THE DOMINANT ATTACHED FILAMENTOUS ALGAE OF LAKE HURON: FIELD ECOLOGY AND BIOMONITORING POTENTIAL 1980

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by

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I. SUMMARY AND CONCLUSIONS

The findings of this investigation support a growing body of literature indicating that growth of the dominant attached filamentous algae (i.e., *Ulothrix, Cladophora* and *Bangia*) in the Great Lakes is controlled by the following environmental factors: temperature, light, turbulence, substrate and nutrients. All three algae preferably colonize exposed and permanent steeply sloping substrates where turbidity is low. Temperature is most important, at least in Lake Huron, in controlling seasonal periodicity, while nutrient availability limits basin wide distribution.

It is evident from this investigation that the remote shoreline of Lake Huron is largely devoid of attached filamentous algae, even though physical requirements for growth are favourable. This is likely because phosphorous levels, and/or possibly halide levels in the case of *Bangia*, are too low to support basin wide growth. Instead, the algae occur locally in association with natural or anthropogenic nutrient sources, where the apparent level of enrichment and general degradation in water quality (at physically comparable locations) is reflected in the type and amount of algae present.

Specifically, it appears that a first sign of nutrient enrichment is an increase in the distribution of *Ulothrix*, followed in order of increasing perturbation by fringing *Cladophora,* submerged *Cladophora*, and finally problem growths of submerged *Cladophora*. Importantly, this sequential occurrence of *Ulothrix* and *Cladophora* in relation to nutrient supply has application as a management tool since nearshore trophic status can be evaluated rapidly and at low cost by visually documenting the presence/absence and abundance of these highly conspicuous forms (although *Bangia* is probably not limited by phosphorus availability in Lake Huron, its occurrence appears symptomatic of advanced degradation in water quality).

The Thirty Thousand Islands of eastern Georgian Bay are the greatest concentration of islands in the world (Ontario Ministry of Tourism and Recreation data); consequently the area represents a vast potential habitat for attached filamentous algae. This is particularly disturbing considering that submerged *Cladophora* annually inundates great expanses of physically similar shoreline in Lakes Ontario and Erie, a direct result of nutrient enrichment. Georgian Bay, therefore, should he monitored closely for any signs of change since even a minor increase in nutrient concentrations may have a major environmental impact (i.e., Jackson and Hamdy (1982) believe that an increase in open lake total phosphorus concentration of only 1 µg/L may be sufficient to initiate basin wide growth of *Cladophora*).

It is apparent from this and other investigations that attached filamentous algae bioaccumulate (10^3 to 10^5X) a variety of elements primarily in proportion to concentrations in the surrounding water. In Lake Huron, the relative magnitude of elemental concentrations in both *Ulothrix* and *Cladophora* is similar (i.e., N, Ca > Al, Fe, Mg, P > Mn > Zn > Pb, Cu > As, Cr, Ni > Co > Cd, Se > Sb > Hg). Differences between algae in their capacity to concentrate certain elements may occur under extreme environmental conditions. In particular, and consistent with algal distributional patterns, *Ulothrix* appears to have a competitive advantage over both forms of *Cladophora* at sequestering phosphorus in cool and dilute turbulent nearshore waters, while fringing *Cladophora* may have a similar competitive advantage over submerged *Cladophora* (no comparable data are available for *Bangia*, although the alga's limited distribution tends to indicate a relatively high requirement for phosphorus).

Significantly, runoff water from the Precambrian Shield may he contributing to elevated concentrations of certain metals (As, Cd, Cu, Ni, Pb, Zn) in attached filamentous algae in eastern Georgian Bay, possibly due to the effects of acid precipitation. While these elevated metals loadings have no apparent stimulatory effect on the growth of filamentous algae, the potential for toxic effects, particularly at higher trophic levels, is of considerable ecological importance, and requires further investigation.

II. RECOMMENDATIONS

The suggestion of elevated metals loadings from the Precambrian Shield and the extreme susceptibility of Lake Huron to environmental degradation from nutrient enrichment, necessitate that every effort be expended to:

i. Maintain background total phosphorus concentrations below 0.005mg/L, which Jackson and Hamdy (1982) believe approximates the lower nutritional limit for *Cladophora* growth.

ii. Improve agricultural methods to reduce nutrient (especially phosphorus) inputs associated with agricultural runoff from the Lake Huron watershed.

iii. Control nutrient (especially phosphorus) inputs from municipal and industrial sources. For example, by strictly limiting effluent nutrient concentrations and by opting for methods of effluent disposal other than direct discharge to the lake.

iv. Define Ministry criteria limiting contaminant concentrations in attached filamentous algae.

v. Quantify and determine the ecological significance of contaminant inputs to Lake Huron from the Precambrian Shield.

vi. Implement an annual water quality surveillance plan for Lake Huron to measure the effectiveness of abatement activities and to identify emerging problems.

III. INTRODUCTION

The green algae *Ulothrix zonata* (Weber and Mohr) Kütz. and *Cladophora glomerata* (L.) Kütz. and the red alga *Bangia atropurpurea* (Roth) Ag. are the dominant attached filamentous forms in the nearshore of the Laurentian Great Lakes. All three algae preferably colonize exposed and steeply sloping substrates and all are highly conspicuous, especially in areas of excessive nutrient enrichment. *Ulothrix* is the most ubiquitous of the three algae although it persists through the entire summer only in the Upper Great Lakes because of its requirement for relatively cool temperatures (optimum temperature for photosynthesis is about 5°C). *Ulothrix* filaments are smooth and unbranched and growth typically occurs as a luxuriant dark green band about 25 cm wide on the waterline. Because *Ulothrix* expends biomass as zoospores, and occupies a relatively minimal substrate area due to high light requirements, it never produces the excessive biomass and related environmental degradation characteristic of *Cladophora* (Verduin 1972, Parker 1979, Parker and Drown 1982, Blum 1982, Garwood 1982, Lorenz and Herdendorrf 1982; Auer *et al.* 1983). No doubt the fact that *Ulothrix* is considered "unworthy" of management explains, in part, why comparatively few studies have actually been undertaken to document its biology.

The proliferation of *Cladophora* is a basin wide symptom of eutrophication in Lakes Erie and Ontario, while in Lakes Michigan and Huron *Cladophora* is confined to areas of local nutrient enrichment; in Lake Superior, temperatures (as well as phosphorus levels) are too low to support the alga, although limited growths have been recorded at river mouths and at a few harbour sites. *Cladophora* is noticeably lighter green than *Ulothrix* and its highly branched filaments have a distinctive rough wooly texture. There are two major growth forms of *Cladophora* in the Great Lakes.

The first form, which is initiated each spring from overwintering holdfasts, grows submerged below the waterline to a maximum depth of about 10 m (although the most abundant growth always occurs in the 0.5-3 m depth zone). It is this form of *Cladophora* that proliferates as vast meadows in the enriched nearshore waters of Lakes Ontario and Erie, and when sloughed, inundates great expanses of residential and recreational shoreline. Wind induced sloughing normally occurs in early summer soon after attainment of temperatures in the "optimal" 15°C range; renewed submerged growth may result when summer temperatures fall below 20-21°C (Neil and Owen 1964, Herbst 1959, Taft and Kishler 1973, Shear and Konasewich 1975, Auer *et al.* 1930, Auer and Canale 1981, Millner *et al.* 1982, Lorenz and Herdendorf 1982, Blum 1982, Graham *et al.* 1982, Neil and Jackson 1982; Jackson 1982).

The second growth form of *Cladophora*, which is rarely mentioned in the literature, is initiated primarily during summer from spores released by the older submerged filaments, usually at temperatures in the 20°C range. This form of *Cladophora* occurs as a robust light green waterline "fringe" about 25 cm wide overlapping, but slightly below, the zone previously dominated by *Ulothrix*. Like *Ulothrix*, fringing *Cladophora* is restricted in its areal coverage, and although highly visible through to freeze up, its growth is never of problematic proportions (Taft and Kishler 1973, Blum 1982, Jackson and Hamdy 1982; Jackson 1982).

Bangia's notoriety stems from the fact that this alga has only recently invaded the Great Lakes from the marine environment (first observed by Blum in 1964, in Buffalo harbour on Lake Erie). Bangia, which is distinctly dark red, is most prevalent in perturbed areas where halide levels are high enough (apparently) to permit growth. The alga is now widespread in Lakes Erie and Ontario and in the southern two thirds of Lake Michigan. Only two populations have been observed in Lake Huron, while Lake Superior appears to he unaffected. Since *Bangia* colonizes the splash zone (to a maximum height of about +1 m), interaction with *Ulothrix* and *Cladophora* is reduced, yet competition can be quite intense near the waterline. Unlike the other algae, *Bangia* may persist year round, although it is most abundant in the early summer at intermediate temperatures. *Bangia* is never a "biomass" problem, at least on the scale of submerged *Cladophora*. Irrespective of biomass production, however, each of the dominant attached algae, singly and in combination, are equally important indicators of ecosystem health (Lin and Blum 1977, Sheath and Cole 1980, Auer and Canale 1981, Garwood 1982; Lorenz and Herdendorf 1982).

Because of their distinctive growth characteristics, widespread distribution and known capacity to concentrate contaminants, attached filamentous algae are particularly suited to application as biomonitors (Prosi, 1979). In the Great Lakes, Anderson *et al.* (1982) used *Cladophora* to assess PCB levels at Harbour Beach in western Lake Huron, while Keeney *et al.* (1976) compared heavy metal levels in *Cladophora* at two sites in eastern Lake Ontario. Since 1980, the Ontario Ministry of the Environment (MOE) has annually monitored contaminant levels in *Cladophora* (and on occasion in *Ulothrix* and *Bangia*) at approximately thirty nearshore sites in Lake Ontario and the Niagara River; these data will soon be available in full in MOE publications, although a partial data set is contained in a recent multi-agency report on the water duality of the Niagara River (NRTC 1984). This investigation, as part of the Great Lakes International Surveillance Plan for 1980, details the field ecology and biomonitoring potential of the dominant attached filamentous algae in nearshore Lake Huron, Georgian Bay and the North Channel.

IV. METHODS

At the intensive study sites in southern Georgian Bay (CTB-inner Collingwood harbour, CTI—harbour mouth, SHB/E—Mary Ward Shoals 5 km west of Collingwood; see Figure 1), field sampling occurred weekly to every two weeks from May through September, 1980 and less frequently at earlier and later dates in the year. Synoptic shoreline surveys of Lake Huron, Georgian Bay and the North Channel were conducted in mid June and again, for the latter two basins, in mid August (see Table 1 and Figure 1). Also, in mid July an aerial survey of the Thirty Thousand Islands of eastern Georgian Bay (Collingwood to Bayfield Harbour) was carried out to confirm broad algal distributional patterns.

At each of the above shoreline sites, surface water temperature, wave height and Secchi depth (when possible) were recorded and samples were collected for determination of total, filtered total and soluble reactive phosphorus, nitrate—nitrite, ammonia, total Kjeldahl nitrogen, silicate (as Si), chloride, conductivity and turbidity. Data for characterizing major algal growths included: a detailed photographic record (35 mm transparencies) of ambient conditions, minimum and maximum algal depth occurrences and standing crop determinations (collected in triplicate only at the intensive sites from wherever the alga was most abundant using a 1/4 or 1/16 m^2 quadrat).

When in sufficient quantity, biomass (minimum 50 g wet weight) was collected for determination of internal elemental composition (essential nutrients, major and trace elements). Each biomass sample, including those for standing crop, was washed with ambient water, squeezed dry, wrapped in absorbent paper and transported on ice to the MOE laboratory in Rexdale, Ontario. The samples were then dried to a constant weight at 50°C prior to analysis (see MOE 1981a). Because of an act of vandalism at the Rexdale laboratory, a number of the samples were lost; this accounts for the paucity of data for some elements in Tables 5, 6, 7, 8, and Figure 6.

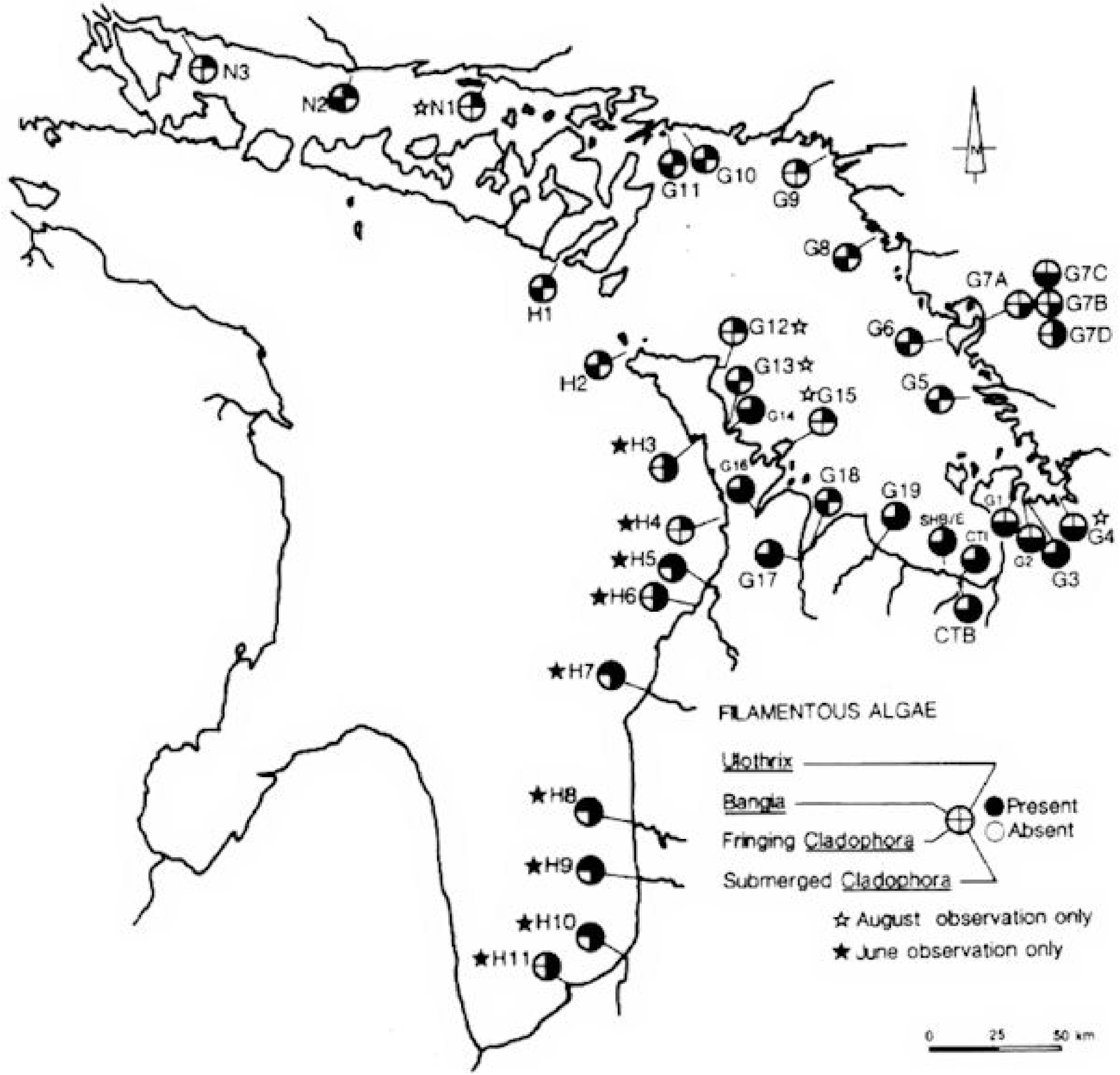

Figure 1. The occurrence of filamentous algae at shoreline sites in Georgian Bay, the North Channel and eastern Lake Huron, 1980.

Table 1. Attached filamentous algae sample sites in Georgian Bay, the North Channel and eastern Lake Huron, 1980.

REGION	SITE	LOCATION	COMMENTS
Georgian Bay	G1	Penetang	Sheltered inner harbour at STP.
	G2	Midland	Sheltered inner harbour at foot of Victoria Street.
	G3		Exposed outer harbour at Midland Marina by STP.
	G4	Sturgeon Bay	Exposed Middle Ground shoals at bay mouth.
	G5	Twelve Mile Bay	Exposed Passage Island at bay mouth.
	G6	Parry Island	Exposed shoal 200 m west of Surprise Island.
	G7A	Parry Sound	McCurry Lake STP outflow: upstream,
	G7B		moderately exposed mouth,
	G7C		moderately exposed shoreline 150 m north,
	G7D		moderately exposed shoreline 150 m south.
	G8	Bayfield Harbour	Exposed shoals at mouth of Hangdog Channel.
	G9	Key Harbour	Exposed shoals 100 m south of Dead Island.
	G10	Killarney	Exposed Red Rock 7 km south east of Killarney (gull colony).
	G11		Exposed shoals at east entrance to Killarney Channel.
	G12	Cabot Head	Exposed shoreline north of Gilles Lake outflow.
	G13	Whipporwill Bay	Exposed shoreline at discharge pipe near G.H. Upton residence.
	G14	Lion's Head	Sheltered shoreline in front of toilets at public dock.
	G15	Cape Crocker	Exposed shoreline near light house.
	G16	Wiarton	Sheltered embayment by urban runoff stream at public dock.
	G17	Owen Sound	Sheltered embayment on east side of Sydenham River mouth.
	G18		Moderately exposed shoreline at STP.

Table 1 (cont'd)

REGION	SITE	LOCATION	COMMENTS
	G19	Meaford	Moderately exposed shoreline on south side of Bighead River mouth.
	SHB/E	Collingwood	Exposed shoals 1 km north of Long Point.
	CTI		Exposed breakwall on east side of harbour mouth.
	CTB		Sheltered inner harbour at public boat launch.
North Channel	N1	Spanish River	Exposed shoal east of Aird Island at navigational marker.
	N2	Blind River	Exposed shoal south of river mouth beside navigational marker (gull colony).
	N3	Bruce Mines	Exposed shoreline near light house south west of public dock.
Lake Huron	H1	South Bay mouth	Exposed shoals on westside of South Bay outlet.
	H2	Tobermory	Exposed shoals1km west of Russel Island.
	H3	Stokes Bay	Sheltered embayment on west side of public dock.
	H4	Oliphant	Exposed point 1 km south of Oliphant.
	H5	Southampton	Exposed/sheltered harbour structures at Saugeen River mouth.
	H6	Port Elgin	Exposed/sheltered harbour structures.
	H7	Kincardine	Exposed/sheltered harbour structures at Penetangore River mouth.
	H8	Goderich	Exposed/sheltered harbour structures at Maitland River mouth.
	H9	Bayfield	Exposed/sheltered harbour structures at Bayfield River mouth.
	H10	Grand Bend	Exposed/sheltered harbour structures at Ausable River mouth.
	H11	Kettle Point	Exposed point at navigational marker.

V. FIELD ECOLOGY

5.1 Intensive Study: Southern Georgian Bay

The intensive study sites in southern Georgian Bay (CTB, CTI; SHB/E) exhibited a broad range in environmental conditions which markedly affected the growth of attached filamentous algae at these locations (Figure 2; Table 2). The major growth controlling factors are generally considered to be: 1) temperature, 2) light, 3) turbulence, 4) substrate and 5) nutrients.

5.1.1 Controlling Factors

Mean Secchi depth, indicative of water clarity, was 1.3 m in the turbid inner harbour at CTB, while the harbour mouth site CTI showed an improvement to 2.0 m. At the shoal site SHB/E, enhanced exchange with offshore waters increased Secchi depth to 4.2 m. Mean temperatures at CTB (17.8°C) and CTI (17.4°C) were about 2°C warmer than at SHB/E-off (15.6°C) where exchange with offshore waters kept temperatures moderate. SHB/E-near (15.8°C) and SHB/E-on (16.6°C), however, showed increasing temperatures with proximity to the shoal. Mean wave height, a measure of water turbulence, was much reduced in the sheltered inner harbour at CTB (4 cm) compared to the moderately exposed harbour mouth site CTI (16 cm). The highest mean value (24 cm) occurred at SHB/E which is exposed to the entire northwesterly fetch of Georgian Say. Substrate in the inner harbour at CTB consisted primarily of limestone and granite cobbles on a gently sloping shoreline. CTI was characterized by large granite boulders and cut limestone blocks used for breakwall reinforcement; the slope here was quite steep. At SHB/E, substrate consisted of ledges and scattered granite boulders; the slope here varied from gently sloping to moderately steep. The mean phosphorus concentration in surface waters at CTB was 0.086 mg/L, reflecting the enriched state of the inner harbour due to municipal waste water discharge. At CTI, which is influenced by the harbour plume and, alternatively, by dilute offshore waters, phosphorus concentrations were reduced to 0.031 mg/L.

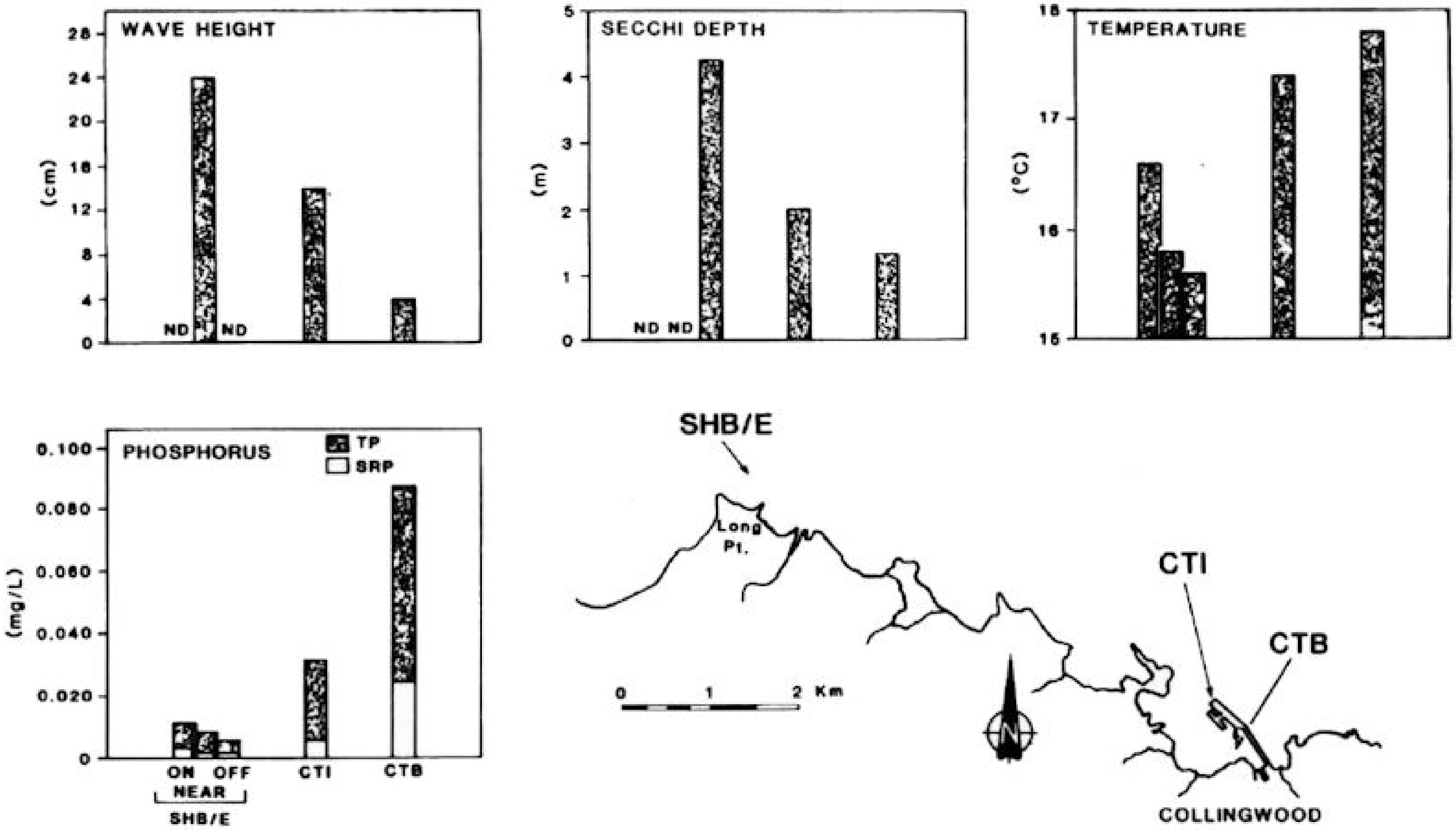

Figure 2. Filamentous algae growth controlling factors at sample sites in southern Georgian Bay, 1980. ND - no data, ON - wave washed pool, NEAR - 1m offshore, OFF - 10m offshore.

Table 2. Filamentous algae growth controlling factors at sample sites in southern Georgian Bay, 1980. Mean values are followed by ± standard deviation, the number of observations in parenthesis and minimum-maximum values.

	CTB	CTI	SHB/E*		
			OFF	NEAR	ON
WAVE	4	14	ND	24	ND
HEIGHT	±6 (14)	± 16 (11)		± 14 (18)	
(cm)	0-20	0-50		5-50	
SECCHI	1.3	2.0	4.2	ND	ND
DEPTH	± 0.5 (8)	±0.7 (12)	±1.6 (8)		
(m)	0.9-2.2	1.2-3.3	2.2-7.0		
TEMPERATURE	17.8	17.4	15.6	15.8	16.6
(°C)	± 4.4 (5)	± 4.8 (5)	± 4.5 (5)	± 4.2 (10)	±3.7 (10)
	12.0-22.5	11.0-22.5	10.00-20.5	10.0-21.0	11.5-21.5
PHOSPHORUS TP	0.086	0.031	0.006	0.008	0.011
(mg/L)	±0.025 (15)	±0.013 (19)	±0.002 (15)	±0.004 (24)	±0.008 (19)
	0.048-0146	0.011-0.060	0.002-0.010	0.003-0.020	0.004-0.035
SRP	0.023	L0.007^{1}	L0.001^{5}	L0.002^{6}	L0.004^{2}
	±0.021 (15)	±0.009 (19)	±0.001 (16)	±0.001 (24)	±0.005 (19)
	0.001-0.084	L0.001-0.040	L0.001-0.004	L0.001-0.004	L0.001-0.011
SUBSTRATE	Limestone - Granite Cobbles	Limestone Boulders	- - - - - - Limestone Ledges - - - - - -		

*	Composite of two shoal sites.
o	Five comparable dates June through August (see circled dates in Figure 3,4,5).
x^n	Superscript n is the number of "less than" values included in the calculation of each mean and standard deviation.
ND	No data.
L	Less than.
ON	Waved washed pool.
NEAR	1 m offshore.
OFF	10 m offshore.

On the shoals at SHB/E, enhanced exchange with offshore waters resulted in near background phosphorus levels of 0.006 mg/L. Importantly, the source of phosphorus for algal growth originated from the emergent shoal itself (i.e., gull excrement) and not the surrounding water where phosphorus concentrations are limiting.

5.1.2 *Ulothrix*

At CTB, *Ulothrix* colonized waterline rocks soon after ice off in mid April. Peak standing crop and maximum depth distribution occurred in early May at temperatures of 10-12°C (Figure 3). Although these favourably cool temperatures were short lived, growth was extremely rapid because of the high nutrient availability in the inner harbour. From mid May onwards *Ulothrix* deteriorated rapidly, especially after late June as temperatures exceeded 15°C. The alga was gone from the inner harbour after late July at temperatures in excess of 22°C and did not reappear during the 1980 field season.

At CTI, *Ulothrix* showed a more gradual increase in biomass after ice off, probably due to periodic influxes of cold nutrient poor offshore waters (Figure 4). Peak standing crop and maximum depth distribution occurred in early June, almost a month later than at CTB, following a period of variable temperatures of 7.5-15°C (temperatures in the inner harbour at CTB were often 2°C warmer over this same time period). Because of CTI's exposed location and more moderate and variable summer temperatures, *Ulothrix* remained relatively healthy right through June and most of July. There was, however, considerable competition for space from upwardly invading submerged *Cladophora* after late May; this effectively restricted the maximum depth distribution of *Ulothrix* at CTI. *Ulothrix* was gone from the harbour mouth by late July due to inhibitory temperatures (above 22°C) and crowding out by newly arrived fringing *Cladophora; Ulothrix* did not reappear during 1980.

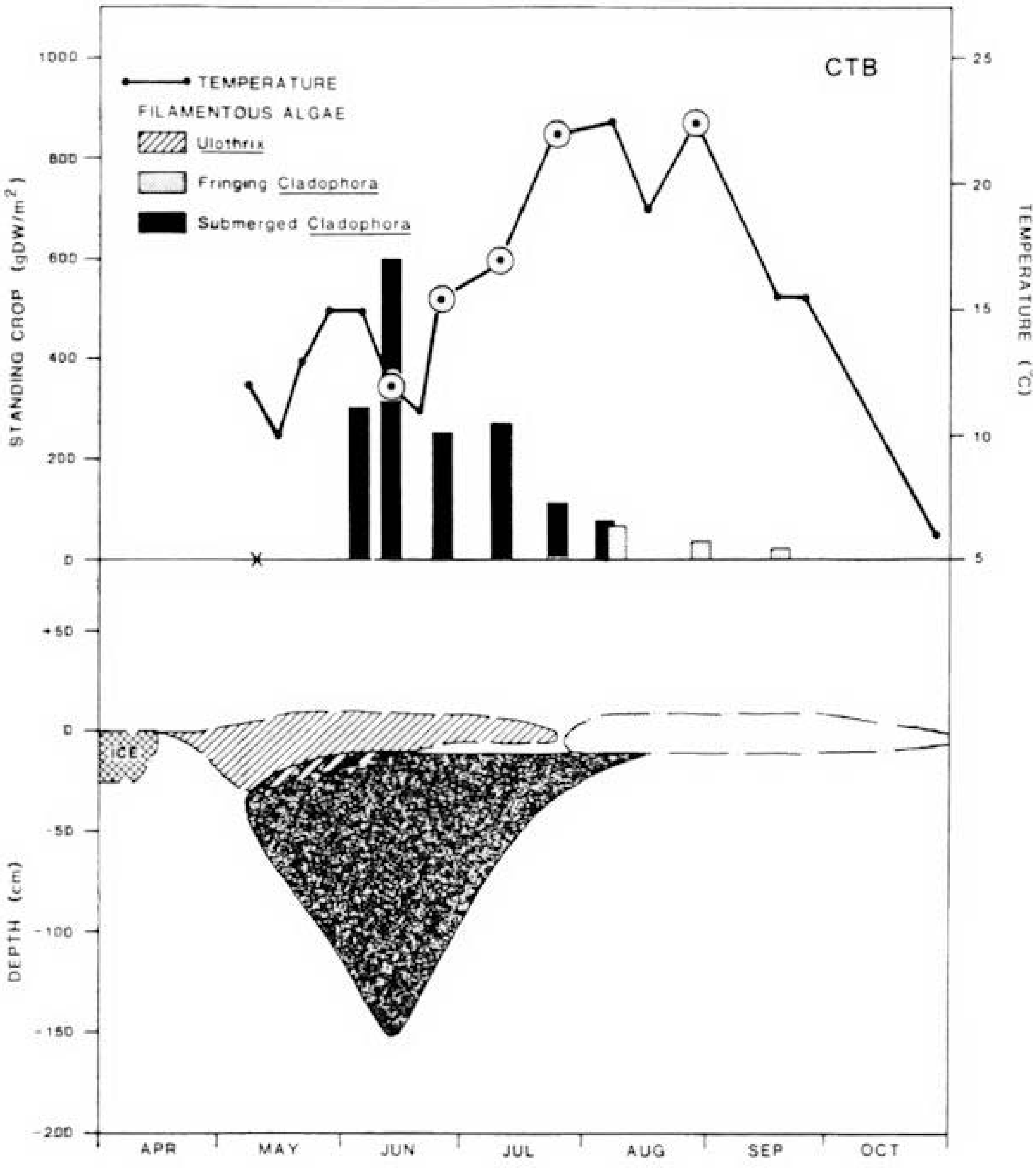

Figure 3. Seasonal trends in water temperature and growth characteristics of *Cladophora* and *Ulothrix* at the inner harbour site (CTB) in Collingwood, 1980. Summary statistics for the circled temperature values are presented in Table 2.X marks the date of *Ulothrix* peak standing crop.

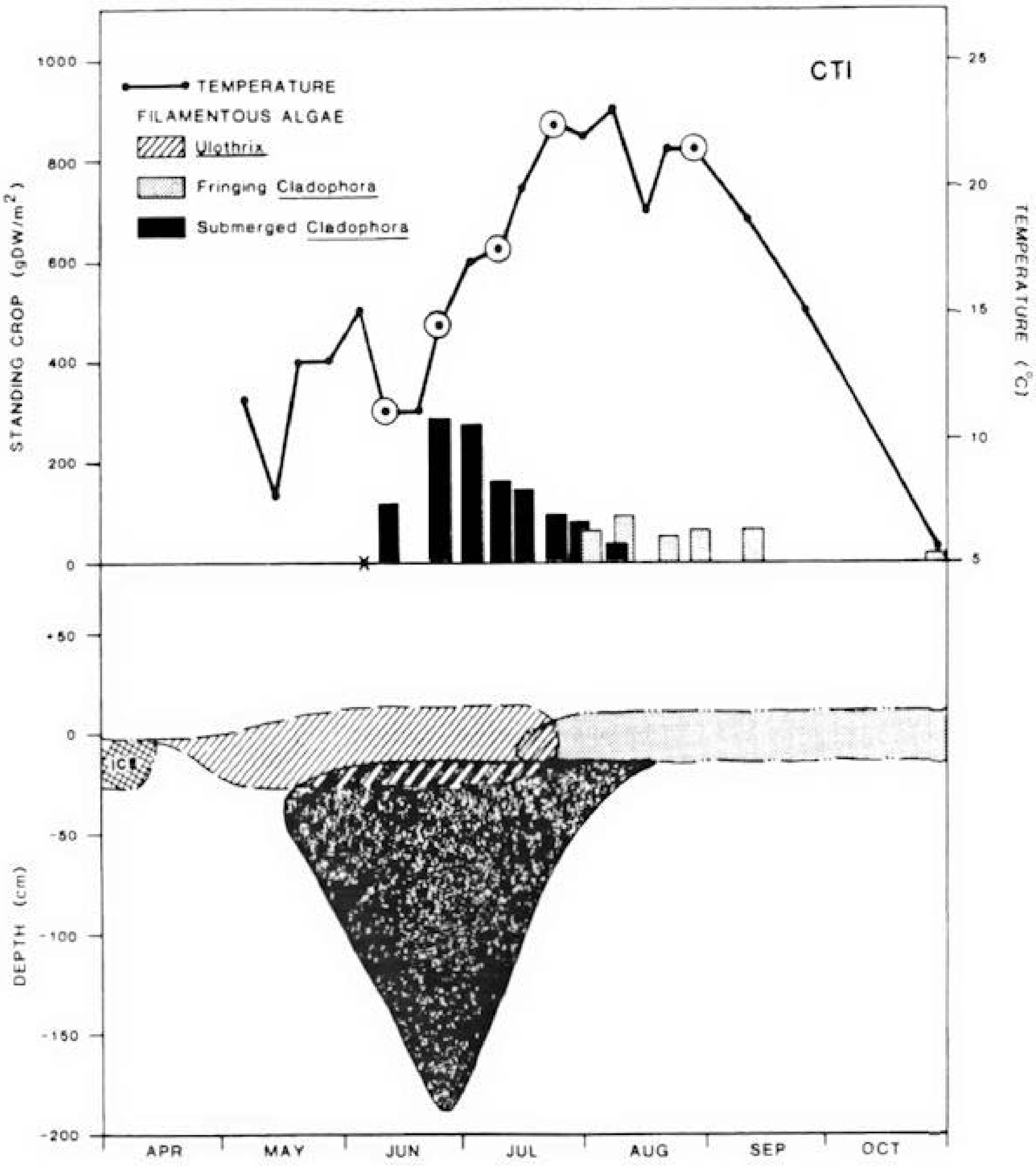

Figure 4. Seasonal trends in water temperature and growth characteristics of *Cladophora* and *Ulothrix* at the harbour mouth site (CTI) in Collingwood, 1980. Summary statistics for the circled temperature values are presented in Table 2. X marks the date of *Ulothrix* peak standing crop.

At SHB/E, tufts of *Ulothrix* were observed in late March under ice cover (Figure 5). Colonization steadily increased following ice off in mid April; however, in late June an abrupt increase in depth coverage occurred (temperatures had remained in the favourable 10-12°C range during the previous month, indicating that photoperiod and/or attainment of maximum daily insolation at this time of the year may play a compensatory role in stimulating growth in nutrient poor waters). Peak standing crop and maximum depth distribution occurred in early July. Importantly, the increased water transparency and lack of significant competition at SHB/E enabled *Ulothrix* to colonize substrate to 70 cm depth, more than twice that at the harbour sites. The alga deteriorated rapidly as temperatures rose above 15°C after mid July. *Ulothrix* almost disappeared from the shoals in late August as temperatures peaked at 21°C; however, with cooler temperatures in September a slight resurgence in growth occurred.

5.1.3 Fringing *Cladophora*

At CTB, fringing *Cladophora* was first noticeable in late July at 0-10 cm depth as a slight increase in biomass bordering the upper edge of the deteriorating submerged growth; the water temperature at this time was 22°C, up 5°C from two weeks previous (Figure 3). Colonization continued so that by early August the more typical "fringing" growth bracketing the waterline was apparent; however, growth was never extensive in the inner harbour because of minimal exposure to wave action. Depth coverage remained relatively constant through September, while standing crop steadily declined; both parameters showed a marked decline during October.

At CTI, "tendrils" of fringing *Cladophora* displacing *Ulothrix* became prominent in mid to late July at temperatures of 20-22°C (Figure 4). These isolated growths originated, in fact, from overwintering holdfasts (in crevices and protected areas missed by ice scour) and were now out-competing *Ulothrix* at the higher water temperatures.

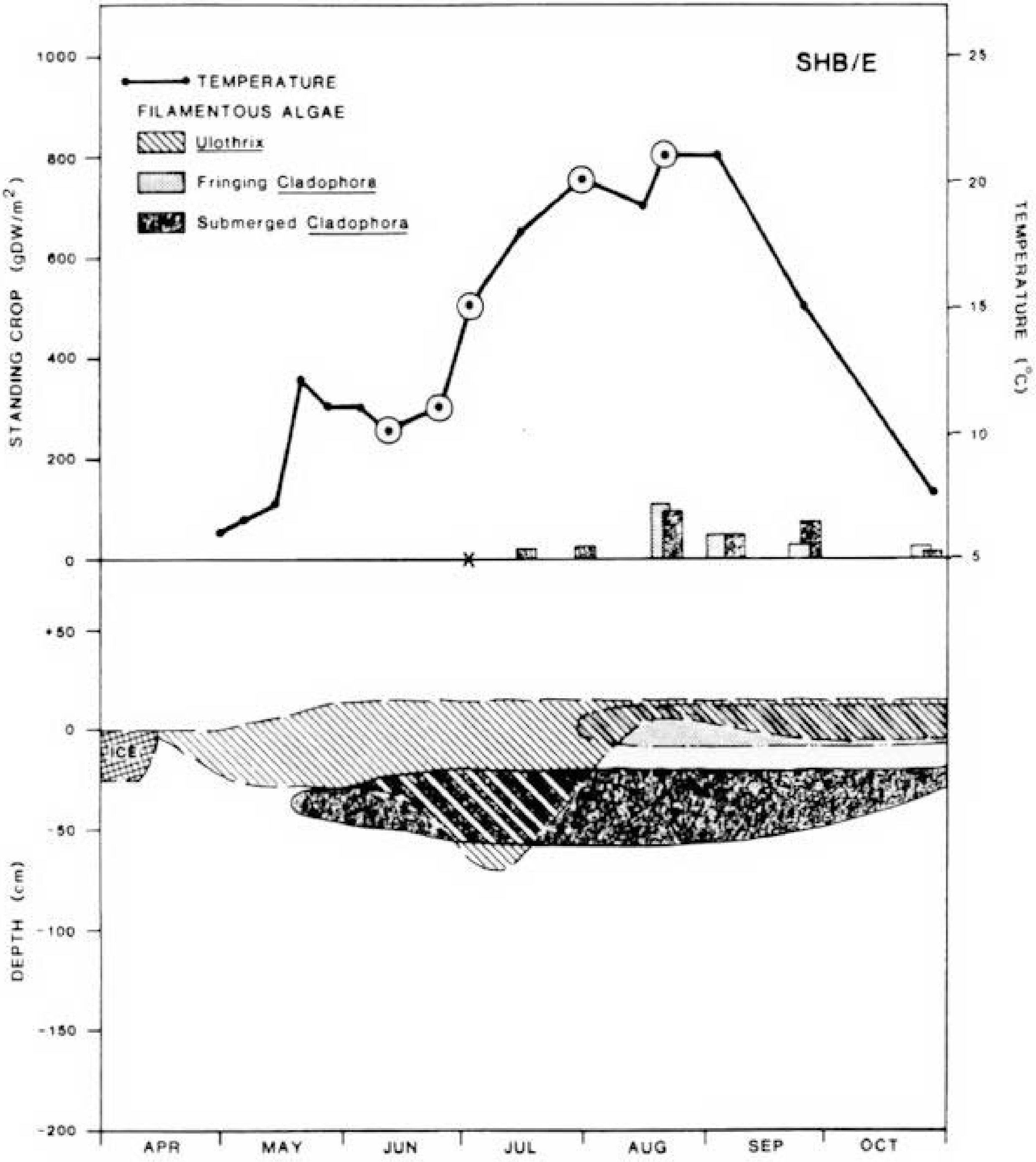

Figure 5. Seasonal trends in water temperature and growth characteristics of *Cladophora* and *Ulothrix* at the shoal site (SHB/E) west of Collingwood, 1980. Summary statistics for the circled temperature values are presented in Table 2. X marks the date of *Ulothrix* peak standing crop.

Ulothrix sloughed from the waterline during the last week in July enabling fringing *Cladophora* to rapidly colonize the newly available substrate (from spores released by the deteriorating submerged growth). Standing crop peaked in early August and remained relatively stable through to mid September. A considerable decrease in standing crop was apparent by late October, although depth coverage remained unchanged.

At SHB/E, fringing *Cladophora* appeared during the last week of July at 20°C following a steady rise in temperatures from 11°C in late June (Figure 5). Standing crop peaked in mid August and steadily declined there after, although depth coverage remained constant through to late October. Compared to CTB and CTI, the areal coverage of fringing *Cladophora* (as well as *Ulothrix* and submerged *Cladophora*) at SHB/E was quite variable from week to week subject to prevailing wave action and its effect on nutrient dispersion and substrate availability.

5.1.4 Submerged *Cladophora*

At CTB, submerged *Cladophora* appeared in early May at about the time *Ulothrix* reached peak standing crop; the former alga was present as a band of filaments at 20-70 cm depth (shallower holdfasts having been removed earlier by ice scour) (Figure 3). Because of excessive nutrient availability in the inner harbour, growth was explosive at temperatures in the "optimal " 15°C range from late May culminating in peak standing crop and maximum depth distribution by mid June. The highly turbid waters in the inner harbour actually reduced the potential for biomass production by severely restricting the depth to which the alga could grow due to light limitation. During July, as temperatures surpassed 22°C, standing crop and depth coverage were greatly reduced and by mid August only stubble remained; there was no resurgence in growth during the fall.

At CTI, submerged *Cladophora* was first noted in mid May, two weeks after its appearance in the inner harbour (Figure 4). Growth started as a band at 25-50 cm depth which rapidly expanded at temperatures of 12-15°C. Peak standing crop and maximum depth distribution occurred in late June; again, about two weeks after the same occurrence at CTB. Peak standing crop at CTI was half that at CTB because of differences in wind-induced sloughing between the sheltered inner harbour and the exposed harbour mouth (even though both populations of submerged *Cladophora* had sufficiently high internal phosphorus levels to permit maximum growth rates (Auer and Canale 1982)). The maximum depth distribution of submerged *Cladophora* was half a meter greater at CTI than at CTB due to lower turbidity at the harbour mouth permitting increased light penetration with depth. Standing crop and depth coverage of CTI had decreased considerably by the end of July at temperatures in excess of 22°C. By mid August only stubble remained and there was no resurgence in growth during the fall.

At SHB/E, submerged *Cladophora* appeared in late May at 20-40 cm depth on the leeward side of the emergent shoal among crevices in the rocks; temperatures over the previous week had risen from 7°C to 12°C (Figure 5). Areal coverage, however, was greatly restricted and growth extremely slow (even at optimal temperatures), likely because of phosphorus limited conditions. Maximum depth distribution was attained in early July, while peak standing crop did not occur until late August; temperatures rose from 15°C to 21°C over this period. The maximum depth distribution of submerged *Cladophora* at SHB/E was only 60 cm, in spite of excellent water clarity.

This depth of water delineated the zone surrounding the shoal sufficiently enriched with nutrients (from gull excrement) to support the algae. Growth of submerged *Cladophora* at SHB/E was highly opportunistic, doing best at one location and then another subject to week to week changes in weather dependent nutrient dispersal and substrate availability. Unlike the harbour sites, biomass on the shoals remained relatively healthy right through the season Indicative of more favourable physical growth conditions, although by late October standing crop and depth distribution had been much reduced.

5.2 Synoptic Survey: Eastern Lake Huron

The Lake Huron shoreline from Sarnia to South Baymouth was surveyed in June, 1980 (and again in August at a limited number of sites) primarily to update the distribution of the red alga Bangia, a recent marine invader to southern Lake Huron. Sheath and Cole (1980) recorded *Bangia* at Southampton in October, 1977, while Auer and Canale (1981) observed it at Goderich in 1979. For comparative purposes, the growth characteristics of *Ulothrix* and *Cladophora* were also noted during the 1980 synoptic surveys.

5.2.1 *Bangia*

Bangia was present at river and harbour mouth sites (H5—Southampton, H7—Kincardine, H8—Goderich, H9—Bayfield; H10—Grand Bend) and absent from less perturbed locations (H3—Stokes Bay, H4—Oliphant, H6—Port Elgin; H11—Kettle Point) (Figure 1). Importantly, these observations indicate that *Bangia* has not migrated further north since Sheath and Cole (1980) first observed the alga in Lake Huron in 1977.

When present, *Bangia* was always in close association with the source of perturbation; characteristically, steeply sloping substrates exposed to wave action supported the healthiest growths. For example, Bangia occurred from the waterline to +100 cm on severely exposed substrates at either side of the Maitland River mouth in Goderich. On less steep or more moderately exposed substrates (i.e., reduced splash zone) Bangia grew from the waterline to +30 or +50 cm. *Bangia* did not grow below the waterline even when *Ulothrix* or *Cladophora* were absent. *Ulothrix*, however, generally displaced *Bangia* to +15 cm above the waterline whenever both algae occurred together. Like *Ulothrix, Bangia* growths were well advanced at the time of the June survey indicating an affinity for cooler spring temperatures.

5.2.2 *Ulothrix*

Ulothrix was present at all eleven sites in eastern Lake Huron, usually as a luxuriant dark green band on the waterline (Figure 1). Areal coverage was greatest at the river and harbour mouth sites, while waste water from local cottages apparently promoted isolated growths at H11-Kettle Point, H3-Stokes Bay and H4-Oliphant. *Ulothrix* was particularly healthy at the northern most sites, typical of growths at similarly exposed remote locations in Georgian Bay. In general, growth was more abundant and healthier outside river mouths than inside, especially on exposed steeply sloping substrates. The deepest occurrence of *Ulothrix* was at H9-Goderich off the Maitland River mouth where the alga was present as a uniform band from 0-30 cm depth and as a lighter growth to at least 50 cm depth. A dramatic illustration of the relationship between *Ulothrix* growth and nearshore nutrient enrichment was apparent at H6-Southampton. *Ulothrix* coverage extended for 150 m north of the Saugeen River mouth in an area clearly affected by the turbid river plume; coverage was sparse, however, by 300 m distance.

5.2.3 Fringing *Cladophora*

Mid-June was still too early in the season to observe typical growths of fringing *Cladophora* in southeastern Lake Huron (Figure 1). There were however, minor occurrences of the alga in crevices where holdfasts had survived ice scour. These filaments usually formed upward projections from the deeper uniform growth to +10 or +15 cm above the waterline. In August, growths of fully developed fringing *Cladophora* were present at H1-South Baymouth and H2-Tobermory. Although none of the southern sites were surveyed in August, it is reasonable to assume that fringing *Cladophora* was a common component of the late summer waterline flora in this region as well.

5.2.4 Submerged *Cladophora*

Submerged *Cladophora* was most abundant at river and harbour mouths and least abundant (H11-Kettle Point; H3-Stokes Bay) or absent (H4-Oliphant) at sites affected by minor nutrient loadings (i.e., waste water from local cottages) (Figure 1). Excessive turbidity prohibited accurate estimates of depth distribution (beyond arm's length) at some of the harbour and river mouth sites, although it is likely that maximum depth did not greatly exceed 1 m because of limited light availability (see Figure 3).

At H9-Goderich at the mouth of the Maitland River, extreme turbidity and wave action limited observations to about 50 cm depth and the only *Cladophora* apparent was a 10 cm wide patch on the waterline (i.e., from overwintering fringing holdfasts).

A short distance south of the Maitland River, however, a small amount of healthy sloughed *Cladophora* was found in the vicinity of the Goderich STP which discharges directly onto the shoreline. Problematic accumulations of submerged *Cladophora* are known to occur annually at this location (MOE 1981b), although at the time of the June survey it was still too early in the season to observe filaments reaching the surface or major shoreline accumulations. Instead, the alga was firmly attached to deeper substrates and probably just beginning its rapid growth phase at temperatures in the 15°C range.

5.3 Synoptic Survey: Georgian Bay/North Channel

5.3.1 *Ulothrix*

In mid June *Ulothrix* was absent from the inner harbour sites in eastern Georgian Bay (G1-Penetang and G2-Midland) and present at other river and harbour sites where water movement was less restricted (G3-Midland, G14-Lion's Head, G16-Wiarton, G17-Owen Sound, G-18 Owen Sound; G19-Meaford) (Figure 1).

Ulothrix was always healthiest on exposed substrates, especially at the cooler remote sites where growth was supported by gull excrement or other nutrient sources of natural (i.e., soil runoff) or anthropogenic origin (i.e., cottage waste water and septic seepage). The heaviest accumulations of *Ulothrix* occurred at G10-Killarney and N2-Blind River where in each case gull colonies supplied locally abundant nutrients for growth.

In mid-July the eastern Georgian Bay shoreline from Collingwood north to Bayfield Harbour was observed and photographed (oblique colour transparencies) from a light aircraft to verify impressions of algal distribution obtained during June. The aerial survey confirmed that *Ulothrix* was the dominant shoreline algae in remote areas of Georgian Bay. *Ulothrix* appeared as an easily recognizable dark green band fringing offshore islands and shoals and points of land. Although the distribution of the alga was widespread, its occurrence was generally quite rare, apparently indicative of natural conditions.

In mid-August *Ulothrix* was gone from all the warmer sheltered areas, except for reminant growths at G14-Lion's Head and G16-Wiarton. Even remote growths were noticeably reduced from June; coverage was no longer uniform and often filaments were shorter and band widths narrower resulting in a general decrease in biomass.

5.3.2 Fringing *Cladophora*

Fringing *Cladophora* was not observed during the June survey of Georgian Bay and the North Channel nor during the July aerial survey of eastern Georgian Bay. In August, however, the alga was present at all but a few locations, but never in great abundance (Figure 1). At remote sites fringing *Cladophora* only covered a fraction of the substrate affected earlier by *Ulothrix*, suggestive of dissimilar efficiencies at concentrating phosphorus for growth in dilute waters (although at perturbed locations areal coverage of the two algal types was roughly comparable). As usual, wherever fringing *Cladophora* occurred, exposed steeply sloping substrates supported the healthiest growths. Extreme environmental conditions, primarily low phosphorus supply in remote areas and restricted water turbulence in perturbed areas, caused atypical growth characteristics (e.g., unusual branching) or prohibited growth altogether.

5.3.3 Submerged *Cladophora*

During the June survey of Georgian Bay and the North Channel, submerged *Cladophora* occurred (in relative abundance) on exposed substrates at harbour and river mouth sites (Figure 1). Maximum depth distribution was only about 100 cm, because of either excessive turbidity (i.e., G1-Penetang) or minimal nutrient enrichment (i.e., G14-Lion's Head). Differential spring warming rates resulted in considerable site to site variability in seasonal development. Submerged *Cladophora* at inner harbour sites (i.e., G-1 Penetang; G2-Midland) had already deteriorated by mid June, while sites closer to open waters (i.e., G3-Midland) supported younger healthier filaments; growths at the remaining sites showed various stages of development.

In addition to the above observations, there were "minor" occurrences of *Cladophora* in shallow pools at G10 and G11-Killarney where temperature and nutrient levels were high enough (apparently) to permit growth (these minor occurrences have been omitted from Figure 1 because they are not strictly representative of nearshore conditions).

The July aerial survey confirmed that significant accumulations of submerged *Cladophora* were restricted to major nutrient sources. For example, the alga was clearly visible on the lakeward breakwall structures of Collingwood harbour (where water clarity was good), while extensive offshore substrates were devoid of the alga (except for minor growths at the emergent shoal site SHB/E).

In August submerged *Cladophora* was absent or reduced considerably at all of the June sites, except at G7-Parry Sound in the vicinity of the McCurry Lake STP outflow. Here growth occurred from 0-100 cm depth and for about 100 m on either side of the stream mouth (macrophytes displaced *Cladophora* at greater depths). Filaments reached 200 cm in length and, in general, growth was prolific. It is not clear, however, why peak growth was delayed until August at this site. Minor occurrences of submerged *Cladophora* in shallow pools were noted again in August at G10 and G11-Killarney, as well as at G6-Parry Island and G8-Bayfield Harbour for the first time. These anomalous growths were particularly difficult to categorize; however, for the sake of consistency they were considered as atypical submerged growths.

5.4 1979 Supporting Data

In addition to the 1980 data presented here, investigations were also carried out in southern Georgian Bay in 1979. A total of twenty-six shoreline sites and six sites on the Mary Ward Shoals were frequented weekly and monthly, respectively, June through September. Synoptic surveys were also carried out between Tobermory (in the west) and Honey Harbour (in the east). Although only a portion of the 1979 data are presented in Jackson and Hamdy (1982), the findings are fully consistent with those of 1980.

IV. BIOMONITORING

Perhaps the most pertinent question with respect to aquatic biomonitors in general, and to filamentous algae in particular, is what do internal levels of elements really mean? Simply put, elemental concentrations in filamentous algae represent a time average of bioavailable supply at the primary trophic level. Filamentous algae acquire most of their elemental load from the surrounding water through mechanisms of adsorption and absorption (both active and passive), while particulate material which cannot be washed from the filaments accounts for the rest (Prosi 1979). This means that elemental levels in filamentous algae are largely implicit of recent water quality.

6.1 Loss On Ignition

Ancillary estimates of loss on ignition (LOI) are useful in flagging those algal samples with exceptionally high inorganic content which violate, to an extreme degree, the basic assumption regarding "bioavailability". The primary cause of abnormally low LOI's appears to be excessive contamination of algal filaments with suspended sediments (Tables 3 and 4 indicate that elemental concentrations in surface sediments and filamentous algae at comparable sites are of the same magnitude). It is important to note, however, that algal samples having unusually low LOI's are still qualitatively useful in assessing environmental contamination, albeit from an increasingly "nonbiological" perspective.

At each of the three intensive sites in southern Georgian Bay, mean LOI's were highest in *Ulothrix* (75 - 89%), followed by fringing *Cladophora* (73 - 82%) and submerged *Cladophora* (55 - 67%), suggesting a direct relationship between length of submersion and algal sediment content (Figure 6 and Table 5). In addition, the highest mean LOI for each alga occurred at the harbour mouth site CTI, indicating efficient "cleansing" of algal filaments by wave action when exposed substrate is comparatively steeply sloping.

Throughout Georgian Bay and the North Channel, LOI's were generally highest in *Ulothrix* at exposed remote sites and lowest in submerged *Cladophora* at inner harbour and river mouth sites; values ranged from an extreme low of 29% in submerged *Cladophora* at

Table 3. Elemental concentrations in water (unfiltered totals) and water to algae concentration factors (CF) for inland lakes (1-Heeney Lake, 2-Plastic Lake) and the Niagara River (3-mouth west shore, 4-mouth east shore), 1981. The data are from unpublished MOE investigations (Acid Precipitation in Ontario Study and the Niagara River Monitoring Program) and represent mean values in time and/or space. *Zygnema* and *Cladophora* were analysed from the inland lakes and the Niagara River, respectively. Conductivity values are approximate.

		Inland Lakes +		Niagara River o	
		1	2	3	4
Al	WATER mg/L	L0.034	0.019	0.150	0.144
	CFX10^3	G 47	188	7.4	11
Fe	WATER mg/L	0.067	0.033	0.121	0.129
	CFX10^3	102	309	15	26
Zn	WATER mg/L	0.014	0.008	0.005	0.006
	CFX10^3	24	30	11	8.5
Pb	WATER mg/L	L0.003	L0.003	L0.004	L0.004
	CFX10^3	G12	G16	G1.4	G4.2
Cu	WATER mg/L	L0.001	L0.001	0.004	0.005
	CFX10^3	G7.9	G12	2.7	2.0
As	WATER mg/L	-	-	L0.001	L0.001
	CFX10^3	-	-	G5.6	G4.2
Cr	WATER mg/L	L0.001	L0.001	0.003	0.003
	CFX10^3	G12	G12	2.6	3.5
Ni	WATER mg/L	L0.001	L0.001	0.003	0.003
	CFX10^3	018	G20	2.2	3.2
Cd	WATER mg/L	L0.0002	L0.0002	L0.0003	L0.0002
	CFX10^3	G6.5	G9.0	G1.7	G4.9
Hg	WATER µg/L	L0.02*	L0.02*	0.11	0.12
	CFX10^3	G4.0	G7.2	0.4	0.5

L	Less than.	+	Conductivity 30 µS/cm.
G	Greater than.	o	Conductivity 280 µS/cm.
-	No data.		
*	Estimated values.		

Table 4. Elemental concentrations in sediment (top 3cm) and sediment to algae concentration factors (CF) for inland lakes (1-Heeney Lake, 2-Plastic Lake), southern Georgian Bay (3-SHB/E, 4-CTI, 5-CTB) and the Niagara River (6-mouth west shore, 7-mouth east shore), 1981. The data are from Ross and Chatterjee (1977) and unpublished MOE investigations (Acid Precipitation in Ontario Study and the Niagara River Monitoring Program) and represent mean values in time and/or space. *Zygnema* was analysed from the inland lakes, while *Cladophora* was analysed from southern Georgian Bay and the Niagara River. Conductivity values are approximate.

		Inland Lakes +		Georgian Bay o			Niagara River :	
		1	2	3	4	5	6	7
Al	SEDIMENT µg/g	15467	19000	-	-	-	3200	4533
	CF	0.1	0.2	-	-	-	0.3	0.4
Fe	SEDIMENT µg/g	21533	48933	4020	10800	11700	8900	13000
	CF	0.3	0.2	0.8	0.5	0.4	0.2	0.3
Zn	SEDIMENT µg/g	148	236	23*	99.1	125	43.3	95.3
	CF	1.8	1.1	2.0	0.9	1.0	1.2	0.5
Pb	SEDIMENT µg/g	130	229	-	-	-	4.7	25.0
	CF	0.3	0.2	-	-	-	L1.2	0.7
Cu	SEDIMENT µg/g	33.6	40.8	-	-	-	7.8	18.7
	CF	0.2	0.3	-	-	-	1.4	0.5
As	SEDIMENT µg/g	-	-	-	-	-	2.3	2.4
	CF	-	-	-	-	-	2.4	1.8
Cr	SEDIMENT µg/g	-	-	11.3	24.5	25.0	13.7	27.7
	CF	-	-	1.1	0.4	0.7	0.6	0.4
Ni	SEDIMENT µg/g	19.9	20.6	11.8	33.3	30.4	5.0	12.3
	CF	0.8	1.0	1.3	0.4	0.4	1.3	0.8
Cd	SEDIMENT µg/g	1.87	2.71	-	-	-	0.52	0.48
	CF	0.6	0.8	-	-	-	1.7	2.0
Hg	SEDIMENT µg/g	-	-	L0.01	0.08	0.18	0.10	0.50
	CF	-	-	-	L0.2	L0.3	0.4	0.1

*	1980 data.	*	Conductivity 30 µS/cm
L	Less than	o	Conductivity 200 µS/cm
G	Greater than	:	Conductivity 280 µS/cm
-	No data		

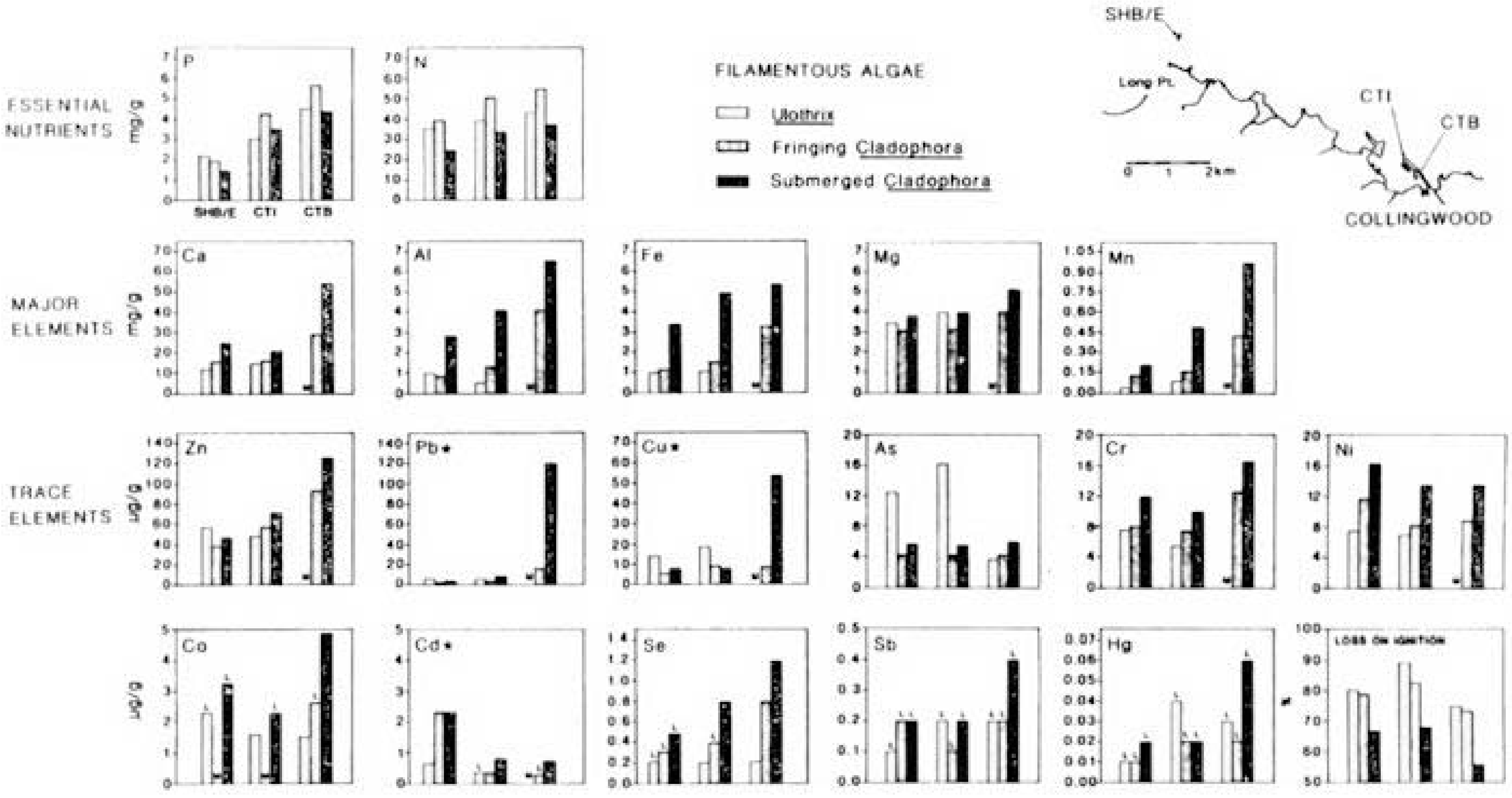

Figure 6. Elemental concentrations in *Cladophora* and *Ulothrix* from southern Georgian Bay, 1980.
* - single values, L - less than, M - missing data.

Table 5. Elemental concentrations in filamentous algae from southern Georgian Bay, 1980. For individual elements an asterisk, (*) marks the algal Type at each site with the highest mean value.

	Element	Unit		ULOTHRIX		FRINGING CLADOPHORA			SUBMERGED CLADOPHORA		
			CTB	CTI	SCB/E	CTB	CLT	SHB/E	CTB	CTI	SHB/E
Essential Nutrients	P	mg/g	4.4	3.0	2.2	+5.6	+4.2	1.9	4.3	3.4	1.4
			±2.5(3)	±2.4(9)	±0.9(12)	±1.8(4)	±1.2(6)	±1.3(6)	±0.9(7)	±1.0(12)	±0.7(12)
			1.6-6.6	1·5-8.9	1.4-4.9	4.2-8.2	7.4-6.0	0.8-4.1	2.7-5.2	1.9-4.7	0.5-2.8
	N		42	38	35	+54	*50	*38	35	33	23
			±7(3)	±14(9)	±20(12)	±11(4)	±9(6)	±11(6)	±13(7)	±18(12)	±12(12)
			36-50	16-57	7-69	44-68	40-67	27-59	11-48	8-68	3-37
Major Elements	Ca		ND	14.9	11.9	30.6	15.9	14.7	*54.8	*20.3	*4.0
				±2.9(4)	±2.9(6)	±28.2(3)	±5.8(5)	±3.8(4)	±17.0(4)	±10.2(6)	±12.4(8)
				10.6-17.0	8.8-17.4	12.0-63.0	9.1-23.2	11.7-20.0	35.8-71.7	8.1-33.1	12.0-51.6
	Al		ND	0.43	1.04	4.04	1.24	0.75	*6.65	*4.15	*2.73
				±0.16(4)	±0.68(7)	± 2.65(3)	±0.48(5)	±0.52(5)	±1.54(4)	±4.10(7)	±2.14(8)
				0.22-0.59	0.23-1.82	2.35-7.10	0.63-1.97	0.46-1.68	5.20-8.26	0.59-9.67	0.86-7.58
	Fe		ND	0.97	0.89	3.22	1.39	1.15	*5.20	*4.92	*3.38
				±0.24(4)	±0.42(6)	±0.49(2)	±0.34(5)	±0.72(4)	±2.50(4)	± 3.78(6)	±2.41(8)
				0.66-1.23	0.33-1.33	2.87-3.56	0.85-1.74	0.64-2.18	1.59-7.68	0.72-9.40	0.98-9.00
	Mg		ND	3.99	3.49	4.01	3.19	3.12	*5.14	*4.03	*3.83
				±0.29(4)	± 0.58(7)	±1.64(3)	±0.87(5)	±0.72(4)	±0.73(4)	±0.73(6)	±1.12(8)
				3.74-4.38	3.01-4.67	2.65-5.83	2.38-4.35	2.22-3.75	4.30-5.94	2.70-4.79	2.27-6.10
	Mn		ND	0.08	0.03	0.42	0.17	0.14	*0.98	*0.49	*0.20
				±0.03(5)	±0.01(6)	±0.13(3)	± 0.06(5)	±0.12(4)	±0.28(5)	±0.29(7)	±0.08(8)
				0.05-0.13	0.02-0.04	0.27-0.56	0.09-0.27	0.06-0.31	0.67-1.26	0.12-0.89	0.09-0.36
Trace Elements	Zn	µg/g	ND	48.7	*56.5	94.4	57.3	38.4	*124.6	71.2	46.4
				±5.9(4)	±30.8(5)	±42.9(3)	±20.2(5)	±10.7(5)	±34.5(4)	±12.6(6)	±9.6(6)
				42.1-56.2	26.7-93.4	76.8-143.9	37.4-84.2	21.8-50.3	81.1-153.8	70.4-95.2	36.0-62.3
	Pb		ND	4.5	*4.8	16.0	2.0	2.0	*120.0	*8.5	3.0
				(1)	±0.1(2)	(1)	(1)	(1)	(1)	(1)	(1)
					4.8-4.9						
	Cu		ND	*18.0	*13.8	8.2	8.5	5.0	*53.5	6.5	7.8
				(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
	As		3.7	*16.3	*12.6	4.2	4.2	4.2	*5.8	5.6	5.7
			±4.4(3)	±12.0(9)	±6.9(11)	±2.9(5)	±1.8(7)	±2.0(6)	±2.8(9)	±3.3(121	±3.7(12)
			1.1-8.8	1.1-33.0	1.2-26.0	1.2-8.4	0.6-5.9	0.6-6.6	1.7-9.9	0.7-11.3	0.3-14.0
	Cr		ND	5.5	7.4	12.9	7.7	8.0	*16.9	*10.2	*12.0
				±0.5(5)	±1.6(4)	±6.9(3)	±2.5(5)	±1.2(4)	±10.5(5)	±4.2(7)	±3.0(6)
				4.9-6.2	6.2-9.7	3.2-20.6	4.2-10.9	8.4-9.2	10.9-35.5	5.4-15.6	9.2-17.8
	Ni		ND	6.5	7.1	8.7	8.0	9.2	*13.3	*13.1	*15.8
				±1.6(5)	±2.5(5)	±7.0(2)	±3.6(5)	±3.3(4)	±3.8(5)	±5.6(7)	5.4(7)
				4.3-8.2	5.1-11.3	3.8-13.7	3.0-13.3	7.4-14.1	10.1-19.8	4.5-20.0	8.0-24.1
	Co		1.5	L1.6^{2}	L2.3^{1}	L2.6^{1}	ND	ND	*4.8	*L2.3^{2}	*L3.2^{1}
			±0.2(3)	±1.2(3)	±1.0(3)	±0.7(4)			±1.5(8)	±1.1(5)	±0.3(2)
			1.4-1.7	L0.9-13.0	2.7-13.0	L0.1-3.4			2.9-7.5	L0.9-3.4	L3.0-3.4
	Cd		ND	L0.3	0.6	L0.3	0.3	*2.3	*0.7	*0.8	*2.3
				(1)	(1)	(1)	(1)	(1)	(1)	(11	(1)
	Se		0.2	0.2	L0.2^{5}	0.8	L0.4^{1}	L0.3^{1}	*1.2	*0.8	+L0.5^{1}
			±0(3)	±0(8)	±0.04(11)	±0.4(5)	±0.2(7)	±0.1(6)	±0.6(8)	±0.4(12)	±0.2(12)
			0.2-0.2	0.2-0.3	L0.1-1.4	0.4-1.3	L0.01-0.7	L0.1-0.5	0.6-2.3	0.2-1.4	L0.1-0.9
	Sb		0.2	L0.2^{3}	L0.1 5	L0.2^{1}	L0.1^{5}	*L.0.2^{3}	*0.4	*L.0.2^{2}	*L0.2^{1}
			±0(3)	±0.1(8)	±0.1(11)	±0.1(6)	±0(7)	±0.2(6)	±0.1(8)	±0.1(12)	±0.1(12)
			0.2-0.2	L0.1-0.2	L0.1-0.3	L0.1-0.3	L0.1-0.1	L0.1-0.5	0.2-0.6	L0.1-0.4	L0.1-0.3
	Hg		L0.03^{2}	*L0.04^{5}	L0.01^{9}	L0.02^{3}	L0.02^{5}	L0.01^{5}	*L0.06^{2}	L.0.02^{6}	*L0.02^{7}
			±0.04(3)	±0.05(8)	±0(9)	±0.02(5)	±0.02(7)	±0(6)	±0.04(8)	±0.02(11)	±0.02(10)
			L0.01-0.08	L0.01-0.13	L0.01-0.01	L0.01-0.06	L0.01-0.05	L0.01-0.01	L0.01-0.13	L0.01-0.06	L0.01-0.07
Loss on Ignition		%	*75	*89	*80	73	82	79	55	67	66
			± 6(3)	± 4(9)	±16(10)	±11(5)	±4(7)	±6(6)	±4(8)	±12(12)	±11(11)
			69-81	81-94	47-90	55-84	78-87	69-85	49-61	43-83	42-73

X^{n} Superscript n is the number of “less than" values included in the calculation of each mean and standard deviation.

ND No data.

G14—Lion's Head (because of excessive sediment content) to a high of 94% in *Ulothrix* at G5—Twelve Mile Bay (Tables 6, 7, 8).

6.2 Concentration Factors

Comparable data for algae, sediments and water in this investigation are limited; however, Tables 3 and 4 include information from representative hard water and soft water sites affected, respectively, by point source (in the Niagara River) and atmospheric/ watershed (in Heeney and Plastic Lakes) metals loading.

The water to algae concentration factors (CF's) for Hg and the major elements Al and Fe were about ten to fifteen times greater at the inland soft water sites (10^4-10^5X) than at the hard water Niagara River sites (10^3-10^4X), indicating that these, and possibly other elements, might be more susceptible to bioaccumulation by primary producers in the nearshore waters of Georgian Bay and the North Channel bordering the Shield (assuming that species differences are minimal) (Table 3). The sediment to algae CF's for Hg, Al and Fe, however, ranged from 0.1 to 0.8 and showed no consistent differences between the soft water and hard water sites.

Water to algae CF's for the trace elements Zn, Pb, Cu, Cr, Ni and Cd were about five times higher at the inland soft water sites than at the Niagara River hard water sites (or about one half the increase observed for Hg, Al and Fe). Sediment to algae CF's again showed no consistent differences between sites for the few remaining trace elements; sediment CF values ranged from 0.1 to 2.4 (Table 4).

6.3 Essential Nutrients

6.3.1 Phosphorus

In southern Georgian Bay mean internal phosphorus levels ranged from 5.6 mg/g in fringing *Cladophora* at CTB to 1.4 mg/g in submerged *Cladophora* at SHB/E, reflecting a pronounced lakeward gradient in phosphorus supply (the capacity for luxury uptake of phosphorus is

Table 6. Elemental concentrations in Ulothrix from Georgian Bay, the North Channel and eastern Lake Huron, 1980.

SITE	DATE	Essential Nutrients (mg/g)		MAJOR ELEMENTS (mg/g)						TRACE ELEMENTS (µg/g)										LOI
		P	N	Ca	Al	Fe	Mg	Mn	Zn	Pb	Cu	As	Cr	Ni	Cd	Co	Se	Sb	Hg	(%)
G5	June	0.3	24	-	0.20	-	-	0.02	150	L3	8.8	6.2	3.8	4.5	L0.3	L3	L0.1	L0.1	L0.01	85
	August	0.6	34	8.1	0.01	0.10	2.23	0.03	170	2.5	10.5	14.8	14.0	5.5	0.3	L1.5	0.2	0.2	L0.01	94
G6	June	0.4	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85
	August	0.9	32	-	-	-	-	-	240	3.8	18.0	12.1	-	-	0.4	L1.5	0.3	0.2	L0.01	89
G8	June	1.1	21	-	0.64	-	-	0.04	200	8.8	8.8	10.0	4.5	9.0	1.3	L3	0.2	0.3	L0.01	86
	August	0.9	34	9.0	L0.01	0.01	2.59	0.01	130	4.9	10.5	15.0	9.0	10.0	0.3	L1.5	0.7	0.1	L0.01	92
G9	June	0.3	77	-	0.16	-	-	0.02	200	6.0	8.0	7.1	L4	11.0	0.9	L3	0.1	0.1	L0.01	84
	August	0.2	21	8.7	0.10	0.04	2.2?	0.01	110	2.4	2.3	9.1	1.6	3.3	0.2	10.5	0.2	0.1	L0.01	88
G10	June	0.5	40	-	0.23	-	-	0.02	100	3.5	13.5	15.0	3.0	7.0	10.3	L3	0.2	0.1	L0.01	85
	August	1.7	49	7.4	0.05	0.01	2.42	0.08	100	8.5	7.2	7.6	1.8	4.0	0.3	10.5	0.2	L0.1	L0.01	86
G11	June	0.3	25	-	0.65	-	-	0.04	110	4.5	11.0	6.8	8.8	5.8	0.4	L3	L0.1	0.1	L0.01	85
	August	-	49	8.3	0.21	0.32	3.18	0.04	96	5.0	8.9	11.3	11.0	6.7	0.3	0.5	0.2	10.1	L0.01	-
G12	August	0.6	26	-	0.13	0.18	2.66	0.06	30	4.0	8.2	-	5.8	-	-	L3	-	-	-	-
G15	August	0.6	22	9.5	0.51	0.40	2.59	0.02	41	L2	6.4	*16.3	L4	5.4	L0.2	L2	0.2	0.1	L0.01	90
G16	June	4.1	30	-	0.92	-	-	0.02	260	6.5	16.8	16.0	5.2	4.5	0.3	L3	0.2	0.2	10.01	
G18	June	1.2	21	-	4.59	-	-	0.03	120	6.0	13.8	10.5	13.2	7.2	0.8	L3	0.1	0.3	10.01	71
G19	June	2.1	42	-	10.97	-	-	0.38	200	6.0	29.2	12.4	17.8	10.8	0.4	L3	0.3	0.2	L0.01	73
N1	August	0.9	30	7.8	0.08	0.60	2.37	0.02	130	9.8	4.2	11.0	L0.9	8.9	0.2	0.3	0.1	0.2	L0.01	86
N2	June	1.8	33	-	1.50	-	-	0.10	75	L3	9.2	3.0	5.8	18.8	0.4	L3	0.2	L0.1	L0.01	86
N3	June	0.5	33	-	0.39	-	-	0.03	200	L3	10.2	10.9	5.8	6.2	0.5	L3	L0.1	0.1	L0.01	90
	August	3.7	20	12.2	0.99	1.32	3.04	0.07	93	2.5	4.6	9.7	2.7	6.2	0.3	0.4	0.2	0.1	L0.01	88
H1	June	0.6	30	-	0.15	-	-	0.02	130	3.0	10.0	10.5	5.5	4.1	L0.3	L3	L0.1	0.1	L0.01	91
	August	0.3	24	8.9	L0.01	0.16	2.50	0.01	57	L1	3.3	10.0	L0.9	L2.7	0.2	L0.2	0.1	L0.1	L0.01	87
H2	June	0.7	36	-	0.12	-	-	0.04	40	7.0	9.8	15.4	4.5	5.2	0.5	L3	0.2	0.2	L0.01	89

*	Highest value among all algae at all synoptic sites.
L0I	Loss on ignition.
-	No data.

Table 7. Elemental concentrations in fringing *Cladophora* from Georgian Bay, the North Channel and eastern Lake Huron, 1980.

Site		ESSENTIAL NUTRIENTS (mg/g)		MAJOR ELEMENTS (mg/g)						TRACE ELEMENTS (µg/g)										LOI (%)
	Date	P	N	Ca	Al	Fe	Mg	Mn	Zn	Pb	Cu	As	Cr	Ni	Cd	Co	Se	Sb	Hg	
G1	August	1.2	24	16.1	1.18	2.70	3.45	1.03	160	12.0	7.5	5.9	9.8	6.3	L0.3	L3	0.4	0.2	L0.01	77
G2	August	3.1	61	-	-		-	-	200	24.0	11.8	4.6	13.5	17.0	L0.3	L3	0.6	0.3	L0.01	59
G3	August	1.2	24	11.5	0.48	0.89	2.06	0.35	160	8.3	5.2	4.0	6.8	7.0	0.4	L3	0.4	0.2	L0.01	77
G4	August	1.2	25	-	-		-	-	190	7.9	15.2	3.9	22.8	15.2	L0.3	L3	0.9	0.2	L0.01	54
G5	August	0.9	34	-	-		-	-	100	2.5	9.0	2.9	12.0	7.5	0.3	L3	0.3	0.2	L0.01	76
G6	August	0.8	32	10.6	0.32	0.37	2.02	0.14	190	5.8	8.8	4.5	15.5	15.0	2.4	L1.5	0.6	L0.1	L0.01	73
G8	August	1.3	40	11.0	0.72	0.83	2.03	0.46	160	5.5	5.6	4.0	5.5	16.0	1.8	0.8	0.9	0.4	L0.01	68
G10	August	1.5	*93	8.6	0.11	0.99	2.47	0.09	120	3.0	2.9	5.7	3.7	7.4	*2.9	L1.5	0.4	L0.1	L0.01	87
G11	August	-	54	-	0.48	-	-	0.18	78	6.3	7.6	6.7	3.3	21.0	0.6	0.4	1.3	0.2	L0.01	75
G13	August	1.3	38	7.7	2.58	0.22	2.62	0.02	50	3.4	8.4	12.3	L2	4.0	0.2	L2	0.2	0.2	L0.01	84
G14	August	3.7	38	10.8	0.51	2.88	3.26	1.13	118	24.0	11.5	3.8	6.5	11.8	0.4	L2	1.1	0.2	L0.01	63
G16	August	1.7	42	-	0.25	-	-	0.36	96	5.0	9.0	6.1	L4	7.2	0.2	L2	0.4	L0.1	L0.01	79
G18	August	1.8	37	14.0	2.73	2.39	3.90	0.64	94	6.0	10.2	6.5	7.6	6.4	L0.2	L2	0.4	0.1	L0.01	75
G19	August	1.5	37	9.35	1.51	1.38	2.30	0.64	63	1.6	13.5	7.2	5.2	7.5	0.3	L2	0.6	0.1	L0.01	79
N2	August	2.7	41	10.9	0.19	1.16	2.88	0.22	79	0.1	4.5	3.5	4.8	20.0	1.0	0.2	0.4	L0.1	L0.01	83
H1	August	2.4	48	11.2	0.13	0.50	3.29	0.06	62	L1.1	3.9	7.3	3.9	4.2	1.4	0.3	0.2	0.2	L0.01	84
H2	August	2.0	52	11.8	0.06	0.43	3.00	0.06	54	L2	4.4	4.3	4.6	4.8	2.1	L2	0.3	0.4	L0.01	81

*	Highest value among all algae at all synoptic sites.
L0I	Loss in ignition.
-	No data.

Table 8. Elemental concentrations in submerged *Cladophora* from Georgian Bay, 1980.

SITE			Essential Nutrients (mg/g)		MAJOR ELEMENTS (mg/g)						TRACE ELEMENTS (µg/g)										LOI
	DATE		P	N	Ca	Al	Fe	Mg	Mn	Zn	Pb	Cu	As	Cr	Ni	Cd	Co	Se	Sb	Hg	(%)
G1	June		2.4	38	-	5.92	-	-	0.08	64	27.0	17.0	2.2	70.8	16.0	0.4	3.5	1.2	0.2	L0.01	59
	August		2.0	19	*27.9	4.19	13.64	*5.39	1.91	80	28.0	12.5	4.2	21.0	15.0	L0.3	4.5	0.8	0.2	L0.01	40
G2	June		2.4	34	-	5.40	-	-	2.48	65	18.0	14.5	3.4	22.5	19.8	0.9	3.0	0.6	0.2	L0.01	60
G3	June		3.7	58	-	0.80	-	-	0.19	45	11.0	5.8	4.7	11.0	8.8	0.5	L3	0.2	L0.1	L0.01	81
	August		1.8	31	13.9	1.38	2.23	2.26	0.05	41	-	8.2	4.6	8.5	8.0	0.2	L1.5	0.2	0.1	L0.01	79
G7	June	B	6.5	41	-	5.08	-	-	1.36	150	17.0	21.8	2.9	17.0	11.8	0.4	5.0	0.2	0.2	L0.01	46
		A	-	54	-	3.80	-	-	2.98	*340	19.0	34.0	1.5	16.0	10.5	0.5	9.0	0.4	-	-	59
	August	D	3.1	29	13.4	6.43	11.50	4.13	2.36	170	*55.0	44.5	3.8	21.3	24.7	0.6	8.8	0.6	0.2	L0.01	50
		C	4.6	57	9.3	1.49	5.32	2.18	1.67	120	18.0	15.0	3.8	10.2	8.2	0.5	3.3	0.4	0.1	L0.01	79
		B	7.6	38	10.4	7.14	*19.86	3.51	*5.19	166	*55.0	*46.4	3.9	28.5	21.0	0.6	*14.2	0.6	0.6	*0.06	49
		A	*13.0	54	15.8	4.82	17.27	2.95	4.70	150	27.0	42.5	2.9	*29.0	16.0	0.6	13.0	0.6	0.3	0.03	66
G14	June		5.0	33	-	3.91	-	-	0.76	130	16.0	11.2	3.2	16.5	11.2	0.6	L3	0.8	0.1	L0.01	29
G16	June		6.3	59	-	2.41	-	-	1.04	170	46.0	20.0	7.2	7.0	15.0	0.6	L3	1.2	0.3	L0.01	58
	August		1.4	33	32.3	2.27	4.04	5.01	4.66	97	34.0	21.0	5.6	6.8	*34.0	0.4	L2	*3.7	0.2	L0.01	66
G17	June		4.1	33	-	-		-	1.69	160	47.0	21.0	7.9	18.0	12.5	0.6	3.8	1.1	0.3	L0.01	53
G19	June		3.3	41	-	*13.94	-	-	1.24	110	5.5	36.5	7.0	18.0	10.2	0.4	4.0	0.6	0.3	L0.01	62

*	Highest value among all algae at all synoptic sites.
LOI	Loss on ignition.
-	No data.

evident in Figure 6 and Table 5). Internal phosphorus levels at the enriched harbour sites GTE and CTI were well in excess of concentrations considered adequate to maintain maximum growth rates (i.e., about 1.5 mg/g for *Cladophora* from Auer and Canale (1982)). At the shoal site SHB/E, internal phosphorus levels were 3-4 times that necessary to "initiate" growth (i.e., about 0.5 mg/g for *Cladophora* from Auer and Canale (1982)) emphasizing the ability of these algae to sequester phosphorus from any available source; in this case from the excrement of gulls which periodically use the emergent shoals as resting areas.

Differences between algae in their ability to concentrate phosphorus were apparent; however, these differences mere not constant between sites likely because of changing environmental conditions (e.g., Auer *et al.* (1983) speculate that temperature may differentially affect the phosphorus kinetics of *Ulothrix* and *Cladophora* in a fashion similar to that for photosynthesis). Internal phosphorus levels were highest in fringing *Cladophora* at the enriched harbour sites, while at the shoal site SHB/E, *Ulothrix* had the highest levels. This may indicate that *Ulothrix* has a competitive advantage over both forms of *Cladophora* at sequestering phosphorus in the cool and dilute turbulent nearshore waters of the Upper Great Lakes; fringing *Cladophora* appears to have a similar competitive advantage over submerged *Cladophora*.

Throughout Georgian Bay and the North Channel internal phosphorus levels ranged from an extreme high of 13.0 mg/g in submerged *Cladophora* at the McCurry Lake STP outflow (G7A-Parry Sound) to 0.2 mg/g in *Ulothrix* at G9-Key Harbour (Tables 6, 7; 8). In general, algae affected by both natural and anthropogenic nutrient sources had elevated phosphorus levels while algae from remote locations had lower levels.

6.3.2 Nitrogen

Although nitrogen is an essential nutrient, it does not limit algal growth in the Great Lakes, except in highly enriched environments where phosphorus is in excess (Schelske 1979). In southern Georgian Bay mean internal nitrogen levels ranged from 54 mg/g in fringing *Cladophora* at CTB to 23 mg/g in submerged *Cladophora* at SHB/E (Figure 6;

Table 5). Unlike phosphorus, internal nitrogen levels were highest in fringing *Cladophora* at all three sites; levels were consistently next highest in Ulothrix.

Throughout Georgian Bay and the north Channel the range in internal nitrogen levels was much less than for phosphorus, indicative of phosphorus limited conditions (Tables 6, 7; 8). The highest nitrogen value recorded was 93 mg/g at G10-Killarney in fringing *Cladophora*, while the lowest value was 19 mg/g at G1-Penetang in submerged *Cladophora*. The former value reflects the extensive use of this remote site by gulls, while the latter value reflects the deteriorated health of submerged *Cladophora* at a sheltered harbour site late in the season.

6.4 Major Elements

Next to nitrogen, calcium was the most abundant element measured in filamentous algae at CTB, CTI and SHB/E in southern Georgian Bay; mean internal Ca values ranged from 11.9 mg/g to 54.8 mg/g (Figure 6; Table 5). Of the remaining major elements (Al, Fe and Mg; as well as the essential nutrient P) all had similar levels (about 10^{-1} of N and Ca), while Mn was least abundant (about 10^{-3} of N and Ca). Mean levels of all the major elements were highest in submerged *Cladophora*, although differences were minimal for Mg. Levels were consistently next highest in fringing *Cladophora*, except at CTI and/or SHB/E for Mg and Al where values were highest in *Ulothrix*. Each of the major elements showed a decreasing lakeward gradient in mean internal levels. The trend was most apparent for Al, Mn, Ca and Fe and least apparent for Mg.

Throughout Georgian Bay and the North Channel the highest metal levels for each alga occurred at known or suspected source loadings (G1-Penetang, G7A, B or D-Parry Sound, G14-Lion's Head, G16-Wiarton, G18-Owen Sound; G19-Meaford) (Tables 6, 7; 8). The only exception occurred at the remote site G11-Killarney, where the highest value for Mg was recorded in *Ulothrix* (Mg showed little site to site variability anyway). Levels of all the major elements were highest in submerged *Cladophora* and the range of values recorded were comparable to those at the intensive sites CTB, CTI and SHB/E in southern Georgian Bay.

6.5 Trace Elements

At CTB, CTI and SHB/E the most abundant internal trace element was Zn (38.4-124.6 µg/g), followed by Pb (2.0-120.0 µg/g) and Cu (5.0-53.5 µg/g); As (3.7-16.3 µg/g), Cr (5.5-16.9 µg/g) and Ni (6.5-15.8 µg/g); Co (1.5-4.8 µg/g), Cd (L0.3-2.3 µg/g) and Se (L0.2-1.2 µg/g); Sb (L0.1-0.4 µg/g) and finally Hg (L0.01-L0.04 µg/g) (Figure 6; Table 5). The data for Pb, Cu and Cd are mostly single samples and should be interpreted with caution. Also, mean values (when relevant) for Co, Cd, Se, Sb and Hg include "less than" values and must be viewed as upper estimates.

Mean levels of all the trace elements were highest in submerged *Cladophora*, except at CTI and/or SHB/E for Zn, Pb, Cu, As and Hg where levels were highest in *Ulothrix*. Site to site trends in mean trace element levels were more complex than for the major elements, although decreasing lakeward gradients were generally apparent for Zn, Pb, Cu, Se, Sb, and Hg. Notably, As and Cd were higher at SHB/E than at either of the harbour sites; Cr and Co showed a slight increase from CTI to SHB/E, although not in excess of CTB levels.

Throughout Georgian Bay and the North Channel the highest values for most trace elements occurred in submerged *Cladophora* at river and harbour sites (Tables 6, 7; 8). In particular, maximum values for Zn (340 µg/g), Pb (55.0 µg/g), Cu (46.4 µg/g), Cr (29.0 µg/g), Co (14.2 µg/g), Sb (0.6 µg/g) and Hg (0.06 µg/g) all occurred in the immediate vicinity of the McCurry Lake STP outflow (G7A, B, D-Parry Sound), while maximum values for Ni (34.0 µg/g) and Se (3.7 µg/g) occurred at G16-Wiarton. Consistent with trends in the Collingwood area, some trace elements were higher at remote sites than at obviously perturbed locations. For example, the maximum values for As (16.3 µg/g) and Cd (2.9 µg/g) occurred, respectively, at G15-Cape Crocker and at G10-Red Rock.

Other trace elements which had elevated, but not maximum, levels at remote sites included: Cr (12.0-15.5 µg/g) at G5-Twelve Mile Bay and G6-Parry Island; Cu (18.0 µg/g) at G6-Parry Island; Ni (15.0-16.0 µg/g) at G6-Parry Island ana G8-Bayfield Harbour; Pb (8.5-8.8 µg/g) at G10-Killarney. Notably, all of these remote sites are located in eastern Georgian Bay bordering the Precambrian Shield, and of all the trace elements, Zn showed the most pronounced gradient between the two major lithological regions. At remote "limestone" sites (H2-Tobermory, G12-Cabot Head, G15-Cape Crocker) internal Zn levels ranged from about 30-60 µg/g, while at the aforementioned remote "Shield" sites internal levels were considerably higher, at about 100-250 µg/g. Apparently, runoff water from the Shield is contributing to elevated concentrations of heavy metals in attached filamentous algae in eastern Georgian Bay.

This apparent " geologically-induced" differential loading of metals to Georgian Bay does not appear to positively affect the distribution and abundance of filamentous algae (see Figure 1), even though Gerloff and Muth (1979) believe that elements other than phosphorus, including vitamin B_1, may at times limit *Cladophora* growth. It is, however, acknowledged by these and many other investigators (e.g., Neil and Owen 1964, Herbst 1969, Auer and Canale 1982; Neil and Jackson 1982), and consistent with the data presented here, that the "primary" critical nutrient limiting the growth of *Cladophora* in the Great Lakes is phosphorus.

This implies that major anthropogenic nutrient additions (i.e., from municipal, industrial, and agricultural sources) responsible for the proliferation of *Cladophora* in the Great Lakes, must generally contain sufficient trace elements and vitamins that these nutrients are seldom limiting under conditions of measurable anthropogenic enrichment. It can be assumed with good certainty, therefore, that should background phosphorus levels in Lake Huron measurably increase in the future, because of anthropogenic nutrient additions, then *Cladophora* will respond prolifically as it has done elsewhere in the Great Lakes, irrespective of the current availability of trace nutrients.

It must not be construed, however, that the suggestion of metals loadings to eastern Georgian Bay has no ecological significance. On the contrary, the issue of metals toxicity, particularly at higher trophic levels, is potentially of great significance since the health of the Lake Huron ecosystem may be at stake. This apparent "early-warning" of metals contamination should not be ignored.

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Appendix 1. Water quality data at filamentous algae sample sites in Georgian Bay, the North Channel and eastern Lake Huron, 1980.

SITE	DATE	DETAILS	Temp (°C)	TP (mg/L)	FTP (mg/L)	SRP (mg/L)	NO_3 + NO_2 (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Si (mg/L)	Cl (mg/L)	Cond (µS/cm)	SS (mg/L)	Turb (FTU)	SD (m)
G1	June	Near	16.0	0.039	0.015	0.008	0.080	0.132	0.47	0.30	6.85	200	7	3.0	-
	August	Near	22.5	0.072	0.061	0.049	0.005	0.118	0.42	1.25	6.55	200	2	0.9	-
G2	June	Near	16.0	0.038	0.015	0.009	0.005	0.148	0.51	0.40	7.05	185	6	2.7	-
	August	Near	22.5	0.135	0.177	0.114	0.040	0.080	0.35	1.25	7.45	200	1	0.7	-
G3	June	Near	16.0	0.039	0.019	0.010	0.010	0.126	0.52	0.40	6.90	185	6	2.5	-
	August	Near	23.0	0.043	0.033	0.031	0.005	0.088	0.37	1.10	7.65	200	4	0.7	-
G4	August	Near	23.0	0.018	0.010	0.007	0.005	0.066	0.43	1.50	8.75	230	4	1.6	-
G5	June	Off	11.5	0.005	0.002	0.001	0.240	0.008	0.14	0.90	4.55	170	1	0.7	10.0
		Near	-	0.003	0.003	L0.001	0.250	0.010	0.13	0.90	4.65	175	L1	0.7	-
	August	Off	21.5	0.003	0.001	0.001	0.210	0.030	0.22	0.65	4.80	180	2	0.6	-
		Near	-	0.019	0.017	0.015	0.235	0.034	0.15	0.70	4.85	180	1	0.4	-
G6	June	Off	13.0	0.005	0.005	0.002	0.245	0.008	0.13	0.60	4.70	170	1	0.7	6.6
		Near	14.5	0.007	0.003	0.002	0.240	0.014	0.15	0.55	4.90	165	1	0.8	-
	August	Near	21.0	0.047	0.047	0.040	0.200	0.026	0.20	0.65	4.55	175	1	0.5	5.7
		On	20.5	0.086	0.060	0.055	0.195	0.118	0.41	0.45	4.55	175	3	1.0	-
G7	June	Off	-	0.103	0.010	0.008	0.235	0.140	0.44	0.95	4.95	90	10	1.7	-
		B	15.0	0.418	0.088	0.058	2.350	8.50	-	3.05	111	600	13	4.g	-
		A	-	0.448	-	0.064	2.550	8.30	-	3.00	107	600	15	4.6	-
	August	Off	-	0.073	0.062	0.062	0.235	0.292	0.57	0.90	9.15	500	1	0.7	-
		D	21.0	0.047	0.037	0.037	0.155	0.070	0.30	0.75	5.20	110	1	0.6	-
		C	22.0	0.076	0.069	0.062	0.140	0.086	0.33	0.50	5.30	105	L1	0.6	-
		B	20.5	0.944	0.560	0.500	3.802	1.560	3.45	3.95	103	500	26	3.8	-
		A	20.5	0.816	0.600	0.475	3.497	1.720	3.53	3.85	85.0	500	13	2.5	-

Appendix 1 - cont'd

SITE	DATE	DETAILS	Temp (°C)	TP (mg/L)	FTP (mg/L)	SRP (mg/L)	NO_3 + NO_2 (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Si (mg/L)	Cl (mg/L)	Cond (µS/cm)	SS (mg/L)	Turb (FTU)	SD (m)
G8	June	Off	14.5	0.005	0.003	0.002	0.215	0.078	0.16	0.75	4.30	165	2	1.0	5.3
		Near	16.5	0.006	0.006	0.001	0.210	0.012	0.17	0.70	4.35	170	1	0.9	-
	August	Near	22.0	0.006	0.003	0.003	0.140	0.044	0.22	0.70	4.50	175	1	0.6	5.6
		On	24.0	0.006	0.002	0.002	0.130	0.020	0.23	1.10	4.55	175	1	0.6	-
G9	June	Off	15.5	0.007	0.003	0.001	0.180	0.008	0.19	0.75	3.70	145	2	1.2	3.7
		Near	15.5	0.009	0.003	L0.001	0.180	0.014	0.24	0.80	3.70	145	2	1.3	-
	August	Near	20.0	0.007	0.004	0.001	0.170	0.022	0.23	0.60	4.40	175	1	0.5	5.7
G10	June	Near	10.5	0.004	0.001	0.001	0.260	0.006	0.13	0.80	4.80	1g0	L1	0.8	8.5
		On	12.0	0.009	0.004	L0.001	-	0.024	0.32	1.10	3.90	140	1	1.1	-
	August	Near	19.0	0.004	0.004	0.001	0.225	0.018	0.16	1.05	4.75	185	L1	0.4	10.8
		On	19.0	0.660	0.580	0.580	0.290	1.970	3.88	0.60	4.30	170	6	1.5	-
G11	June	Near	11.5	0.006	0.004	0.002	0.250	0.012	0.10	0.70	4.80	185	L1	0.8	7.5
		Un	11.5	0.010	0.002	L0.001	0.120	0.016	0.22	0.55	4.90	185	*2*	1.0	-
	August	Near	19.0	0.006	0.003	0.003	0.205	0.024	0.74	0.90	4.75	185	2	1.0	-
		On	21.0	1.280	0.900	0.880	0.125	4.890	8.10	0.40	2.65	140	20	5.1	-
G12	August	Near	18.0	0.046	0.044	0.039	0.250	0.036	0.15	0.55	5.35	200	2	0.8	-
G13	August	Near	1g.0	0.048	0.046	0.043	0.250	0.006	0.12	0.80	5.10	197	L1	0.4	-
G14	June	Near	12.0	0.016	0.004	0.001	0.420	0.004	0.70	0.95	5.50	215	4	2.3	-
	August	Near	19.0	0.065	0.030	0.028	0.285	0.020	0.27	0.75	5.70	210	15	3.3	-
G15	August	Near	19.0	0.055	0.033	0.032	0.250	0.012	0.1F	0.75	5.05	195	12	4.9	-

Appendix 1 - cont'd

SITE	DATE	DETAILS	Temp (°C)	TP (mg/L)	FTP (mg/L)	SRP (mg/L)	NO_3 + NO_2 (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Si (mg/L)	Cl (mg/L)	Cond (µS/cm)	SS (mg/L)	Turb (FTU)	SD (m)
G16	June	Near	17.0	0.057	0.019	0.005	0.505	0.046	0.85	0.70	14.5	270	7	4.9	-
	August	Near	19.5	0.031	0.020	0.070	0.205	0.030	0.19	0.80	5.00	190	3	1.3	-
G17	June	Near	13.0	0.025	0.006	0.002	0.470	0.024	0.28	0.90	11.0	305	9	7.3	-
	August	Near	21.0	0.110	0.004	0.004	0.270	0.050	0.60	0.75	18.0	265	84	27	-
G18	June	Near	12.5	0.026	0.003	0.003	0.420	0.004	0.25	0.55	6.75	215	17	16	-
	August	Near	20.0	0.031	0.005	0.002	0.215	0.050	0.28	0.50	6.20	215	22	8.8	-
G19	June	Near	15.0	0.080	0.012	0.010	2.299	0.050	0.67	2.10	6.45	390	53	43	-
	August	Near	20.0	0.014	0.002	0.001	0.245	0.013	0.16	0.75	4.95	195	3	7.7	-
SHB/E	June	Off	11.5	0.009	0.002	0.001	0.265	0.006	0.16	0.70	4.80	190	5	2.8	-
		Near	11.0	0.020	0.002	0.001	0.270	0.008	0.17	0.90	4.85	195	12	2.5	-
	August	Off	19.0	0.004	0.001	0.001	0.240	0.019	0.15	0.75	4.95	190	3	1.7	*2.7*
		Near	-	0.005	0.002	0.002	0.240	0.015	0.14	0.65	4.90	190	6	2.0	-
		On	-	0.006	0.002	0.002	0.230	0.013	0.17	0.70	4.90	190	6	1.7	-
CTI	June	Near	11.0	0.034	0.006	0.003	0.240	0.038	0.27	0.75	6.10	200	10	5.8	-
	August	Near	19.0	0.041	0.015	0.015	0.225	0.039	0.35	0.90	6.10	205	10	6.0	-
CTB	June	Near	11.0	0.066	0.011	0.004	0.230	0.032	0.43	0.75	7.45	215	10	5.1	-
	August	Near	19.0	0.091	0.046	0.044	0.025	0.287	0.71	0.85	7.90	225	11	6.5	-
N1	August	Near	20.0	0.002	0.002	0.002	0.710	0.020	0.70	1.20	4.35	160	L1	0.3	9.5

Appendix 1 - cont'd

SITE	DATE	DETAILS	Temp (°C)	TP (mg/L)	FTP (mg/L)	SRP (mg/L)	NO_3 + NO_2 (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Si (mg/L)	Cl (mg/L)	Cond (µS/cm)	SS (mg/L)	Turb (FTU)	SD (m)
N2	JUNE	Near	15.0	0.006	0.003	L0.001	0.705	0.012	0.19	1.55	2.75	115	2	1.5	3.1
		On	15.0	0.0??	0.003	L0.001	0.215	0.032	0.31	1.55	2.75	115	10	1.7	-
	AUGUST	Near	19.0	0.044	0.040	0.040	0.700	0.078	0.16	1.20	3.40	135	1	0.7	G4.0
N3	JUNE	Near	12.0	0.005	0.003	0.001	0.270	0.014	0.1?	1.20	3.00	135	3	2.1	2.6
	AUGUST	Near	17.0	0.044	0.038	0.036	0.250	0.028	0.16	1.05	2.g5	130	2	1.4	?.5
N1	JUNE	Off	10.0	0.005	0.007	L0.001	0.355	0.010	0.16	0.75	4.95	200	3	0.8	7.3
		Near	10.0	0.004	0.002	0.001	0.260	0.008	0.13	0.80	5.05	195	1	0.8	-
	AUGUST	Near	17.0	0.052	0.049	0.047	0.220	0.016	0.19	0.90	5.35	705	1	0.6	-
N2	JUNE	Off	8.5	0.003	0.002	L0.01	0.310	0.010	0.14	0.g0	4.90	195	2	0.7	9.8
		Near	9.0	0.006	0.002	0.001	-	0.064	0.15	0.85	4.90	195	3	0.8	-
	AUGUST	Near	17.0	0.042	0.04?	0.03g	0.760	0.026	0.17	0.55	5.30	200	1	0.4	10.2

Off	10 m offshore.
Near	1 m offshore.
On	Wave washed pool.
L	Less than.
G	Greater than.
-	No data.