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The Areal and Vertical Distribution of *Cladophora glomerata* in Western Lake Erie and its Interaction with the Zebra Mussel (*Dreissena polymorpha*)

A Technical Report

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ABSTRACT

Historically the growth of the attached, filamentous green alga *Cladophora glomerata* in western Lake Erie has been limited by the availability of hard substrate and sufficient light for colonization. The introduction of the exotic zebra mussel (*Dreissena polymorpha*) into western Lake Erie has impacted both of these limiting factors. Since both organisms require similar substrate for colonization the interaction/competition between the species is potentially great. The introduction of the filter-feeding zebra mussel has resulted in improved water clarity thus increasing light penetration and potentially expanding the vertical distribution of benthic algae. Field surveys were conducted to determine the areal and vertical distribution of *Cladophora* during the peak biomass period using SCUBA in the early 1980's, prior to the zebra mussel invasion. The surveys sites were revisited in 1992 to determine if changes had occurred in the distribution of *Cladophora* and to investigate the interaction of *Cladophora* and zebra mussels on bedrock habitat. The study's primary result was that an increase in water clarity has not resulted in extending the vertical distribution of *Cladophora* due to competition for substrate with zebra mussels. *Cladophora* dominated the area from the splash zone down to approximately 1.5 m where competition for substrate began with zebra mussels. The bedrock lake bottom was generally dominated by zebra mussels at depths greater than 2 m even though adequate light levels were available for *Cladophora* colonization.

INTRODUCTION

The invasion of non-indigenous species into the Great Lakes has had great impacts on the lacustrian ecosystem. The recently introduced zebra mussel (*Dreissena polymorpha*) is no exception. Since first identified in Lake St. Clair in 1988, this mollusk has rapidly colonized all of the Great Lakes, with the western basin of Lake Erie being one of the most heavily infested areas. Significant problems and financial impacts have already occurred with water supply intakes in Lake Erie (Conference Proceedings 1990). Little is known about the effects this exotic species will have on native species and the Great Lakes ecosystem. One of the organisms potentially impacted by zebra mussels is *Cladophora glomerata*.

Cladophora glomerata is an epilithic, macroscopic, green alga that commonly inhabits streams and the littoral zone of lakes in North America. In areas of the Laurentian Great Lakes where sufficient nutrients, light, and substrate are available, large amounts of *Cladophora* are produced (Lorenz et al. 1991). The standing crop of *Cladophora* can reach 100 to 400 g dry wt m^{-2} with filament lengths approaching one meter (Canale and Auer 1982, Lorenz and Herdendorf 1982). Currents and wave action often dislodge and deposit large windrows of this alga onto shorelines resulting in nuisance accumulations and noxious odors from decaying biomass. To the public, this is very tangible evidence of excessive algal growth, frequently interpreted as environmental degradation. However, *Cladophora* also plays an important role in the ecology of the nearshore region by supporting diverse and abundant populations of epiphytic and browsing organisms (Lorenz et al. 1991, Lorenz and Monaco 1988, Lowe et al. 1982, Lorenz 1981).

Western Lake Erie has been one of the most productive regions in the Great Lakes and has supported *Cladophora* growth since at least the mid 1800's (Taft and Kishler 1973). Phosphorus is not a limiting factor to *Cladophora* colonization or growth in this basin as it can be in other areas of the Great Lakes (Lorenz 1981). *Cladophora* colonization has been limited by the availability of adequate substrate and high light attenuation due to turbidity (Lorenz et al. 1991, Monaco 1985, Lorenz 1981).

Previous studies in the early 1980's by the authors have documented the areal and vertical distribution of *Cladophora* in the western basin of Lake Erie prior to the introduction of zebra mussels (Lorenz et al. 1991, Monaco 1985, Lorenz 1981). Basin-wide surveys were conducted using a boat, SCUBA, and aircraft during the peak standing crop period of 1981, 1982, 1983. Fourteen of 25 *Cladophora* survey sites had suitable substrate for evaluating the vertical distribution of the alga. The sites investigated consisted of mostly bedrock and included shoreline areas, island shelves, and submerged shoals.

The objective of the current study was to determine what influence the recently introduced zebra mussel has had on the areal and vertical distribution of *Cladophora glomerata* in western Lake Erie. Since both organisms require similar substrate for colonization the interaction/competition between the two is potentially great. The hypothesis of this study was that the depth of *Cladophora* colonization had increased due to increased water transparency and decreased light attenuation that has resulted from zebra mussel water filtering activities. By revisiting the 14 sites previously studied we were able to conduct a comparative study to determine if the vertical distribution of *Cladophora* has increased after the invasion of the zebra mussel. In addition, we compared the 1992 *Cladophora* biomass estimates to 1979-1983 biomass data from Lorenz's (1981) and Monaco's (1985) studies at two sampling sites.

METHODS

Surveys were conducted over a large portion of the western basin of Lake Erie to provide a comprehensive data base on the areal and vertical distribution of *Cladophora* during the peak standing crop period in late June and early July in 1992. Seventeen sites had suitable substrate for evaluating the vertical distribution of *Cladophora* in relation to light (Fig. 1). Fourteen of the 17 sites were the same sampling locations studied in the early 1980's. The sites consisted mostly of limestone or dolomite bedrock and included shoreline areas, island shelves, and submerged shoals. A boat and SCUBA techniques were used to determine the distributional patterns of zebra mussels and *Cladophora*, the deepest depth of *Cladophora* colonization, and to collect algal biomass samples at two historical monitoring sites.

At each site the maximum depth of *Cladophora* colonization was determined visually by SCUBA divers. The maximum depth of *Cladophora* was defined where trace amounts of the alga was observed growing. Zebra mussel density, shallowest depth of colonization, and competition for substrate was noted. Water temperature (mercury thermometer), Secchi disk transparency (20-cm diameter), and a vertical light profile were obtained at each site. Light was measured with protomatic photometer. Data on the vertical distribution of *Cladophora* and light values from the surveys were used to determine if the maximum depth of *Cladophora* colonization had generally increased in response to the increase in light availability.

At Stony Point, Michigan and South Bass Island, Ohio sites (Fig. 1), four depths were sampled to investigate variations in *Cladophora* biomass with depth and to compare the results to previous studies. Biomass samples were collected at 0.5, 1.0, 2.0, and 3.0 m. With the aid of SCUBA a 0.25 m^2 ring was placed on the Lake bottom and *Cladophora* was "picked" clean from the substrate and placed into sampling jars. The standing crop samples were cleaned of debris, organisms, and sediment by rinsing with a fast stream of water and blotted dry prior to biomass analysis. Dry weight of the samples were determined at 64 °C and 104 °C. The standing crop values were multiplied by four to obtain biomass estimates expressed as gm^{-2}.

RESULTS AND DISCUSSION

Areal and Vertical Distribution

Cladophora colonization was found throughout the western basin of Lake Erie wherever suitable natural or artificial substrate was available in both the 1992 and early 1980's studies. Zebra mussels, which were absent in the early 1980's, were observed at all sites in 1992. In western Lake Erie natural bedrock substrate accounts for only 3% of tho Lako bottom. Most of the bedrock is concentrated in the island region, where 6% of the bottom provides suitable habitat for zebra mussel and *Cladophora* colonization (Verber 1957, Herdendorf and Braidech 1972, Lorenz et. al 1991). Even though only a small portion of the Lake provides suitable substrate to support these two organisms, their impact has drawn considerable attention. The multitude of zebra mussels occupying this relatively small area in western Lake Erie have been credited with large improvements in water clarity throughout the entire basin. Secchi disk depths at the 1992 sites ranged from 0.6-4.3 m compared with means of 0.7-2.6 m for the same sites in the early 1980's (Lorenz et al. 1991). Light extinction coefficients varied from 0.15 to 1.05 m^{-1} for the sites in 1992 and from 0.70 to 1.85 m^{-1} in the early 1980's. The mean extinction coefficient of 0.51 m^{-1} for 1992 was less than half the early 1980's mean of 1.15 m^{-1}. Although the 1992 data represent only one point in time, it appears that water clarity has improved when compared to the early 1980's (Figures 2 and 3). Water temperatures in late June during both survey time periods ranged from 20-24 °C.

The maximum vertical depth of *Cladophora* colonization varied with location, ranging from 1.8 to 4.9 m at the 17 sites investigated in 1992 (Table 1). The maximum depth of *Cladophora* colonization for all 1992 sites averaged 2.9 m. Our previous study, prior to the introduction of zebra mussels, found a wider and deeper range from 1.5 to 7.0 m with a mean maximum depth of 3.5 m (Lorenz et al. 1991). At the typical 1992 site, zebra mussels began to appear with spotty and clumped distribution around 1.5 m, increasing in density with increasing depth. By approximately 2.5 m zebra mussels colonized nearly 100 percent of the bedrock lake bottom. *Cladophora* colonization, which began with lush growth at the splash zone, was inversely related to zebra mussel colonization and began declining after 1.5 m of depth. At maximum depth of *Cladophora* colonization only trace amounts occurred. *Cladophora* at these deeper depths (2-4 m) was observed mainly attached to the bedrock substrate with minimal attachment on zebra mussel shells. The major zone of transition between the two competing species, where one became dominate over the other, generally covered an area within a 0.5 m depth. Depending on the site, zebra mussels became dominate over *Cladophora* at depths ranging from approximately 2.0-2.5 m, with *Cladophora* colonizing the shallower depths. The segregation of habitat was most prevalent around island sampling sites. At open lake shoal and reef sites zonation was not as dramatic between the two species.

Based on 1992 field extinction coefficients, the mean light available at the maximum observed depth of *Cladophora* colonization in western Lake Erie was 239 $\mu Em^{-2}s^{-1}$. This value is well above the reported field minimum light level for growth of 29 $\mu Em^{-2}s^{-1}$ (Lorenz et al. 191) and the 35 $\mu Em^{-2}s^{-1}$ value necessary for positive net photosynthesis under laboratory conditions (Graham et al. 1982). Based on light measurements, the alga in 1992 was capable of much deeper colonization than what was observed (Table 1). Based on 1992 light extinction coefficients the mean maximum depth that *Cladophora* was capable of growth was 8.35 m compared to the 2.9 m observed. At all sites the maximum depth of *Cladophora* colonization was no longer light limited as it had been in the early 1980's (Lorenz et al. 1991). However, the maximum depth of *Cladophora* colonization in 1992 was limited by competition for bedrock habitat with zebra mussels at approximately 2.0-2.5 m.

At nine of the 14 comparative sites the vertical distribution of *Cladophora* was shallower in 1992 than in the early 1980's. This was in direct conflict with what had been predicted based on the fact that *Cladophora* had been strictly light limited and that light penetration had increased in the 1990's. Thus at two thirds of the sites, the potential for extending the depth of colonization from the increased availability of light (attributed to zebra mussel filtering activities) was offset by substrate competition from the zebra mussel. The remaining five sites that had deeper colonization were all sites that had relatively shallow 1981-1983 maximum depths (Table 1). At these sites the increased light levels did allow *Cladophora* to grow deeper up to the point where zebra mussels out competed the alga for substrate even though light levels were adequate for deeper *Cladophora* colonization. Based on the overall study results the vertical distribution of *Cladophora* in western Lake is limited not only by adequate substrate and sufficient light levels, but now the alga must compete with the zebra mussel for colonization on bedrock substrate.

Our sampling was done at the beginning of the zebra mussel summer spawning period. In the fall (September-October) zebra mussels are reported to colonize the shallow littoral zone (0-0.5 m) and are found on boat docks near the water line where *Cladophora* often colonized in the summer (John Hagman, pers. comm.). However, the mussels are not present the following spring in the shallow habitat or on boat docks. We believe that mussels were not at shallower depths around the islands because they had been removed by ice scour and wave action during the winter. Thus, the shallow littoral zone and its associated barren and hard bedrock substrate is available for *Cladophora* to colonize during its spring growth period. This may account for the natural zonation of the two species around the island region.

In the Great Lakes *Cladophora* reproduces asexually through flagellated zoospores (Monaco 1985). At depths where ice scour is not severe enough to remove zebra mussels the filter feeding zebra mussel may be consuming *Cladophora* zoospores in the spring. This would limit the amount of *Cladophora* colonization at depths greater than approximately 1.5 m around the island region. Only trace amounts of *Cladophora* were found on substrate colonized nearly 100 percent by zebra mussels. Very little incidence of epizooitic colonization of *Cladophora* on the shells of dead or alive mussels was observed. However, the blue-green alga *Phormidium* was observed at many of the sampling sites and it often colonized directly on zebra mussels and rocks.

Biomass

Results of the 1992 biomass collection at South Bass Island and Stony Point sampling sites are shown in Table 2. In addition, the mean biomass for these sites from the 1979-1982 from Lorenz (1981) and Monaco (1985) are shown for comparative purposes.

Only a limited comparative discussion is warranted because of the limited 1992 data to compare to the 1979-1982 mean maximum biomass results. The South Bass station had similar standing crop values in 1992 compared to the mean 1979-1982 results at the 0.5, 1.0 and 2.0 m depths. At this site significant *Cladophora* biomass was found at 3 m in 1992 where it previously had not been recorded in the early 1980's.

At Stony Point a wide variation in the standing crop of *Cladophora* at the 0.5 and 1m depth occurred over the two time periods. However, the standing crop at 2 m was similar and no *Cladophora* was found at the 3 m depth for either time period. It is possible that the biomass data at this site was relatively low because the peak biomass period at the shallower depths had occurred prior to the June 30, 1992 sampling date.

Predicted *Cladophora* Depth

Using a derived mean photoperiod incident light value (807 $\mu Em^{-2}s^{-1}$), the minimum light value for *Cladophora* growth (29 $\mu Em^{-2}s^{-1}$), and site specific extinction coefficients, Lorenz et al. (1991) used the Beer-Lambert equation to predict the maximum depth of *Cladophora* growth. A linear regression model of the observed maximum depth of growth versus the predicted depth indicated a good fit for the model ($r^2 = 0.68$; $p = < .001$) when light was the limiting factor for colonization. However, using identical methods and substituting the 1992 survey site specific extinction coefficients a poor model fit was obtained (r^2= 0.02; p=.587). Thus, the correlation between the maximum depth of *Cladophora* colonization and light availability is dramatically reduced. Increased water clarity in the basin has not resulted in an increase in the vertical distribution of *Cladophora*. We conclude the Lorenz et al. (1991) model of the maximum depth of *Cladophora* and a minimum light level for growth relationship is no longer valid in western Lake Erie due to competition for hard substrate with the recently introduced zebra mussel. The vertical distribution of *Cladophora* on hard bedrock habitat is now limited by competition with the exotic zebra mussel.

This competition for colonization on hard substrate may have significant effects on the ecology of Lake Erie. Phytoplankton quantity and its primary production may have decreased due to filtering of the water by zebra mussels. Currently around the island region up to an 85 percent decrease in diatom abundance as been reported (Dr. Ruth Beeton, pers. comm.) A reduction of phytoplankton primary production in western Lake Erie may be compensated by an increase in benthic alga biomass and associated primary production and an increase in the distribution of higher aquatic plants. It is not possible with the limited 1992 biomass data and no estimates of benthic algal production to determine if a decrease in phytoplankton primary production is comparatively compensated by benthic algal primary production. Our 1992 study indicates that the biomass of the dominant benthic alga, *Cladophora glomerata*, has not increased based on its areal and vertical distribution. An important ecological study would be to determine the sources and rate of primary production currently in western Lake Erie and compare these results to historical data to determine shifts in primary production and its sources.

Concluding Comments

Based on this study it does not appear that an increase in the vertical distribution of *Cladophora* has occurred in association with increased water clarity from zebra mussels filtering the water column in western Lake Erie. Areal and vertical distribution and biomass data did not show a dramatic increase in *Cladophora* biomass as might have been predicted. Thus, if a decrease in phytoplankton production is occurring, it may not be offset by an increase in benthic algal production from *Cladophora glomerata*. This potential decrease in overall primary production could have significant ecological impacts on western Lake Erie. Due to the short-term nature of the study we can only speculate why an apparent zonation is occurring in the shallow littoral zone between *Cladophora* and zebra mussels. In addition, we offer some plausible reasons why *Cladophora* was not occurring at deeper depths throughout western Lake Erie even though adequate light levels were available. We encourage researchers and students of the lake to expand on our work to further address the relationships of benthic algae and the recently invaded zebra mussel.

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TABLE 1.Western Lake Erie Cladophora field survey results

Survey Sites	Secchi Depth (m)	Extinction Coefficient (m-1)	Calculated Light at maxium depth of Cladophora (µEm-2s-1)	1992 Maximum Depth of Cladophora (m)	1981-1983Mean Maximum Depth of Cladophora (m)	Predicted Maximum Depth of Cladophora based on Lorenz et al. 1991 model. (m)
South Bass Island	4.27	0.37	164	4.30	3.10	8.99
Gull Island Shoal	2.20	0.37	131	4.90	3.10	8.99
Catawba Island	2.35	0.39	320	2.40	1.60	8.53
Marblehead Peninsula	0.60	1.05	47	2.70	2.00	3.17
West Sister Island	2.23	0.91	157	1.80	3.60	3.66
Kelleys Island 1	1.85	0.73	140	2.40	4.20	4.56
Kelleys Island 2	3.10	0.48	255	2.40	nd	6.93
East Sister Island	1.70	0.88	98	2.40	3.50	3.78
Stony Point	2.20	0.40	274	2.70	1.60	8.32
Middle Ground Shoal	2.15	0.41	157	4.00	4.50	8.11
Sheridan Point	2.45	0.45	209	3.00	nd	7.39
Chickenolee Reef	2.57	0.43	112	4.60	4.80	7.73
Colchester Reef	3.70	0.28	412	2.40	6.70	11.88
North Bass Island	2.74	0.34	263	3.30	4.10	9.78
Middle Bass Island	2.32	0.26	505	1.80	nd	12.79
Middle Sister Island	4.25	0.15	616	1.80	2.50	22.17
Hen Island	2.70	0.46	203	3.00	3.30	7.23

Table 2. 1992 *Cladophora* biomass data (gm^{-2}) and mean maximum biomass data from the 1979-1982 monitoring stations at South Bass Island, OH and Stony Point, MI. Approximate sampling date for both time periods was Julian day 180.

South Bass Island Station,

Depth (m)	June 29, 1992		Mean 1979-1982	
	Temperature			
	64° C	104° C	64°C	104°C
	Biomass (gm^{-2})			
0.5	96	92	94	89
1.0	90	85	109	104
2.0	68	67	76	72
3.0	56	54	0	0

Stony Point Station,

Depth (m)	June 30, 1992		Mean 1979-1981	
	Temperature			
	64° C	104° C	64°C	104°C
	Biomass (gm^{-2})			
0.5	31	30	66	63
1.0	12	12	49	47
2.0	13	13	8	8
3.0	0	0	0	0

Figure 1. Location of Cladophora/Zebra Mussel sampling sites, Lake Erie, 1992

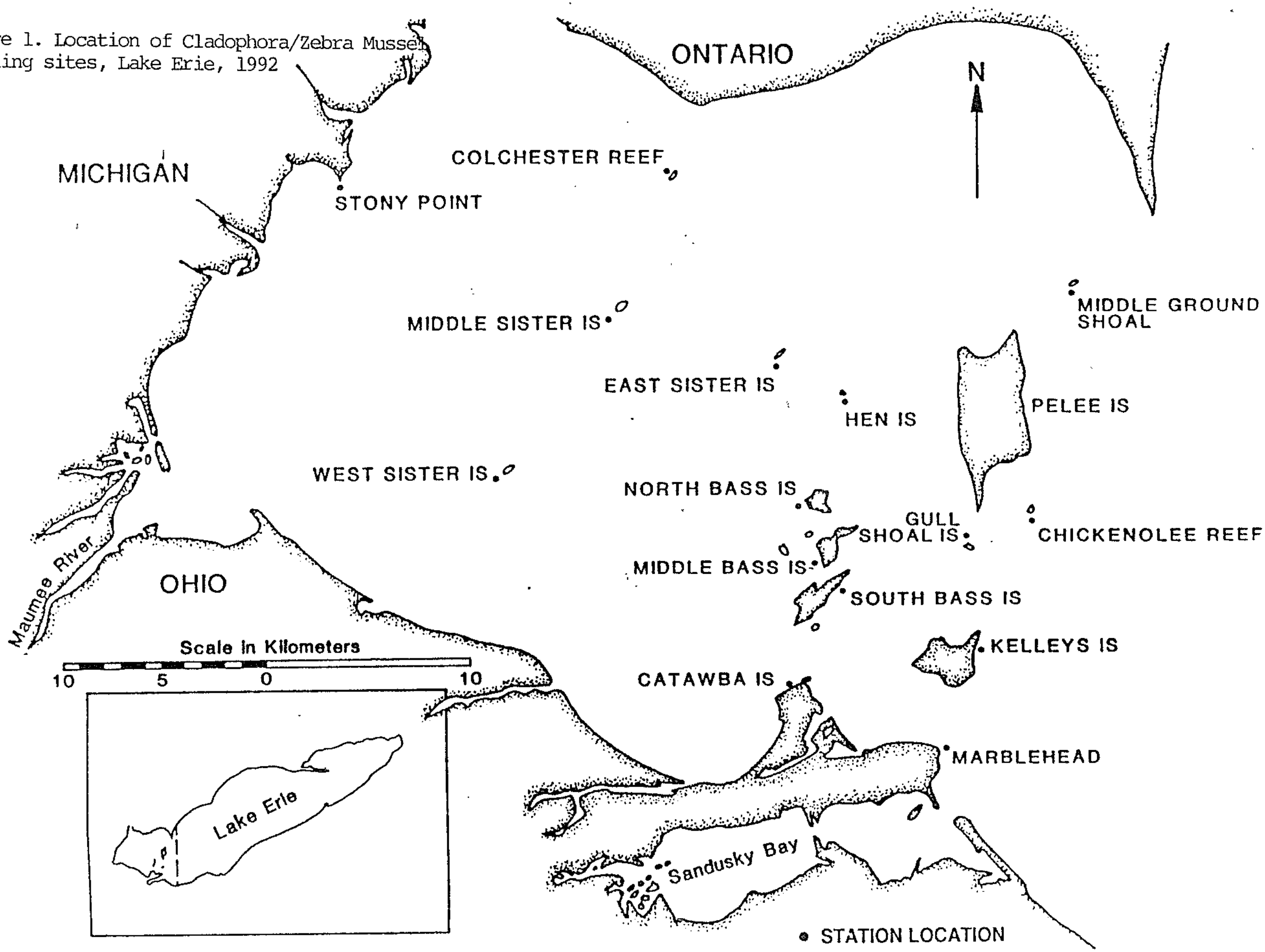

Figure 2. Secchi depths for 1992 and 1980's survey sites

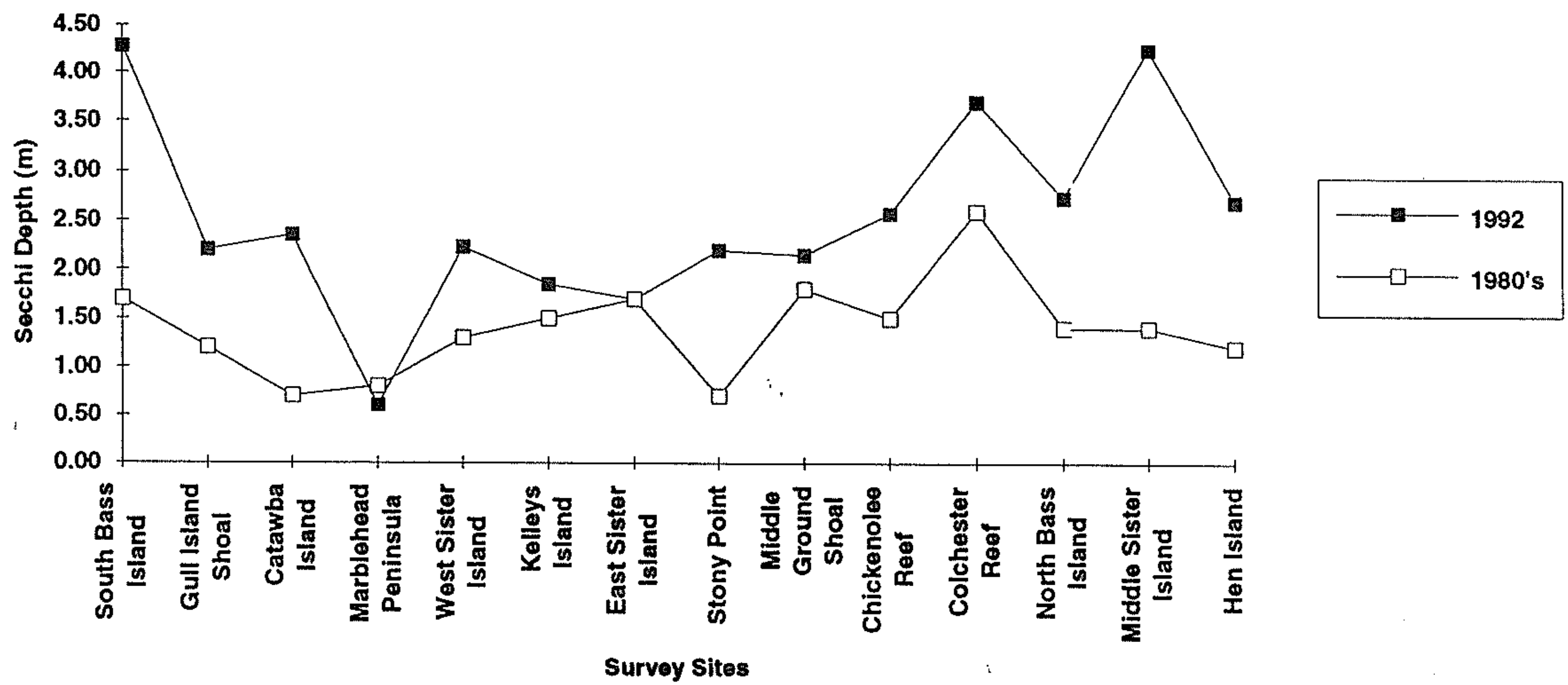

Figure 3. Light extinction coefficients for 1992 and 1980's survey sites