

**OCCURRENCE OF THE ALGA
CLADOPHORA
ALONG THE NORTH SHORE
OF EASTERN LAKE ERIE
IN 1995**

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**Occurrence of the Alga
Cladophora
Along the North Shore
of Eastern Lake Erie
in 1995**

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SUMMARY

The growth, wash-up and subsequent decay of quantities of the alga *Cladophora* along the shoreline, as a consequence of nutrient enrichment, was historically a problem in parts of the Great Lakes. The consequence of excessive *Cladophora* growth and shoreline fouling is primarily the degradation of use and enjoyment of shoreline associated with recreational activity and habitation, but has also included depreciation of property value. Efforts to reduce phosphorus levels in the Great Lakes over the last two decades have gone a long way to alleviate or eradicate the *Cladophora* problem. Complaints of shoreline fouling by algae in 1993 and 1994 on the north shore of the eastern basin of Lake Erie suggested that this is an area where *Cladophora* problems continue to occur, however, there had been no recent monitoring to determine the extent or severity of the problem. In July 1995 a survey was conducted to determine the extent of the growth of *Cladophora* along the shoreline of eastern Lake Erie from Fort Erie to Port Dover. The objectives of the study were to:

- (1) document the amounts of *Cladophora* occurring over areas of suitable habitat (i.e. rocky bottom) along the shoreline,
- (2) assess whether *Cladophora* occurs at nuisance levels along the shoreline of eastern Lake Erie and as such presents a problem, and,
- (3) evaluate the findings in relationship to the factors which are known to control the growth of *Cladophora*.

The survey determined that there were substantial quantities of *Cladophora* growing in the shallow waters (0-2 m depth) along the north shore of eastern Lake Erie from Fort Erie to Port Dover in July 1995. The surface coverage of *Cladophora* at the 16 areas of rocky bottom surveyed was high, ranging from 60 to 100%. A lawn of filaments at least 5 cm thick covered the areas of rocky bottom at all sites. More extensive lawns of up to 20 cm in thickness were observed at a number of sites; at ~40% of the sites median thickness was 10 cm or greater.

The observations made on the accumulation of *Cladophora* along the shoreline at the time of the survey indicated that nuisance levels of the alga resulting in degraded aesthetic conditions occurred at approximately 25% of the sites. Quantities of

washed-up and rotting algae with an associated disagreeable odour were observed along the shoreline at the Splatt Bay (west of the Grand River), Featherstone Point Sandusk Creek mouth and Peacock Point. Lesser and varying quantities were observed onshore at other sites. Based on the one-time observations of the survey it did not appear that there were grossly-apparent aesthetic problems.

The ambient nutrient regime of the nearshore zone of the eastern basin is clearly sufficient to sustain extensive growth of *Cladophora*. It is uncertain whether the observed background levels of *Cladophora* growth (i.e. the lowest levels of occurrence) are adequate to cause nuisance levels of shoreline accumulation. It is suspected that the greater than average abundance of *Cladophora* observed at a number of sites was a consequence of a local source of nutrient loading.

The analysis of collected samples of *Cladophora* for phosphorus and nitrogen suggests that at most sites *Cladophora* growth is highly phosphorus limited. The implication is that *Cladophora* growth will be very responsive to changes in loading of phosphorus, both increases and decreases, relative to existing ambient levels.

The limited water quality sampling conducted at the time of the survey did not identify any locations where nutrient levels were considered to be high. The concentrations of total phosphorus were slightly above the interim Provincial Water Quality Objective of $20 \mu\text{g L}^{-1}$ at three sites. Nutrient and ion levels at sites in the vicinity of the Grand River mouth appeared to be slightly elevated compared to other areas.

There is insufficient information to determine whether the extent or magnitude of nuisance occurrences of *Cladophora* in 1995 were different from recent years. Comparison of tissue phosphorus information from collections in 1985 from a number of the same general areas sampled in 1995 suggests that tissue P concentrations were lower in 1995. Since the concentration of P in *Cladophora* tissue is an indicator of nutrient sufficiency, the implication is that growth conditions were less nutrient rich in 1995 than in 1985. In contrast, the surface coverage of *Cladophora* observed in 1995 appears to be more extensive than reported for some of the same general areas sampled in 1985.

The availability of habitat as determined by light penetration may be more of a factor in determining the success of *Cladophora* in 1995 compared with earlier work in Lake

Erie during the 1970-80's. There is an indication that the amount of bottom area available for *Cladophora* growth has increased, possibly substantially, since 1991-1992 as a consequence of an increase in water clarity, which is thought to have been mediated by dreissenid mussels (zebra and quagga mussels).

The information collected in this survey suggests that *Cladophora* growth will likely be responsive to new point-sources of nutrients over areas of rocky bottom. The potential for creating *Cladophora* fouling problems should be considered in the evaluation of new sources of P loading over, or adjacent to, bottom types suitable for *Cladophora*.

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1.0 INTRODUCTION

The growth, wash-up and subsequent decay of quantities of algae along shorelines as a consequence of nutrient enrichment were historically problems in parts of the Great Lakes (MOE 1973). In Lake Erie during the 1960's and 1970's fouling of shoreline with mats of algae, consisting predominately of the filamentous green alga *Cladophora*, was a common occurrence (Millner and Sweeney 1982, Shear and Konasewich 1975, MOE 1973). The nature of the problem was two-fold. The algae covered the shallow portions of the lake bottom creating a visually disagreeable lawn of algae. More annoying was the fouling of shoreline that occurred when the algae died back in early to mid summer. Rafts of rotting and foul smelling algae would wash up on shore diminishing the recreational potential of the lakeshore. In the past, economic costs associated with the depreciation of shoreline property values was cited as an adverse consequence of fouling of shoreline by *Cladophora* in the northeast of Lake Erie (Osmerod 1970, as cited in Shear and Konasewich 1975).

Efforts to reduce phosphorus levels in the Great Lakes over the last two decades have gone a long way to alleviate or eradicate the *Cladophora* problem (e.g. Painter and Kamaitis 1985, Painter and McCabe 1987, Neilson *et al.* 1995). Complaints of shoreline fouling by algae in 1993 and 1994 on the north shore of the eastern basin of Lake Erie suggested that this is an area where *Cladophora* problems continue to occur, however, there had been no recent monitoring at the shore to determine the extent or severity of the problem. It was uncertain whether the continued abundance of algae in some areas was a consequence of localized nutrient enrichment, or ambient nutrient levels that in some areas were adequate to sustain *Cladophora* growth.

In July 1995 a survey was conducted to determine the extent of the growth of *Cladophora* along the shoreline of eastern Lake Erie from Fort Erie to Port Dover. The objectives of the study were to:

- (1) document the amounts *Cladophora* occurring over areas of suitable habitat (i.e. rocky bottom) along the shoreline,
- (2) assess whether *Cladophora* occurs at nuisance levels along the shoreline of eastern Lake Erie and as such presents a problem, and,

- (3) evaluate the findings in relationship to the factors which are known to control the growth of *Cladophora*.

The environmental factors which regulate the growth of *Cladophora*, including light, temperature and nutrients, have been studied in the field and under controlled laboratory conditions and are reasonably well understood. Numerical models have been developed to predict growth rates of *Cladophora* under field conditions as functions of light, water temperature, and the concentration of inorganic phosphorus (Canale and Auer 1982, Painter and Jackson 1986). Predictions derived from these models (or model components) can be used to evaluate the possible success of *Cladophora* with respect to the key environmental factors which determine its ability to grow. Accrual of algal material cannot be easily predicted given that standing biomass is a function of both production and loss processes, with the loss processes being very difficult to predict without detailed study (Painter and Jackson 1986).

The growth and wash-up of *Cladophora* is highly seasonal following a predictable pattern but with considerable variation among areas and years in the exact timing of events. Typically a lawn of *Cladophora* is regenerated from filament fragments surviving from the winter during a period of active growth in the spring after water temperature reaches ~50°F (10°C) (Taft and Kishler 1973). As water temperature rises to ~65°F (18°C) in early summer protoplasmic growth ceases and a period of natural detachment (sloughing) of algal filaments commences extending from late June to July. There may be a fall resurgence in growth but it is not as extensive as in the spring. Neil and Jackson (1982) followed the seasonal development of *Cladophora* at Rathfon Point in eastern Lake Erie in 1979. Maximum biomass was observed in the first half of July as water temperature approached 20°C. Following this period algal material became senescent and was sloughed away and deposited in sheltered embayments. Similar trends were noted in 1979 and 1980 in western Lake Erie by Lorenz and Herdendorf (1982).

The invasion of the Great Lakes by the dreissenid mussels (zebras and quagga mussels) may have created a situation conducive to the growth of benthic plants by removing planktonic material from the water and increasing light penetration through the water column. *Cladophora* grows on the lake bottom as aggregates of filaments

subject to self-shading. Adequate light exposure is needed to maintain a high growth rate, even when nutrients levels are high. For example, the depth distribution of *Cladophora* under eutrophic conditions is typically very shallow (most biomass from 1-3 m depth) because of poor water clarity. A documented impact of dreissenid mussels on environmental conditions in Lake Erie is the lowering of concentrations of phytoplankton in the waters of infested areas (Nicholls and Hopkins 1993), resulting in increased light penetration to the lake bottom (Leach 1993). Consequently, the depth to which plants previously limited by light can potentially grow has likely increased.

2.0 SURVEY DESIGN AND METHODS

The quantity of *Cladophora* present along the shoreline, either growing in the lake or washed onshore, was surveyed at 16 sites in eastern Lake Erie in July 1995 (Table 1, Figure 1). Sites were selected based on:

- 1) location of historical sampling areas for *Cladophora*, and,
- 2) location of areas with suitable habitat (i.e. areas of rocky shoreline) as determined from detailed descriptions of bottom type by St. Jacques and Rukavina (1973) and Rukavina and St. Jacques (1971).

A depth-stratified random sampling design was used to estimate the percentage cover and thickness of *Cladophora* filaments growing over the 0-2 m depth. The occurrence of *Cladophora* within 0.25 m² quadrants was visually estimated over four depth zones (0-0.5 m, 0.5-1.0 m, 1.0-1.5 m and 1.5-2.0 m). At each survey location the percentage cover, and minimum, median and maximum thickness of *Cladophora* were determined for 5 random placements of a quadrant in each depth zone. At most sites, a total of 20 quadrants were observed. The thickness measures refer to the height of the *Cladophora* mat as it lay in the water and does not represent filament length. The estimates are for *Cladophora* which was attached to substratum.

The areal biomass of *Cladophora* was estimated using a semi-quantitative approach which combined limited quantitative sampling for biomass with the results of the visual survey. At each site, five 0.25 m² quadrants were cleared of *Cladophora* and material was retained for determination of dry weight. The five samples were collected over the depth range of the survey, targeting patches that corresponded to the high, medium and low range of thickness as determined in the visual survey. A conversion factor was calculated for each site to convert estimated average areal volume (percentage cover X median thickness X quadrant area) to areal biomass. The conversion factor (dry weight *Cladophora* per unit volume of *Cladophora*) was determined by dividing the dry weight in a sample quadrant by the visual estimate of volume of *Cladophora*. The results for the five biomass samples at each site were averaged.

At each site samples of *Cladophora* were collected over the depth zones used in the visual survey for tissue analysis. The *Cladophora* samples were rinsed of debris, placed in bags and stored on dry ice. The frozen samples were freeze dried and analyzed for loss on ignition (LOI), total P and kjeldahl N (subsequently referred to as total N). Analyses were conducted by the MOE Laboratory Services Branch Etobicoke laboratory using standard methods for plant tissues.

Grab samples of water were collected at 0.5 m and 1.0 m depths. Samples were analyzed for macronutrients, chloride and turbidity using standard MOE methods. Samples were stored on ice until delivery to the MOE's Etobicoke lab. Water temperature and conductivity (extrapolated to 25°C) were measured in the field.

Field observations were made of shoreline features including the wash-up of *Cladophora* and any associated odour.

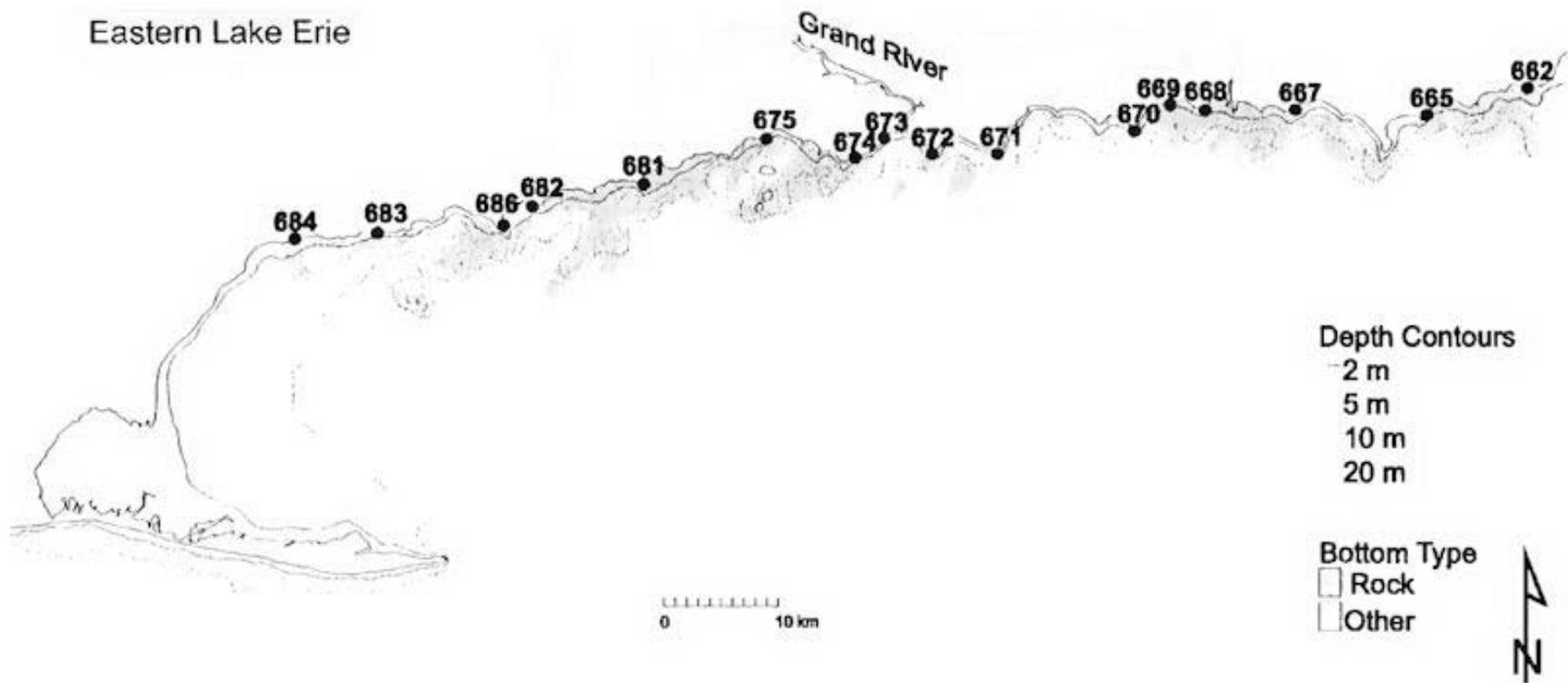


Figure 1: Map of eastern basin showing location of sampling locations including: A) station position, B) depth contours (2, 5, 10, 20 m) and, C) zone characterized by Rukavina and St. Jacques (1971) and St. Jacques and Rukavina (1973) as rock/ rock type.

Table 1: Locations of survey sites and dates of the *Cladophora* surveys.

Station	Station Number	Latitude (D M S)	Longitude (D M S)	Sampling Date
Bertie Bay	662	42 53 02	78 51 01	07/10/95
Windmill Point	665	42 51 55	79 03 09	07/17/95
Whitemans Point	667	42 52 17	79 11 03	07/17/95
Sugar Loaf Point	668	42 52 19	79 16 28	07/11/95
Rathfon Point	669	42 52 36	79 18 35	07/11/95
Morgans Point	670	42 51 27	79 20 46	07/11/95
Mohawk Point	671	42 50 32	79 29 01	07/12/95
Rock Point	672	42 10 35	79 32 57	07/12/95
Splatt Bay (Grand R.)	673	42 51 20	79 35 49	07/12/95
Grant Point	674	42 50 29	79 37 34	07/13/95
West of Low Point	675	42 51 22	79 42 53	07/13/95
Featherstone Point	681	42 49 27	79 50 18	07/13/95
Sandusk Creek Mouth	682	42 48 33	79 57 03	07/19/95
Peacock Point	686	42 47 43	79 58 47	07/17/95
Nanticoke	683	42 47 23	80 06 23	07/19/95
Port Dover	684	42 47 12	80 11 22	07/19/95

Note: coordinates refer to a shoreline point in the immediate area of where the survey was conducted.

3.0 SURVEY FINDINGS

3.1 Extent of the occurrence of Cladophora

Extensive growth of *Cladophora* was observed over rocky substrata at all survey sites from Fort Erie to Port Dover. The average surface cover by *Cladophora* ranged from 60 to 100% of the bottom over the 0.5 - 1.5 m depth interval among sites (Table 2). With the exception of two sites, Rock Point (station 672) and Nanticoke (station 683), surface cover was ~90% or higher.

There were few cases where gradients in surface cover were apparent over depth zones. At several sites, coverage was lower in the 0 - 0.5 m zone than at greater depths (Table 2). The most extensive coverage was typically found in the 1.0 - 1.5 m or 1.5 - 2.0 m depths of water. There was no indication that the coverage of *Cladophora* declined with depth over the 0 - 2 m depth with the exception of the Nanticoke site (683) where there was a marked decline in *Cladophora* coverage beyond 1.5 m.

The thickness of the algal layer varied widely among locations. Lawns of algae were observed at most sites, and, prolific beds of filaments were found at several sites. Median thickness of *Cladophora* at depths of 0.5 - 1.5 m ranged from just under 5 cm to ~20 cm (Figure 2). Median thickness was ~10 cm or greater at seven sites including, Rathfon Point (669), Mohawk Point (671), Splatt Bay (673), Grant Point (674), Featherstone Point (681), Sandusk Creek (682) and Peacock Point (686). The background level (i.e. low range) of median thickness of *Cladophora* was ~5 cm suggesting that over other areas of suitable substrata on the north shore of the eastern basin that a layer of at least 5 cm median thickness would have been found.

The pattern of variation in median thickness over the four depth ranges surveyed varied from site to site (Figure 3). At roughly six sites there was no difference in median thickness with depth. At three sites (stations 667, 668, and 681) thickness increased with depth. Still at three other sites (671, 675, and 683) there was a pattern of decreasing thickness with depth. At other stations the differences in median thickness with depth were more variable.

Table 2: Percent cover of substrata by *Cladophora* at survey sites.

Station Number	Depth (m)				
	0 - 0.5 (Mean)	0.5 - 1.0 (Mean)	1.0 - 1.5 (Mean)	1.5 - 2.0 (Mean)	0.5 - 1.5 (Mean)
662	88	94	83	100	89
665	83	98	98	WW	98
667	76	86	98	98	92
668	79	95	100	100	98
669	70	95	86	96	91
670	78	92	100	78	96
671	100	95	94	84	94
672	80	66	54	98	60
673	93	100	100 ¹	ND	100
674	100	88	100	ND	94
675	90	84	98	100	91
681	95	100	100	100	100
682	98	98	98	100	98
686	100	100	PV	PV	100
683	92	70	82	49	76
684	88	100	88	NSS	94

Note :

WW - heavy wind and waves; could not sample beyond 1.5 m depth

ND - no observations; conditions prevented snorkelling

PV - poor visibility; large quantity of detached *Cladophora* lying on bottom prevented observations

NSS - No suitable substrate; substrate changed from rock to gravel

¹ - observation from 1 to 1.3 m only; limit of visibility from surface

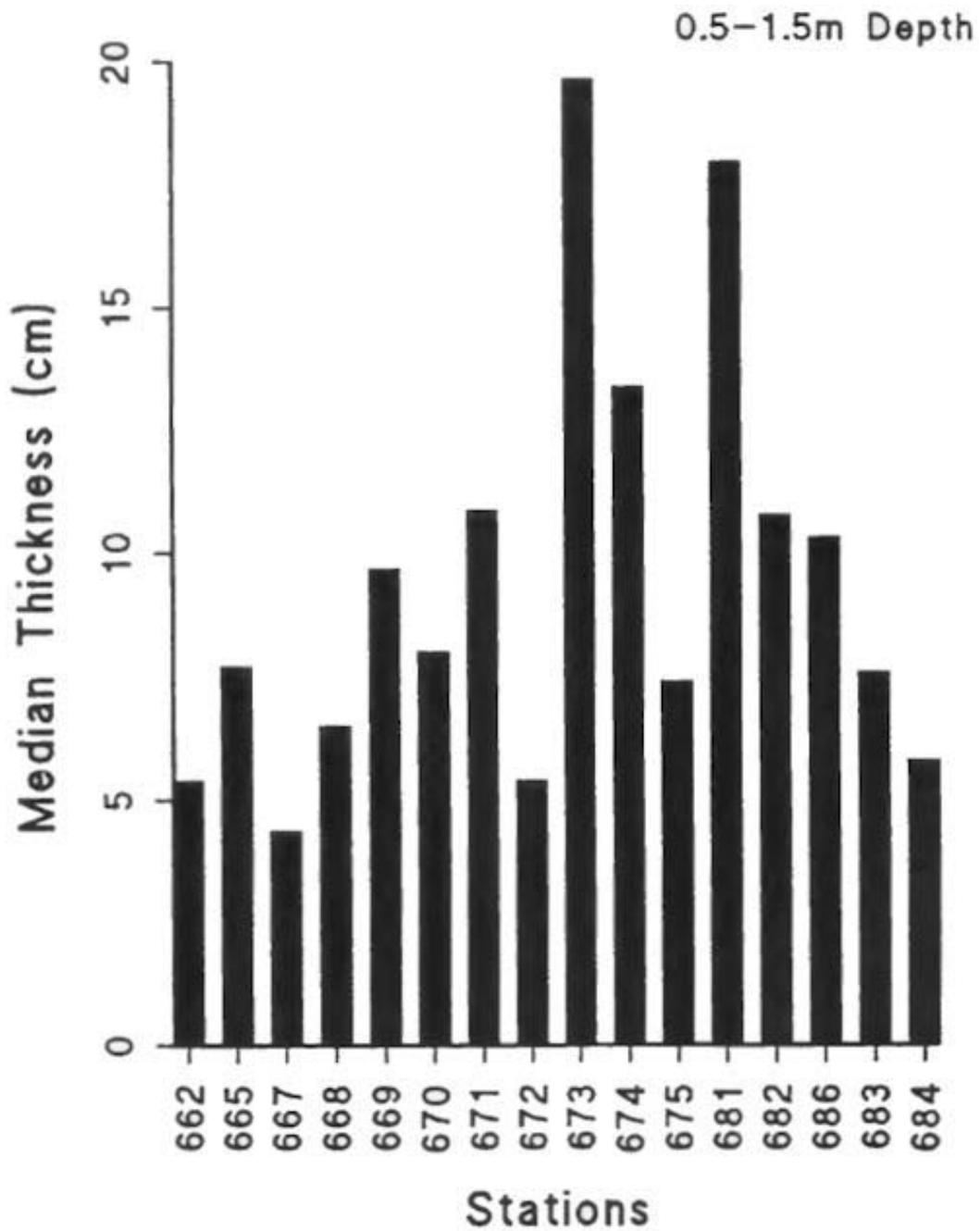


Figure 2. Histogram of median thickness of *Cladophora* averaged over the 0.5 to 1.5 m depth at survey sites.

The areal biomass of *Cladophora* was estimated over the range of depth intervals surveyed. Areal biomass varied widely among sites ranging from a high of ~ 600 g m⁻² at Featherstone Point (station 681) to a low of ~50 g m⁻² at the Nanticoke site (station 683) (Table 3). Areal biomass exceeded 200 g m⁻² at all but five sites but was below 400 g m⁻² at all sites except Featherstone Point and Grant Point (station 674).

The correspondence between median thickness and areal biomass among sites was poorer than expected. The two measures of the extent of *Cladophora* development give a different picture of the relative amounts of algae among sites. Featherstone Point and Grant Point fall out as sites with extensive growth of *Cladophora* with both measures. However, areal biomass is lower at several sites than suggested by the relative median thickness. At Splatt Bay, median thickness approached 20 cm (greatest of any site), yet the areal biomass was relatively low (<200 g m⁻²). Similarly other sites with relatively thick *Cladophora* layers including stations 669, 671, 682 and 686 did not have proportionately higher areal biomass than other sites.

There are several possible explanations for the weak correspondence between median thickness and areal biomass. The *Cladophora* lawns were at the point in the developmental cycle when the population was dying back because of the sub-optimal temperatures. Quantities of fresh and decaying material were observed washed up on shore at many sites. It is likely that the extent of the sloughing of *Cladophora* varied among sites. Thermal conditions, nutrient regime and exposure, which are factors that affect the timing and extent of sloughing, varied among sites.

If sloughing is considered a thinning process (i.e. areal biomass decreases without a change in the thickness of the layer), then variation in the timing and rate of thinning would be expected to strongly distort the correspondence between median thickness and areal biomass. The conversion factors used to estimate areal biomass provide an indication of how the density of *Cladophora* within the algal layer varied among sites. The conversion factors varied between 0.9 and 8.6 mg-dry weight cm⁻³ (Table 3, Figure 4).

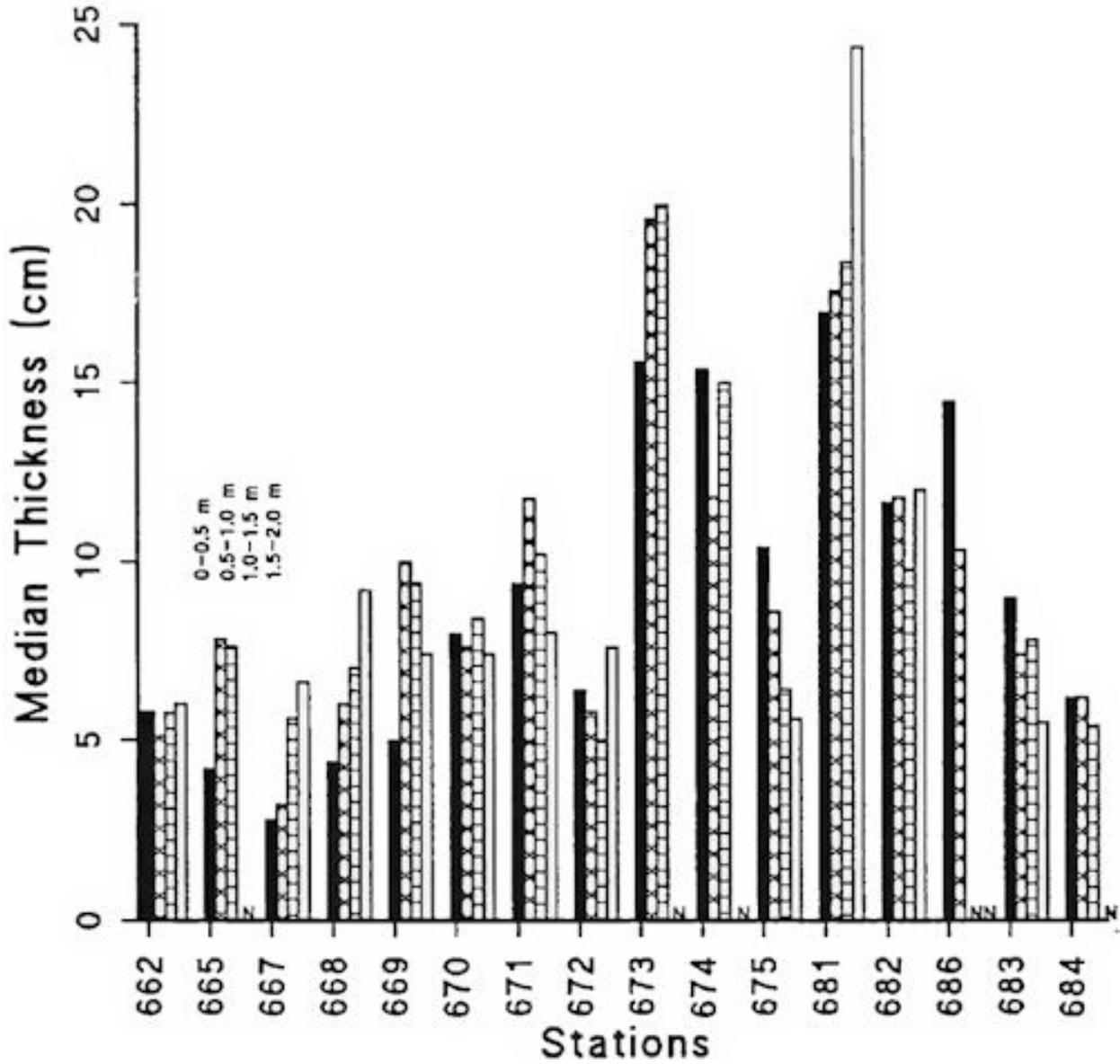


Figure 3. Histogram of median thickness of *Cladophora* over depth zones at survey sites.

Table 3: Information used to estimate the areal biomass of *Cladophora* at survey sites.

Station Number	Percent Cover	Median Thickness (cm)	Conversion Factor (mg crn ⁻³)	Estimated Areal Biomass (g m ⁻²)
662	91	5.7	6.6	340
665	93	6.5	5.4	330
667	90	4.6	8.6	360
668	94	6.7	3.5	220
669	87	8.0	3.2	220
670	87	7.9	5.7	390
671	93	9.8	3.4	310
672	75	6.2	1.5	71
673	98	18	1.0	180
674	96	14	3.3	440
675	93	7.7	5.0	360
681	99	19	3.2	600
682	99	11	1.4	150
686	100	12	2.7	320
683	73	7.4	0.9	49
684	92	5.9	1.7	92

Note: The percent cover and median thickness estimates are for the average over all the depth zones sampled at a site. Refer to Table 2 and Figure 3 for details of the depth intervals sampled at sites. The conversion factors were determined from biomass sampling (see section 2.01). The estimated areal biomass was determined as: percent cover x median thickness conversion factor x 10⁴ (cm⁻²/m⁻²)

A correlation was observed among conversion factors, the predominating colour of *Cladophora*, and the clarity of the lake at the time of sampling. The colour of *Cladophora* varied dramatically among sites. At many sites it was a pale yellow-green yet at other sites it was a dark green colour. A common feature at some sites was for the base of the filament mass to have a stronger green colour than the top of the filament mass. The sites with the highest conversion factors (i.e. the sites with the densest mats of *Cladophora* filaments) tended to be yellow-green in colour (Figure 4). Conversely, the sites with the lowest conversion factors tended to have dark green *Cladophora*.

One interpretation of these observations is that the *Cladophora* filaments had adjusted the cellular concentrations of chlorophyll among sites to adapt to differing light regimes. Similar observations were reported by Taft and Kishler (1973). They noted that *Cladophora* growing under low light conditions (bluffs, deep water, and under sand) consisted of dark green filaments. On well lighted shelving *Cladophora* approached a canary yellow colour. The relatively low conversion factors at some sites may be a consequence of light limitation on growth. Put another way, at the sites where the *Cladophora* is strongly pigmented there may not be adequate light to support optimal biomass development for the prevailing nutrient regime.

A further complicating factor in the determination of areal biomass was the presence of small dreissenid mussels attached to filaments. Given the prevalence of dreissenid mussels over the study areas and the intimate association between dreissenid mussels and *Cladophora* beds it is unavoidable that some number of mussels were present in the *Cladophora* samples taken for determination of biomass. It is possible that at some sites the areal biomass estimates (and conversion factors) are biased high because of the contamination of the samples with bits of dreissenid mussels. The areal biomass estimates should be interpreted cautiously and in the absence of further data it is recommended that the relative extent of *Cladophora* among sites be inferred from the field measurements of median thickness (Table 3).

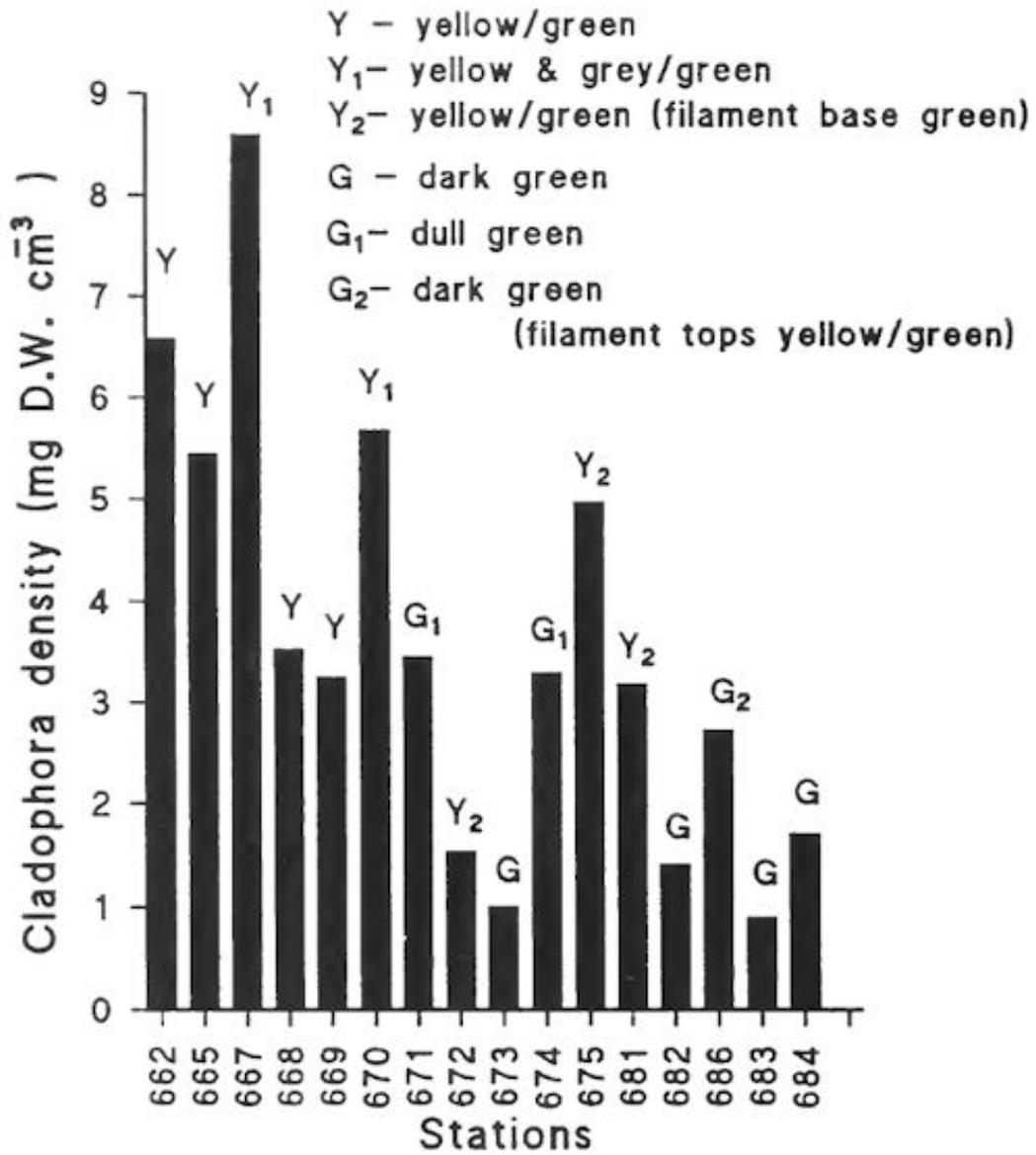


Figure 4. Histogram of conversion factors used to estimate *Cladophora* areal biomass among sites.

The shoreline adjacent to the survey sites was considered to be fouled by decaying mats of washed-up *Cladophora* at several locations. At most sites 1-2 m wide thin bands of *Cladophora* were observed washed-up on shore with little adverse impact apparent at the time of the survey. Considerably more material was found at some sites. The more badly fouled sites included Peacock Point (686), Sandusk Creek mouth (682), Featherstone Point (681) and Splatt Bay (673) (just west of the Grand River). At these sites decaying *Cladophora* resulted in a strong odour. It should be recognized that the evaluation of shoreline fouling is qualitative and subjective.

3.2 Nutrient Levels in *Cladophora* Tissue

In the Great Lakes, phosphorus (P) is thought to be the nutrient limiting the growth of *Cladophora* in most instances. The concentrations of P in *Cladophora* tissue can be used to assess the nutrient sufficiency of *Cladophora* and to predict growth rate. Auer and Canale (1982) used the Droop model to quantify the relationship between net specific growth rate of *Cladophora* and the concentration of P in the tissues of the alga under optimal growth conditions. Concentrations of P in *Cladophora* tissue can also be used to predict the responsiveness of *Cladophora* to changes in ambient nutrient status.

When the 1995 tissue P data (as % of dry weight) are plotted on the curve of growth rate as a function of tissue P developed by Auer and Canale (1982), the data suggest that *Cladophora* growth was highly P limited (Figure 5). Concentrations were below 0.05% P, the minimum concentration considered necessary to support growth, at seven sites. At four sites P concentrations were between 0.05% and 0.1 %, suggesting relatively low growth rates (< 50% of maximum) under acutely limiting P levels. Concentrations were above 0.1% but below 0.15%, a concentration range suggestive of moderate growth rates (60-70% of maximum) and conditions where P is strongly limiting, at four sites. The Nanticoke site (683) was the only location where tissue P was greater than 0.2% a range indicative of a high growth rate and only moderate limitation by P.

Painter and Kamaitis (1985) recommended that estimates of tissue macro nutrients be corrected for ash content when comparing results among areas or over time because of variability in the ash content of samples. The varying concentrations of ash among *Cladophora* collections are thought to be a consequence of variability in the precipitation of calcium carbonate onto the *Cladophora* filaments. The organic content (as approximated by loss on ignition) of the *Cladophora* tissue samples varied from 36.3 to 78.8 % of dry weight (Table 4).

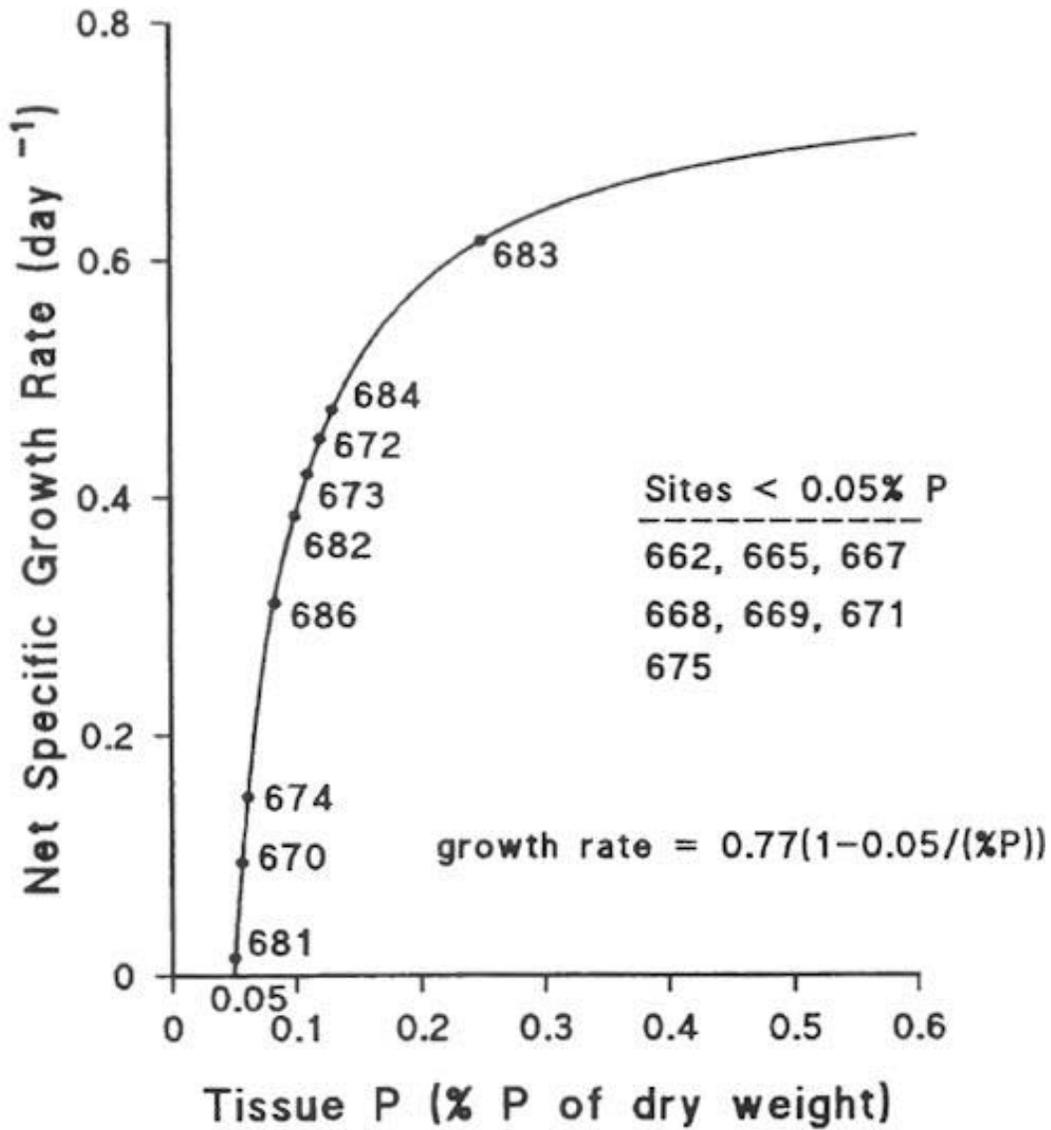


Figure 5. Graph of the relationship between tissue P and net specific growth rate of *Cladophora* given by Auer and Canale (1982). The tissue P concentrations of the 1995 *Cladophora* collections are plotted, by site, on the curve (solid circles).

Table 4: Mean concentrations of phosphorus and nitrogen in *Cladophora* tissue collected at sites in 1995.

	Station Number	Phosphorus % ash- free DW (sd n=4)	Nitrogen - % ash-free DW (sd n=4)	Loss On Ignition mg g ⁻¹ (sd n=4)
Bertie Bay	662	0.093 (0.023)	3.6 (0.27)	520 (92)
Windmill Point	665	0.087 (0.018)	3.1 (0.67)	470 (81)
Whitemans Point	667	0.075 (0.023)	2.8 (0.50)	360 (106)
Sugar Loaf Point	668	0.091 (0.040)	2.9 (0.64)	470 (236)
Rathfon Point	669	0.077 (0.027)	3.1 (0.54)	480 (132)
Morgans Point	670	0.12 (0.014)	3.8 (0.27)	500 (103)
Mohawk Point	671	0.074 (0.019)	3.0 (0.24)	620 (57)
Rock Point	672	0.18 (0.004)	4.3 (0.35)	710 (37)
Splatt Bay (Grand R.)	673	0.22 (0.056)	4.9 (1.42)	570 (91)
Grant Point	674	0.12 (0.045)	4.3 (1.38)	480 (98)
West of Low Point	675	0.072 (0.021)	2.8 (0.45)	500 (91)
Featherstone Point	681	0.096 (0.036)	3.9 (1.26)	530 (88)
Sandusk Creek mouth	682	0.16 (0.085)	4.5 (1.46)	690 (86)
Peacock Point	686	0.13 (0.070)	2.9 (0.74)	668 (42)
Nanticoke	683	0.31 (0.073)	5.0 (0.76)	790 (9.6)
Port Dover	684	0.26 (0.12)	4.6 (0.98)	560 (81)

Tissue P as percent ash free dry weight (AFDW) varied from 0.072% to 0.31% (Table 4). Concentrations were below 0.1% AFDW at 8 sites. Tissue P was over 0.2% AFDW at three sites, Splatt Bay (673), Nanticoke (683) and Port Dover (684). Intermediate concentrations ranging from 0.1 to 0.2% AFDW were measured at Morgans Point (670), Rock Point (672), Grant Point (674), Sandusk Creek mouth (682) and Peacock Point (686).

There is considerable disparity between the inferences on growth conditions suggested by the tissue P data and the observations of *Cladophora* present at the sites. The high variability in the loss on ignition data among sites strongly suggests that material other than *Cladophora* filaments were present in the samples. It is likely that the tissue P estimates based on dry weight are biased low in some cases and this may account for the instances where tissue P concentrations were below the minimum tissue concentration for growth despite appreciable quantities of *Cladophora* being present at the sites.

The tissue N data suggest that N was not growth limiting at the survey sites. Tissue N content varied from 1.0 to 4.0% of dry weight. Concentrations were above 1.1% of dry weight, the concentration considered to be the critical level for growth (Mantai *et al.* 1982), with one exception. At the Whitemans Point station (667) the N concentration was 1.0% of dry weight. However, the tissue N to P molar ratio was 86:1 and strongly suggests that P was the growth limiting macro nutrient.

3.3 Nearshore Nutrients Levels - July 1995

The lake concentrations of TP were relatively low at most sites at the time of the survey. Mean concentrations were low, $< 10\mu\text{g L}^{-1}$, at three sites in the eastern range of the survey (Table 5). At other sites TP ranged from 11 to $26\mu\text{g L}^{-1}$ TP slightly exceeded the interim Provincial Water Quality Objective of $20\mu\text{g L}^{-1}$ at three sites; Whitemans Bay (667), Splatt Bay (673) and Mohawk Point (671).

The variation in concentrations of ortho-phosphate among sites was unrelated to TP concentrations (Table 5). The sites east of the Grand River did not have measurable

ortho-phosphate with the exception of one replicate sample which contained a trace quantity. Ortho-phosphate was undetectable at nine sites; minimum reportable value was $0.5 \mu\text{g L}^{-1}$. The highest concentrations were observed at the Sandusk Creek and Nanticoke sites where the average ortho-phosphate concentration was $3.5 \mu\text{g L}^{-1}$.

Ammonium concentrations followed a trend among stations similar to that of ortho-phosphate. At sites where ortho-phosphate was not detected, ammonium ranged from 9 to $19 \mu\text{g L}^{-1}$. At stations where ortho-phosphate was detected, ammonium concentrations were slightly higher ranging from 22 to $45 \mu\text{g L}^{-1}$. A relatively small range of low concentrations of nitrate+nitrite was noted among sites. The highest concentration, $290 \mu\text{g L}^{-1}$, was measured at Splatt Bay. At other sites nitrate+nitrite was between 70 and $180 \mu\text{g L}^{-1}$. Organic N concentrations were fairly uniform among stations ranging from 205 to $301 \mu\text{g L}^{-1}$ with two exceptions. Concentrations were slightly higher at Whitemans Point and Splatt Bay; concentrations were 401 and $378 \mu\text{g L}^{-1}$, respectively.

The only other measures of water quality examined in the survey were chloride and conductivity as indicators of loadings of ionic materials. The variation in the concentrations of chloride among sites suggests the two sites in the vicinity of the Grand River mouth are affected by a local source which presumably is the Grand River (Table 5). The extent and direction of the Grand River plume at the time of sampling, which was westward tending and visibly extending for some distance into the lake support this contention. Chloride concentrations were 34.8 and 24.6 mg L^{-1} at Splatt Bay (673) and Grant Point (674), respectively, compared with a range of 15.2 to 16.8 mg L^{-1} at other stations with the exception of Rock Point (672) immediately to the east of the Grand River where the chloride concentration was 17.4 mg L^{-1} . Painter and McCabe (1987) studied the impact of the Grand River plume on water quality and *Cladophora* P concentrations along the adjacent eastern and western shores of the lake in June and July 1985. They reported elevated nitrate, silicate and kjeldahl nitrogen concentrations within 2 km east and 3 km west of the river mouth. Tissue P concentrations were elevated as far as 2 km to the east of the river mouth. An earlier study by Nicholls *et al.* (1983) suggested that the Grand River affected water quality along the adjoining shoreline extending 5-10 km from the river mouth during the summer.

Table 5: Nutrient and water quality measurements at survey sites in July 1995.

Station Name	Station	Temperature (°C)	Turbidity (FTU)	Cl (mg L ⁻¹)	Conductivity (µS cm ⁻¹)	Total P (µg P L ⁻¹)	Ortho phosphate (µg P L ⁻¹)	Ammonium (µg N L ⁻¹)	Nitrate + Nitrite (µg N L ⁻¹)	Organic N (µg N L ⁻¹)
Bertie Bay	662	24.0	0.56	15.7	251.0	5 t	< 0.5 nd	11	110	229
Windmill Point	665	24.6	1.11	15.9	267.5	7 t	0.8 t	22	113	258
Whitemans Point	667	26.2	3.73	16.8	287.0	26	< 0.5 nd	19	80	401
Sugar Loaf Point	668	20.6	0.98	15.9	250.5	6 t	< 0.5 nd	14	153	216
Rathfon Point	669	21.8	1.36	16.0	249.5	13	< 0.5 nd	10	83	220
Morgans Point	670	22.5	2.85	15.8	253.0	19	< 0.5 nd	9 t	180	241
Mohawk Point	671	19.4	0.89	16.3	247.0	20	< 0.5 nd	11	108	269
Rock Point	672	21.5	0.63	17.4	252.5	11	< 0.5 rid	9 t	15	301
Splatt Bay (Grand R.)	673	24.2	1.68	34.8	380.0	21	2.0	42	290	378
Grant Point	674	21.1	0.59	24.6	318.0	16	1.8	33	70	287
West of Low Point	675	23.4	0.53	15.4	249.5	16	< 0.5 nd	10	75	220
Featherstone Point	681	23.4	5.43	15.2	247.5	15	< 0.5 nd	12	90	298
Sandusk Creek Mouth	682	21.3	3.81	16.0	248.5	17	3.5	30	95	230
Peacock Point	686	21.4	2.11	16.0	263.0	13	1.5 t	45	100	205
Nanticoke	683	18.9	2.64	15.7	234.0	13	3.5	33	95	237
Port Dover	684	20.5	1.97	16.0	250.0	12	2.3	29	80	241

Note: Values are means of results for samples collected at 0.5 m and 1 m depths.

nd - not detected at 0.5 µg L⁻¹;
t - a measurable trace amount

Water temperature at all stations was near or above the temperature where the physiological performance of *Cladophora* is expected to deteriorate. Water temperature ranged from 18.9 to 26.2 °C among sites (Table 5). Temperature was below 24 °C and above 22°C at eight sites. Day to day variation in weather conditions and possibly differing susceptibility to upwelling may account for the wide range in temperatures among sites.

3.4 Comparison of the Occurrence of *Cladophora* in 1995 with Past Conditions

There is limited data with which to compare conditions between 1995 and past years. The observations on the growth and shoreline accumulation of *Cladophora* in eastern Lake Erie from periodic surveys between 1958 and 1967 in MOE (1973) provide a qualitative impression of the extent of the *Cladophora* problem in the 1960's, however, there is little information which can be directly compared with the present study. Descriptions of *Cladophora* growth at Rathfon Point and Grabells Point in June and early July of 1962 provide a limited basis for comparison with the present study.

On June 6th at both sites, there was nearly 100% cover of rocky bottom to a depth of ~13 ft (4 m). Filament length was 3-5 inches (7.6 -12.7 cm). There was an obvious lessening of filament length and percent cover between 9 ft (2.7 m) and 13 ft (4 m). On June 27, the extent of the growths had increased and filaments on the beds were as much as 10 inches (25.4 cm) in length. The next observations on July 6th did not indicate any extensive additional growth and no further growth was observed after this time. The description of shoreline fouling observed during the 1960's (MOE 1973) strongly suggests that the magnitude of fouling was considerably worse than observed in 1995.

Painter and McCabe (1987) provide observations on the occurrence of *Cladophora* along the north-eastern shore of Lake Erie from Point Abino to Featherstone Point in 1985. They reported that *Cladophora* growth was minimal, with heavy growth confined to the mouth of the Grand River and unspecified locations affected by point sources of nutrients. Percent cover of *Cladophora* was <20% at 24 of 32 sites (75%). Coverage was >80% at three sites directly to the east of the Grand River and between 50-80% at 5 scattered sites. The surface coverage of *Cladophora* observed in 1995 (Table 2) appears to be more

extensive than in 1985, however, the comparison is biased because of the deeper range of depths surveyed in the earlier study. The station map provided by Painter and McCabe (1987) shows 12 sites directly onshore, 13 sites at 10 m depth or deeper, and the remaining sites between shore and 10 m depth.

Shear and Konasewich (1975) identified only one source of areal biomass information for eastern Lake Erie up to 1975. The results of an unpublished survey of five locations along the south shore of the eastern basin by Kleveno in 1968 are cited in Shear and Konasewich (1975). A biomass estimate of 155 g m^{-2} of organic material (presumed to be loss on ignition) which equated to $\sim 310 \text{ g m}^{-2}$ DW (it was assumed that LOI was $\sim 50\%$ of dry weight) was reported.

Biomass data collected in 1977 at sites near Dunkirk New York are reported by Mantai *et al.* (1982). The areal biomass of *Cladophora* growing near the water surface on a concrete breakwall was determined on 2-4 day intervals between June and August. A maximum biomass of roughly 400 g m^{-2} DW was reached in mid June. A period of relatively high ($<250 \text{ g m}^{-2}$), yet variable biomass, persisted until mid July.

Areal biomass data collected in 1979 at Rathfon Point on the north shore of the eastern basin are reported by Neil and Jackson (1982). Areal biomass was surveyed on ten occasions between June and October; the data are plotted in Figure 6. The present survey also included a site on Rathfon Point, however, the strong seasonal variability in biomass which typifies *Cladophora* makes it difficult to compare the one-time results collected in 1995 with the 1979 study. The mean areal biomass of *Cladophora* estimated at Rathfon Point in 1995 was 220 g m^{-2} which was considerably less than the mean peak biomass of $\sim 500 \text{ g m}^{-2}$ measured in 1979, albeit earlier in July. Given the dramatic decline in biomass observed after June 1979 (Neil and Jackson 1982) it is clear that year to year variability in the timing of the onset of the period of die-back will greatly affect any comparison in results at points in time between years. A meaningful comparison between years would require multiple sampling periods over the period of ascending biomass through to the early period of decline. There do not appear to be any other published biomass data for the north shore.

Biomass data collected at two areas along the south shore in 1979 indicated lower levels than reported for Rathfon Point in 1979. Millner *et al.* (1982) reported on the seasonal development of *Cladophora* biomass over the 0-3 m depth at sites near Hamburg New York and Walnut Creek Pennsylvania. The maximum biomass of 211 and 57 g m² at Hamburg and Walnut Creek sites, respectively, were observed in mid July.

There is more historical data on the concentration of macro nutrients in *Cladophora* than exists for areal biomass. Painter and Jackson (1986) and others have noted that while tissue P data are more stable over time than biomass estimates, tissue P levels do fluctuate over the short term and from year to year. The *Cladophora* study by Millner *et al.* (1982) in 1979 at sites near Hamburg, New York and Walnut Creek, Pennsylvania included measurement of tissue nutrients. Tissue P concentrations varied over time in a similar pattern at both areas. Concentration decreased from moderate levels (maximum concentrations of ~0.38% P of DW and ~0.25% of DW at Hamburg and Walnut Creek, respectively) in June to low levels (<0.1% P of DW) in July which persisted through to September.

Tissue P data collected at Rathfon Point in 1979, 1980 and 1985 suggest varying degrees of P limitation (Painter and Jackson 1986). In 1979, the tissue P concentration averaged 0.1 % P of AFDW (Table 6); the 1995 result in this study is within the range of the 1979 estimates. In 1980, the mean concentration was 0.19% with a higher range of estimates than in 1979. The 1985 P concentrations were intermediate to the 1979 and 1980 levels (Table 6).

Painter and Jackson (1986) provide information on the concentrations of P in *Cladophora* tissue for 14 sites in the eastern basin in 1985. The data, as extrapolated from figures in the Painter and Jackson (1986) report, are summarised in Table 6. Nine of the 14 geographic areas which were surveyed in 1995 were surveyed in 1985, however, the proximity of the collection sites between studies is not known making direct comparison of the results by site inappropriate. In 1985, the average tissue P concentration was between 0.1 and 0.2% P AFDW at 11 sites (79% of sites) and above 0.2% P AFDW at two sites (14% of sites). By comparison in 1995, considering the sites over the same geographic range (i.e. the 12 sites east of, and including, Featherstone Point), eight of

the sites (67%) had tissue P concentrations $<0.1\%$ P AFDW and only three sites (25%) had tissue P concentrations between 0.1 and 0.2% P AFDW. The comparison suggests that the P availability has decreased since 1985 and that *Cladophora* is possibly more P limited than in 1985. This inference appears to contradict the previous discussion suggesting that the development of the biomass between Point Abino and Featherstone Point, as suggested by percent cover, was greater in 1995 than in 1985.

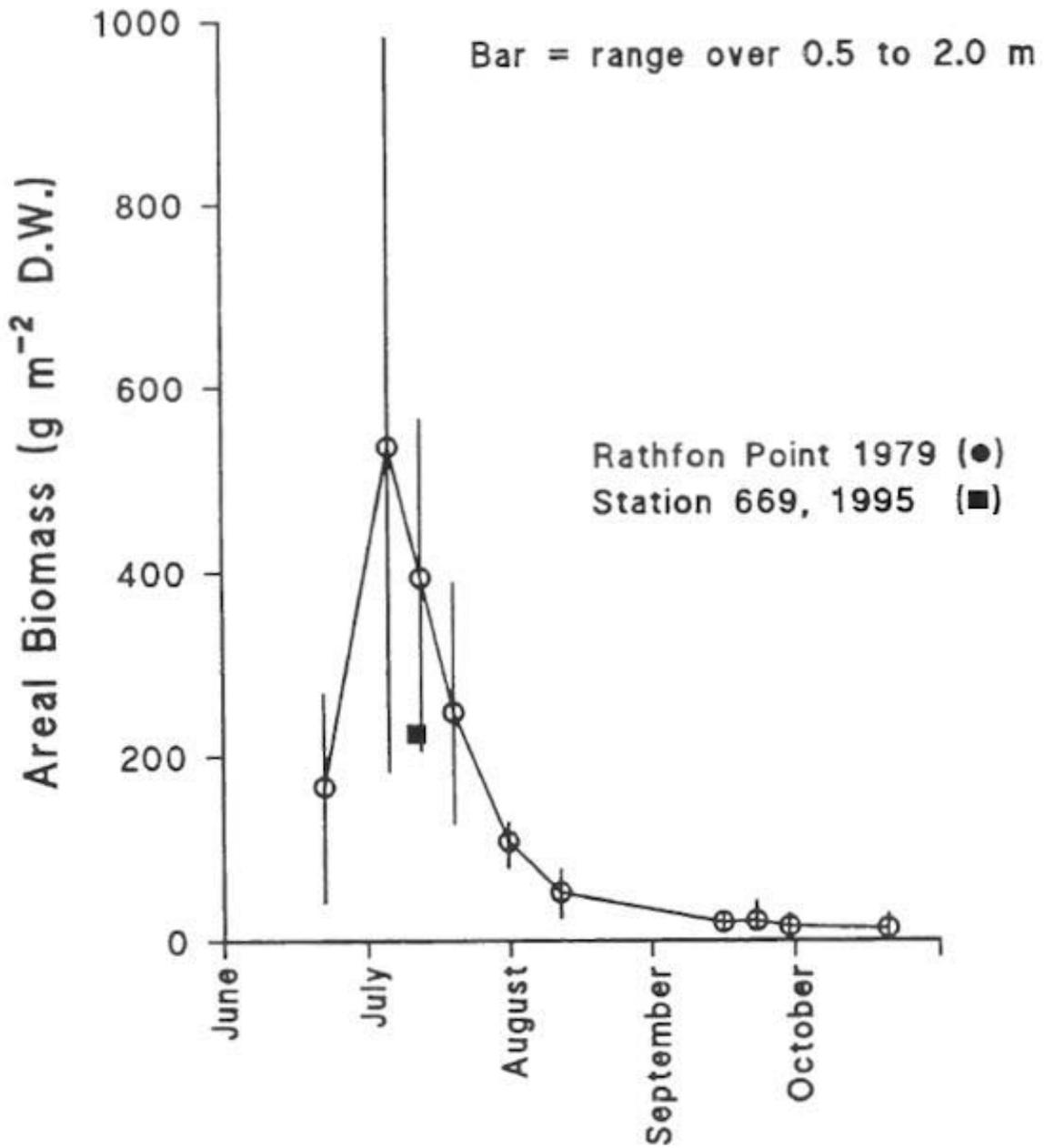


Figure 6. Graph of areal biomass of *Cladophora* at Rathfon Point from June - November 1979 (circles) and areal biomass at station 669 (Rathfon Point) in July 1995 (square). The 1979 data were taken from Neil and Jackson (1982).

Table 6: Concentration of P in *Cladophora* tissue from Eastern Lake Erie collected from 1979 - 1985 as given by Painter and Jackson (1986).

Site	Date	Depth	Percent Tissue P (ash - free DW)	
			range (N)	mean
Abino	June - July 1985	NR	0.11 - 0.23 (4)	0.16
Whitemans Point	June - July 1985	NR	0.11 - 0.18 (4)	0.15
Rathfon	June - Aug.1979	1.0	0.07 - 0.11 (6)	0.10
Rathfon	June - Aug.1980	1.0	0.09 - 0.45 (8)	0.19
Rathfon	June - July 1985	NR	0.13 - 0.21 (14)	0.16
Morgans	June - July 1985	NR	0.10 - 0.18 (4)	0.14
Mohawk	June - July 1985	NR	0.11 - 0.15 (4)	0.13
Mohawk Island	June - July 1985	NR	0.16 - 0.21 (3)	0.19
Rock No 1	June - July 1985	NR	0.14 - 0.22 (4)	0.17
Rock No 2	June - July 1985	NR	0.25 - 0.38 (3)	0.32
Grand River	June - July 1985	NR	0.28 - 0.53 (3)	0.42
Grant	June - July 1985	NR	0.10 - 0.18 (4)	0.14
Low	June - July 1985	NR	0.09 - 0.15 (3)	0.13
Evans	June - July 1985	NR	0.11 - 0.18 (4)	0.14
Miller	June - July 1985	NR	0.08 - 0.11 (4)	0.09
Featherstone	June - July 1985	NR	0.14 - 0.18 (4)	0.16

Note: Data were estimated from graphs of Tissue P versus Date (figures 6 - 8, 27 - 39) in Painter and Jackson (1986).

NR = not reported

3.5 Factors Controlling *Cladophora* Growth

PHOSPHORUS

The concentration of phosphorus in the lake water needed to prevent the development of *Cladophora* lawns is uncertain but is likely low. Jackson and Hamdy (1982) used an empirical relationship between water TP and tissue concentrations of P in *Cladophora* to predict the increase in TP above ambient concentration that would be needed to stimulate growth of *Cladophora* over areas of bare rocky bottom in southern Georgian Bay. They suggested that the minimum cell quota (given as 0.04% P DW) occurred at an ambient TP of approximately $5 \mu\text{g L}^{-1}$ which was consistent with their observation that *Cladophora* was absent from many areas of Georgian Bay where average TP was $\sim 5 \mu\text{g L}^{-1}$.

They reasoned that an increase in tissue concentration above the minimum cell quota for P would promote a low rate of growth. They concluded that an increase of $1 \mu\text{g L}^{-1}$ above ambient would be adequate to promote growth. Further, a TP concentration of $15 \mu\text{g L}^{-1}$ was predicted to be adequate to sustain rates of growth approaching maximum levels (i.e. rates corresponding to 0.1 % tissue P). They concluded, based on the sporadic occurrence of *Cladophora* in Georgian Bay in association with sites of nutrient enrichment, that *Cladophora* was extremely efficient at scavenging nutrients and would colonize suitable substratum given the slightest nutritional advantage.

Periodic elevation of external P concentrations above ambient may affect the amount of *Cladophora* biomass which accrues over a growth season since the excess supply of P may be captured and used to sustain a relatively higher rate of growth during the period of enrichment and possibly for a short time after external P concentration returns to ambient levels. Mantai et al. (1982) documented the short-term variability (2-4 day intervals) in tissue P of *Cladophora* growing in eastern Lake Erie over the period late May to early July. Pulses in soluble reactive P in the water were followed by a sharp increase in tissue P which subsequently declined within a day or two after the pulse. Painter and Jackson (1986) also reported rapid, but short lived, increases in *Cladophora* tissue P in correspondence with short-term increases in P concentrations in water associated with storm events in Lake Ontario. Based on simulation of effects of elevated nutrients on

growth rate during upwelling events Painter and Jackson (1986) suggested that in clear shallow water there would be an increase in production during the event, however, there would be no benefit in terms of continued increased production once epilimnetic water returned.

There is possibly a nutritive relationship between dreissenid mussels and *Cladophora*. Dreissenid mussels and *Cladophora* coexist intimately on the same areas of rocky shoreline, Large populations of dreissenid mussels were observed growing among the *Cladophora* lawns (and on each other) over the survey range. The possibility exists that *Cladophora* benefits from the presence of dreissenid mussels by scavenging macro nutrients from their wastes. Nutrients may be generated by the breakdown and leaching of faecal and pseudo-faecal material deposited among the *mussel / Cladophora* beds. Heath *et al.* (1995) observed that zebra mussels had a strong effect on phosphorus dynamics in a short-term mesocosm experiment. In a high zebra mussel treatment (2,928 individuals in an enclosure 1 m diameter and 2 m deep) soluble reactive P was elevated compared with the control over the six day duration of the experiment.

LIGHT

Exposure to adequate light for photosynthesis is a key factor determining the extent of development of *Cladophora*. Typically, the beds of *Cladophora* in nutrient enriched area of the Great Lakes in the past did not extend very deeply into the lake because of light limitation with depth. *Cladophora* has moderate light requirements to achieve optimal levels of growth. Graham *et al.* (1982) reported that the light compensation point for *Cladophora* was between 25-35 $\mu\text{E m}^{-2} \text{s}^{-1}$ at temperatures between 5-20 °C. Optimum light intensity was reported to lie in the vicinity of 300-600 $\mu\text{E m}^{-2} \text{s}^{-1}$ at temperatures from 13-17 °C (the optimal temperature range for growth). The estimates were determined from assays using lab culture under controlled conditions using a *Cladophora* strain isolated from Lake Huron.

There has been an increase in the water clarity of areas of Lake Erie in recent years (Leach 1993). As an example of the changes which have been observed in the eastern basin, secchi depth information from 1988 to 1995 for a monitoring station offshore of

Fort Erie (station 1340) is provided in Figure 7. Prior to 1991, secchi depth did not exceed 4 m. In subsequent years the range of secchi depth has increased. During a survey in May 1995 the secchi depth was 8.5 m.

The secchi depth measurements at station 1340 prior to 1991 compared with measurements in 1995 provide a basis for formulating hypothesis on the nature of the effect that the changing light regime may have had on the development of *Cladophora*. Light extinction coefficients can be approximated from secchi depth and used to predict light regime with depth under a given surface irradiance. Secchi depth was converted to light extinction coefficients (k) using the formula:

$$k = 1.35/\text{secchi (m)}$$

(Canale and Auer 1982 and confirmed for Lake Erie by Painter and Jackson 1986).

In May 1995 k was -0.2 at station 1340 based on direct light measurements. If for discussion purposes, a near maximal sub-surface irradiance of $\sim 1800 \mu\text{E m}^{-2} \text{s}^{-1}$, k value of -0.2, and minimum optimal light requirement of $300 \mu\text{E m}^{-2} \text{s}^{-1}$ are assumed, then it is predicted that there would be periodically optimal light conditions down to a depth of ~ 9 m. In contrast, prior to 1991 at station 1340, maximum k was estimated as -0.39, which under the same assumptions would suggest that optimal light would periodically be present to a depth of between 4-5 m. These predictions are simplistic given the crude estimates of the light regime, the limited data, and the fact that the growth rate of *Cladophora* over a depth gradient, while greatly determined by light, is also a function of temperature and nutrient changes with depth. Nonetheless this examination of secchi measurements suggests the hypothesis that the depth of optimal development of *Cladophora* has likely increased in recent years.

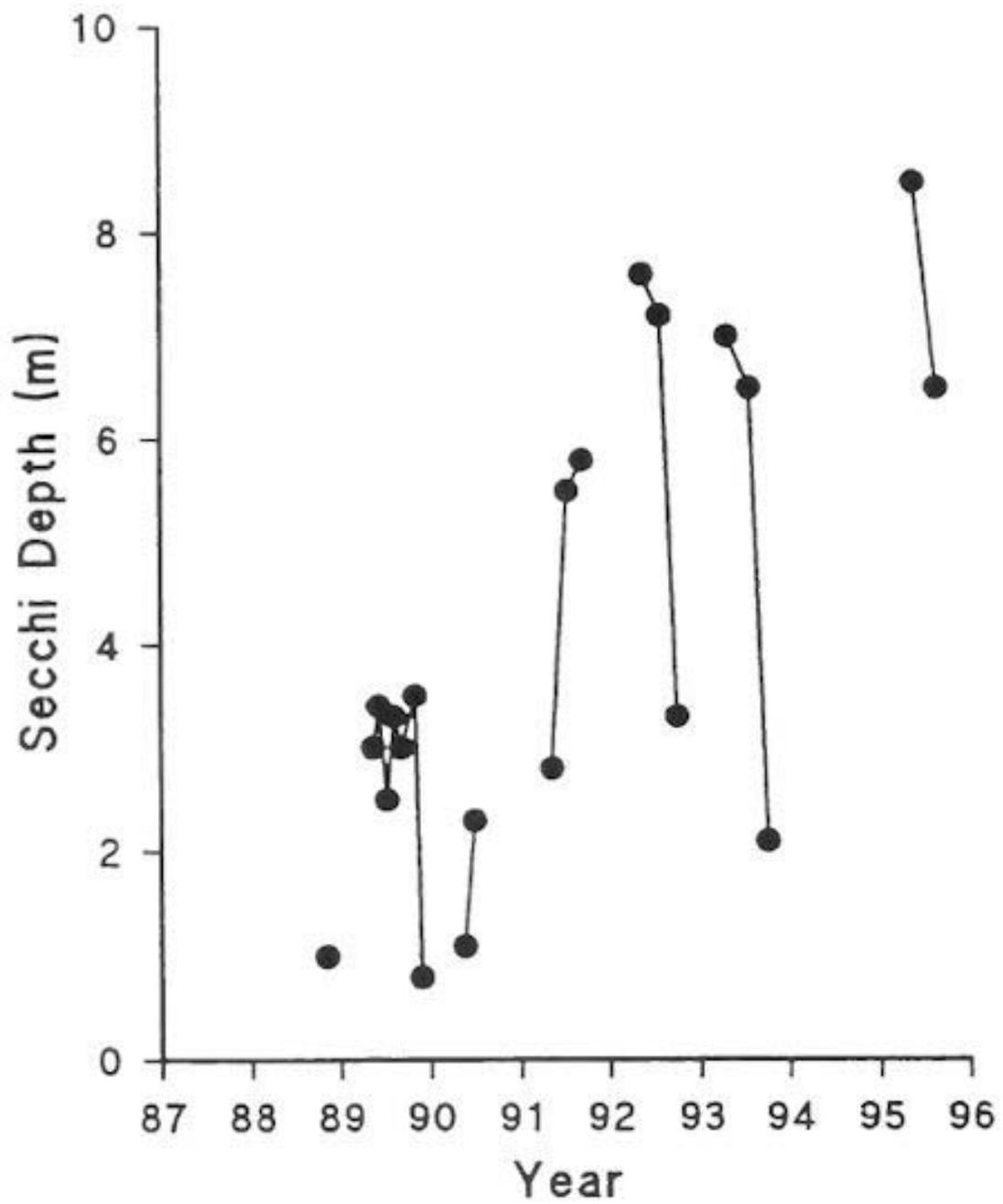


Figure 7. Graph of secchi depth at station 1340, offshore of Fort Erie in eastern Lake Erie from 1988 to 1995. Water depth is ~9 m.

HABITAT

Cladophora is a filamentous alga which requires a stable surface upon which to attach in the high energy environment of the littoral zone of the Great Lakes. The lawns of filaments usually grow upon rocky surfaces as well a variety of man-made structures and sometimes upon sediment (presumably more stable deposits in deeper water). The key factor determining available habitat appears to be the amount of rocky bottom which occurs above a depth where there is adequate light for the growth of *Cladophora*.

The areas of rocky bottom along the north shore of the eastern basin are documented. Rukavina and St. Jacques (1971) and St. Jacques and Rukavina (1973) surveyed and mapped the bottom along the north shore to a depth of 20 m. The substrate maps in these publications were digitized and used to approximate the surface area of rocky bottom (areas classified as bedrock). The digitized maps of areas of rocky bottom were then overlaid on an electronic navigation chart of the eastern basin (Canadian Hydrographic chart 2120) using GIS (SPANS). The depth soundings on the navigational chart were used to estimate depth contours using the triangulated irregular network (TIN) procedure in SPANS. Surface area of rocky bottom was then calculated as a function of depth.

The surface area of rocky bottom increases with depth. Based on the water level of chart datum there is roughly 260 km² of bedrock bottom in the eastern basin down to 20 m depth of which approximately 60% is below 5 m in depth. There is an estimated 95 km² of rocky bottom between 5 and 10 m depth. The surface area which can be exploited by *Cladophora* will be strongly affected by the adequacy of light levels to support growth over the 5-10 m depth (see Figure 1).

4.0 CONCLUSIONS

There were substantial quantities of *Cladophora* growing in the shallow waters (0-2 m depth) along the north shore of eastern Lake Erie from Fort Erie to Port Dover in July 1995. The surface coverage of *Cladophora* at the 16 areas of rocky bottom surveyed was

high, ranging from 60 to 100%. A lawn of filaments at least 5 cm thick covered the areas of rocky bottom at all sites. More extensive lawns of up to 20 cm in thickness were observed at number of sites; at ~40% of the sites median thickness was 10 cm or greater.

The observations made on the accumulation of *Cladophora* along the shoreline at the time of the surveys indicated that nuisance levels of the alga, resulting in degraded aesthetic condition, occurred at approximately 25% of the sites. Appreciable quantities of washed-up and rotting algae with an associated disagreeable odour were observed along the shoreline at Splatt Bay (west of the Grand River), Featherstone Point, Sandusk Creek mouth and Peacock Point. Lesser and varying quantities were observed on shore at other sites; the one-time observations of the survey suggested that there was not a grossly-apparent aesthetic problem.

The ambient nutrient regime of the nearshore zone of the eastern basin appears to be sufficient to sustain extensive growth of *Cladophora*. It is uncertain whether the observed background levels of *Cladophora* growth (i.e. the lowest levels of occurrence) are adequate to cause nuisance levels of shoreline accumulation. It is suspected that the greater than average abundance of *Cladophora* observed at a number of sites was a consequence of some local source of nutrient loading. Further investigation is required to determine the relationship between the extent of *Cladophora* growth in the littoral zone and the manifestation of shoreline fouling.

The analysis of samples of *Cladophora* for phosphorus and nitrogen collected at sites suggested that at most sites *Cladophora* growth is highly phosphorus limited. The implication is that *Cladophora* growth will be responsive to changes in loading of phosphorus, both increases and decreases, relative to existing ambient levels.

The limited water quality sampling conducted at the time of the survey did not identify any locations where nutrient levels were considered to be high. There was an indication that nutrient and ion levels at sites in the vicinity of the Grand River mouth were slightly elevated compared to other areas.

An issue beyond the scope of this study is the question of the extent to which the inputs of nutrients from the local drainage basins may account for the observed *Cladophora* growth. The position of *Cladophora* in the immediate nearshore suggests it may be responsive to shore-based inputs of nutrients, even if the nutrient inputs are effectively diluted as they mix with the open lake.

Dreissenid mussels and *Cladophora* coexist intimately on the same areas of rocky shoreline. A question that suggests itself is whether *Cladophora* benefits from the presence of dreissenid mussels by intercepting macro nutrients leached from the wastes of dreissenid mussels.

There is insufficient information to determine whether the extent or magnitude of nuisance occurrences of *Cladophora* in 1995 were different from recent years. Comparison of tissue phosphorus information from collections in 1985 from the same general areas sampled in 1995 suggests that tissue P concentrations were lower in 1995. Since the concentration of P in *Cladophora* tissue is an indicator of nutrient sufficiency, the implication is that growth conditions were less nutrient rich in 1995 than in 1985. In contrast, the surface coverage of *Cladophora* observed in 1995 appears to be more extensive than reported for some of the same general areas sampled in 1985.

The availability of habitat as determined by light penetration may have been more of a factor in determining the success of *Cladophora* in 1995 when compared with earlier work in the Lake Erie during the 1970-80's. There is a possibility that the amount of bottom area available for *Cladophora* growth has increased since 1991-1992 as a consequence of an increase in water clarity, which is thought to have been mediated by dreissenid mussels. Key questions which have not been addressed by this study are: 1) what is the depth to which the lawns of *Cladophora* penetrate into the lake?, and, 2) is a lower rate of growth over a larger area as problematic as a higher rate of growth over a more limited area with respect to shoreline fouling?

5.0 RECOMMENDATIONS

The information collected in this survey suggests that *Cladophora* growth will likely be responsive to new point-sources of nutrient over areas of rocky bottom. The potential for creating *Cladophora* fouling problems should be considered in the evaluation of new sources of P loading over, or adjacent to, bottom types suitable for *Cladophora*.

Nuisance levels of *Cladophora* resulting in shoreline fouling were observed at several sites along the north shore of the eastern basin of Lake Erie which should be further examined to better characterize the problem, and to evaluate the sources of the nutrient enrichment, which may be local, and likely lead to excessive *Cladophora* growth.

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