winter months. It is heavily encrusted with diatoms. Growth in the spring occurs as an extension of this filament and contains few diatoms. (Photo by Gina LaLiberte).

growth was observed in the sites at the Door Peninsula and further north. It appears that even though growth starts later at the northern sites, this does not affect their peak biomass, as levels were similar at St. Martin Island as they were in Hika Bay (Figure 11).

Management Implications and Recommendations

This project has shown that P levels in the nearshore waters are locally impacted by riverine inputs. Sites located near river mouths had higher P levels. This is especially evident in the southern sites. The Cedarburg site is the only one not located near a river mouth and it had lower P concentrations in the nearshore waters (Figure 5a). The higher P levels associated with rivers is a function of land use in the rivers' watersheds. Agriculture and urbanization are large parts of the land use in this part of the state. The significance of agriculture as a source of nutrients is shown clearly by the trend in nitrate. Nitrate levels are much lower off the Door Peninsula and north where there is little agricultural activity (Figure 5d).

Even though nutrient levels decline from south to north, this is not true of the *Cladophora* biomass. Biomass off St. Martin Island in the north is as high or higher as biomass is in Hika Bay just north of Sheboygan in the south. Either the *Cladophora* growth is not responding to P or other P sources are important besides riverine inputs from the land. Since Figure 14a clearly shows a significant relationship between P and productivity and other studies have documented the positive relationship between *Cladophora* growth and P levels, phosphorus is an important determinant in *Cladophora* growth. It appears that there is another important source of P for nearshore algal growth other than runoff. This source is most likely from the open water of the lake. Even though P levels are lower in the open lake than in the nearshore, the constant influx of off shore waters provides a significant source of P.

Although the input of off shore nutrients to the nearshore area occurred prior to the resurgence of *Cladophora* problems around 1990, the change that facilitated *Cladophora* growth was the arrival of dressinid mussels in 1988. These mussels provide a substrate for *Cladophora* attachment, as well as nutrients for the algal growth. The filter feeding of the mussels resulted in improved water clarity which allowed the *Cladophora* to grow in deeper water. The mussels also likely recycle the P from the off shore waters more than would have occurred prior to their arrival and this further increases *Cladophora* growth.

The investigative survey conducted over the past 4 years has provided a wealth of information on the occurrence and extent of *Cladophora* growth along the western Lake Michigan nearshore areas. In addition, systematic water quality sampling filled an informational void and provided valuable insights into ambient nearshore nutrient concentrations and dynamics. As a whole, this activity provided an opportunity for both research and management staff to substantially increase our broad understanding of limnological issues facing the Great Lakes.

Our recommendations for future activities are outlined below.

In 2008:

- Refine sampling technique for biomass measurements
- Conduct a scoping study for establishment of a continuous monitoring station at Kewaunee Shoals Light station. Station measurements may include light, temperature, current speed and direction, turbidity, water chemistry sampling, underwater camera and transmitting capabilities. Potential partners include the USGS and UW-Milwaukee WATER Institute.
- Continue data analysis, working with UW-Milwaukee WATER Institute to enhance the *Cladophora* growth model and information dissemination

In 2009:

- Continue the systematic sampling survey on a biennial basis. Include the same list of physical, chemical, and biological parameters at the same sampling sites.
- Deploy potential continuous monitoring station.

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