Organic Tissue Stoichiometry of *Cladophora glomerata* and its Relation to Coastal Land Use in the Laurentian Great Lakes

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required revisions, as accepted by my examiners.

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Abstract

The relationships between C:N:P (carbon, nitrogen, and phosphorus) stoichiometry of *Cladophora glomerata* and land use characteristics in selected nearshore areas of the lower Laurentian Great Lakes were determined during two years of field sampling of coastal areas. In the past, bi-national reduction of point sources of P-loading resulted in reduced *C. glomerata* biomass; however, currently *C. glomerata* is resurging and it has been suggested that non-point source P loading, which may have increased with increasing populations and coastal land use changes, may be the cause. Study of the Halton shoreline, Lake Ontario, in 2006 demonstrated that *C. glomerata* nutrient stoichiometry has a strong seasonal relationship as internal P concentrations at 2 and 5 m depths decline to as low as 0.5 μg/mg dw during the rapid early summer growth period, well below the literature value of 1.6 μg/mg dw indicative of P limitation. Samples at 10 m maintained a constant surplus in P throughout the summer as light was the greater controlling factor at this depth. Along with ambient dissolved P, *C. glomerata* internal P increased sharply during the September and October surveys to approximately 3.5 μg P/mg dw at 2 m stations. Throughout the 2006 growing season both water chemistry and *C. glomerata* nutrient stoichiometry did not identify any direct point source influencing algal growth as indicated by tissue stoichiometry.

Land use comparisons between the urbanized Halton region and the non urban sites of Presqu'ile Provincial Park and Peacock Point (Lakes Ontario and Erie, respectively) indicated significantly higher enrichment in both nitrogen and phosphorus at the 10 m urban stations as internal P concentrations were elevated and both N and P nutritional

status indicators (C/P, C/N, and N/P) were much lower compared with non-urban sites. Areas with relatively more human impact (Port Credit and Halton on Lake Ontario) had higher internal P concentrations in *C. glomerata*.

Through empirical evidence, nutrient status ratios predict the onset of P limitation for *Cladophora glomerata* within the Great Lakes to have values for C:P > 505 and N:P > 41, whereas zero positive growth was estimated to begin when C:P > 1246 and N:P > 75.

Natural stable isotope abundances of ^{13}C were indicative of benthic algal production as $\delta^{13}C$ values from *C. glomerata* tissue samples during the early summer rapid growth period varied with depth to the 5 m depth contour. Though, overall ^{13}C algal signals were a function of offshore changes in DIC-$\delta^{13}C$ patterns throughout the year they were consistently lower in *Cladophora* tissue at shallower depths suggesting high photosynthetic demand for CO_2 reduced isotopic photosynthetic fractionation. This trend was evident along most shorelines and from year to year, verifying the use of ^{13}C stable isotope to define periods of potentially carbon-limited production. ^{13}C and ^{15}N did not identify any significant difference between urban and non urban shorelines. Similarly, stable isotopes were inconclusive in measuring local point source impacts. Similarly, point sources were also not apparent from measuring water chemistry and *C. glomerata* tissue parameters. The use of ^{15}N isotopes in tracing *C. glomerata* filament origins may be of merit as persistent depth relationships were observed at all sites in Lake Erie and Ontario.

Acknowledgements

More than two years, 300 or more 5 a.m. Tim Horton coffees, a gazillion litres of gas, transportation of over 9 tons of water into the Grand River watershed, and a sudden and sad good bye to our secchi disk has gone by, and I'm not sure what has changed. However, during this time, I've written several chapters on an alga whose name I still have a difficult time pronouncing, was almost taken out by *E. coli*, have logged many hours of SCUBA, travelled to several conferences, seminars, and field stations in and out of Canada, and am adept at using a variety of aquatic instruments from the PAM, to the R.A.K.E, to Gravol. Actually, a lot has changed and there have been a LOT of people that have made this ride possible.

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Dedications

In memory of

Johannes H. Houben

and

Wilfred J. Maloney.

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Chapter 1: General Introduction

Cladophora is a benthic, attached, filamentous green macroalga and is described fully in Van den Hoek's (1963) review of the numerous species within this taxon. Of the 11 freshwater species of *Cladophora*, *C. glomerata* is believed to be the dominant attached algae along much of the nearshore zone throughout the Great Lakes during the warmer months of May to September (Bellis & McLarty 1976). However, *C. glomerata* exhibits high morphological plasticity with respect to seasonal and environmental conditions as well as water turbulence (Herbst 1969; Graham 1982), which has made consistent identification difficult (Dodds & Gudder 1992). A study in Medway Creek, Ontario, originally identified several species of *Cladophora*, only to find after year-round observations that it was all *C. glomerata* in various life phases (Bellis & McLarty 1967). Recent molecular genetic research suggests that there may be only one North American species, *C. glomerata*, with several potential varieties, including strong evidence that the Great Lakes populations may be distinct from other North American populations (K.M. Müller, University of Waterloo, ON, personal communication; Ross 2006). This recognition of variation during life history combined with molecular phylogenetic techniques and traditional systematic studies may eventually delineate a distinctive Great Lakes *Cladophora* variety (Müller, personal communication). For the purposes of this study, *Cladophora* and *C. glomerata* will be used interchangeably until the taxonomy of freshwater *Cladophora* has been further examined.

In recent years, *C. glomerata* has been considered an indicator of eutrophication in the Great Lakes and a nuisance as vast mats have been reported to wash up on shore, clogging water intakes and fishing lines during mid to late summer. The following

sections describe the ecology and physiological needs of this alga before discussing prior, related research.

1.1 *Cladophora glomerata:* Ecology and Physiology

Cladophora glomerata grows on hard substrates and is recognized as having two relatively rapid vegetative growth periods (Bellis & McLarty 1967; Mantai & Haase 1977; Lorenz & Herdendorf 1982) (Fig. 1.1). The first and longest period of rapid growth occurs from spring to early summer as the over-wintered rhizoidal base initiates rapid vertical growth once temperatures begin to rise above 15ºC (Herbst 1969), although some growth in lab cultures has been reported as low as 5ºC when sufficient light and nutrients are supplied (Graham et al. 1982). Maximum biomass is accrued from mid-June to early July when lake temperatures are approaching their maximum, which is approximately 20-25ºC. During this time, zoosporangia develop in the apical cells of the main and lateral branches. Asexual zoospores are subsequently released into the water column (Van den Hoek 1963; Bellis & McLarty 1967; Bold et al. 1980). The remaining filaments are much less branched and often become silted and covered with epiphytic diatom growth before eventually detaching completely from the rhizome and washing up on shore in vast quantities where the detached mass desiccates and rots (Wood 1968 & 1975; Whitton 1970; Taft & Kishler 1973). This detachment phenomenon has been correlated to several factors, including upper temperature limits (Bellis 1968), phosphorus limitation (Auer & Canale 1982a), and the physiological imbalance between growth and loss rates at the base of filaments due to light limitation from self-shading (Higgins et al. 2005b). The newly germinated zoospores begin the second period of growth in August, along with continued

regrowth of the remaining attached filaments, which continues into early autumn. Once temperatures drop and ice formation begins in late fall and winter, the remaining rhizomes coalesce into dense akinetes, or over-wintering resting spores.

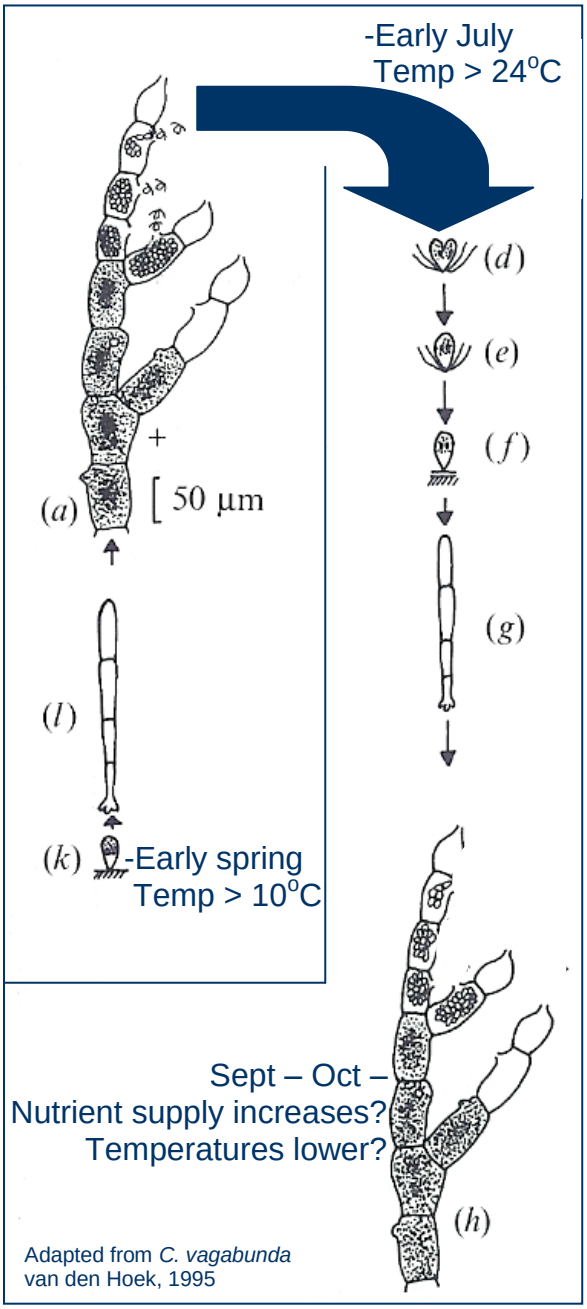

Figure 1.1: *Cladophora glomerata* life cycle, adapted form *C. vagabunda* in van den Hoek et al. (1995).

Single *C. glomerata* filaments can grow up to 30-60 cm in length in Lakes Ontario and Erie (Herbst 1969; Higgins et al. 2005a) and up to 100 cm in streams (Bellis & McLarty 1967). Areal biomass is generally greatest at depths of 1-5 m, with up to 100% coverage in mid-summer (Higgins et al. 2005a). At shallower depths, turbulence may be a factor in removing longer filaments, while light limitation begins to have a greater role as depth increases. These beds may be habitat for molluscs, crayfish, and small fish, but during periods of rapid growth grazing pressure is minimal suggesting that *C. glomerata* is poorly utilized by many animals (Taft 1975).

Minimum light requirements for *C. glomerata* photosynthesis range from 28-44 $\mu M/m^2/s$ of photosynthetically active radiation (PAR) irradiance, and consequentially, depth limits for attached *C. glomerata* growth have been described depending on the transparency of the overlying water (Taft 1975; Lester et al. 1988). On average, high light environments (300-600 $\mu M/m^2/s$ PAR) and moderate temperatures (18-24ºC) are optimal for maximum growth and photosynthesis, though a wide range of tolerance has been recorded across North American lakes and streams (Table 1.1).

High turbulence and strong currents also appear to be essential to the growth and establishment of *C. glomerata*. Because nutrient demand is high during periods of rapid growth, vigorous currents may be necessary to ensure adequate or even a continuous supply of nutrients to the filaments (Whitford & Shumacher 1961 & 1964; Herbst 1969). As described in Raven (1981), *C. glomerata* is, technically, a haptophyte, meaning that the rhizoid base does not actually take root into the sediment but rather fastens to hard substrates. This life strategy inhibits nutrient uptake directly from the substrate and

sediments, making it depend solely on the soluble nutrient concentrations within the local water column. Relatively strong currents are needed to ensure that diffusion of CO_2 and/or dissolved bicarbonates can be maintained through the cell-water interface boundary layer to sustain high rates of photosynthesis and ensure rapid removal of waste products. Hard substrates, such as bedrock, molluscs, and synthetic structures (concrete piers) are thus critical for basal cell attachment and anchoring (Bellis & McLarty 1967; Herbst 1969; Whitton 1970) to allow *C. glomerata* to survive in moderately turbulent environments. Indeed, shallow, alkaline waters are also important for optimum photosynthesis and respiration rates (Bellis & McLarty 1967).

Table 1.1. Light and temperature requirements for growth and photosynthesis of the benthic macroalga *C. glomerata* as reported in the scientific literature.

Parameter	Levels	Notes	Reference
Light	28 µmol/m^2/s	Light limitation	Taft 1975
	44-104 µmol/m^2/s	Light Compensation	Lester et al. 1988
	300-600 µmol/m^2/s	Maximum photosynthetic rate	Graham et al. 1982
	790 µmol/m^2/s	Light saturation	Lester et al. 1988
	8:16	Optimal Light:dark photoperiod (hours)	Cheney & Hough 1983 Hoffman 1984
	2-4 m	Max depth for growth in west Lake Erie	Lorenz & Herdendorf 1982
Temperature	13-17^{o}C	Maximum photosynthetic rate	Graham et al. 1982
	15-20^{o}C	Maximum photosynthetic rate	Taft 1975
	20-25^{o}C	Optimum growth	McNaught 1964
	15-30^{o}C	Lab cultures	Bellis 1968

Physiological growth requirements are also largely dependent on phosphorus concentrations, light availability, and temperature (Canale & Auer 1982a). As seen in phytoplankton when light and temperature are in excess, nutrient limitation can occur

(Hecky & Kilham 1988). In aquatic plants, it is the intracellular concentrations of nitrogen (N) and phosphorus (P) that determine growth rates. Growth limitation occurs as internal nutrient concentrations approach the minimum cell concentrations for essential nutrients and micronutrients that support growth. In *C. glomerata*, phosphorus is generally considered the primary limiting nutrient (Freeman 1986; Lapointe & O'Connell 1989). Dissolved inorganic orthophosphate is the principal form of P directly taken up by algae for growth (Gerloff & Fitzgerald 1976). Excessive concentrations of P are the most commonly cited nutrient relating to nuisance *C. glomerata* abundances (Herbst 1969; Wong & Clark 1976; Auer & Canale 1982a; Freeman 1986; Painter & Kamaitis 1987; Painter & Jackson 1989). In North America only one record of nitrogen limitation in *C. glomerata* was noted in a Montana stream (Lohman & Priscu 1992), where molar ratios of cellular N:P ratios were lower than 16:1.

Phosphorus compounds within plants and algae are, in general, grouped into structural, functional, and surplus forms. The surplus fraction may be a source of P during periods of external P-limitation, thus measures of surplus P could potentially provide an indication of long-term trends with respect to P availability within lakes as opposed to instantaneous measurements from water samples. This surplus P is a balance between accumulation from the water and dilution through growth as surplus P is transformed into structural and functional forms of P. Consequently, higher internal P will indicate more P available to support continued growth (Droop 1974; Lin 1977; Kilham & Hecky 1988), if light and temperature are not limiting. Conversely, lower internal P can begin to reduce growth rates until the minimum cell quota is reached and growth ceases. In *Chlorella vulgaris,* stored P remains very low during growth and is at a

maximum during stationary phases (Aitchison & Butt 1973). Lin (1977) also saw this similar pattern in *C. glomerata*. Greater storage capacity of phosphorus versus nitrogen in *C. glomerata* has also been observed (Lohman & Priscu 1992). Two important factors affecting P accumulation are the algal growth cycle and external concentrations of dissolved P (Kuhl 1974). *C. glomerata* does exhibit alkaline phosphatase activity under P stress so both dissolved organic and inorganic forms of P may be used (Healey & Hendzel 1979a). Auer and Canale (1980) also describe that, as P uptake is inversely proportional to internal P surpluses, filaments located further away from regular, continuous P sources will have lower internal stores but can quickly take up P in a pulse loading event. This is also critical in understanding the impacts of non-point sources of P and other nutrients. This storage and rapid uptake capacity contribute to the capacity of *Cladophora* to dominate coastal areas where P becomes available aperiodically with storm or runoff events. Once established, the high biomass of *C. glomerata* will allow it to shade out benthic microalgae as well as to restrict their access to nutrients in the water column. However, in turn, *Cladophora* provides substrate for epiphytic microalgae (Whitton 1970).

Attempts to control algal growth in lakes have often focused on the reduction of phosphorus loading in order to achieve concentrations low enough to promote phosphorus-deficiency and decreased growth of *C. glomerata*. Several authors have determined threshold nutrient concentrations for algae in general and also specifically for *C. glomerata*, with 0.6 μg P/mg dry weight of algal tissue mass being agreed upon as the critical limit for growth (Gerloff & Fitzgerald 1976; Wong & Clark 1976; Gerloff & Muth 1984). *C. glomerata* tissue C:N:P ratios (Table 1.2) range widely in situ and in

culture depending on other variables. Carbon is generally considered to be in excess in most systems and Choo et al. (2002) describe several mechanisms for inorganic carbon uptake that can be induced during periods of potential carbon limitation: dehydration of bicarbonate to carbon dioxide by carbonic anhydrase, direct uptake of bicarbonate, and involvement of a proton pump. Therefore, carbon, relative to P and N, is unlikely to limit *C. glomerata* biomass production in alkaline waters although it may occasionally reduce growth rates. *C. glomerata* can use ammonia and nitrate as N sources. Nitrate has been increasing in the Great Lakes in the last few decades and now concentrations rarely, if ever, drop to concentrations that would be considered potentially limiting, i.e. < 300 µg/L dissolved inorganic nitrogen (Herbst, 1969).

Table 1.2. Critical tissue nutrient levels and ratios for *Cladophora glomerata* and other benthic algae.

Parameter	Level	Notes	Reference
P	0.6-1.6 µg P/mg dw	Lab and Field	Gerloff & Fitzgerald 1976
	1.6 µg P/mg dw	Field	Wong & Clark 1976
	1-6 µg P/mg dw	46 macroalgae species	Duarte 1992
N	11-15 µg N/mg dw	Lab and Field	Gerloff & Fitzgerald 1976
			Wong & Clark 1976
			Auer & Canale 1982#2,3
	2.0-42 µg N/mg dw	46 macroalgae species	Duarte, 1992
C:P, N:P, C:N	265, 38, 18	*Cladophora* sp. (marine)	Atkinson & Smith 1983
(molar)	164, 18, 9	*Cladophora* sp. (freshwater)	Raven 1981
	119, 17, 7	Benthic microalgae	Hillebrand & Sommer 1999
	90-185, 13-22, 5-10	46 macroalgae species	Duarte 1992

In summary, the physiology and range of growth of *C. glomerata* are commonly limited by light (depth), water temperature, substrate, and phosphorus (Neil & Owen

1964; Herbst 1969; Healey & Hendzel 1979b; Auer & Canale 1980). As well, under phosphorus-limited conditions, internal stores of phosphorus typically regulate growth.

1.2 Past and Present Research

Eutrophication of the Laurentian Great Lakes was a recognized problem as early as 1933 (Neil & Owen 1964). The filamentous green alga, *Cladophora glomerata*, was a major factor in this concern as vast algal mats washed up along the shorelines, causing property devaluation and clogging of water intakes and fishing gear, and was aesthetically displeasing for recreational use (Herbst 1969). As an attached, benthic alga, *C. glomerata* can thrive along rocky shorelines with the hard waters of the Great Lakes ensuring adequate dissolved inorganic carbon concentration. If the nutrient supplies of N and P are high enough, it can establish large crops on hard substrates, including bedrock and mussel shells, exploiting the moderate current action and wave turbulence in these large lakes thereby making it a key indicator species for eutrophication. Throughout the 1950s and 60s, *C. glomerata* was prominent along rocky shorelines in Lakes Michigan, Erie, and Ontario, while localized blooms were observed near larger urban centres in Lake Huron. Very few sightings occurred in Lake Superior. The relatively lower abundances of *C. glomerata* in Lake Huron and Superior may be related to lower phosphorus loadings (McLarty 1960; Neil & Owen 1964; Bellis & McLarty 1967) and/or temperature reducing growth and length of growing season. Critical nutrient concentrations in water for *C. glomerata* growth have been determined to be 30 μg/L for total dissolved phosphorus and 300 μg/L for dissolved inorganic nitrogen if all other conditions are optimum (Herbst 1969; Taft 1975). Lakes Erie, Ontario, and Michigan

were found to be highly eutrophic and well above these levels during this era (a Milwaukee site observed concentrations of 1000 μg/L of total dissolved phosphorus (TDP) on average over a year) while Huron and Superior were still relatively low in phosphorus at that time (Herbst 1969).

Factors influencing eutrophication in the Great Lakes were determined to be detergents, increasing municipal wastes (Bowen & Valiela 2001), and agricultural runoff. *C. glomerata* played a relatively minor role in aquatic communities before anthropogenic nutrient enrichment became widespread (Whitton 1970). The International Joint Commission initially targeted excessive nutrient loadings, specifically point-source effluent inputs of phosphorus, as a major cause of eutrophication after extensive studies were undertaken in the late 1960s and early 70s (Shear & Konasewich 1975). Phosphorus was targeted specifically, as it was the factor with the greatest effect in increasing eutrophication and was directly correlated with human activity (Taft 1975). Phosphorus was also targeted for control as it is the easiest factor to control relative to other key *C. glomerata* growth variables, such as the amount of sunlight entering the littoral zone, lake temperature, and inorganic nitrogen loading. Apart from the obvious logistical issues of controlling light and temperature at lake scales, nitrogen is more difficult to remove from sewage than P and it can also be fixed biologically from atmospheric gases if it is in deficit within aquatic ecosystems. Natural phosphorus loading is limited in the natural environment as it is largely related to erosional processes as phosphate readily complexes with mineral surfaces. In 1972, through the International Lake Ontario – St. Lawrence River Water Pollution Board (ILOWPB), legislation was enacted to regulate levels of phosphate in detergents to be no greater than 5% (Stevens & Neilson 1987). Wastewater

treatment plants were to lower their P content in effluent to levels lower than 1.0 mg TP/L. This was achieved through the Great Lakes Water Quality Agreement, also in 1972 (Dolan 1993). With the onset of phosphorus regulation, offshore concentrations of total phosphorus (TP) declined (see Figure 1.2) along with phytoplankton abundances offshore and *C. glomerata* biomass and internal P in the nearshore (Neil 1975; Painter & Kamaitis 1987; Stevens & Neilson 1987; Makarewicz et al. 1993). At this time, development of the first *C. glomerata* growth model (Auer & Canale 1982b, Canale & Auer 1982a) focusing on a P point-source site in Lake Huron was in progress (Fig. 1.3). This project was crucial in management programs as it was successful in predicting peak *C. glomerata* biomass based on photosynthetically active radiation (PAR), soluble reactive phosphorus (SRP), water temperature, and *C. glomerata* carrying capacity (Canale & Auer 1982b).

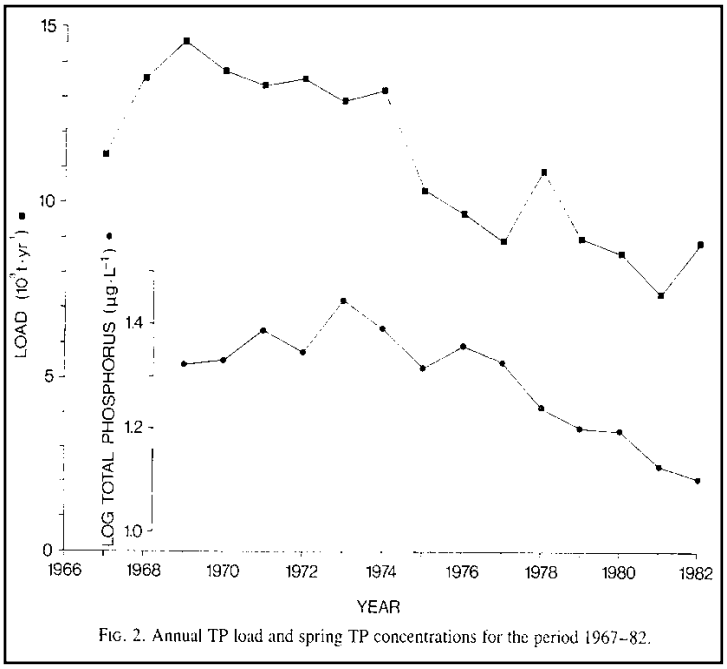

FIG. 2. Annual TP load and spring TP concentrations for the period 1967–82.

Figure 1.2: Annual total phosphorus (TP) load and spring TP concentrations for the period of 1967-82 in Lake Ontario. (From Stevens and Neilson, 1987)

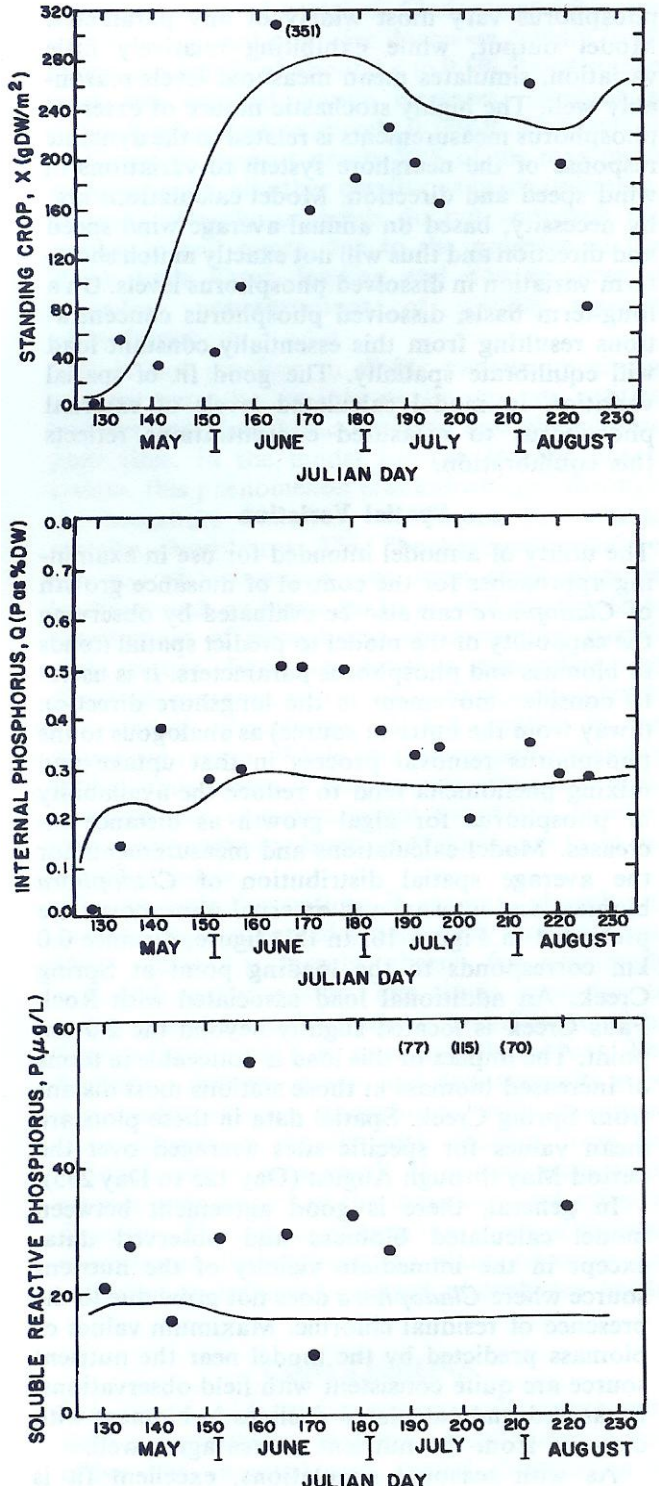

Figure 1.3: Seasonal dynamics of model-calculated and measured biomass density, internal phosphorus, and soluble reactive phosphorus. Peak biomass is estimated to occur in late June to early July at a site in Lake Huron. (From Canale and Auer, 1982a).

As phosphorus reduction and application of growth models proved to be successful in *C. glomerata* management, few records of continued research or mention of *C. glomerata* are evident until the mid-1990s when once again large algal mats reappeared along shorelines (DeJong 2000; L. Moore, Ontario Clean Water Agency personal communication). Moreover, this resurgence was puzzling as relatively low concentrations of phosphorus were still being maintained offshore and at direct loading points. This suggested that nonpoint-sources, such as increased populations (Fig. 1.4), largely due to rapid urbanization and increased industrial farming, had potentially comparable impacts to point sources via diffuse introduction of additional nutrients and suspended sediments into coastal areas.

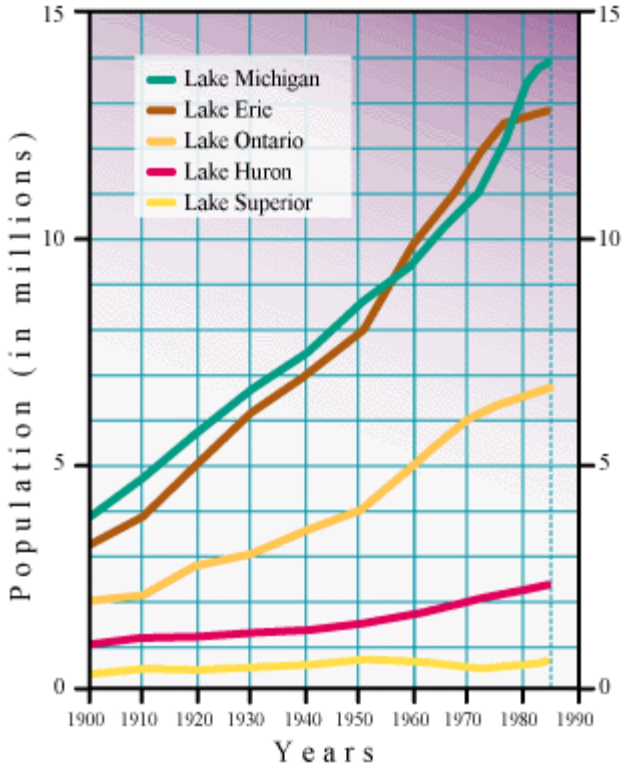

Figure 1.4: Population growth rates in the Laurentian Great Lakes basins (Hiriart-Baer unpublished).

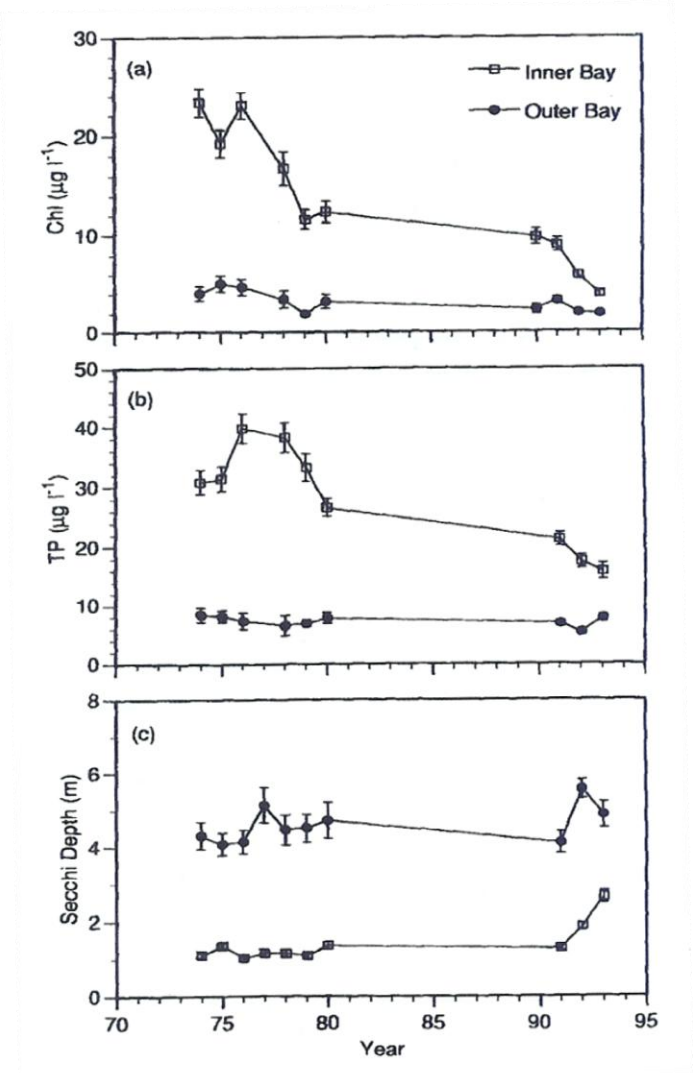

Figure 1.5: Annual means of water quality parameters from inner and outer Saginaw Bay: a) chlorophyll, b) total phosphorus, c) Secchi disk depth, before and after dreissenid mussel invasion in 1991. Error bar is one standard error. (From Fahnenstiel et al, 1995).

The contemporaneous Great Lakes invasion of dreissenid mussels during the 1990s (Vanderploeg et al. 2002) may have also contributed to the resurgence of *Cladophora glomerata.* As benthic filter feeders capable of attaching to hard substrates, it has been hypothesized that dreissenids a) intercept and detain nutrients from catchments and prevent them from mixing rapidly into the offshore zones, b) increase light availability as

suspended particulates are filtered out – up to an 88% increase in secchi depth in Saginaw Bay, Lake Huron (Fahnenstiel et al. 1995), and c) extend hard substrate habitat for *Cladophora glomerata* with their increasing biomass (Hecky et al. 2004). Fahnenstiel (1995) also noted a decrease in pelagic chlorophyll and total phosphorus concentrations in Saginaw Bay (Fig. 1.5) along with increased benthic algal productivity. Other studies have also observed decreased concentrations of soluble reactive P, ammonium, nitrate, silicate, and chloride in western Lake Erie after dreissenid establishment (Holland et al. 1995; Nicholls et al. 1999; Makarewicz et al. 2000). Although TP did not change much in these studies, it is clear that mussels have a disproportionately large impact on P recycling and flux in near shore areas potentially displacing nutrients from the water column to the benthos (Hecky et al. 2004).

Declines in phytoplankton populations (reducing nutrient competition for *C. glomerata*) and increased clarity (Arnott & Vanni 1996; Conroy et al. 2005) have also been determined to relate to the filter-feeding mussels. Though it has been argued to have decreased lake eutrophication, increased clarity has allowed large stands of submerged macrophytes and benthic macroalgae to expand colonization of lake beds (Skubinna et al. 1995). Recent studies have shown no great increase in biomass of *C. glomerata* per unit area; however, as light determines the lower limit of C. *glomerata* growth and increases growth at all shallower depths until P becomes limiting (Arciszewski 2005; Higgins et al. 2005b), the increase in clarity has allowed an increase in the range of habitat area from depths of 2-4 m in the 1970s (Auer et al. 1982) to 2-10 m in 2005/06 (personal observations), potentially resulting in greater biomass per linear meter of shoreline (DeJong 2000).

The resurgence of *Cladophora glomerata* following the dreissenid invasion has led to recalibration and revision of the "Canale and Auer" model. Higgins et al. (2005a&b) developed the *C. glomerata* Growth Model (CGM) in eastern Lake Erie, expanding the original model to incorporate nonpoint-sources of P and greater depths, from the 0-3 m depths in the Canale and Auer (1982b) model to depths of 10 m (Higgins et al. 2005b). The CGM was successful in predicting *C. glomerata* growth, biomass, and internal phosphorus concentrations in eastern Lake Erie. However, further research into varying land use along the shoreline and related impacts at a lake-scale comparison may elucidate even greater complexities affecting *C. glomerata* growth dynamics and critical sources of P loading that allow for the recent production of this nuisance alga.

1.3 Thesis Overview

My research objective is to determine the temporal and spatial variation in nutrient stoichiometry of *Cladophora glomerata* within the lower Laurentian Great Lakes. In Chapter 2, a detailed profile of *Cladophora* stoichiometry along the heavily urbanized Halton region nearshore zone is presented and discussed relative to strong point sources along this shoreline. Temporal variability and the relative impact of localized point sources on *C. glomerata* growth were measured in 2006. In Chapter 3, the influence of urban land use compared to rural and natural shorelines as well as inter-lake variability of *C. glomerata* nutrient status is discussed from surveys over both 2005 and 2006. The stable isotopes ^{13}C and ^{15}N were measured in both the 2005 and 2006 surveys in an attempt to identify nutrient sources for N and relative photosynthetic rates in Chapter 4.

An overall summary of all research conclusions and potential implications of the research follow in Chapter 5.

Chapter 2: *Cladophora glomerata* Nutrient Stoichiometry along the Urbanized Shoreline of Halton Region, Lake Ontario

2.1 Abstract

A spatio-temporal survey of water quality and Cladophora glomerata nutrient content along an urbanized portion of the Region of Halton shoreline on Lake Ontario was conducted over the 2006 field season. This was in response to this highly urbanized region being inundated with vast benthic algal mats that detached each summer to wash up on beaches leading to citizen complaints. Four depth transects spaced along 12 km of shoreline with stations at the 2, 5, and 10 m depth contours, as well as one offshore station at 35 m, were measured for light, temperature, water chemistry, and internal nutrient stoichiometry for the benthic alga, *Cladophora glomerata*. Ammonia concentrations were the only nutrient source identified as potentially related to potential point sources. However, no distinct influence on *C. glomerata* nutrient content could be traced back to localized point sources, such as the inflow of 16 Mile Creek or any of the waste water treatment plant effluents or storm water drains along the surveyed coastline. A strong seasonal relationship with dissolved phosphate and internal *C. glomerata* phosphorus content was observed as both declined in concentration during the spring and summer growing season to levels of severe internal phosphorus limitation (< 1.0 μg P * mg dw^{-1}), before increasing to over 5 μg-P * mg dw^{-1} by September 19, 2006. Light limitation was also found to be a strong influence on algal nutrient content at depths greater than 5 m. *C. glomerata* abundance was also found at depths of at least 10 m

during peak biomass, suggesting greater areal extent of the macroalgae compared to historical records.

2.2 Introduction

Sixteen Mile Creek enters the north western portion of Lake Ontario at Oakville, Ontario, and influences the Region of Halton shoreline. It is located at the centre of the Golden Horseshoe, a highly urbanized tract of land that runs from the Niagara Peninsula on the south, around the western end of Lake Ontario to Whitby on the north, encompassing Hamilton and Toronto (Fig. 2.1). In recent years, large mats of detached benthic green algae have been reported to be washing up on beaches, clogging water intakes, and reeking havoc on fishing gear along this coastline.

Shoreline algal fouling was thought to be a problem of the past solved through costly investments to remove P from detergent and wastewater streams in the 1970s. Over the last half century, the Great Lakes community tackled eutrophication, reducing both nutrient loading and the overall concentrations of nutrients within the lakes, specifically phosphorus in the form of phosphate (Stevens & Neilson 1987). The eutrophication of the 1950s and 60s was directly characterized by the steady increase in the ubiquitous benthic algal biomass of *Cladophora glomerata* up until the International Joint Commission, in 1975, recommended the regulation of phosphorus concentrations in detergents and direct loadings via sewage treatment plants to their parent governments (Shear & Konasewich 1975). The subsequent decline in phosphorus loadings and offshore concentrations in the late 1970s into the 1980s (Fig. 1.2) were also paralleled by the decline of *C. glomerata* biomass.

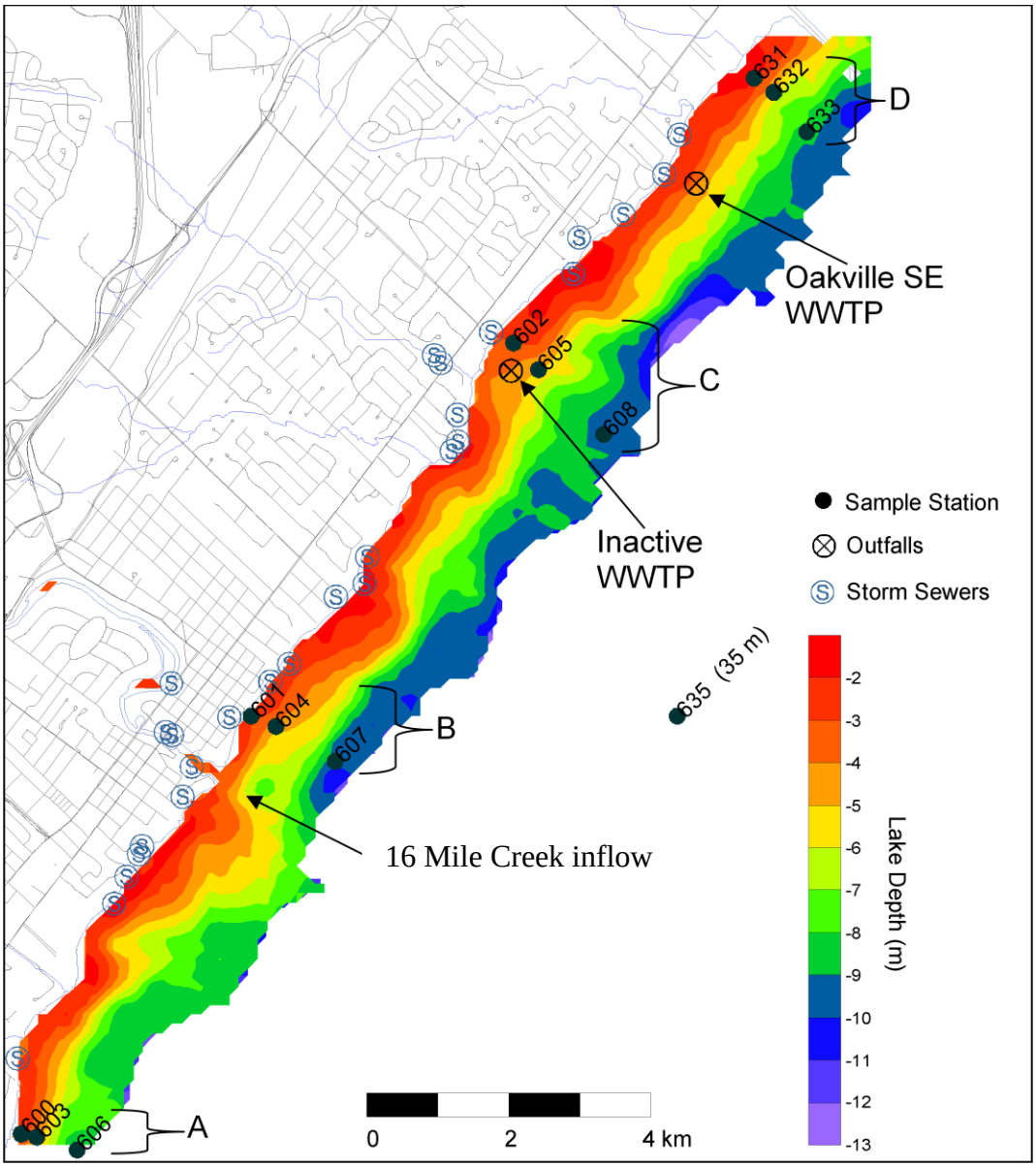

Figure 2.1: Halton shoreline and sampling stations for 2006 seasonal and spatial survey. Surveys were conducted from April 6 until October 19 on a monthly schedule with increased frequency in April and June to measure initial spring conditions and peak biomass, respectively. The four transects are labelled west to east as A-D.

However, as the biota of the Great Lakes has continued to change due to continuing establishment of exotic organisms, and human populations within the watershed have steadily increased, particularly in urban areas, there has again been a noticeable change in benthic algal shoreline fouling complaints levels (Bowen & Valiela 2001). Large

detached mats of the benthic alga *C. glomerata* were once again being reported in the mid-1990s and this continues today. The well-documented dreissenid invasion of the early 1990s has been implicated in ecosystem re-engineering by increasing hard substrate area, improving water clarity, and transporting nutrients either from the pelagic to the benthos, or retained in the nearshores, preventing transport to the offshore zone (Fahnenstiel et al. 1995; Hecky et al. 2004). Urbanization has also had an increasing impact on the coastal regions of the Great Lakes through increased shoreline degradation, including shoreline hardening to prevent shore erosion and loss of wetlands, and more extensive impervious land cover, with the latter two both increasing the frequency and volume of pulse runoff events. With these wide-scale processes potentially influencing the resurgence in *C. glomerata* growth, it was decided that the relative influence of localized point sources and temporal variation on *C. glomerata* nutrient stoichiometry must first be delineated along a 12 km stretch of shoreline within the Region of Halton. A recent assessment (Aquafor Beech 2005) of nutrient loading at all major lake inputs concluded that 16 Mile Creek and the Oakville South East WWTP were the most influential inputs along the Halton shoreline spanning from Joshua Creek to Burlington Beach. The survey included all watercourses, storm sewers directly accessing Lake Ontario in Halton Region, and waste water treatment plant (WWTP) outfalls within the study area. With this background information a survey was designed to evaluate the influence of these point sources on *Cladophora* growth.

Adams and Stone (1973) noted that site differences in *C. glomerata* productivity were related to nutrient levels, while seasonal differences were driven by temperature. Seasonal fluctuations in internal nutrient stoichiometry must first be established before

searching for spatial trends along this 12 km reach of shoreline or other shorelines. It was hypothesized that there would be significant seasonal changes in *C. glomerata* internal carbon, nitrogen, and phosphorus concentrations at all stations based on seasonal changes in nutrients, temperature, light transparency, photoperiod, and *C. glomerata* biomass. It was further hypothesized that, over the season, the internal nutrient concentrations or photosynthetic rates of *C. glomerata* would be influenced by proximity to significant nutrient point source inflows relative to more distal locations. Trends in these factors may be similar among all stations and the nutrient in least supply will control growth rates when ample light and substrate permit growth. Temporal effects were studied over the 2006 growing season along the Halton shoreline. From April to October, surveys were carried out at least once monthly, with greater frequencies in early spring and early summer to increase temporal resolution for quantification of initial nutrient levels and peak biomass, respectively.

The relative significance of localized point-sources to *C. glomerata* stoichiometry is compared along the Halton shoreline to determine if point sources of nutrients can affect growth conditions for *C. glomerata* at local scales. It was hypothesized that local point sources would result in higher internal nutrient concentrations in *C. glomerata* growing nearer to those sources. For the spatial assessment in this study, nutrient point-sources will be defined as waste water treatment plant (WWTP) effluents, direct storm sewer outfalls, streams entering coastal areas, or any discrete input relative to the 12 km of shoreline surveyed. Nonpoint-sources will be regarded as more diffuse inputs from coastal sheet runoff, phosphorus recycled by dreissenid mussels covering the lake bottom which would include phosphorus imported from the atmosphere or the open lake. The

offshore open lake can be a non-point source or sink of nutrients to or from the nearshore especially if dreissenid mussels have changed the capacity of the nearshore to retain nutrients in particulate form; e.g. by consuming phytoplankton cells originating from the offshore. The relative significance of point- and nonpoint-sources to support *C. glomerata* growth was be evaluated through repeated transect surveys designed to determine the importance of these different sources of coastal nutrient loading.

In the Great Lakes, the chemistry and physical environment of the overlying water controls *C. glomerata* growth (Higgins et al. In press). Most monitoring programs include water chemical analyses, physical conditions, and meteorological observations, but few collect algal tissue samples, which can be assayed directly to determine nutrient status of this nuisance macroalga. Moreover, if currently monitored parameters can be determined to be proxies for algal growth, then the more intensive tissue collection may not be required and growth can be predicted from water column characteristics from routine surveys. Field surveys were designed to assay a broad range of physical and chemical conditions including general indicators for coastal urban pollution such as chloride concentrations. Nutrient, temperature, and physical parameters were also assessed to identify spatial patterns related to point and non-point influences along the surveyed shoreline.

In summary, the spatial and temporal variation of environmental factors relevant to *Cladophora* growth along the Halton Region shoreline was assessed in 2006 and compared with the nutrient stoichiometry of the plant tissue. Four depth transects, centred on the major tributary, 16 Mile Creek, to the study area, were selected to ensure

that major point sources along the Halton shoreline were included in order to determine their relative influence on the stoichiometry and growth potential of *Cladophora glomerata* for future management considerations.

2.3 Methods

2.3.1 Survey Site and Field Sampling

The survey site was located in the western end of Lake Ontario centred on the mouth of 16 Mile Creek in Oakville, Ontario (Fig. 2.1). This river is in a highly urbanized watershed within the Greater Toronto Area (GTA). The adjacent contiguous shoreline segment studied includes four smaller streams as well as the large and central 16 Mile Creek. There is also a waste water treatment plant outfall (Oakville South East WWTP) at the northeast end of the shoreline section. Thirteen stations were sampled throughout the 2006 field season, twelve of which were located along four transects (Fig. 2.1), spaced three or more kilometres apart to avoid pseudoreplication (Palmer 1968) and extending over 2, 5, and 10 m depth contours. The final station was located centrally 2.5 km offshore, at a depth of 35 m to act as an offshore reference point taken to represent open lake conditions. Sampling was carried out monthly from April to October 2006, with increased frequency in April and June to capture initial growth conditions and peak biomass, respectively.

2.3.2 Physical Measurements

Typically at each station during each survey, temperature and conductivity profiles were performed using a CTD profiler. Similarly, photosynthetically active radiation

(PAR) depth penetration was also measured using a Li-Cor radiometer. Using PAR measurements versus depth, the PAR attenuation coefficient (K_d) was calculated and subsequently used to determine PAR at depth. Underwater video was also collected periodically for benthic substrate verification, abundance of *Cladophora*, and dreissenid (Ozersky unpublished data) presence. Hydroacoustic algal biomass estimates were also measured (Depew unpublished data) along the shoreline at the time the transects were sampled.

2.3.3 Water column sampling and analyses

At each station sampled, water samples were collected midway through the water column. If thermal structure was present at the 5 and 10 m stations, then one sample was collected mid-epilimnion and an additional sample was collected 1 m off the bottom. All water collections were performed using a Niskin bottle. Samples were stored in dark coolers at lake temperature for transport to the laboratory. Laboratory measurement of water chemistry and internal *C. glomerata* nutrients were carried out for each sample. Total P (TP), total dissolved P (TDP), soluble reactive P (SRP), and particulate phosphorus concentrations in the water column (Table 2.1) were determined according to methods from Stainton et al. (1977) using an Ultraspec 3100 Pro UV/Visible Spectrophotometer and a 10 cm cuvette. TP samples were unfiltered, TDP and SRP were both filtered using 0.2 µm polycarbonate filters, and PP samples were filtered on glass fibre filters (GF/F), nominal pore size 0.8 µm. Additional ions, including nitrate, chloride, and sulphate, were measured using ion chromatography (Dionex DX 500, Dionex AS17, and AG17 guard column, respectively). Ammonium was determined by

fluorometry (Holmes et al. 1999). Total suspended solids were measured by filtering 2-3 L of lake water onto pre-combusted (500ºC for 4 hr) and pre-weighed glass fibre filters (GF/F), drying for 24 hrs at 65ºC and reweighing. Chlorophyll-*a* concentrations were measured by fluorometry (Smith et al. 1999). Particulate nutrients, carbon (C) and nitrogen (N), were filtered onto pre-combusted GF/F filters, pore size 0.8 µm. Nutrient status indicators for phytoplankton were determined using molar particulate nutrient ratios; C:N, C:P, and N:P. Reference values used as indicators of phytoplankton nutrient deficiency for C:P, C:N, and N:P are greater than 129 (P deficient), 8.3 (N deficient), and 22 (P deficient), respectively, (Healey & Hendzel 1979, 1980). These values are also summarized and contrasted with Lake Erie data (Guildford et al. 2005) where similar values were attained within the eastern basin. Moderate nutrient deficiency in those Lake Erie phytoplankton samples was observed as mean C:P and C:N atomic ratios were measured to be 212 and 9.3, respectively.

Table 2.1. Measurements and profiles of physico-chemical parameters and *C. glomerata* tissue at near shore sites in the Great Lakes, 2005/06

Water Chemistry	*Cladophora* Tissue Analyses	Physical Measurements
Total CNP	Total CNP	Depth
Particulate CNP	$\delta^{13}C$	Wind
TDP	$\delta^{15}N$	Surface Temperature
SRP	Chl-*a*	Depth Temperature
SRSi		YSI (Salinity, DO, PAR)
NH_3		Secchi
NO_3^-		LiCor
Cl^-		
Chl-*a*		
AFDW		
F_v/F_m (PAM)		

2.3.4 Internal *C. glomerata* Nutrient Chemistry and Physiology

Cladophora glomerata samples were collected by use of a sampling rake. This instrument is a standard rigid flat rake affixed to a rope that connects to the sampling vessel. The method involved tossing the rake overboard and dragging it along the substrate in order to collect sufficient algal biomass for analysis. Algal tissue samples were then stored in dark coolers at lake temperature until laboratory analysis. Tissue samples were subsequently washed in deionized water, freeze-dried, and stored at -4ºC, to prevent cell degradation until internal tissue nutrients (carbon, nitrogen, and phosphorus) were measured. For phosphorus content analysis, ground tissue samples were combusted, autoclaved with saturated potassium persulfate for acid digestion and then measured on an Ultraspec 3100 Pro UV/Visible Spectrophotometer using a 5 cm cuvette according to a modified protocol from Stainton et al. (1977). Internal P concentrations were measured as a percentage of ash-free dry weight (AFDW) by combusting and reweighing dried algal material prior to the above mentioned potassium persulfate digestion. As %P AFDW values are not commonly reported, this data is simply used for discussion with historical records. *C. glomerata* carbon and nitrogen concentrations were determined using a CE-440 Elemental Analyzer (Exeter Analytical, Inc.). Chlorophyll-*a* concentrations were measured via fluorometry using acetone extraction from ground tissue samples (Krause & Weis 1991; Maxwell & Johnson 2000; Hagerthey et al. 2006). Four internal algal nutrient ratios were measured, including C:N, C:P, N:P (molar) and C:Chl-*a*.(μmole/μg).

Finally, during each survey benthic hydro-acoustic measurements were performed by cruising the vessel at intervals of 75 m between and at each station on a continuous basis in order to estimate areal *C. glomerata* biomass through interpolation (unpublished data, D. Depew, University of Waterloo).

2.3.5 Statistical Analyses

Statistical analyses were performed using Systat 10.2 (Wilkinson 1996) to determine if there are significant differences in *C. glomerata* nutrient composition between seasons, stations, and depths. Hypolimnetic and epilimnetic water chemistry was tested with a paired t-test to determine if thermal structure was consistent enough to promote varying environments between the benthic layer and the pelagic zone. Seasonal variation was subsequently assessed graphically and with a one-way analysis of variance, comparing spring, summer, and autumn data. The spatial variation of individual stations along the Halton shoreline was determined by use of a two-way analysis of variance using depth and transect as the two factors. Each station was labelled by depth (2, 5, or 10 m), and transect (a, b, c, or d), excluding the 35 m offshore station. Finally, nearshore stations at 2, 5, and 10 m were contrasted with the offshore 35 m station with a one-way analysis of variance over the four depths. Several analyses of variance were performed to determine if seasonal and spatial relationships existed in water and algal nutrient chemistry and to identify potential nutrient point sources. Data were log transformed when necessary to achieve a normal distribution.

2.4 Results

2.4.1 Physical Properties of the Halton Coastal Zone

During the month of April, water temperatures were approximately 6.0ºC. On average, lake temperature during the survey on May 8 was 9.9ºC. This increased quickly to 17.6ºC by June 8, a month later. Temperatures fluctuated during late June and July as upwelling events were evident by the cooler temperatures and lack of thermal structure (Fig. 2.2). Temperatures increased to 19.5ºC by August 1, and were measured at 18.8ºC on September 14, before declining rapidly over the next month to as low as 5.0ºC on October 19, due to the decline in atmospheric temperatures and photoperiod.

Based on these temperature trends, water chemistry (section 2.4.2), and *C. glomerata* nutritional status and abundance (section 2.4.3), there appears to be three distinct seasons along the Halton shoreline that our data will be categorized for analyses:

Spring - surveys from April 6, the earliest date surveyed, to May 8, 2006.

Summer - spanned the surveys from June 8 to August 1.

Autumn - data included the September 14 and our final survey on October 19.

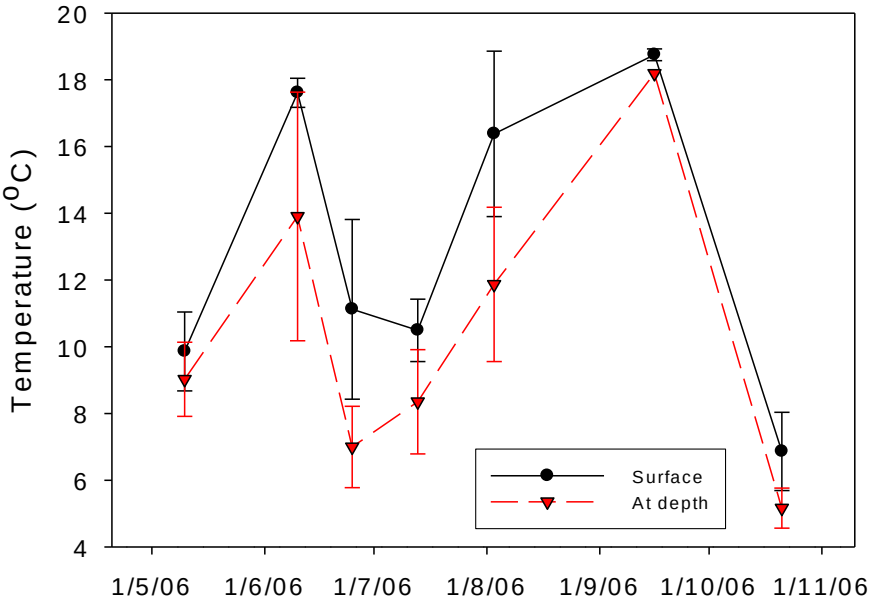

Figure 2.2: Water column temperature along the Halton shoreline at surface and 1 m from bottom. Stratification (as defined as greater than $1^{o}C\ m^{-1}$ change in water temperature within the water column for the majority of stations sampled that date) occurred on Aug. 1, 2006, whereas most other survey dates were during spring or fall turnover or summer upwelling (cooling) events.

Measurements of water clarity included light extinction (kPAR) (Fig. 2.3), suspended solids (TSS) (Fig. 2.4), and ash free dry weight (AFDW). 2-way analyses of variance tested the independent and interactive effects of depth and transect (Table 2.2). The kPAR values were consistently higher at 2 m stations in both summer and autumn (insufficient data for analysis for spring was gathered) and indicated that water clarity was lower at transects "B" and "D", adjacent to 16 Mile Creek and the Oakville Southeast WWTP, respectively. As well, both TSS and AFDW at a 2 m station, 631, was

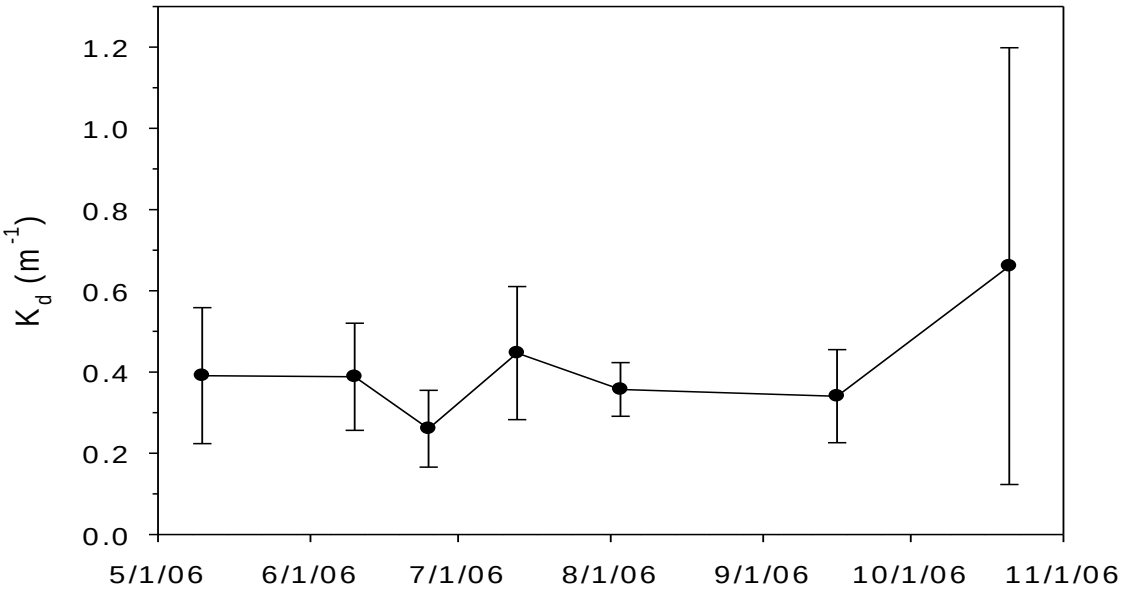

Figure 2.3: Light extinction coefficient (K_d) along the Halton shoreline, 2006, at all depths. Error bars indicate standard deviation.

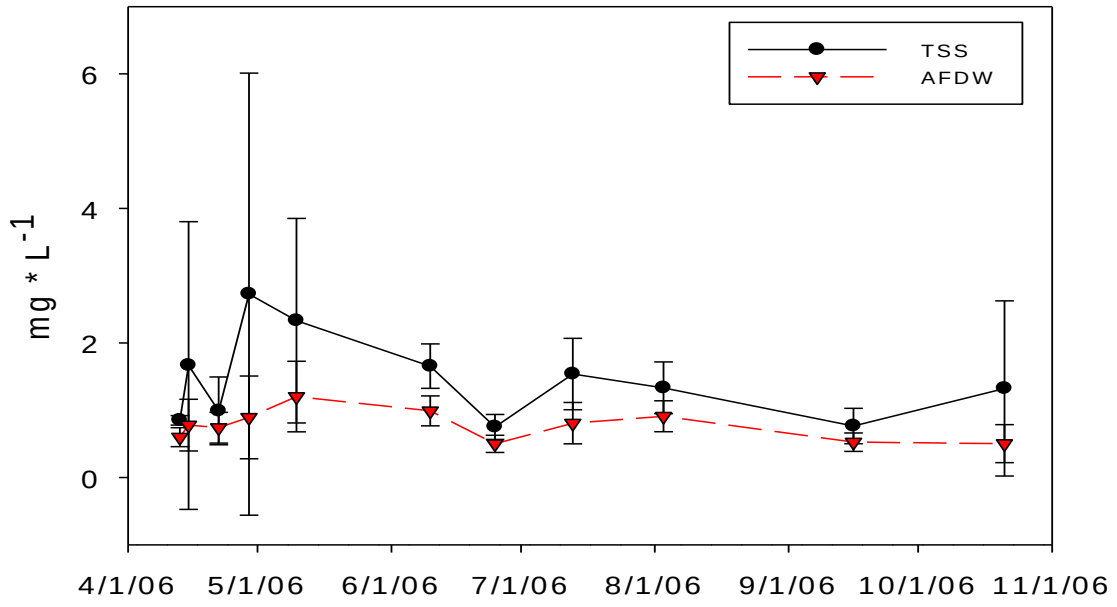

Figure 2.4: Total suspended solids (TSS) and ash freed dry weight (AFDW) of samples along the Halton shoreline, 2006, at all depths. Error bars indicate standard deviation.

Table 2.2: Spatial analyses of physical parameters and *Cladophora* internal nutrients. 2-way ANOVA factoring transect and depth during the summer of 2006. Abbreviations and units as in Table 2.3. * indicates statistically significant (P<0.05).

Parameter	Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Surface	Transect	0.604	3	0.201	0.01	0.998
Temperature	Depth	1.976	2	0.988	0.06	0.946
	Interaction	4.403	6	0.734	0.04	1.000
Depth	Transect	2.444	3	0.815	0.06	0.980
Temperature	Depth	114.13	2	57.065	4.23	0.023*
	Interaction	6.553	6	1.092	0.08	0.998
K_{PAR}	Transect	0.148	3	0.049	3.88	0.013*
	Depth	0.411	2	0.205	16.12	0.000*
	Interaction	0.034	6	0.006	0.45	0.842
%Io at Z	Transect	476.22	3	158.74	3.20	0.029*
	Depth	9187.251	2	4593.625	92.55	0.000*
	Interaction	284.861	6	47.477	0.96	0.462
pH	Transect	0.053	3	0.018	0.46	0.715
	Depth	0.101	2	0.05	1.29	0.285
	Interaction	0.091	6	0.015	0.39	0.884
Alk	Transect	0.002	3	0.001	0.34	0.794
	Depth	0.001	2	0.001	0.28	0.757
	Interaction	0.004	6	0.001	0.29	0.942
Tissue	Transect	1.664	3	0.555	1.99	0.138
Chl-a	Depth	6.306	2	3.153	11.33	0.000*
	Interaction	3.531	6	0.588	2.11	0.083
Tissue C	Transect	1570.586	3	523.529	1.60	0.212
	Depth	78.137	2	39.069	0.12	0.888
	Interaction	1161.814	6	193.636	0.59	0.734
Tissue N	Transect	65.891	3	21.964	1.81	0.169
	Depth	501.634	2	250.817	20.63	0.000*
	Interaction	124.821	6	20.803	1.71	0.155
Tissue P	Transect	0.332	3	0.111	0.75	0.534
	Depth	7.287	2	3.643	24.60	0.000*
	Interaction	0.74	6	0.123	0.83	0.555
Tissue C:Chl-*a*	Transect	114.41	3	38.137	0.45	0.717
	Depth	1078.909	2	539.455	6.42	0.005*
	Interaction	355.324	6	59.221	0.70	0.649
Tissue C:P	Transect	75282.754	3	25094.251	0.36	0.784
	Depth	1949260.731	2	974630.366	13.88	0.000*
	Interaction	126235.624	6	21039.271	0.30	0.932
Tissue C:N	Transect	11.955	3	3.985	1.91	0.150
	Depth	105.734	2	52.867	25.39	0.000*
	Interaction	8.516	6	1.419	0.68	0.666
Tissue N:P	Transect	80.329	3	26.776	0.12	0.949
	Depth	4161.507	2	2080.753	9.20	0.001*
	Interaction	471.038	6	78.506	0.35	0.906
Tissue P	Transect	22.109	3	7.37	3.38	0.032*
(AFDW)	Depth	102.593	2	51.296	23.56	0.000*
	Interaction	45.446	6	7.574	3.48	0.011*

found to be significantly greater during the spring surveys (two-way ANOVA, F=10.174, p = 0.001) though no relationship to nutrient status indicators was evident. This station was in close proximity to the same WWTP outfall. Furthermore, water clarity, as determined by TSS and k_{PAR}, was clearest on June 23, corresponding with the strongest upwelling event as observed through water temperature measurements (Table 2.3).

Table 2.3: 2006 daily means of biological, chemical, and physical nutrient variables. C/P, C/N, N/P = particulate carbon, nitrogen, and phosphorus, atomic ratios; Chl = chlorophyll *a* (µg/L); TP = total phosphorus (µg/L); SRP = soluble reactive phosphorus (µg/L); NO_3^- = nitrate (µg/L); SRSi = soluble reactive silicon (µg/L); Cl^- = chloride ion (µg/L); kPAR = extinction coefficient of photosynthetically active radiation (m^{-1}); TSS = total suspended solids (mg/L); Alk = alkalinity (meq/L). "ANOVA-Seasonal" tests seasonal variation of Spring, Summer, and Autumn data; Water chemistry analyses were performed on pooled samples from both surface and one metre off bottom, when available, from all depth contours: 2, 5, and 10 m stations, on each survey date.

	Spring	Summer					Autumn		ANOVA
	Apr 11-28	May-08	Jun-08	Jun-23	Jul-11	Aug-01	Sep-14	Oct-19	Seasonal
Biological									
C/P	237	264	267	244	269	189	137	147	0.000
C/Chl	19.4	38.5	23.9	47.0	17.8	23.2	52.5	50.8	0.000
C/N	8.0	8.0	7.2	7.5	7.3	6.9	7.6	8.7	0.000
N/P	30.5	32.7	37.0	32.7	36.9	27.1	17.9	16.6	0.000
Chl	2.17	1.05	2.10	0.52	2.04	1.64	0.43	0.48	0.000
Chemical									
TP	8.31	8.28	9.78	5.82	7.89	9.83	18.37	12.72	0.000
TDP	4.65	4.20	3.86	3.02	3.74	4.28	10.99	7.88	0.000
SRP	3.26	1.74	0.83	0.93	1.07	0.61	7.63	4.18	0.000
TN		756	817	779	686	505	429	602	0.000
NO_3^-	409	339	310	321	271	241	235	327	0.001
NH_3	43.9	38.5	44.0	33.7	26.4	36.6	91.7	17.1	0.000
SRSi	511	274	373	580	365	275	751	1189	0.000
Cl^-	22	16	17	15	13	13	14	14	0.000
Physical									
Temp		9.86	17.61	11.12	10.49	16.38	18.75	6.86	
k_{PAR}		0.391	0.388	0.260	0.447	0.357	0.341	0.661	0.034
TSS	1.73	2.33	1.66	0.75	1.54	1.33	0.76	1.32	0.005
Alk		1.77	1.84	1.78	1.82	1.77	1.73	1.81	

2.4.2 Water Column Nutrient Chemistry

As it was apparent that upwelling events had occurred based on temperature data and turbidity measures, epilimnetic and hypolimnetic water chemistry was compared to

determine the effect on thermal stratification. Due to the lack of statistical differences between the two thermal layers, data for most water chemistry parameters (Table 2.4) have been pooled for subsequent analyses where appropriate.

Table 2.4: Paired t-Test results contrasting epilimnetic water chemistry with hypolimnetic, during the summer (Jun. 8 - Aug.1) and Autumn (Sep. 14 - Oct. 19). Spring observations were during isothermal periods and only one water sample per station was collected midway in the water column. Abbreviations and units as in Table 2.3. * - Denotes p-value less than 0.05.

Parameter	Summer		Autumn	
	t	p	t	p
TSS	2.19	0.040*	1.23	0.259
AFDW	2.39	0.026*	1.23	0.258
Chl-*a*	1.47	0.156	2.35	0.051
Particulate C	2.07	0.050	2.81	0.026*
Particulate N	2.26	0.034*	2.71	0.030*
Particulate P	2.24	0.036*	1.38	0.211
TP	1.69	0.104	0.34	0.744
TDP	-0.57	0.573	-0.08	0.463
SRP	-0.04	0.966	-0.89	0.404
NO_3^-	-0.88	0.390	0.29	0.780
NH_3	-0.24	0.810	0.59	0.581
TN	0.53	0.604	0.62	0.561
Cl	-0.21	0.838	-1.58	0.159
SO_4^{2-}	-0.71	0.483	-1.84	0.108
SRSi	-1.99	0.058	-1.68	0.136

Phosphorus concentrations, total (TP), total dissolved (TDP), and soluble reactive (SRP), displayed strong seasonal patterns overall (Fig. 2.5). Mean spring and summer TP concentrations were 7.9 and 8.3 µg/L, respectively, followed by a two-fold autumn increase to 15.6 µg/L. TDP and SRP concentrations were on average drawn down to 3.73 and 0.86 µg/L by mid summer, respectively, before increasing to 9.44 µg-TDP/L and 5.91 µg-SRP/L in the autumn surveys.

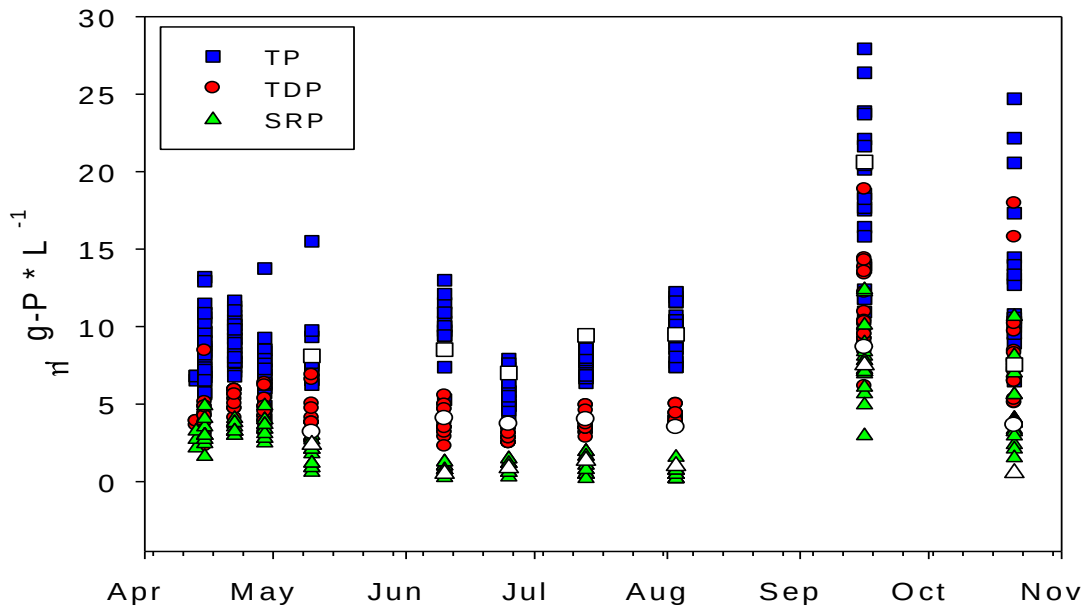

Figure 2.5: Total, Dissolved, and Soluble Reactive Phosphorus concentrations along the Halton shoreline, 2006, in µg P/L. Data was collected at 2, 5, and 10 m nearshore stations as well as one 35 m (white symbols) offshore station, which was often within the range of values found nearshore.

Individual stations were also tested statistically to determine if any point sources had a significant influence on water chemistry. Two-way analysis of variance over the 4 transects and the 3 depths (Fig. 2.1) during the summer surveys were performed for each separate chemical and biological variable (Table 2.5). No significant point sources for TP, TDP, or SRP were found during the summer. As there were no potential point sources, we contrasted these same nearshore stations with our 35 m offshore station in one-way analyses of variance that tested 2, 5, 10, and 35 m stations during the summer (Table 2.6). Again, we found no statistical difference between our nearshore stations and the offshore for phosphorus parameters.

Table 2.5: Spatial analysis of water chemistry along the Halton shoreline. 2-way analysis of variance factoring depth (2, 5, and 10 m) and transect (a, b, c, and d), (see Fig. 2.1 for locations), during the summer, Jun. 8 - Aug. 1, 2006. Abbreviations as in Table. 2.3

Parameter	Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
TSS	Transect	0.145	3	0.048	0.18	0.910
	Depth	0.198	2	0.099	0.37	0.694
	Interaction	1.126	6	0.188	0.70	0.653
AFDW	Transect	0.117	3	0.039	0.41	0.748
	Depth	0.013	2	0.006	0.07	0.935
	Interaction	0.203	6	0.034	0.35	0.905
Part C:Chl-*a*	Transect	534.468	3	178.156	0.60	0.617
	Depth	2000.286	2	1000.143	3.37	0.041*
	Interaction	2068.550	6	344.758	1.16	0.338
Part C:P	Transect	14651.261	3	4883.754	1.03	0.384
	Depth	10315.923	2	5157.961	1.09	0.342
	Interaction	6566.389	6	1094.3989	0.23	0.965
Part N:P	Transect	244.529	3	81.51	1.05	0.375
	Depth	245.363	2	122.681	1.59	0.213
	Interaction	89.659	6	14.943	0.19	0.978
Part C:N	Transect	534.468	3	0.456	1.44	0.239
	Depth	2000.286	2	0.064	0.20	0.818
	Interaction	2068.55	6	0.528	1.67	0.143
TP	Transect	3.344	3	1.115	0.21	0.891
	Depth	0.123	2	0.061	0.01	0.989
	Interaction	3.120	6	0.520	0.10	0.996
TDP	Transect	3.177	3	1.059	1.12	0.348
	Depth	3.528	2	1.764	1.86	0.163
	Interaction	5.366	6	0.894	0.95	0.470
SRP	Transect	0.411	3	0.137	0.71	0.547
	Depth	0.265	2	0.133	0.69	0.505
	Interaction	0.734	6	0.122	0.64	0.700
NO_3^-	Transect	30908.236	3	10302.745	2.74	0.051
	Depth	2348.706	2	1174.353	0.31	0.733
	Interaction	18019.094	6	3003.182	0.80	0.575
NH_3	Transect	3903.355	3	1301.118	3.96	0.012*
	Depth	1248.269	2	624.134	1.90	0.159
	Interaction	2057.543	6	342.924	1.04	0.407
TN	Transect	45112.157	3	15037.386	0.38	0.765
	Depth	6256.861	2	3128.430	0.08	0.923
	Interaction	237654.328	6	39609.055	1.01	0.429
Cl	Transect	2.132	3	0.711	0.12	0.947
	Depth	13.372	2	6.686	1.14	0.325
	Interaction	13.361	6	2.227	0.38	0.889
SO_4^{2-}	Transect	0.821	3	0.274	0.10	0.959
	Depth	6.703	2	3.352	1.23	0.298
	Interaction	16.492	6	2.749	1.01	0.426
PSi	Transect	35642.228	3	11880.743	0.51	0.678
	Depth	6138.367	2	3069.184	0.13	0.877
	Interaction	40240.756	6	6706.793	0.29	0.941
SRSi	Transect	58476.291	3	19492.097	0.54	0.657
	Depth	391801.544	2	195900.772	5.42	0.007*
	Interaction	96675.338	6	16112.556	0.45	0.845

Table 2.6: Testing if nearshore is different from offshore in water chemistry. Analysis of variance of depth influence on water chemistry during each season, Halton, 2006. Abbreviations and units as in Table 2.3.

	Spring NB: no 35 m data		Summer		Autumn	
Parameter	F	p	F-ratio	P	F	p
TSS	0.86	0.460	0.88	0.456	1.58	0.211
AFDW	0.75	0.501	0.49	0.693	1.63	0.200
Part C:Chl-*a*			2.43	0.072		
Part C:P			1.09	0.360		
Part N:P			1.48	0.230		
Part C:N			0.12	0.949		
TP	4.42	0.046*	0.04	0.990	0.35	0.787
TDP	5.33	0.030*	1.32	0.274	2.36	0.087
SRP	1.94	0.206	0.55	0.651	1.81	0.163
NO_3^-	0.01	0.989	0.67	0.571	3.19	0.035*
NH_3	2.82	0.112	1.39	0.251	0.09	0.964
TN	1.36	0.305	0.70	0.559	1.30	0.296
Cl	1.74	0.230	0.83	0.481	1.80	0.164
SO_4^{2-}	0.76	0.495	0.83	0.481	0.42	0.737
PSi	1.36	0.309	2.59	0.060	1.26	0.304
SRSi	10.11	0.005*	4.59	0.005*	0.72	0.544

* - Denotes p-value less than 0.05.

Total nitrogen, nitrate, and ammonia were then assessed over 2006. Autumn concentrations of total nitrogen (TN) were found to be lower relative to spring and summer values (Table 2.3) as were nitrate concentrations. However, ammonia concentrations slowly declined from the spring into summer before increasing dramatically in September. Spatial analyses (Table 2.5) of nitrogen species indicated that TN and nitrate had no spatial variation; but, during the summer surveys, ammonia varied significantly with respect to location along the shoreline. It was evident that transect D, the transect furthest east in Figure 2.1, was elevated in ammonia as the average concentration was 51 µg-NH_3/L while the other three transects and even our offshore station averaged 30 µg-NH_3/L during this same period. No relationship with depth, i.e.

distance from shore, was identified (Table 2.5) and no contrast between nearshore and offshore water conditions was evident (Table 2.6).

Phytoplankton nutrient status indicators displayed some variation seasonally (Table 2.3). Particulate C:P and N:P molar ratios were both indicative of phosphorus deficiency during the spring and summer (Fig. 2.6 & 2.7). C:N ratios were typically below threshold values for N deficiency throughout the year (Fig. 2.8). No spatial variation for particulate nutrient ratios was observed (Table 2.5). Further, no significant difference in nearshore and offshore waters was measured (Table 2.6) during the summer surveys.

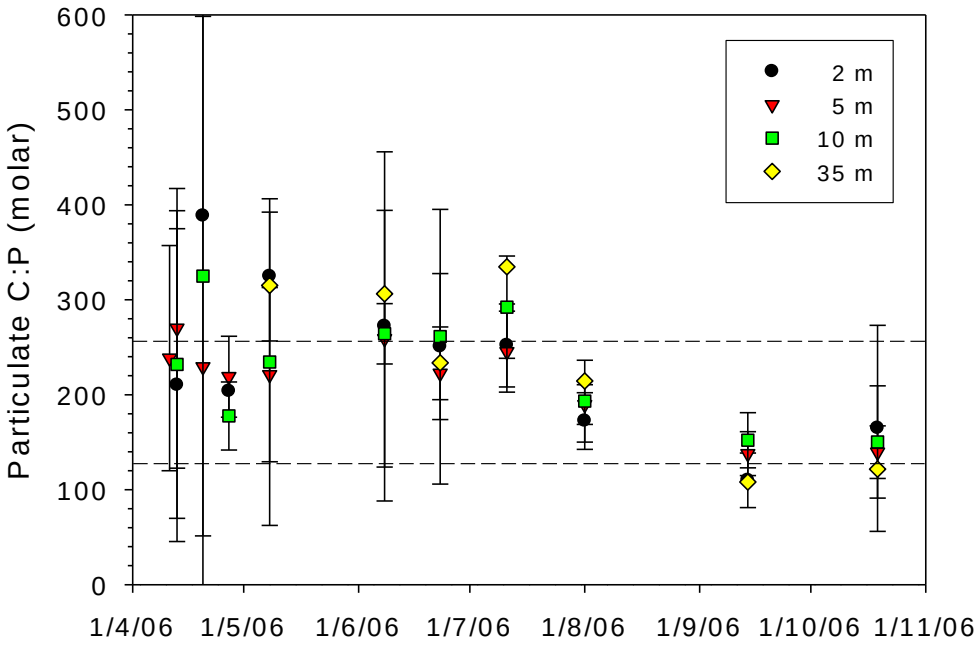

Figure 2.6: Phytoplankton C:P molar ratios along the Halton shoreline, 2006. Data points represent averages at each depth across all four transects, error bars represent the 95% CI. Values above dashed lines represent moderate (129) and severe (258) P deficiency (Guildford et al. 1994).

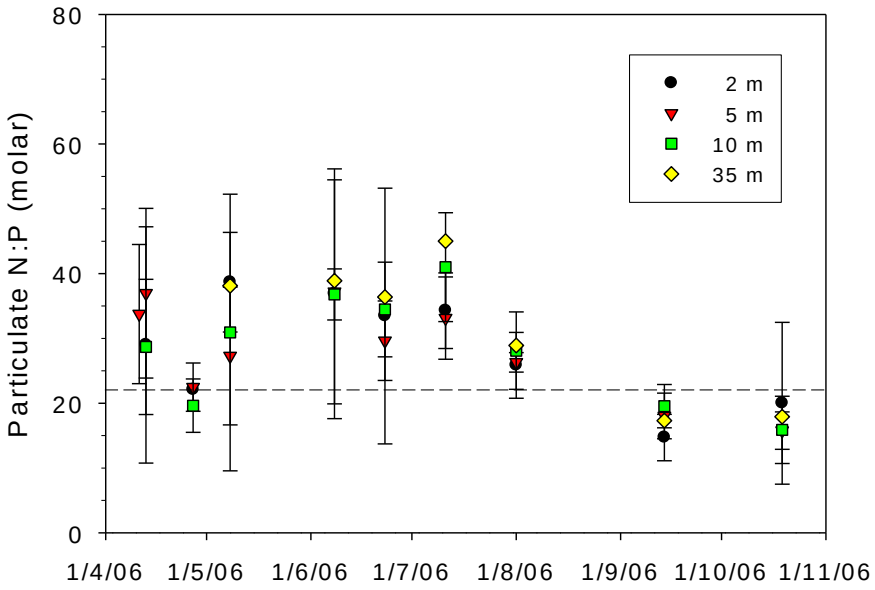

Figure 2.7: Phytoplankton N:P molar ratios along the Halton shoreline, 2006. Data points represent averages at each depth across all four transects, error bars represent the 95% CI. Values above 22 represent P deficiency (Guildford et al. 1994).

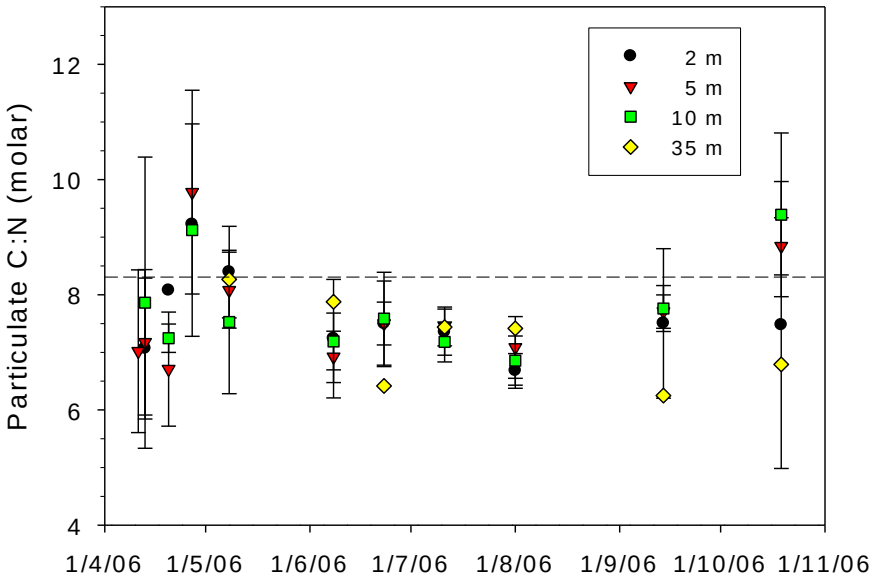

Figure 2.8: Phytoplankton C:N molar ratios along the Halton shoreline, 2006. Data points represent averages at each depth across all four transects, error bars represent the 95% CI. Values greater than 8.3 display moderate N deficiency, whereas severe N deficiency begins at 14.6, not shown (Guildford et al. 1994).

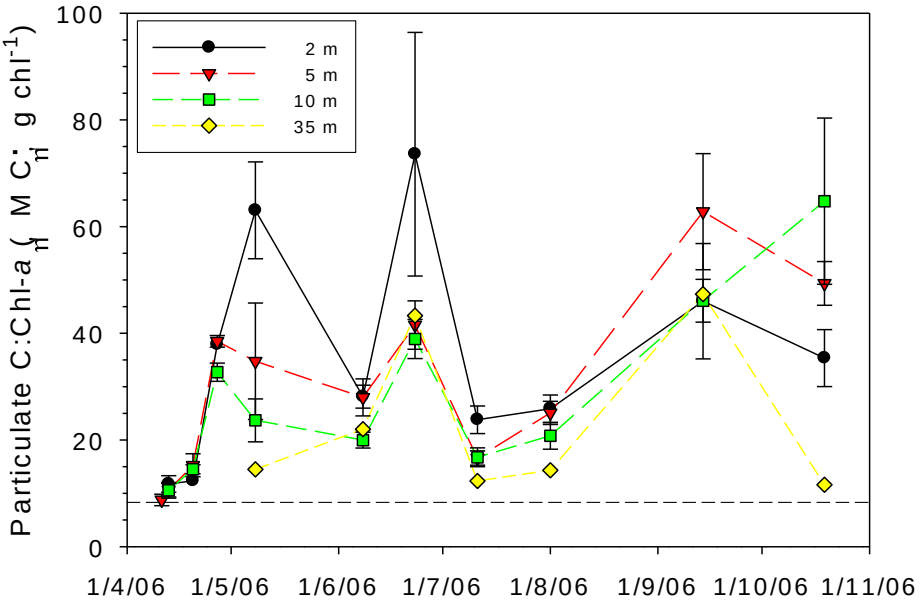

Figure 2.9: Particulate C: chlorophyll-*a* ratios along the Halton shoreline, 2006. Data points represent averages at each depth across all four transects, error bars represent the standard error. Values above 8.3 (dashed line) represent severe nutrient (N or P) deficiency, whereas moderate nutrient deficiency begins at 4.2, not shown (Guildford et al. 1994).

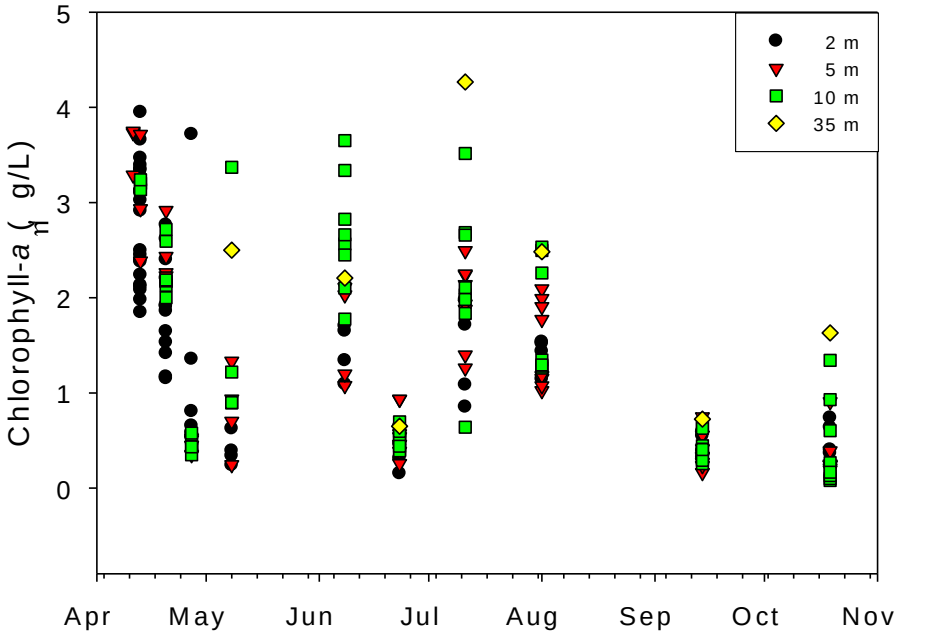

Figure 2.10: Planktonic chlorophyll-*a* concentrations along the Halton shoreline over the 2006 season delineated by depth.

Particulate carbon:chorophyll-*a* ratios (Fig. 2.9) were generally above 8.3, indicating severe nutrient deficiency (Guildord et al. 1994). Seasonal values increased in late April and early May, specifically at shallower stations. The surveys on June 8 and July 11 were found to have declined from earlier in the year, while the June 23 survey saw an increase in the C:Chl-*a* ratio; with greater fluctuation nearer to shore. No individual point source was identified (Table 2.5), though a significant relationship with depth was found, as 10 m stations consistently had higher chlorophyll concentrations with respect to 2 and 5 m stations. It would appear that chlorophyll-a concentrations tend to be higher further from shore (Fig. 2.10), but no significance difference between the nearshore and our offshore station was determined (Table 2.6).

Other chemical parameters also displayed variable seasonal relationships. Soluble silicon had higher concentrations during the autumn months (Table 2.3) across all stations and was significantly greater at 10 m stations during the spring and summer months (Table 2.6), however, results at 35 m in summer were comparable to 2 and 5 m stations and were not significantly different in autumn. Chloride ion concentration was greater in the spring relative to both summer and autumn concentrations, indicative of the effect of spring runoff and higher catchment flows at that time (Table 2.3). There was also a noticeable difference in chloride concentrations between 2 m stations and both 10 and 35 m stations during the autumn again consistent with a catchment runoff affecting shallow stations nearest the shorelines. Alkalinity was also observed to be higher only in the summer at all stations (Table 2.3).

To summarize, the results from water chemistry measurements show that most parameters have a seasonal pattern, while only chlorophyll-*a* concentrations displayed any relationship with depth (Fig. 2.10). In attempts to identify point source influences, water clarity (k_{PAR}) was found to be lower at the 2 m station (601, Fig. 2.1) adjacent to 16 Mile Creek and at the 2 m station (633, Fig. 2.1) near the Oakville Southeast WWTP outfall, as well as higher concentrations of ammonia were found at transect D (Fig. 2.1), adjacent to the same WWTP outfall.

2.4.3 *C. glomerata* Internal Nutrient Chemistry

In general, *C. glomerata* nutrient stoichiometry exhibited a strong seasonal pattern with phosphorus (Fig. 2.11) and nitrogen (Table 2.7): both were depleted in the summer, followed by a sharp increase in concentration during the September and October surveys at 2 m stations. Spatial variation in *C. glomerata* nutrient C:P, C:N, and N:P ratios appeared to be related to light, as each decreased with depth, suggesting light limitation at greater depths with respect to external nutrient supplies. Temperature appeared to be a controlling factor in *C. glomerata* biomass as spring and autumn seasons were low in biomass at both 5 and 10 m stations, as indicated by the number of sample collections (Fig. 2.12). No point source influence was indicated in *C. glomerata* nutrient status indicators.

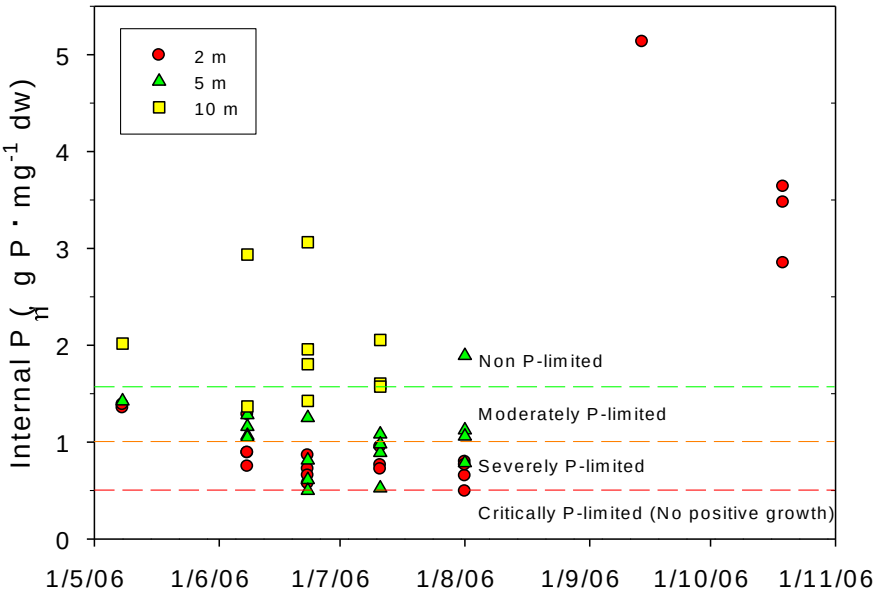

Figure 2.11: *Cladophora* internal phosphorus concentrations over 2006 along the Halton shoreline, Lake Ontario. 10 m stations exhibit higher P concentrations on each sample date. Wong & Clark (1976) determined that P-limited *Cladophora* growth begins below 1.6 µg P/mg dw and the Droop equation used to model specific growth as a function of internal P concentrations has an inflection point at a P concentration of 1.0 µg/mg dw (Auer & Canale, 1982; Higgins, 2005). As well, the critical concentration of internal P for positive *Cladophora* growth is 0.5 µg P/mg dw (Gerloff & Fitzgerald, 1976).

Visible macroalgae were not observed during any of the surveys in April, and were first visible on the May 8 survey (Fig. 2.12). Short tufts of filamentous algae were observed at all four 2 m stations, although enough material for tissue nutrient analyses was available only at stations 600 and 601, which are located ~3 km southwest of, and immediately northeast of the 16 Mile Creek input, respectively. One sample was collected at station 604, the 5 m station directly offshore of 601, and adjacent to the creek input. As well, one collection at a 10 m station, 608, was accomplished. During the June 8 survey, complete coverage at the 2 and 5 m stations was observed and samples were collected. Two 10 m stations, 606 and 608, also had sufficient algal growth for rake

Table 2.7: 2006 daily means of internal *Cladophora* nutrient variables. C/P, C/N, N/P = carbon, nitrogen, and phosphorus, atomic ratios; Chl = chlorophyll *a (*µg/mg DW); "ANOVA-Seasonal" tests variation between Spring, Summer, and Autumn data; * - Summer and Autumn data tested only; ** - n = 1.

	Spring		Summer				Autumn		ANOVA
	Apr 11-28	May-08	Jun-08	Jun-23	Jul-11	Aug-01	Sep-14	Oct-19	Seasonal
C									
2 m		329	320	306	315	299	302**	219	
5 m		334**	303	312	314	319			
10 m		318**	318	303	313				
N									
2 m		28.8	25.5	22.6	25.1	21.3	43.4**	28.4	
5 m		32.4**	28.1	23.2	24.1	28.5			
10 m		31.0**	36.6	33.6	30.8				
P									
2 m		1.4	0.9	0.7	0.8	0.7	5.1**	3.3	
5 m		1.4**	1.1	0.8	0.9	1.22			
10 m		2.0**	2.1	2.1	1.7				
C:P									
2 m		621	900	1151	1016	1152	152**	171	0.000
5 m		604**	691	1140	1001	750			0.370
10 m		406**	440	405	474				0.920
C:Chl									
2 m		41.8	20.9	28.0	32.5	30.5	3.9**	10.3	0.007*
5 m			23.7	16.1	20.0	18.1			
10 m			17.1	14.7	11.0				
C:N									
2 m		13.4	14.7	15.9	14.8	16.4	8.1**	9.0	0.000
5 m		12.0**	12.7	15.8	15.2	13.1			0.232
10 m		11.9**	10.4	10.7	12.1				0.573
N:P									
2 m		46.5	61.5	72.0	68.7	70.3	18.7**	19.0	0.000
5 m		50.3**	54.6	70.9	66.6	56.4			0.547
10 m		34.0**	41.1	37.5	40.3				0.650
Chl									
2 m		0.66	1.43	0.95	0.99	1.00	6.46**	1.87	0.003*
5 m			1.28	1.63	1.36	1.57			
10 m			2.42	1.99	2.39				

collection. Complete coverage was observed, and collection of *C. glomerata* samples was performed at all depths and stations on the June 23 survey, and was almost the same case on the July 11 survey. No sample was collected at a 10 m station, 633, which is unrelated to the absence at station 600 as these two stations are located on the two most opposite corners of the survey region. The survey on August 1 coincided with the beginning of the main sloughing period as no algae were evident at any 10 m station, though samples were

still collected at all 2 and 5 m stations. The September 14 survey indicated that sloughing was complete as benthic filamentous algal material was only abundant enough for collection only at the 2 m station on transect D. On October 19, however, we again observed a slight increase of algal material, though only at 2 m stations, for transects A, B, and D (Fig. 2.1). *C. glomerata* algal samples were not available for collection at any 5 or 10 m stations on Oct. 19.

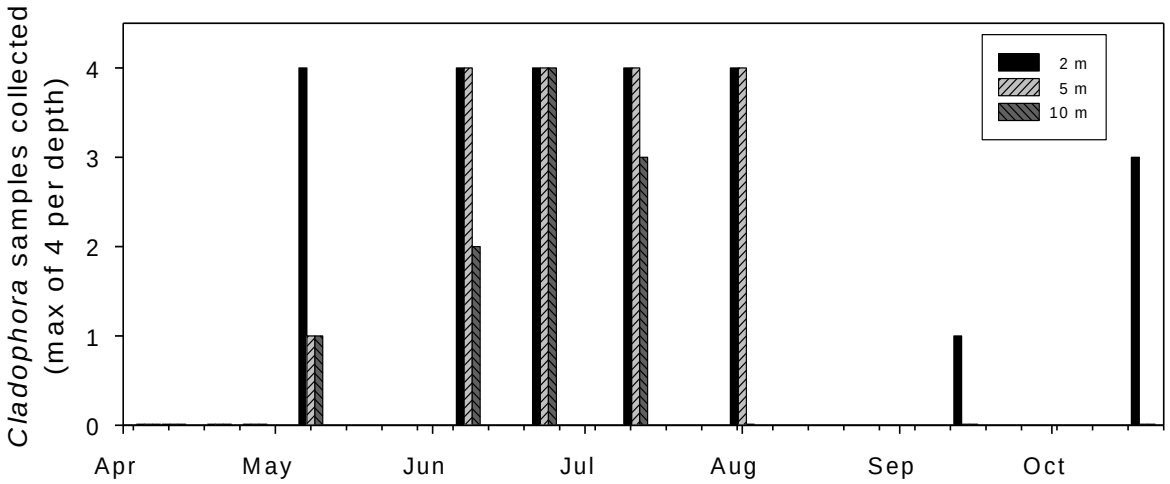

Figure 2.12: Depth categorized *Cladophora* sample collections (present or absent) over the 2006 survey along the Halton shoreline. Four stations were surveyed at each of 2, 5, and 10 m depths, for a total of 12 stations. After April 27, 2006, 2 m stations exhibited *Cladophora* growth through to October 19 when we last surveyed. Samples at 5 m stations were collected from May 8 until August 1, and *Cladophora* samples at 10 m stations were only collected during the June and July surveys.

C. glomerata internal P concentrations exhibited similar seasonal patterns (Fig. 2.11) as water column soluble reactive phosphorus (SRP). For all stations mean spring concentrations of 1.4 μg P/mg of dry weight (DW), declined during the summer to 1.1 μg

P/mg DW by August 1, before increasing 3-fold in the autumn to 3.8 µg-P/mg DW. Spatial variation during the summer was assessed in a 2-way ANOVA (Table 2.7) that tested depth and transect. This was done to find potential point sources (e.g. 16 Mile Creek input and WWTP outfall) affecting tissue nutrient content located near our sampling stations. Throughout the summer there was a significant depth relationship (Table 2.2) as 10 m stations were higher in internal phosphorus concentrations (Fig. 2.13). None of the four transects had any statistically significant effect and thus no point sources were identified by their effect on internal P concentration (2-way ANOVA, F=0.75, p=0.534). Spring and autumn data, because of sparse *Cladophora* stands, were insufficient to apply the same statistical analysis.

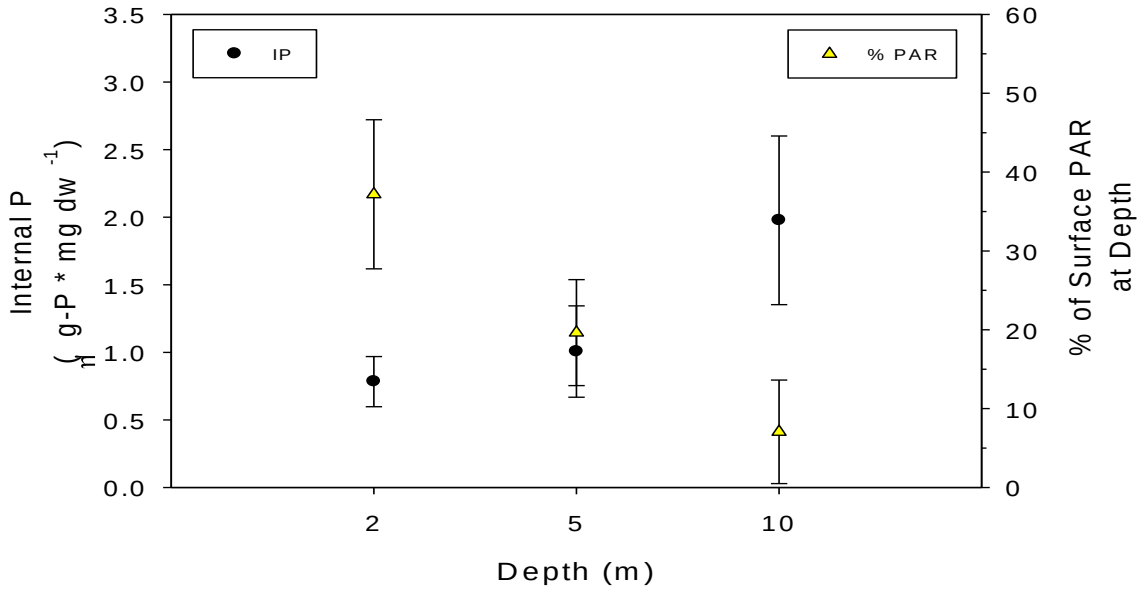

Figure 2.13: Peak growing season (Jun. 8 – Aug. 1) values for internal *C. glomerata* P concentrations at Halton, 2006, as a function of depth with percent of surface irradiance at depth. Data points at each depth are from all locations along the Halton shoreline.

Though shoreline-wide seasonal patterns in water column SRP concentrations were similar to *C. glomerata* internal P trends, no direct relationship was exhibited between internal *C. glomerata* P and overlying SRP on a station by station basis during the summer (Fig. 2. 14).

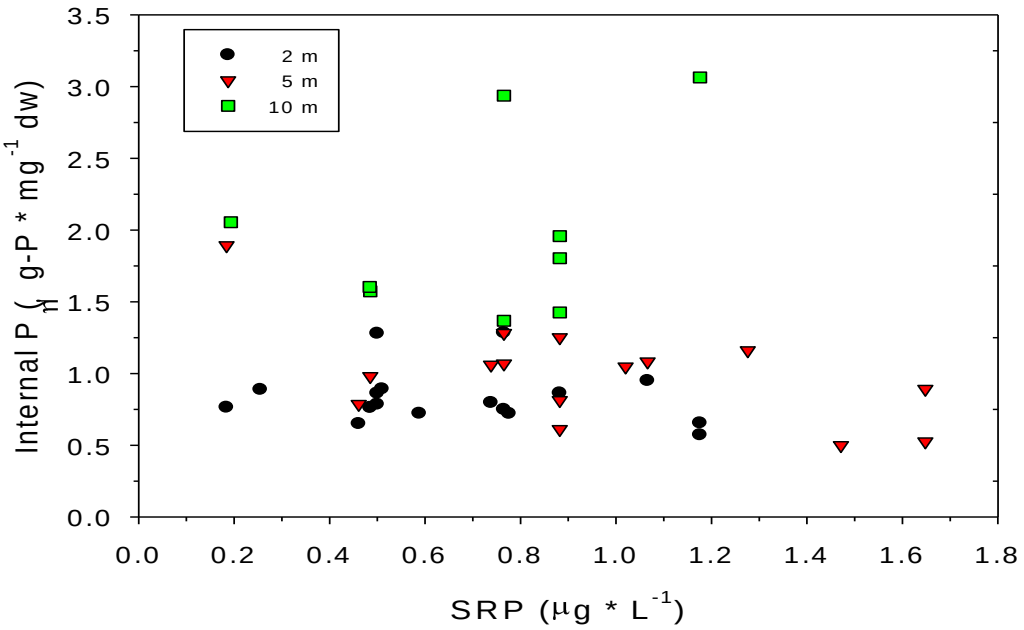

Figure 2.14: Halton summer paired values for internal *C. glomerata* P and water column SRP concentrations, 2006, plotted by depth, 2, 5, and 10 m.

Little seasonal variation in *C. glomerata* internal carbon concentrations was observed (Table 2.7), and internal carbon concentrations had no relationship with depth (Table 2.2). Internal nitrogen concentrations declined slightly during the summer surveys (Table 2.7) though remained above noted critical concentrations for growth of 11-15 µg N/mg dw (Gerloff & Fitzgerald 1972). Nitrate concentrations were also found to decrease below the critical level of 300 µg N/L (Herbst 1969) by August (Fig. 2.15), however, no relationship between algal samples and internal nitrogen concentrations was observed (Fig. 2.16). Internal nitrogen concentrations also displayed a strong depth relationship

(Table 2.2) as 10 m stations were significantly elevated with respect to both the 2 and 5 m stations (ANOVA, F=20.63, p<0.000).

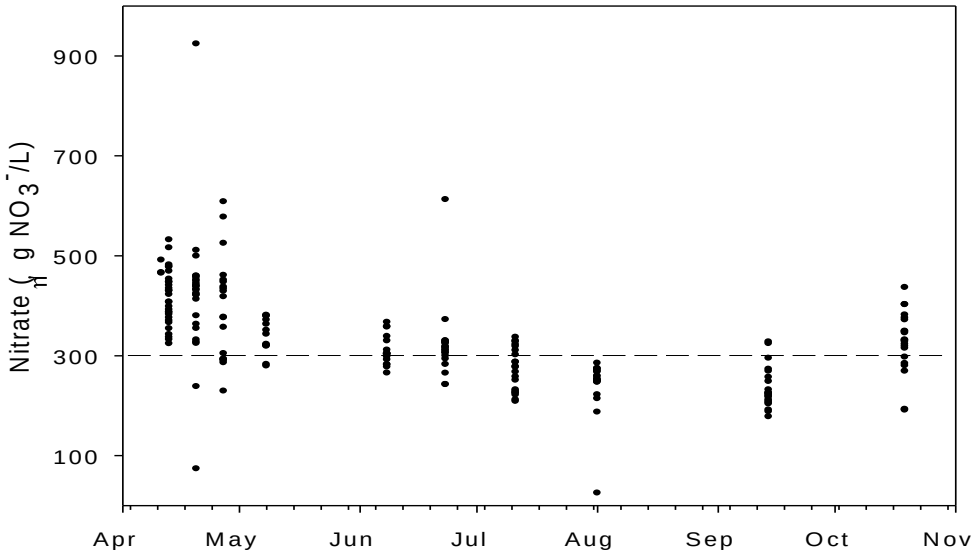

Figure 2.15: Dissolved nitrogen (µg Nitrate/ L) along the Halton shoreline, 2006. The dashed line (300 µg/L) represents the general algal limit for external dissolved nitrogen concentrations (Herbst, 1969).

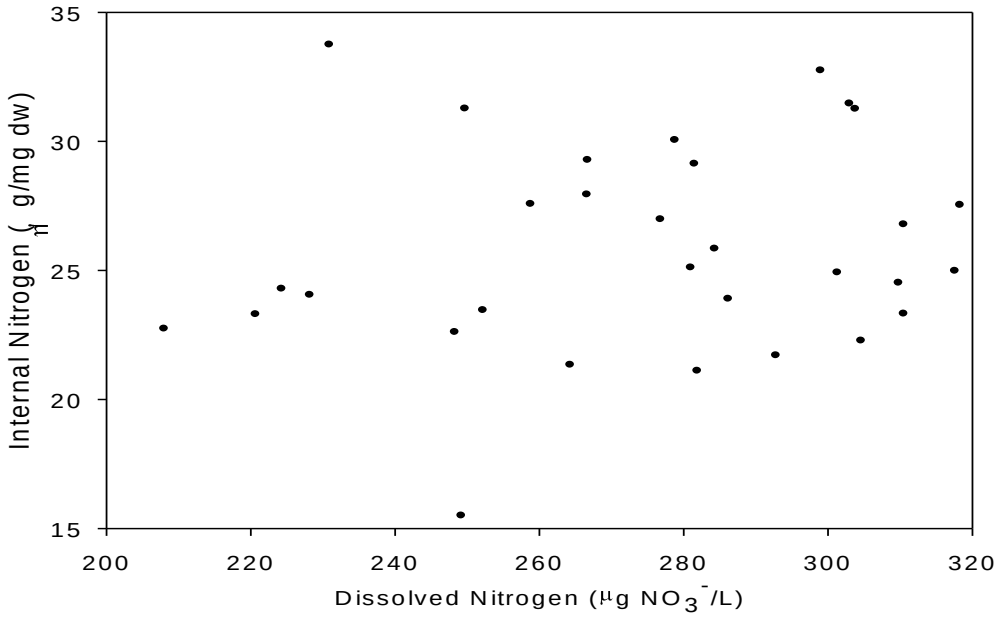

Figure 2.16: *Cladophora* internal nitrogen concentrations plotted against dissolved nitrogen. Paired samples with concentrations under the algal limiting value of 300 µg NO_3^-/L were plotted, Halton shoreline, 2006.

Internal nutrient ratios, C:P, C:N, and N:P (molar), all showed a decrease with depth (Table 2.3) with 10 m stations being significantly (Table 2.2) less than 2 and 5 m stations. Seasonal trends for all three internal nutrient ratios, C:P, C:N, N:P, were similar at 2 m stations. Spring nutrient ratios were found to be lower than in the summer (Table 2.3), as a result of lower internal P concentrations in summer, and autumn nutrient ratios were much lower than both spring and summer values. Tissue samples were not available in sufficient amount to analyze depth relationships at 5 and 10 m stations in both the spring and autumn surveys.

Throughout the 2006 Halton surveys, no individual station (Fig. 2.1) exhibited significant divergence from mean internal *C. glomerata* nutrient concentrations or ratios (Table 2.2), suggesting that no point source nutrient influence was present.

2.5 Discussion

Observations from the 2006 Halton surveys indicated that water chemistry displayed a strong seasonal cycle, especially SRP, with a summer draw down followed by a relatively large increase in both TP and SRP in the autumn surveys. Consistent depth trends in water chemistry over the full year were not present indicating that the inshore water mass at times of sampling was well mixed at least out to 10 m depth. Furthermore, anthropogenic indicators, such as chloride ions, were not elevated at any single station. 2 m stations adjacent to 16 Mile Creek and the Oakville Southeast WWTP outfall recorded higher turbidity in the form of elevated light extinction coefficients (Table 2.2 and 2.3). It was also found that transect D adjacent to the same WWTP outfall had significantly

higher concentrations of ammonia. It was observed that an adjacent pier may have retained particulate matter in the area because of local circulation effects. The LOSAAC Water Quality Study (Aquafor Beech Ltd. 2005) identified within a larger span of the Halton shoreline that watercourses and 3 WWTP outfalls (two to the southwest outside our survey area) were the largest annual inputs of TP (13 904 kg and 13 969 kg, respectively) and NH_3 (12 996 kg and 14 000 kg, respectively) and that storm sewers discharging directly into Lake Ontario had negligible inputs (TP: 707 kg, NH_3: 1 227 kg). Watercourses were by far the greatest input of TSS (9 400 957 kg) as they contributed 98% of the total annual input. 16 Mile Creek was the greatest watercourse source of TP (4471 kg-P * $year^{-1}$), SRP (545 kg-SRP * $year^{-1}$), and NH_3 (6866 kg-NH_3 * $year^{-1}$). It was not stated which of the three Oakville WWTP had the greatest outfall of nutrients, although the total input of the three WWTP outfalls for TP (13 200 kg-TP * $year^{-1}$) and NH_3 (13 000 kg-NH_3 * $year^{-1}$) within the LOSAAC study (2005) is approximately equal to the total input of TP (14 200 kg-TP * $year^{-1}$) and NH_3 (13 500 kg-NH_3 * $year^{-1}$) for all watercourses. TSS, however, is negligible at WWTP outfalls (53 369 kg-TSS * $year^{-1}$) (LOSAAC 2005).

Considering these annual inputs of nutrients, it is interesting to note that only transect D displayed increased concentrations of NH_3 (Table 2.5), and it is the transect nearest to the Oakville Southeast WWTP outfall. However, *C. glomerata* internal nutrient composition along this transect did not suggest elevated uptake of N in this area. This could be due to P being the limiting nutrient as described earlier; however, nearshore water currents might play a part. Several studies measured water velocities within the very nearshore zone (<15 m) at similar shores in Pickering (Leon 2007) and Oshawa

(Csanady 1972) to be of the order of 5.0 cm * s^{-1} on average with increases to 10 cm * s^{-1} occurring. This is likely the case for our stations from 2 to 10 m depths, though, it was suggested that our 35 m station would have had even greater velocities on average of about 15 cm * s^{-1} (Csanady 1972). Considering these moderate current velocities, the impacts of nutrient inputs from 16 Mile Creek and the Oakville Southeast WWTP outfall may be masked by rapid water column mixing. Further, inputs from rivers outside of our study site, such as Bronte Creek to the west, which was the second largest watercourse input in 2005 (Aquafor Beech 2005), may also contribute along with external WWTP outfalls. However, the detection of transect effects on turbidity and ammonia closest to the Oakville SE plant indicates that water quality effects are detectable but they are not translated into the benthic algae. Most likely this is because N (both as nitrate and ammonia) are in excess of that required for *Cladophora* growth. Internal N content is most likely dependent on the internal P concentration. There would be no advantage in storing internal N when it is continuously in excess in the environment.

C. glomerata algal abundance also displayed a seasonal cycle as 2 m stations were first to develop benthic algal biomass followed by greater accumulation at deeper depths as the summer peak growing season progressed. The reverse pattern followed as only 2 m stations exhibited *C. glomerata* abundance on our last survey in late October. The prominence of the *Cladophora* only at 2 m stations likely indicates the critical role of light availability both early and late in the growing season as photoperiod and solar elevation wax and wane over the season. Several theories exist attempting to explain the determining factor(s) for the sudden sloughing of *C. glomerata* that typically occurs mid to late summer. Briefly it is thought that either one, or a combination of nutrient

limitation, temperature stress, metabolic stress due to self-shading and shear or wave stress (Higgins et al. In press) act on the basal cells of *C. glomerata*, reducing filament health and strength and the ability to maintain attachment to the hard substrate. Within our study, observation of the pattern of sloughing along the Halton shoreline countered this notion: nutrient limitation did not seem to be a factor as algal filaments that sloughed earliest at 10 m stations were much higher in P concentrations. Also, the theorized upper temperature limits for *C. glomerata* growth and sloughing would not be critical in our study as the cooler 10 m stations detached first. Wave action would also not be as big of a factor at 10 m depths with respect to the high energy wave zone experienced at 2 and 5 m stations. This leaves metabolic stress due to light limitation which has previously been considered as a factor only as a factor due to self shading in dense stands of *Cladophora* (Higgins et al In press). However metabolic stress may actually start first at the deepest stations once the summer solstice is past; and therefore, sloughing occurs earlier at 10 m stations and later at 2 and 5 m stations were self-shading may also contribute to the metabolic stress. As light extinction coefficients at 10 m were averaged to be 0.32 m^{-1} over the summer, resulting available PAR for *C. glomerata* growth at this depth would be 7% of surface PAR, approximately 140 µmoles*$m^{-2}s^{-1}$ on average, which is much lower than the reported optimum range of 300-600 µmoles/m^2/s photosynthesis (Graham et al. 1982). Subsequent sloughing at shallower depths with greater light environments may be due to a combination of P limitation and light limitation due to self-shading at maximum biomass (Higgins 2005). This characterization of growth also illustrates that *C. glomerata* along the Halton shoreline is now common at depths of at least 10 m, contrary to historical records (Canale et al. 1982; Painter & Kamaitis 1987) of depth relationships for

Cladophora. Furthermore, it appears that the depth at which light limitation begins along the Halton shoreline is approximately 5 m or greater as significantly higher internal phosphorus concentrations were only observed at our 10 m stations (Table 2.3 and Fig. 2.11). This contrasts with Canale et al. (1982) in that light limitation in their study impacted *C. glomerata* growth at depths as shallow as 1.5 m at their Lake Huron study site.

Although internal *C. glomerata* nutrient stoichiometry also demonstrated seasonal variation, there was also a strong depth relationship with C:P, N:P, and C:N internal nutrient ratios, indicative of an increasing influence of light with depth. A depth relationship (Fig. 2.13) has been established for the peak biomass period, which includes the June and July samples. Internal nutrient concentration increased with depth suggesting light, and not nutrient availability is the key determinant of internal P concentrations beyond depths of 5 m.

In general, the water quality stations in the surveyed area were relatively homogeneous. There were no consistent trends for any one location along the Halton shoreline over the growing season that were significantly different from the other stations, indicating a lack of local effects in either water chemistry or algal nutrient status. Only ammonia concentration along the transect closest to the Oakville SE WWTP were notably different from the other transects. There was no evidence found for any strong nutrient point source, regardless of the proximity to outfalls such as 16 Mile Creek and waste water treatment plant outfalls affecting the nutrient composition of the sampled *C. glomerata*. It is possible that such locations exist at a finer scale than we sampled, e.g.

along one of the hydroacoustic transects which were done continuously and at closer intervals than the water sampling, one potential hot spot for algal biomass was located directly between several water quality stations (unpublished data, D. Depew, University of Waterloo),. If this was a potential point source influence, it may not have been resolved in the nutrient status data by any one sampling station. However, a more likely explanation for the observed homogeneity in both water quality and *C. glomerata* composition may be the pervasive influence of the dreissenid mussels. Dreissenids remove particulate matter and excretes nutrients into the water column and waste material on the bottom. Mussels were present virtually everywhere, and areal coverage was often greater than 75% as observed with the underwater camera. This relative uniformity and the high mussel biomass (with 3.84 g/m^2 at depths of 0-3.5 m within the ice-scour zone, ranging from 71.77 – 101.83 g/m^2 at depths of 3.5-17.5 m Ozersky, unpublished data, University of Waterloo), may explain the observed homogeneity in water column properties.

Wong and Clark (1976) determined that phosphorus-limited *C. glomerata* growth begins as internal P concentrations decline below 1.6 μg P/mg dw. Subsequently, the Droop equation used to model specific growth as a function of internal phosphorus concentrations has an inflection point at a phosphorus concentration of 1.0 μg/mg dw (Auer & Canale 1982b), below which severe phosphorus limitation results (Higgins et al. 2005a). As well, the critical concentration of internal phosphorus for zero positive growth (minimum cell quota) has been recorded as 0.5 μg P/mg dw (Gerloff & Fitzgerald 1976). According to these phosphorus limitation categories, our samples indicated that during the spring, all 2 and 5 m stations were moderately phosphorus limited, while the single 10

m sample was not. Internal phosphorus concentrations continued to decline into the summer at 2 and 5 m stations, becoming severely phosphorus limited and even critically limited at one 2 m station. One exception was at a 5 m station in early August, which was not considered phosphorus limited and is perhaps related to the onset of major *C. glomerata* sloughing. Notably, these trends are in contrast to 2 m results published for the northern shore of eastern Lake Erie (Higgins et al. 2005a) over the period of 2001-2002 as spring data for cell quotas from that study were above values indicative of the onset of phosphorus limitation. The period from early August until early October, which is considered to be a time of moderate phosphorus limitation in Lake Erie (Higgins et al. 2005), is conversely a period of very high internal and non-limiting water column phosphorus concentrations along the Halton shoreline. Correspondingly, a general increase in planktonic chlorophyll-*a* concentrations is seen throughout the spring and summer (Fig. 2.10) with the exception of the June 23 sampling when an upwelling event occurred, corresponding with low temperatures measured. Declining planktonic Chl-*a* concentrations were then seen in September through October, suggesting a combination of zooplankton grazing (a noticeable increase in zooplankton activity was observed while processing samples) added to mussel grazing, declining photoperiod, and lower productivity were limiting phytoplankton abundance. All three factors are consistent with the higher SRP concentrations (Fig. 2.5) observed during this period. Consequently, photoperiod and temperature declined during this autumn period and may have been a strong influence on plant growth and consequently the accumulation of surplus phosphorus in the water column. Compared with historical records, the decline in mid-summer *C. glomerata* internal phosphorus concentrations from 1972-1983 (Painter &

Kamaitis 1987) has been maintained to the present (Fig. 2.17). Throughout the observed period of our study, the offshore concentrations at the 35 m station were well within the range of values of the shallower stations suggesting that offshore and even lake wide changes in nutrient concentrations were affecting nearshore conditions suggesting relatively rapid advection through the study area. Such rapid flushing reinforced by dreissenid grazing may best account for the spatial homogeneity observed in this study.

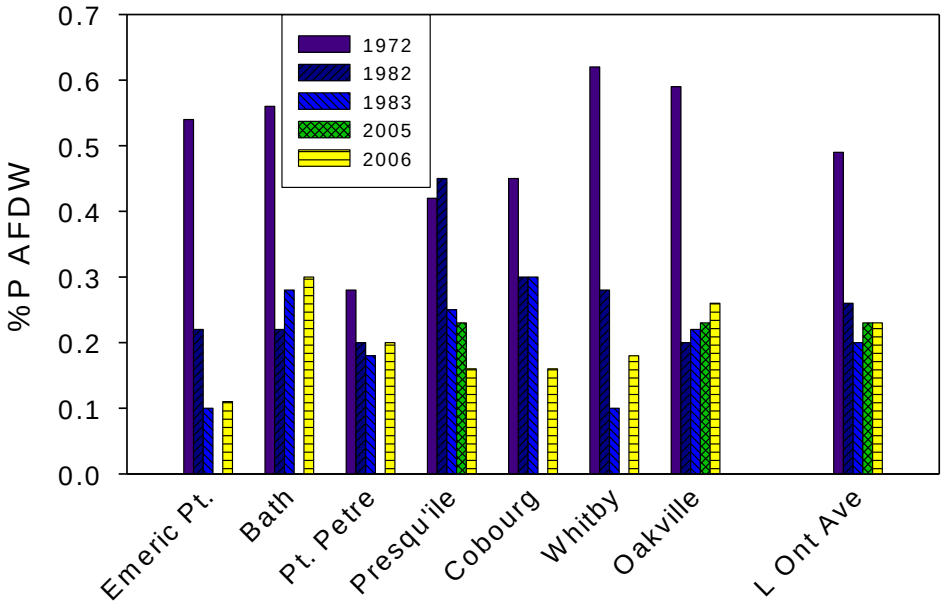

Figure 2.17: *Cladophora* internal phosphorus concentrations as a percent of ash free dry weight throughout Lake Ontario, over four decades at depths of 0.0 - 3.0 m. Data for 1972, 1982, and 1983, from Painter and Kaimitis (1987).

The result that *C. glomerata* internal P and overlying SRP concentrations displayed little direct relationship may simply reflect that instantaneous measurements of water chemistry may not have directly demonstrated the long-term lake trends typical of internal nutrient concentrations (Auer & Canale 1982b). Simple relationships between ambient P fractions and internal P concentrations would only be expected to persist and

be evident if a steady state were achieved between growth and external P concentrations. The surplus uptake, of which *C. glomerata* is capable (Higgins et al. In press), combined with pulses in P loading, would make such a steady state highly unlikely especially at the bi-weekly and monthly sampling intervals of the study. Much higher temporal sampling resolution would be required to determine the relationship between

Nitrate concentrations were also found to decline over the peak growing season to below the 300 μg NO_3^-/L threshold suggested for N limitation of *Cladophora* (Herbst 1969) on Aug. 1, before increasing on the Sept. 14 survey, thus coinciding with the period of maximum lake temperature and algal sloughing (Fig. 2.11). However, no correlation was observed between nitrate and *C. glomerata* internal N (Fig. 2.16), further suggesting that temperature and the more severe P-limitation are key drivers for algal growth and sloughing.

2.6 Conclusion

The implication of these findings in relation to the nearshore phosphorus shunt (Hecky et al. 2004) is that the resurgence of the benthic macroalga, *Cladophora glomerata*, is not a direct result of increased pollution in the form of either increased urban populations or related point sources, but more likely a result of either the recent dreissenid reengineering of the nearshore (in the form of nutrient recycling, increased water column clarity, and increased hard surface habitat) or increased offshore transport of nutrients to the nearshore. However, considering that the offshore nutrient status has been consistently oligotrophic in Lake Ontario since the 1980s (Hecky et al. 2004) the

latter possibility seems unlikely. Further, pelagic and *C. glomerata* tissue phosphorus concentrations have both been maintained at lower levels than historically found throughout the 1960s and 70s (Fig. 2.17) (Painter & Kamaitis 1987) and our nearshore stations were not elevated in nutrients with respect to the offshore station, specifically with phosphorus. This indicates that a potential dreissenid influence on *C. glomerata* resurgence may be directly related to increased light regimes and increased hard surface, and further by increased P retention due to the combined effects of dreissenid excretions and plant growth along the nearshore zones to greater depths. As there is now more *Cladophora* and dreissenid biomass per unit shoreline, and therefore more stored P per unit shoreline than prior to dreissenids, there is more P cycling within this nearshore area. This indicates that dreissenid mussels have increased the availability of P for benthic algal growth in the nearshore enough to enable water clarity effects (i.e. extending light penetration and increasing the depth range of growth). This is supported by the fact that historical data for *C. glomerata* research rarely exceeded the 3 m depth contour (Canale et al. 1982; Painter & Kamaitis 1987), whereas the 2006 survey that we performed along the Halton shoreline and other recent research (Higgins 2005a) indicate that light environments may be near light saturation for *C. glomerata* growth at depths of up to 5 m. Thus, as algal biomass per square meter remains similar to historical measurements at shallower depths (2 m) (Painter & Kamaitis, 1987), the resurgence is likely related to an increase in growth per linear unit of shoreline as *C. glomerata* has been collected consistently at depths of 10 m during peak biomass in mid summer and has also been observed at 15 m depths on occasion (personal observation).

Dreissenids have facilitated the expansion in *Cladophora* habitat through increased water clarity and also provided a new source of P from the consumption of pelagic particulate nutritive material and the regeneration of nutrients from the lake bottom. Although increased intensity of urban point source loading at streams and outfalls did not contribute to localized growth in this study, the presence of dreissenids to harvest particulate nutrients by filtration and return them through excretion along the lake bottom may enable more P availability for benthic plants even in the absence of any increase in total P loadings from the catchment. This is also a cause of concern for the management of *Cladophora* and catchment nutrients. Compared to the historical situation, the dreissenid population have the capacity to may amplify by recycling the effect of any increase in total P loading. P still limits the growth and biomass of Cladophora at shallower depths (out to 5 m) and would respond to any further increase in the availability of P.

Chapter 3: Landscapes of the Great Lakes Shorelines and their Relationship to the Nutritional Status of *Cladophora glomerata*

3.1 Abstract

Nutrient stoichiometry of the benthic filamentous alga, *Cladophora glomerata*, was surveyed over 2005 and 2006 on depth transects along both urban and non-urban shorelines within the lower Great Lakes. At depths less than 10 m, *C. glomerata* nutrient composition was independent of shoreline land use although there was a strong dependency of nutrient concentrations on depth across all shorelines and transects The urbanized shorelines in western Lake Ontario had indication of relative phosphorus enrichment as benthic algal samples within the light limited zone (> 5 m depth contour) displayed higher internal phosphorus concentrations with respect to non-urban sites in both Lake Erie and Ontario. *C. glomerata* nutrient status ratios were empirically found to be largely dependent on phosphorus concentrations regardless of spatial and temporal variation and described the onset of phosphorus limitation to be greater than 505 for C:P (molar ratios), and greater than 42 for N:P. Zero positive growth was occurred at 1246 for C:P, and 76 for N:P, based on published critical phosphorus concentrations.

3.2 Introduction

Land use patterns in coastal areas of the lower Great Lakes are changing, especially due to increased urbanization (Botts & Krushelnicki 1995; Bowen and Valiela 2001). This increase in population density can lead to an increased volume of wastewater treatment discharge, despite meeting concentration standards for treated effluents; increased direct runoff due to extensive non-permeable land cover; and increased storm sewer runoff volume (Herbst 1969; Beeton 2002) (Fig. 1.4). Even along rural shorelines adjacent land use is changing as a result of more intensive farming practices including feedlot operations and efforts to recycle animal wastes on to the land surface. In this study, shorelines adjacent to urban and rural landscapes will be contrasted, and it is expected that the benthic, filamentous green alga, *Cladophora glomerata*, will have an internal nutrient composition that will vary significantly between these two categories of coastal land use. Prior studies have detailed the first two significant historical changes within the Great Lakes watershed that were influential on lake nutrient dynamics: colonial land clearing and the onset of industrial-scale use of fertilizers and detergents (Fig. 3.1). However, the latest large-scale shift within our natural environment has been the increasing urban population and the associated impacts this can have on coastal systems but these impacts are still being defined as the urbanization trend continues.

C. glomerata has been an indicator species for Great Lakes eutrophication since 1933 (Neil & Owen 1964). This organism is extremely successful in habitats with a hard substrate (Dodds & Gudder, 1992; DeJong 2000), high light availability (Taft 1975;

Graham et al. 1982; Lorenz & Herdendorf 1982; Cheney & Hough 1983; Hoffman and Graham 1984; Lester et al. 1988; Lorenz et al. 1991; Arciszewski 2005), high nutrient fluxes (Wong & Clark 1976; Auer et al. 1982; Gerloff & Muth 1984; Higgins et al. 2005a), and moderate currents (Bellis & McLarty 1967; Whitton 1970), making much of the bedrock and boulder coastline of the Great Lakes optimal for benthic algal growth when nutrients are increased. Table 1.1 and 1.2 summarize ranges of values for light, temperature, and nutrients within which *C. glomerata* can grow.

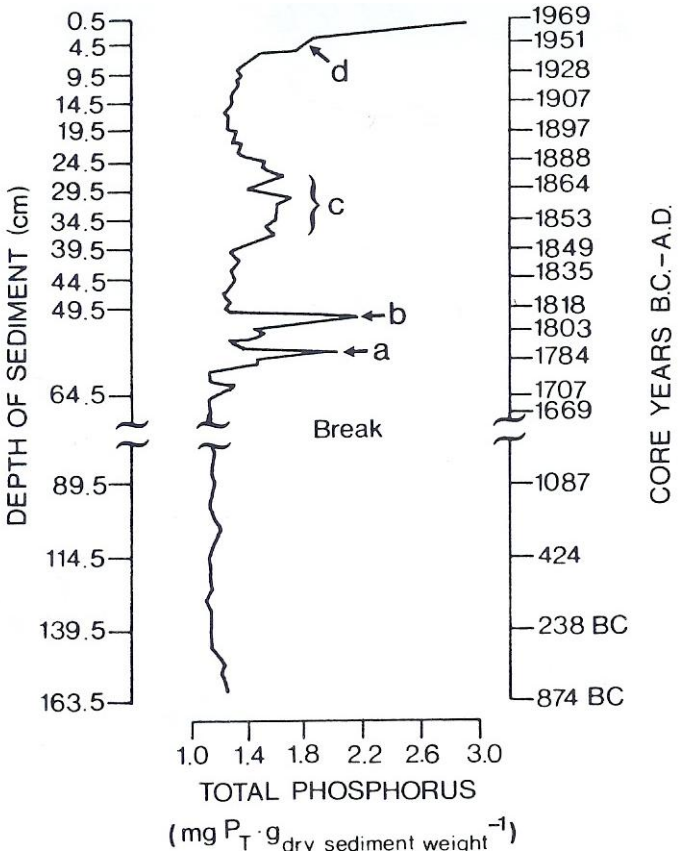

Figure 3.1: Total phosphorus concentrations measured in the Glenora-C core extracted from the Bay of Quinte, 1978 (Sly 1986). *a* and *b*) reflects soil loss during periods of earliest land clearance near the Bay, *c*) period of poor agricultural practices, *d*) increasing agricultural industrialization and stepwise increase (~1950) represents the introduction of detergents.

The focal point for present eutrophication management, and the only practical option, is the controlling of phosphorus loadings. Phosphorus loadings have declined since the early 1970s (Stevens & Neilson 1987) (Fig. 1.2) due to limits set for phosphate-based detergents and waste water treatment plant effluents in the International Joint Commission's Great Lakes Water Quality Agreement signed in 1972. Total phosphorus concentrations declined steadily in the Great Lakes along with the decrease in phosphorus loadings as seen in Beeton's review (2002) of freshwater lakes from 1976-1990. However, these are lake-wide annual estimates and the regional effects of varying shoreline uses or local amplification of point sources may have alternative impacts on nearshore systems. In recent years the establishment of the dreissenid mussels in the lower Great Lakes has caused a broad range of changes in coastal habitats (reviewed by Hecky et al. 2004). Over this same time period, complaints about shoreline fouling and clogging of water intakes and fishing nets by the benthic filamentous alga *Cladophora glomerata* have increased as well. Consequently a study was undertaken to determine the spatial extent of Cladophora and its nutrient composition in relation to shoreline use in the lower Great Lakes.

The spatial variability in *C. glomerata* nutrient stoichiometry was determined in a broad survey across the lower Great Lakes, Huron, Erie, Ontario, in 2005 and 2006. Surveyed shorelines were chosen to represent two broad riparian land use classes: urban and non-urban. Lake Simcoe was also surveyed as representing non-urban land use on a smaller lake. *C. glomerata* shoreline fouling has not been reported in Simcoe despite the recent establishment of dreissenid mussels (Nicholls 1998), which has been implicated in the resurgence of the *C. glomerata* problem in the Great Lakes (Hecky et al. 2004). In

Simcoe, macrophyte communities may successfully out-compete *C. glomerata* for nutrients or nutrient conditions may not be appropriate for *C. glomerata* growth.

3.3 Methods

3.3.1 Survey Sites

In 2005, field surveys were performed at several locations on Lakes Huron, Erie, and Ontario in early June and late July, as an attempt to describe water quality and Cladophora compositions at the beginning and end of its period of maximum growth (citation). In order to assess coastal land use effects, a sampling design to contrast urban and non-urban shorelines was employed. The 2005 sampling sites are listed in Table 3.1 and were selected guided by historical records (Painter & Kamaitis 1987, Higgins et al. 2005a) of occurrence of *Cladophora* and physical characteristics.

Table 3.1. 2005 nearshore sampling sites on the Great Lakes and Lake Simcoe, 2006, in the nearshore (2-10 m depths).

Lake	Site	Site Type	Spring	Summer
Huron	Cape Chin	Non-urban	Jun-15	Aug-04
	Pike Bay	Non-urban	Jun-13	
	Southampton	Non-urban		Aug-08
Erie	Peacock Pt	Non-urban	May-05	Jul-12
	Grand River	Non-urban	May-11	Jul-15
Ontario	16 Mile Cr.	Urban	Jun-01	Jul-25
	Credit River	Urban	Jun-02	Jul-21
	Presqu'ile Park	Non-urban	Jun-08	Jul-27
Simcoe	SW Islands	Non-urban	May -16	Aug-08

At each site, a 3x3 sampling matrix consisting of three transects, three or more kilometres apart (Palmer 1968), and sampling three depths (2, 5, and 10 m) was implemented by boat-based sampling (see Figure 2.1 for example of design).

The 2005 spatial surveys were augmented with the addition of a snorkel survey at more locations on Lake Ontario and two surveys in Lake Simcoe in 2006, increasing the variety and number of shoreline sites. The snorkel survey incorporated several sites sampled in 2005 as well as new locations (Table 3.2). Only one transect was made at each snorkel site and to no greater depth than 3 m. Algal samples were collected at 0.5, 1.0, 1.5, and 3.0 m depths, while a water sample was collected at the 1.5 m station (at mid-water column; 0.75 m) at each site. Lake Simcoe was also sampled in May and August of 2006 using the 3x3 sampling matrix described above for 2005. The sites surveyed for spatial variation in 2006 are listed in Table 3.2. All sites from 2005 and 2006 are labelled in Figure 3.2.

Table 3.2: 2006 Snorkel Survey Sites for near shore (0-3 m depths) study of the Great Lakes.

Lake	Site	Site Type	Date
Huron	Pt. Farms	Non-urban	Aug-25
	Inverhuron	Non-urban	Aug-25
	Southampton	Non-urban	Aug-25
Erie	Peacock Pt.	Non-urban	Jun-22
	Grant Pt.	Non-urban	Jun-22
	Rock Pt.	Non-urban	Jun-22
	Rathfon Pt.	Non-urban	Jun-22
Ontario	16 Mile Cr.	Urban	Jul-24
	Whitby	Urban	Jul-7
	Cobourg	Urban	Jun-29
	Presqu'ile	Non-urban	Jun-29
	Pt. Petre	Non-urban	Jun-29
	Bath	Non-urban	Jun-29
	Emeric Pt.	Non-urban	Jun-29

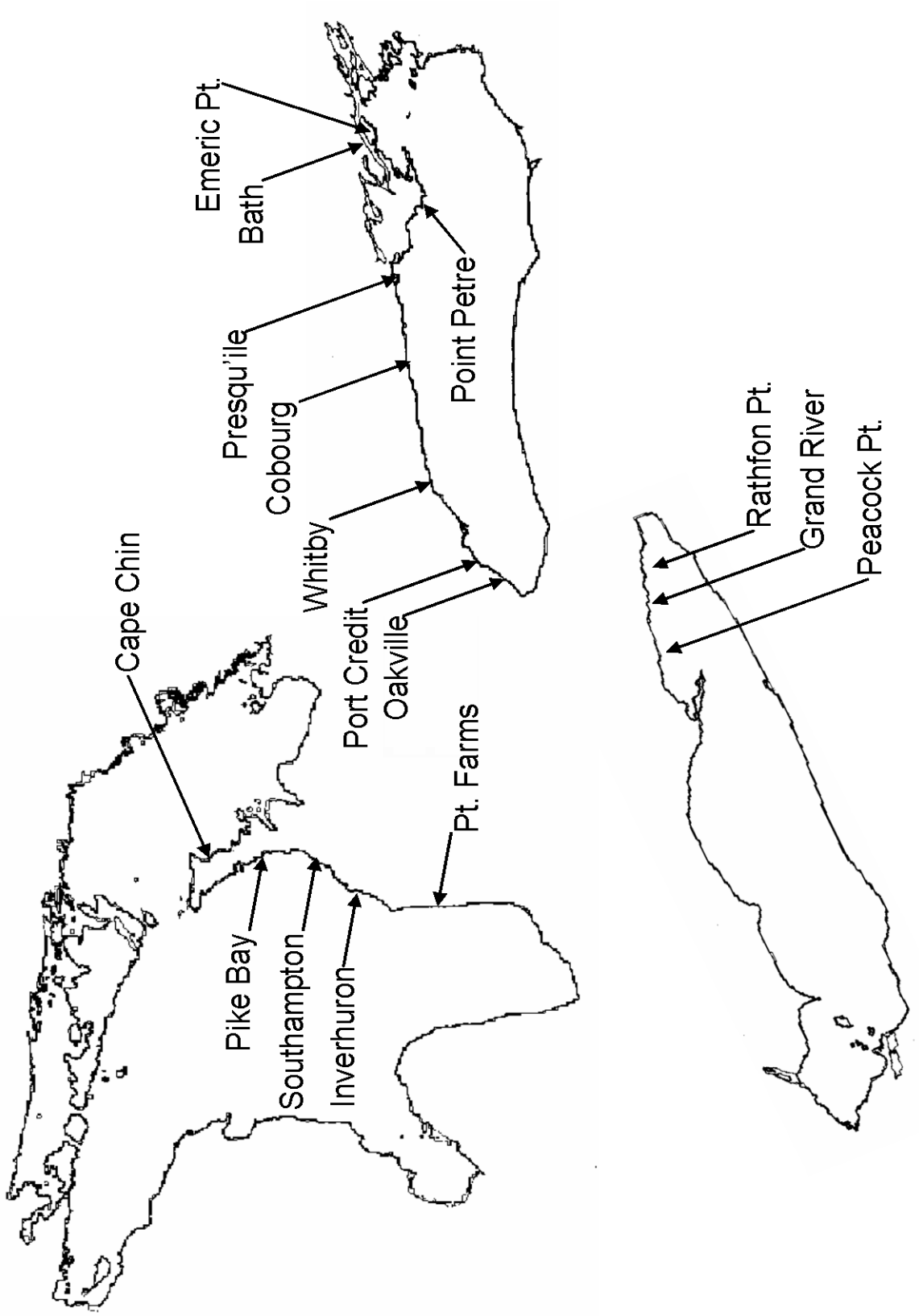

Figure 3.2: Sites surveyed over the 2005 spatial, the 2006 temporal survey at Oakville, Halton Region, and the 2006 snorkel surveys.

Land-use was broadly categorized as urban or non-urban (Table 3.3). Major urban centres sampled (Port Credit, Oakville, and Whitby) were within the Golden Horseshoe at the west end of Lake Ontario, with populations of 110 000 to 670 000 inhabitants. Population density of the urban centre, Cobourg, is substantially lower, with a population of 18 000. With the exception of the Southampton site (3084 inhabitants) at the mouth of the Saugeen River at Lake Huron, the non-urban sites have 1100 or fewer inhabitants (Table 3.3). The town of Dunnville has a modest urban population of approximately 13 000, and is situated approximately 8 km upstream of the Grand River mouth on Lake Erie; thus, the site is not considered urban as it does not have direct contact with the nearshore stretch that was surveyed.

Table 3.3. Population statistics for sampling sites over the 2005-2006 seasons.

Lake	Site	Category	SubCategory	Population	Census
Ontario	Port Credit (Credit River, within Mississauga)	Urban	> 500 000	668000	2001
Ontario	Halton Region (16 Mile Creek)	Urban	100 000 - 500 000	165613	2006
Ontario	Whitby	Urban	100 000 - 500 000	111184	2006
Ontario	Cobourg	Urban	15 000 - 20 000	18210	2006
Huron	Southampton (Saugeen River)	Non Urban	1 000 - 5 000	3084	
Ontario	Bath	Non Urban	1 000 - 5 000	1100	2001
Erie	Grand River	Non Urban	< 1000	<1000	
Erie	Grant Pt.	Non Urban	< 1000	<1000	
Erie	Rock Pt.	Non Urban	< 1000	<1000	
Ontario	Emeric Pt.	Non Urban	< 1000	<1000	
Simcoe	Georgina and Thorah Islands	Non Urban	< 1000	<1000	2005
Erie	Peacock Pt.	Non Urban	< 1000	<1000	
Ontario	Presqu'ile Prov. Pk.	Non Urban	< 1000	<1000	
Huron	Pt. Farms	Non Urban	< 1000	<1000	
Ontario	Pt. Petre	Non Urban	< 1000	<1000	
Erie	Rathfon	Non Urban	< 1000	<1000	
Huron	Inverhuron	Non Urban	< 1000	300	

3.3.2 Physical Measurements

Temperature and conductivity profiles were performed using a CTD profiler. As well, photosynthetically active radiation (PAR) was measured using a Li-Cor radiometer. Using PAR measurements versus depth, the PAR attenuation coefficient (K_d) was calculated and subsequently used to determine PAR at depth. Video was also collected on most boat-based surveys when equipment was available for benthic substrate verification and mussel abundance (unpublished data, T. Ozersky, University of Waterloo) in deeper waters.

3.3.3 Water Column Nutrient Chemistry

At each depth site sampled in 2005 and at Lake Simcoe in 2006, water samples were collected midway through the mixed layer. If thermal structure was present at the 5 and 10 m stations, then one sample was collected mid-epilimnion and an additional sample was collected 1 m from bottom. During the snorkel survey, 2006, water samples were collected midway in the water column at the 1.5 m depth contour. All water collections were performed using a Niskin bottle. Samples were stored in dark coolers for transport at lake temperature for transport to the laboratory.

Nutrient concentrations of the water column were determined on the collected water samples. Laboratory measurement of total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), and particulate phosphorus concentrations (Table 2.1) were performed according to a method from Stainton et al. (1977) using an Ultraspec 3100 Pro UV/Visible Spectrophotometer and a 10 cm cuvette. TP samples

were unfiltered, TDP and SRP were both filtered using 0.2 µm polycarbonate filters, and PP samples were filtered on glass fibre filters, using a pore size of 0.8 µm. Additional ions, including nitrate, chloride, and sulphate were measured using ion chromatography (Dionex DX 500, Dionex AS17, and AG17 guard column, respectively). Ammonium was determined by fluorometry (Holmes et al. 1999). Total suspended solids were measured by filtering 2-3 L of lake water onto pre-combusted (500^{o}C for 4 hr) and pre-weighed glass fibre filters (GF/F), drying for 24 hrs at 65^{o}C and reweighing. Chlorophyll-*a* concentrations were measured by fluorometry (Smith et al. 1999). Particulate nutrients, carbon (C) and nitrogen (N), were filtered on pre-combusted GF/F, pore size 0.8 µm. Nutrient status indicators for phytoplankton were determined using (C:N), (C:P), and (N:P) molar particulate nutrient ratios. Values to be used as indicators of phytoplankton nutrient deficiency for C:P, C:N, and N:P are greater than 129, 8.3, and 22, respectively (Healey & Hendzel 1979, 1980). These values are also summarized and contrasted with Lake Erie data (Guildford et al. 2005) where similar values were attained within the eastern basin. Moderate nutrient deficiency in those Lake Erie phytoplankton samples was observed as C:P and C:N atomic ratios were measured to be 212 and 9.3, respectively.

3.3.4 Internal *C. glomerata* Nutrient Chemistry and Physiology

Cladophora glomerata samples were collected by use of a sampling rake. This instrument is a standard rigid flat rake affixed to a rope that connects to the sampling vessel. The method involved tossing the rake overboard and dragging it along the substrate in order to collect sufficient algal biomass for sampling. Algal tissue samples

were then stored in dark coolers at lake temperature until laboratory analysis. Tissue samples were subsequently washed in deionized water, freeze-dried, and stored (- 4^{o}C) until internal tissue nutrients (carbon, nitrogen, and phosphorus) were measured. For phosphorus content analysis, ground tissue samples were combusted, autoclaved with saturated potassium persulfate for acid digestion, and measured on an Ultraspec 3100 Pro UV/Visible Spectrophotometer using a 5 cm cuvette according to a modified protocol from Stainton et al. (1977). *C. glomerata* carbon and nitrogen concentrations were determined using a CE-440 Elemental Analyzer (Exeter Analytical, Inc.). Chlorophyll-*a* concentrations were measured via fluorometry using acetone extraction from ground tissue samples (Krause & Weis 1991; Maxwell & Johnson 2000; Hagerthey et al. 2006). Four internal algal nutrient ratios were measured, including C:N, C:P, N:P (molar) and C:Chl-*a*.(μmole/μg).

During each survey, benthic hydro-acoustic measurements were performed by cruising the vessel at transect intervals of 75 m between and at each sampled station on a continuous basis in order to estimate areal coverage and biomass of *C. glomerata* (unpublished data, D. Depew, University of Waterloo).

3.3.5 Statistical Analyses

Statistical analyses of data were performed using Systat 10.2 (Wilkinson 1996). Water chemistry and *C. glomerata* nutrient composition was tested in individual analyses of variance of all sites as several lakes were contrasted. We then looked to see if urban or

non-urban sites varied significantly from each other as opposed to sites within the same lake. Data were log transformed if necessary to achieve a normal distribution.

3.4 Results

3.4.1 Coastal Land Use, 2005

Lake Huron exhibited clearer waters as particulates and chlorophyll-*a* concentrations were much lower than in Lake Erie, Ontario, or Simcoe (Fig. 3.3), leading to lower light extinction coefficients (k_d). Suspended solid measurements also indicate that Lake Huron was much clearer at the Southampton and Cape Chin sites.

Our urban sites and Lake Simcoe generally had lower k_d. In contrast, the non-urban site in Lake Erie at the Grand River, was typically higher in chlorophyll-*a* and particulate C and N concentrations relative to other sites. However, particulate C:P and N:P ratios also indicated that the Grand River site was more P stressed than other sites. The urban sites in Lake Ontario and the sites located in Lake Simcoe had, on average, greater particulate P concentrations (Table 3.4).

Water concentration measurements showed that the non-urban sites in Lake Erie and Ontario, were significantly lower in TP and TDP (Table 3.4), and that SRP concentrations were even below detection limits at Lake Erie non-urban sites, though the non-urban site at Presqu'ile Provincial Park in Lake Ontario had substantially higher concentrations of this form of SRP (Fig. 3.3). Total nitrogen was higher in Lake Erie, while Lake Huron and Simcoe were significantly lower than average (Table 3.4). Nitrate

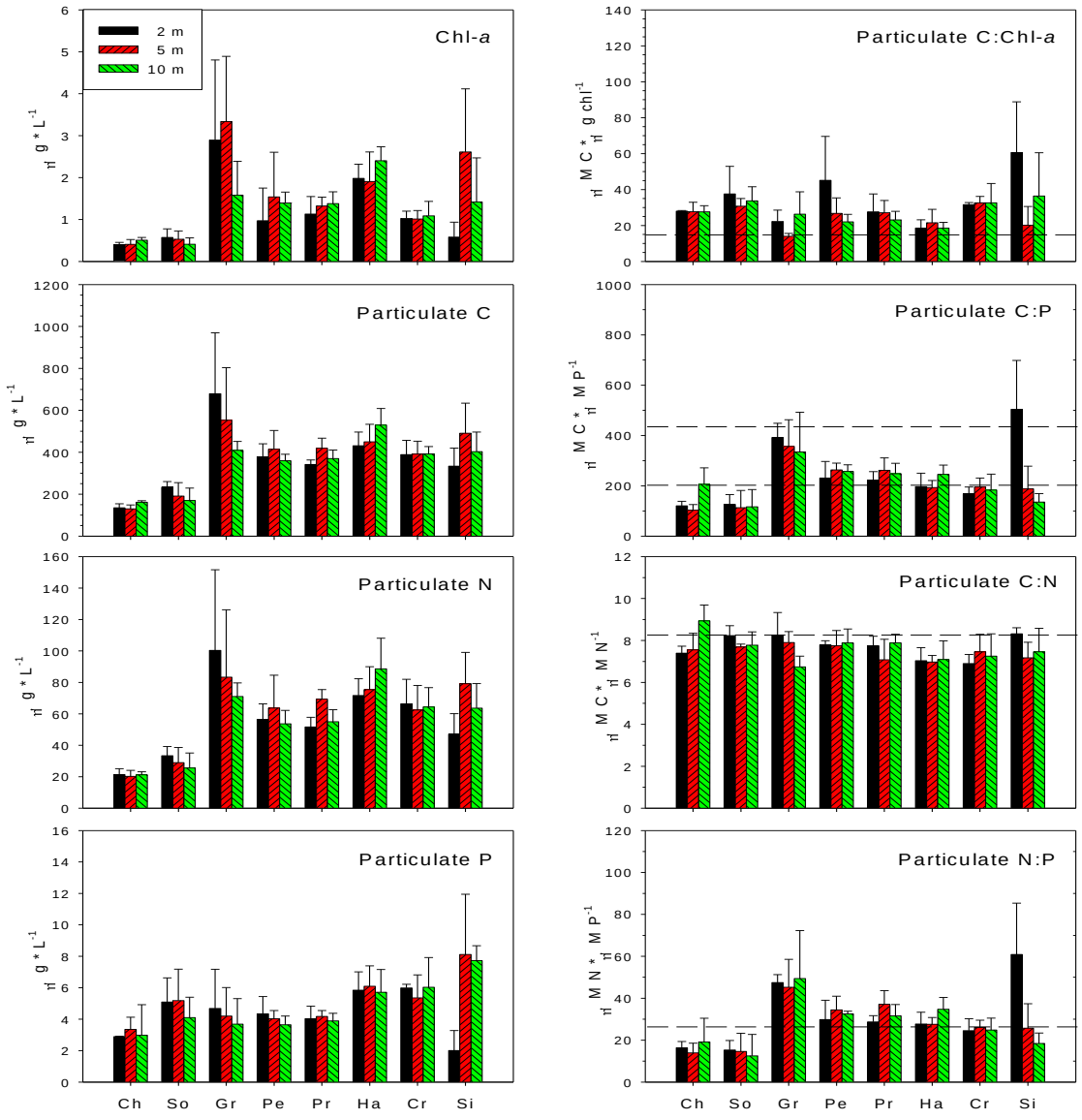

Figure 3.3: 2005 summer means for biological variables (this page), chemical and physical parameters (page X), and *C. glomerata* internal nutrient composition (page X) plotted by site. Error bars indicate one standard deviation. Data was grouped by site as follows, sites from Lake Huron: Ch = Cape Chin and So = Southampton, from Lake Erie: Gr = Grand River, Pe = Peacock Pt., from Lake Ontario: Pr = Presqu'ile Provincial Park, Ha = Halton, Cr = Port Credit, and from Lake Simcoe = Si. At each site, each depth (2, 5, and 10 m) was analyzed individually. Broken lines in the particulate nutrient ratio plots identify nutrient deficiency, i.e. results above the line indicate increasing nutrient deficiency (Guildford et al. 1994).

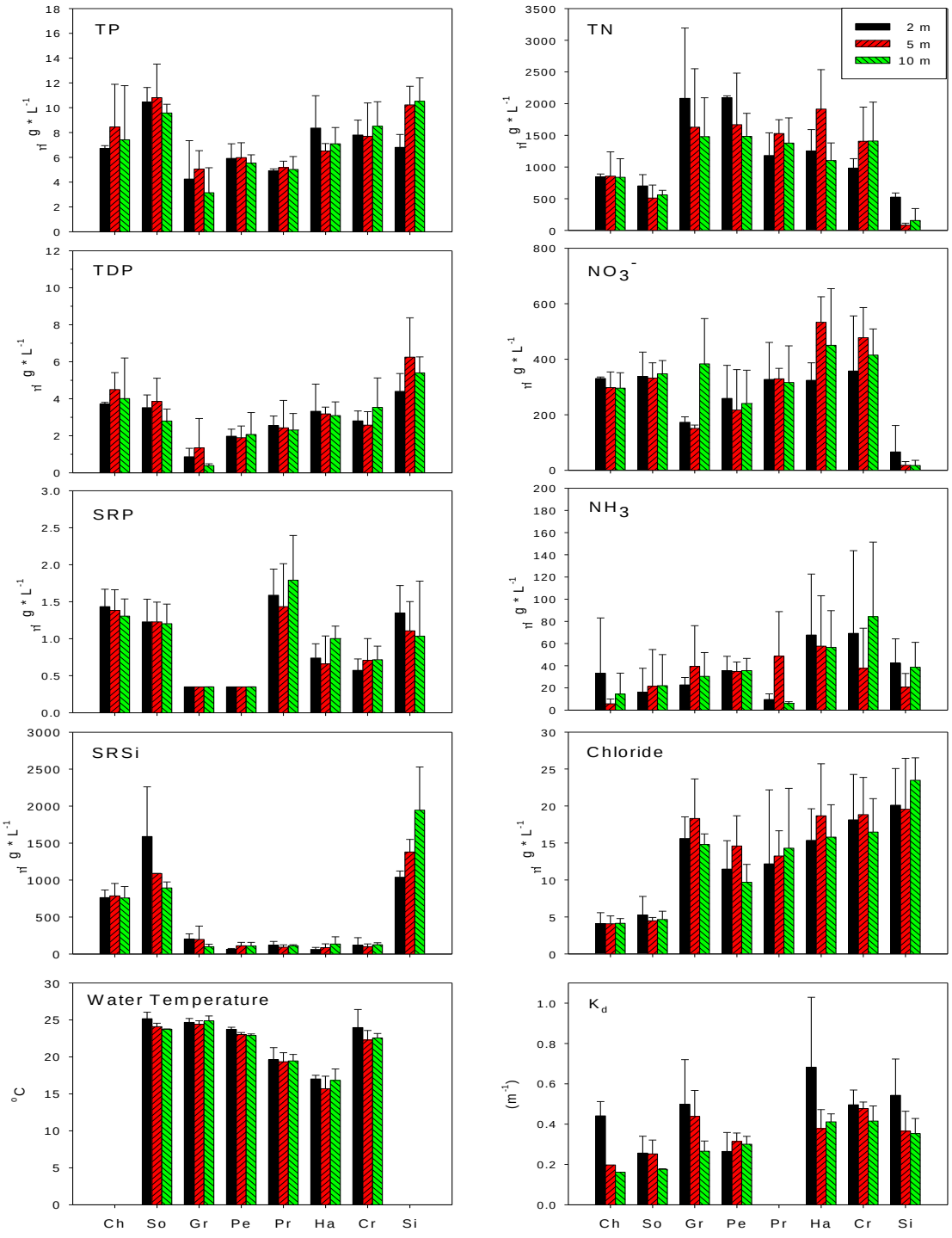

Figure 3.3: Continued from page 25. Note: SRP measurements for sites Grand River and Peacock Point in Lake Erie were all below detection (0.35 µg * L^{-1}).

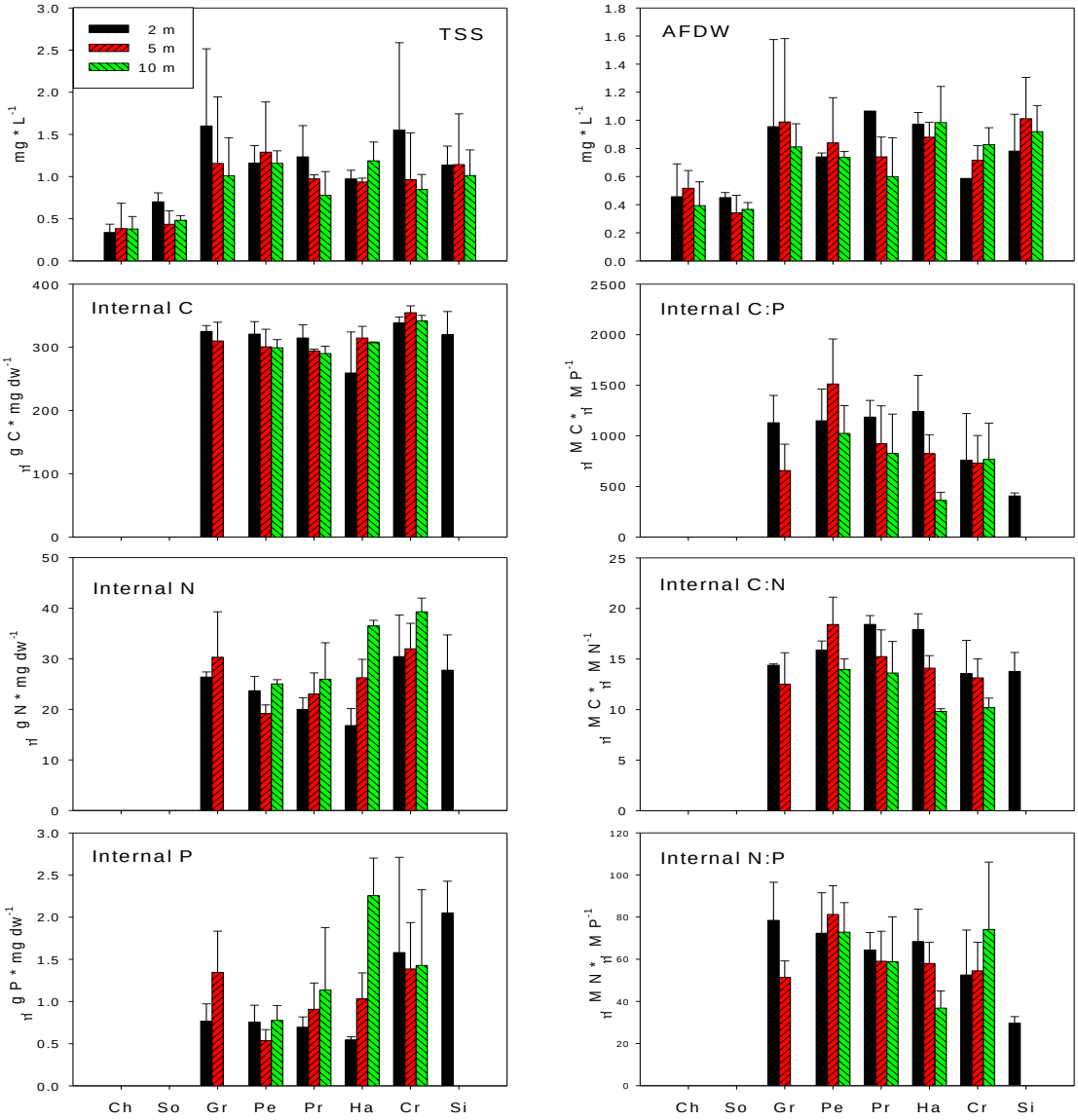

Figure 3.3: Concluded from page 25-26. *C. glomerata* tissue samples were not abundant enough for collection in Lake Huron at Southampton (So) nor Cape Chin (Ch) during summer surveys, 2005.

concentrations were observed to have almost the reverse pattern as our urban sites in Lake Ontario were greater (Fig. 3.3), however, Lake Simcoe remained significantly lower (Table 3.4). Also, ammonia concentrations were observed to be greater at our urban sites (Fig. 3.3).

Table 3.4: Midsummer means of physical, chemical, and biological variables. Means are taken from all stations and depths at each site. Sites at Lake Huron (H): Ch = Cape Chin, So = Southampton; Erie (E): Gr = Grand River, Pe = Peacock Pt.; Ontario (O): Pr = Presqu'ile Provincial Park, Ha = Halton, Cr = Port Credit; Sim = Lake Simcoe. Data from all depths and transects at a location contribute to the mean. ANOVA tests for significant differences among locations, and all tests are highly significant. na = data is not available.

	H-Ch Rural	H-So Rural	E-Gr Rural	E-Pe Rural	O-Pr Rural	O-Ha Urban	O-Cr Urban	Sim Rural	ANOVA F	p
Biological										
C:Chl-*a*	27.7	33.9	22.2	28.8	25.2	19.6	32.4	48.6	7.18	0.000
C:P	150	118	355	253	245	216	185	289	5.13	0.000
C:N	8.09	7.88	7.41	7.82	7.65	7.04	7.26	7.75	2.53	0.020
N:P	18.3	15	47.9	32.5	32.2	30.7	25.3	35.9	6.08	0.000
Chl-*a*	0.45	0.48	2.35	1.34	1.3	2.14	1.04	0.76	17.56	0.000
C	144	193	512	380	375	480	391	336	26.55	0.000
N	20.9	28.6	81.4	57.4	57.8	80.3	64	51.5	24.52	0.000
P	3.07	4.62	4.07	3.92	4.00	5.88	5.75	6.62	3.07	0.006
Chemical										
TP	7.58	10.1	3.9	5.77	5.04	7.16	8.04	9.42	11.65	0.000
TDP	4.1	3.25	0.75	2	2.4	3.18	3.01	5.13	17.49	0.000
SRP	1.36	1.22	0.35*	0.35*	1.65	0.82	0.68	1.17	28.58	0.000
TN	845	583	1667	1647	1366	1424	1323	287	18.95	0.000
NO_3^-	304	341	273	238	322	453	428	22.5	25.89	0.000
NH_3	16	20.3	30.7	35.3	17.5	59.3	62.6	39.7	4.22	0.000
SRSi	768	1119	150	99.1	109	102	115	1591	69.29	0.000
Cl^-	4.11	4.76	16	11.6	13.5	16.6	17.7	22.3	32.50	0.000
Physical										
Temp	na	24.2	24.7	23.1	19.5	16.5	22.7	na	119.73	0.000
K_d	0.28	0.22	0.37	0.30	na	0.46	0.46	0.41	6.61	0.000
TSS	0.37	0.51	1.19	1.2	0.94	1.05	1.03	1.31	8.66	0.000
AFDW	0.45	0.38	0.92	0.78	0.68	0.95	0.77	0.95	7.74	0.000

Soluble silicon was significantly greater in Lake Huron and Simcoe by as much as a factor of 10 with respect to Lake Erie and Ontario. Chlorine concentrations were significantly lower at Lake Huron sites (Table 3.4) and were typically higher at our urban sites and in Lake Simcoe.

C. glomerata tissue samples were collected at most depths in Lake Erie and Ontario during the summer cruises, however, no samples were collected at 10 m at the non-urban site at Grand River in Lake Erie. Samples were only collected at 2 m stations in Lake Simcoe and at no sites in Lake Huron. *C. glomerata* internal nutrient composition showed little variation in carbon other than at 10 m urban stations (Fig. 3.3) where the urban site at Port Credit had significantly higher C per unit dry weight (Table 3.5). Tissue nitrogen concentrations showed a similar pattern as both urban sites, Port Credit and Halton, had significantly higher concentrations at 10 m again (Table 3.5). Stations at 5 m also showed elevated concentrations of N at urban sites with respect to the non-urban sites at Peacock Point and Presqu'ile (Fig. 3.3), though the results from the Grand River site were also elevated in N. For both C and N no significant difference in tissue concentrations was found at 2 and 5 m stations. Lake Simcoe and the urban site at Port Credit were found to have the highest tissue P concentrations at 2 m stations (2.05 and 1.58 µg/mg dw, respectively), being significantly higher than the other sites (Table 3.5) by a factor of two to three. At 5 m stations, Port Credit had the highest concentrations in P (1.39 µg/mg dw), though the non-urban site at Grand River had comparable concentrations (1.34 µg/mg dw). At 10 m stations, both urban sites in Lake Ontario had the highest P concentrations. Halton had an average of 2.26 µg-P/mg dw and Port Credit had an average of 1.43 µg-P/mg dw in *C. glomerata* tissue samples (Fig. 3.3).

Nutrient ratios for *C. glomerata* samples indicate that 10 m stations at urban sites had lower C:P and C:N than non-urban, both suggesting less P and N stress to the alga at 10 m depth. Trends for nutrient ratios at 2 and 5 m stations are less obvious as there is

considerable overlap and variation. Lake Simcoe was found to have significantly lower values for C:P and N:P at 2 m stations (Table 3.5) with respect to the Great Lakes sites.

Table 3.5: Midsummer means of *C. glomerata* internal nutrients. C, N, P = carbon, nitrogen, and phosphorus. Sites at Lake Huron: Ch = Cape Chin, So = Southampton; Erie: Gr = Grand River, Pe = Peacock Pt.; Ontario: Pr = Presqu'ile Provincial Park, Ha = Halton, Cr = Port Credit; Si = Lake Simcoe. Sites with no data are indicative of insufficient biomass for sample collection.

	Depth	Site								ANOVA	
	(m)	Ch	So	Gr	Pe	Pr	Ha	Cr	Si	F	p
C:P	2			1129	1149	1185	1238	758	406	3.46	0.040
	5			657	1512	921	823	731		3.34	0.043
	10				1024	827	362	766		2.21	0.175
C:N	2			14.4	15.9	18.4	17.9	13.6	13.8	3.91	0.028
	5			12.5	18.4	15.2	14.1	13.1		3.14	0.052
	10				14.0	13.6	9.8	10.2		3.98	0.060
N:P	2			78.5	72.3	64.3	68.4	52.5	29.7	3.65	0.034
	5			51.4	81.3	59.1	58.0	54.5		2.76	0.074
	10				72.8	58.8	36.8	74.2		1.81	0.234
C	2			325	321	315	259	338	320	1.90	0.175
	5			310	301	318	315	355		2.03	0.150
	10				299	302	307	342		17.98	0.001
N	2			26.4	23.7	20.0	16.8	30.4	27.7	2.97	0.061
	5			30.3	19.2	27.7	26.2	32.0		2.37	0.107
	10				25.0	27.8	36.5	39.3		8.19	0.011
P	2			0.77	0.76	0.70	0.55	1.58	2.05	3.97	0.026
	5			1.34	0.54	1.15	1.03	1.39		2.46	0.097
	10				0.78	1.13	2.26	1.43		2.34	0.160

3.4.2 The Grand River Influence

As the influence of 16 Mile Creek along the Halton shoreline was assessed to have relatively low impacts on *C. glomerata* nutrient composition (Chapter 2), the impacts of the Grand River were analyzed to determine if nutrient loading from a much larger

watershed, which houses over 600 000 people and large tracts of agricultural land, would either impact the stations immediately adjacent to the river mouth (Mouth transect, Table 3.6) or inundate the entire 12 km stretch of shoreline surveyed. During the spring survey, May 11, 2005, a large run-off event had occurred recently and was evident by higher.

Table 3.6 Biological indicators sampled at the Grand River, May 11, 2005, designated by thermal structure and transect (West, Mouth, and East). Results within the epilimnion immediately adjacent to the river mouth are elevated significantly in particulate matter relative to the two transects 6 km east and west

	Epilimnion			Hypolimnion		
Parameter	West	Mouth	East	West	Mouth	East
Temperature (°C)	11.5	12.9	11.1	5.7	5.7	7.9
k_d (m^{-1})	0.30	0.74	0.34			
Chl-*a (µg/L)*	0.94	10.13	1.45	1.15	2.57	1.47
TSS (mg/L)	0.65	5.26	0.83	0.47		0.64
AFDW (mg/L)	0.54	2.50	0.56	0.37		0.68
Particulate C (µg/L)	253	973	243	282	347	244
Particulate N (µg/L)	37.2	139.6	39.6	42.0	55.0	39.0
Particulate P (µg/L)	1.5	6.9	2.1	1.3	2.8	2.0
C:P (molar)	512	401	298	561	343	317
C:N (molar)	8.0	8.1	7.2	7.8	7.4	7.3
N:P (molar)	64	49	42	72	47	43
TP (µg/L)	7.3	12.8	6.3	6.1	9.4	6.3
TDP (µg/L)	4.9	5.9	3.7	3.9	3.9	3.5
SRP (µg/L)	3.3	4.4	3.4	5.3	5.2	0.7
NO_3^- (µg/L)	334	1453	564	189	411	396
NH_3 (µg/L)	6.6	9.0	2.1	5.9	16.2	
TN (µg/L)	1012	2448	1550	730	1085	1058
PSi (µg/L)	36	758	124	33	59	10
SRSi (µg/L)	170	121	135	256	255	171

Light attenuation coefficients (k_{PAR}), total suspended solids (TSS), and ash free dry weight (AFDW), along the transect directly adjacent to the river's mouth, relative to the two transects 6 km east and west of the Grand River inputs (Table 3.6). As well, epilimnion nutrients concentrations, especially TP and nitrate were elevated greatly

compared to hypolimnion concentrations along the "Mouth" transect. Particulate CNP concentrations, chlorophyll-*a*, TP, TDP, SRP, TN, NO_3^-, and PSi concentrations were up to 40-fold and often 6-fold higher in the assumed plume. However, the runoff even was confined to a warmer surface plume that spread over deeper cooler water. The thermal stratification in the spring restricts vertical mixing of nutrient and strong vertical concentration gradients result Further, when algal collections and subsequent water chemistry was measured two months later, July 15, no vertical variation in nutrient concentrations was observed for this same transect with respect to the west and east transects. Precipitation data within the watershed also indicated rain had not occurred for 28 days prior to sampling on July 15, 2005 (Environment Canada 2007) and river runoff was approaching summer low values.

3.4.3 2006 Survey

In 2006, surveys were repeated at sites from 2005, and also at additional sites (Table 3.2) using snorkels. Water and algal samples were collected at depths ranging from 0.5 to 3.0 m (Table 3.7). Collection at each site was performed once during peak summer biomass, which was between late June and August, 2006, depending on historical patterns of *C. glomerata* growth within each lake. Water chemistry revealed that all sites, excluding Bath, were below detection for soluble reactive phosphorus concentrations (0.50 μgP/L) and nitrate concentrations ranged from 172 – 584 μg/L. No significant variation between land use and *C. glomerata* internal stoichiometry was observed in these surveys; however, the urban sites at Halton, Whitby, and Cobourg did have the lowest internal *C. glomerata* C:P and N:P nutrient ratios. *C. glomerata* samples from all sites

Table 3.7: 2006 midsummer chemical and internal *Cladophora* nutrient variables. C/P, C/N, N/P = carbon, nitrogen, and phosphorus, atomic ratios; SRP = soluble reactive phosphorus; NO_3^- = nitrate; SRSi = soluble reactive silicon; TSS = total suspended solids. All chemical variables are results for one sample collected at each site, except at Grand River, where n = 2; *Cladophora* nutrient results are means of three samples per site collected from depths ranging from 0.5 - 3.0 m.

	Ontario							Erie			Huron		
	Halton	Whitby	Cobourg	Presqu'ile Park	Point Petre	Bath	Emeric Point	Peacock Point	Grand River	Rathfon Point	Point Farms	Inverhuron	Southampton
	Urban	Urban	Urban	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural
Chemical													
SRP (µg/L)	0.50*	0.50*	0.50*	0.50*	0.50*	2.50	0.50*	0.50*	0.50*	0.50*	0.50*	0.50*	0.50*
NO_3^- (µg/L)	384	584	278	219	297	211	235	172	384	152	402	317	310
SRSi (µg/L)	100	200	80	40	20	240	100	20	20	20	700	600	840
TSS (mg/L)	1.40	1.20	1.00	1.50	0.80	0.90	1.10	5.90	4.00	2.60	12.80	0.80	11.40
Cladophora internal nutrient stoichiometry													
C/P (molar)	807	918	1448	1220	1547	796	1869	981	1026	1851	1170	581	1070
C/N (molar)	15.5	20.8	13.9	19.7	20.0	15.1	18.1	16.8	16.8	20.2	17.0	16.4	14.0
N/P (molar)	52.0	50.3	102.4	62.4	77.3	52.2	103.8	57.0	60.4	91.1	69.8	35.3	72.6

NB: * - SRP concentration is lower than detection limit= 0.50 µg P/L.

displayed phosphorus deficiency as C:P ratios were greater than 581 and N:P ratios were greater than 52, except for at the non-urban site of Inverhuron, Lake Huron, where N:P ratios averaged 35.

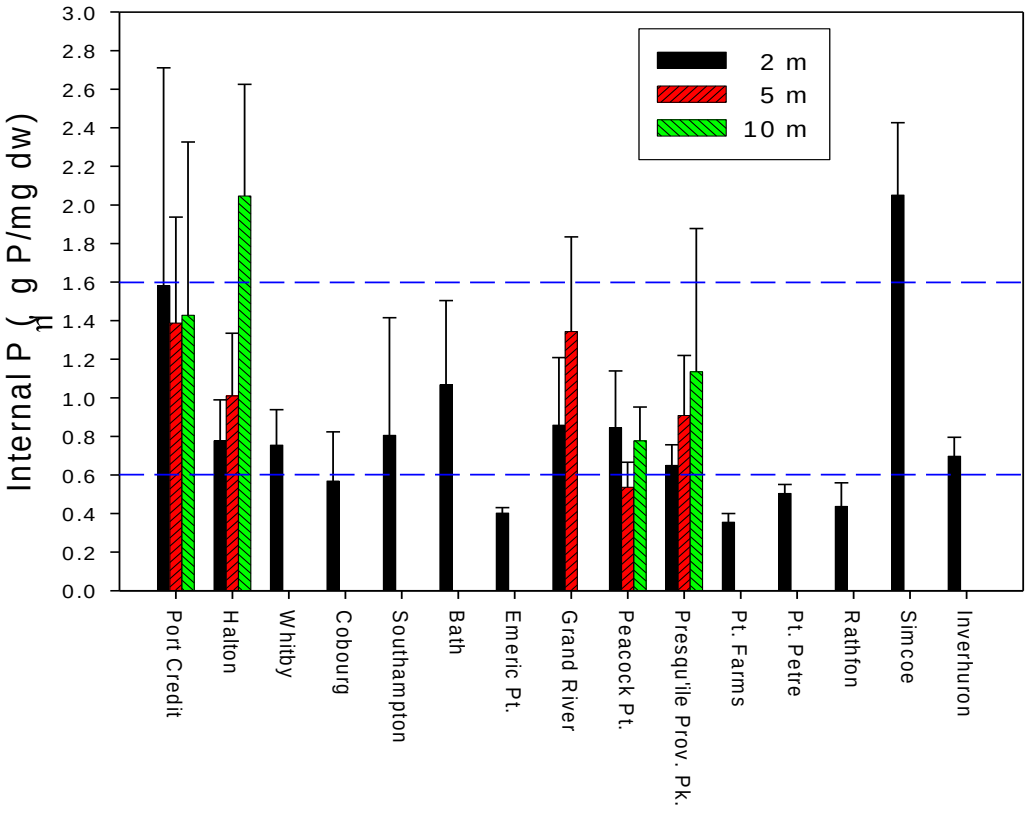

Figure 3.4: Shoreline contrasts for *Cladophora* internal P concentrations across the Great Lakes during the summer peak biomass period. Survey sites along the x-axis are listed in order of decreasing population and show that the large populated centres of Oakville and Port Credit, within the highly urbanized region of the Golden Horseshoe, are somewhat enriched in P relative to most non urban sites by depth. Two exceptions are at the Grand River site, which is subject to a large riverine influence, and the three samples collected near the islands in south eastern Lake Simcoe where very little *Cladophora* growth was observed. Dashed blue lines are the field and laboratory measurements for *Cladophora* phosphorus limitation at 1.6 and 0.6 µg P/mg dw, respectively.

C. glomerata internal phosphorus samples were also analyzed from summer data (Fig. 3.4) from all sites surveyed in 2005 and 2006. Sites were compared with relevance to population size; Port Credit and Oakville were the largest urban centres at one end of the gradient, with populations well over 100 000 inhabitants, while most sites had less than 1000 inhabitants, such as the Presqu'ile Provincial Park and Point Farms sites on Lakes Ontario and Huron, respectively. It was observed that with the addition of sites surveyed in 2006 that large urban areas may be slightly enriched in phosphorus as *C. glomerata* internal P concentrations were elevated with respect to the sites with very low human impact, which had phosphorus concentrations below the critical concentration of 0.6 µg P/mg dw (Wong & Clark 1976). The sites with midway populations or urbanization are somewhat variable, though, and many sites were only sampled at the 2 m depth. Further analysis of tissue samples collected from greater depths may provide stronger evidence to support the above results.

3.4.4 *C. glomerata* Internal Nutrient Ratios

Regardless of *C. glomerata* sample location and date of collection, an empirical autocorrelation between internal nutrient C:P and P concentrations as well as N:P and P was obtained (Fig. 3.5). Using the survey data and published results of limiting concentrations of *C. glomerata* internal P per dry biomass from laboratory (0.6 µg P/mg dm) and field (1.6 µg P/mg dm) studies, molar ratios for *C. glomerata* nutrient limitation were determined for every site where *C. glomerata* samples were collected over 2005 and 2006. Using the field values, empirical thresholds for P limitation were determined to be C:P atomic ratio 505 and N:P atomic ratio 41 within the Great Lakes. Further, with the

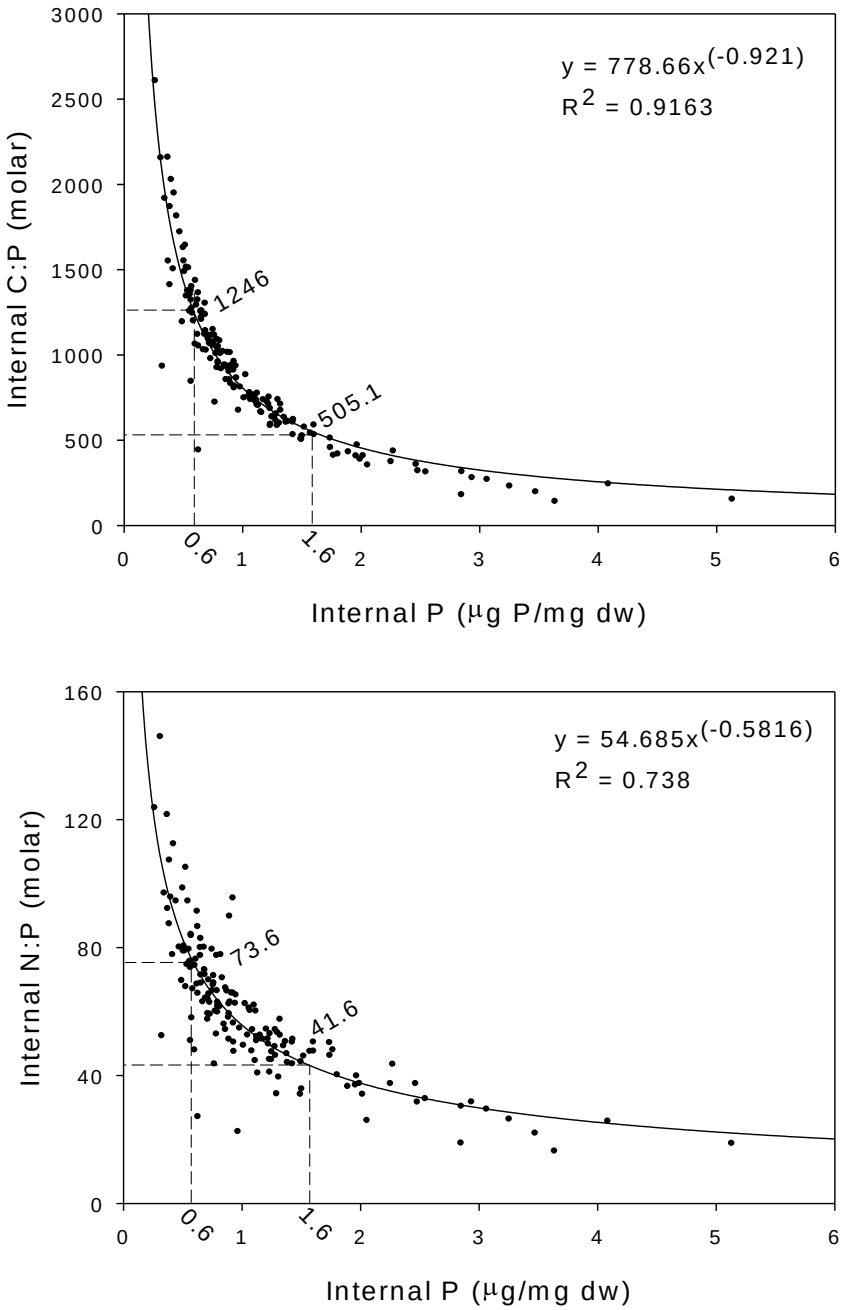

Figure 3.5: *Cladophora* molar tissue nutrient ratios, C:P and N:P, plotted against *Cladophora* internal P concentrations from samples collected over 2005-2006 throughout the Great Lakes. The variance in C:P and N:P is almost entirely a result of variance in internal P concentrations and that P is controlling algal growth. Using published critical P concentrations, we have empirically derived nutrient status indicators for the onset of P limitation, C:P > 505.1; N:P > 41.6, (Wong & Clark, 1976: 1.6 µg P/mg dw) and for zero positive growth, C:P > 1246; N:P > 75.6 (Gerloff & Fitzgerald, 1976: 0.6 µg P/mg dw) for *Cladophora* within the Great Lakes.

evidence from this N:P versus P relationship, it was found that, regardless of how high internal P concentrations reached in these systems, the N:P ratio never decreased below 19, indicating that N was being assimilated at a constant proportion to P at these stations that were elevated in nutrients, suggesting further that P is the key driver for nutrient limitation within these lakes. The most enriched P samples were collected in autumn when water column TP concentrations were highly elevated.

Tissue stoichiometry at shallower stations was similar across lakes and shorelines. Only at greater depths i.e. the 10 m samples were differences among shorelines evident with urban shorelines having lower C:P, N:P and C:N ratios. Growth under light saturation drives all Cladophora to similar low tissue P concentrations and stoichiometric ratios regardless of lake or shoreline. Only under low growth rates at sub-saturation irradiance do differences in tissue stoichiometry emerge that can be related to higher nutrient availability along urban shorelines.

3.5 Discussion

Trends in *C. glomerata* internal nutrient status at urban and non-urban sites were found to reflect relatively stable conditions at each individual site in 2005. Within Lake Ontario, the urbanized shorelines at Halton and Port Credit were mainly P and N enriched relative to C at 10 m stations during the summer with respect to the non-urban sites at Presqu'ile Provincial Park and Peacock Point (Fig. 3.3). There was little variation in internal nutrient composition at shallower depths in the summer as well as during the spring. Contrasts between the urban shorelines and the Grand River area in Lake Erie

were limited to summer data and depths of 5 m or less for *C. glomerata* nutrient status indicators and were thus, inconclusive as apparent differences in algal stoichiometry may be only occurring at 10 m where light limits the rate of *Cladophora* growth. The influence of the Grand River as a point source was also assessed. Turbidity, nutrients, and chlorophyll-*a* concentrations were all elevated greatly along the transect directly in front of the river plume on the May 11 survey during high spring flows. This, however, was seen within the epilimnion primarily indicating that the relatively warm plume was confined to the surface while hypolimnion results below the plume were similar to concentrations measured at the adjacent transects outside of the river plume. However,, no benthic algal samples were collected on that date to verify the river's influence on *C. glomerata* nutrient composition. However, the brevity of the spring peak runoff and its occurrence before *Cladophora* cover is well established and the fact that *C. glomerata* nutrient composition is a function of longer term trends (Auer & Canale 1982b), the influence of the Grand River spring runoff nutrient pulse on benthic algal nutrient dynamics may not be significant. Certainly at the time of the summer peak biomass the 2 m sites on the Grand River transects are not different than nearby Peacock Point transects. However, the higher internal P concentration at 5 m sites and the lack of *Cladophora* at 10 m on the Grand River transects suggest that the effect of the suspended load (and resulting higher light extinction coefficients) may limit the areal extent of *Cladophora* to shallower depths..

A comparison of the urban Halton transects with the non-urban Peacock Point on Lake Erie yielded similar results to the comparison with Presqu'ile results, indicating that the urban site may be enriched in P at 10 m. No difference between the two shorelines at

2 and 5 m depths was apparent with respect to *C. glomerata* internal C:P, C:N, and N:P results, again suggesting that at shallower depths and conditions of high PAR, *C. glomerata* growth can exceed P uptake and availability in the environment. This may result in the lower P concentrations within the *C. glomerata* stands, regardless of point source and shoreline land use impacts. 10 m urban stations may be greater in internal P concentrations compared to non urban sites. However, 10 m may also just be indicating greater light penetration as K_d values at both Halton and Port Credit are higher (Table 3.4) The results at Grand River may also suggest this similar light limitation as 5 m internal P is much higher than 2 m and mean K_d is also higher. Also note low C:chl in Table 3.4 for Grand River and Halton stations but the differences in TP and SRP — again, light (K_d) seems as important as TP and SRP concentrations in causing the higher *C. glomerata* internal P at deeper stations. Also, Lake Simcoe was consistently enriched in P as *C. glomerata* tissue concentrations indicated, which may be a result of differing lake systems as Simcoe is a much smaller and shallower lake. Biotic differences may also be important and the importance of grazing control on lower energy shorelines in Simcoe may be a factor in keeping Cladophora biomass low and not nutrient limited. The finding that 10 m stations at urban shores are more P rich may be due to the potential that nutrient enrichment along a shoreline can only be measured with stoichiometric relationships at deeper depths once light limitation has occurred. At the shallower light saturated stations of 2 and 5 m, P uptake generally lags internal dilution by tissue growth resulting in declining P concentration during rapid summer growth. Overall, the majority of *C. glomerata* samples, regardless of shoreline, were P limited. Exceptions include

most 10 m stations and the 2 m autumn samples at Halton, several samples along the highly urbanized Port Credit shoreline, and Lake Simcoe.

It is proposed that use of the algal internal nutrient ratios, N:P, to determine *C. glomerata* nutritional status may be of greater benefit than absolute tissue nutrient measurements as a proportion of dry mass (Fig. 3.5). This is suggested because calcium carbonate accumulation, epiphytic diatom growth, and larger investments in carbon-based structural cell components may influence dry weight measurements during periods of nutrient limitation but may not be directly related to nutrient status, cellular processes, and stoichiometric balances. This is explored further in the next chapter.

Chapter 4: Stable Isotopes in *Cladophora glomerata* as Indicators of Nutrient Source and Production

4.1 Abstract

Along the Halton shoreline, Lake Ontario, seasonal variation in dissolved inorganic carbon $\delta^{13}C$ values strongly influenced the $\delta^{13}C$ signature within tissue samples of the benthic alga, *C. glomerata*. However, during the onset of rapid spring growth, light saturated algal filaments differed in $\delta^{13}C$ values from light limited stations and offshore trends as higher photosynthetic demand for carbon by *Cladophora* diminished the local dissolved carbon pool within the algal beds. No appreciable seasonal variation in $\delta^{15}N$ values was observed from benthic algal tissue samples collected over the same period. $\delta^{15}N$ values did not indicate a distinctive nutrient point source for *C. glomerata* along any of the surveyed shorelines. However a significant relationship with depth was observed as samples in shallower near shore stations were consistently more enriched in ^{15}N. Point sources such as the adjacent 16 Mile Creek input or a proximal waste water treatment plant outfall were not influential in significantly affecting the stable isotope signature of *Cladophora*. After contrasting urban and non-urban shorelines within Lake Erie and Ontario, it was observed that urban shorelines do not influence $\delta^{13}C$ and $\delta^{15}N$ values within *C. glomerata* tissue samples with respect to non-urban shorelines. Inter-lake variation and review of offshore dissolved carbon and nitrogen isotope values suggested that *C. glomerata* beds along the northern shore in eastern Lake Erie are enriched in both ^{13}C and ^{15}N compared to Lake Ontario, however the Grand River may be a large influence on $\delta^{13}C$ values over extensive lengths of adjacent shoreline. As well, there is a

persistent depth relationship with ^{15}N, though unique to each section of shoreline surveyed, as algal filaments collected at shallower depths were heavier in ^{15}N. This suggests that a gradient in heavy nitrogen from overland runoff mixing with lighter dissolved inorganic nitrogen inputs from offshore is occurring, or, alternatively, that use of more isotopically heavier nitrate at shallower depths is taking place due to higher photosynthetic demand reducing isotopically lighter ammonia pools. The observation of this depth relationship with *C. glomerata* $\delta^{15}N$ values may have potential value in tracing sloughed algal biomass to its original depth of growth within the lake.

4.2 Introduction

During the last two centuries, settlement and industry have altered Great Lake nutrient dynamics on both lake and regional scales. Large tracts of land were cleared for modern agriculture, and industrial and municipal water needs and uses have altered the nearshore regions. Direct inputs to the lakes and erosional processes have introduced high concentrations of particulate matter, dissolved nutrients, and also compounds such as fertilizers and industrial by-products, which influence nutrient cycling and at times lead to coastal eutrophication. Along the rocky littoral shorelines of the Great Lakes, this can cause development of large beds of benthic filamentous algae, namely, *Cladophora glomerata*. Largely, this has been correlated with phosphorus enrichment of the lake water. Subsequent management programs to remove such excessive phosphorus loadings to the lakes to decrease algal growth have been successful in the past (Taft 1975, Sweeney 1993).

Recently, there has been a resurgence in *C. glomerata* coastal fouling. This may be the result of a complex set of processes mediated by dreissenids and referred to as the nearshore phosphorus shunt (Hecky et al. 2004). This relates phosphorus recycling, increased water clarity, and extended benthic habitat, attributable to the coastal reengineering by exotic dreissenid mussels. However, seasonal and spatial variability in the growth of *C. glomerata* need to be understood in terms of not only altered habitat but also the sources for nutrients sustaining its growth. The potential variability in nutrient concentrations between urban and non urban shorelines as well as nutrient point sources,

such as major rivers and waste water treatment plant outfalls, were analyzed with the use of carbon and nitrogen stable isotopes (^{13}C and ^{15}N). The use of carbon stable isotopes ($\delta^{13}C$) has been effective in tracing nutrient sources within food webs (Leggett 1999) and also evaluating the importance of benthic photosynthesis (Hecky & Hesslein 1995) in ecosystems. Nitrogen isotope values ($\delta^{15}N$) have been used in the determination of relative trophic level within food webs (Leggett 2000) as well as in the identification of nitrogen sources (Kendall 1998). The principle in using stable isotopes in studies is based on the relative proportions of stable isotopes and how they are altered in natural systems by fractionation during uptake and chemical transformation. The frequency with which the two most abundant carbon stable isotopes occur within the environment is approximately 1/99, ^{13}C:^{12}C, respectively, and is expressed as parts per thousand differences from a standard in terms of δ values (Peterson & Fry, 1987). The δ value of an isotope is calculated as:

$$\delta X = [(R_{sample}/R_{standard})\text{-}1] \times 10^3,$$

where X is ^{13}C, or any other isotope under study such as ^{15}N, and R is the corresponding ratio $^{13}C/^{12}C$. A decrease in the δ value would indicate a depletion in heavy isotope, where inversely, an increase in δ value indicates an increase in heavy isotope. The property that distinguishes two carbon atoms is that ^{12}C has 6 protons and 6 neutrons, while ^{13}C has one additional neutron, which alters the atomic mass properties of carbon only through diffusion rates as the heavier carbon atom will react slower with respect to ^{12}C (Fry 2006). Due to fractionation and mixing of these two isotopes as they are moved across phase boundaries, assimilated into tissue, and expelled as waste

products, identifiable trends can be found depending on initial concentrations of carbon sources and carbon uptake kinetics within biochemical reactions. Table 4.1 lists the common $\delta^{13}C$ values found in various sources of particulate matter to lakes. Similarly, ^{15}N and ^{14}N are the two nitrogen stable isotopes and have a relative frequency of 1/272, respectively (Kendall 1998). As well, a list of known $\delta^{15}N$ values within lakes is in Table 4.2.

Table 4.1: Published $\delta^{13}C$ values for sources of particulate and dissolved carbon to lakes

Source		$\delta^{13}C$ (‰)	Reference	Notes
Terrestrial Plants	C3	-32 to -22	Kendall et al. 2001	Compiled from various sources
	C4	-16 to -9	Kendall et al. 2001	Compiled from various sources
	CAM	-34 to -11	Deines 1980	Compiled from various sources
Soil Organic Matter		-32 to -9	Kendall et al. 2001	Based upon typical ranges for C3 and C4 plants, since d13C of soil organic matter reflects d13C of plants growing in soil
Aquatic Macrophytes		-36 to -6	Deines 1980	Compiled from various sources
Phytoplankton		-36 to -16	LaZerte 1983; Grey et al. 2000	For Lake Memphremagog, Quebec, and 16 lakes in UK
Bacteria		-29 to -27	Embury 2000	For water column of Lake 164, ELA in northern Ontario
Sewage POM		-29 to -21	Maksymowska et al. 2000	Compiled from various sources

In this paper, a localized shoreline study in the western end of Lake Ontario over the 2006 growing season will be used to analyze the natural abundance of $\delta^{13}C$ within the dissolved inorganic carbon pool as well as $\delta^{13}C$ and $\delta^{15}N$ within *C. glomerata* algal tissue samples. Seasonal variation, light relationships, and potential nutrient point sources will

be delineated. Further, a larger spatial comparison of *C. glomerata* internal $\delta^{13}C$ and $\delta^{15}N$ will be used to contrast urban and non-urban shorelines across Lake Erie and Ontario. It is hypothesized that $\delta^{13}C$ and $\delta^{15}N$ in water and algal samples will aid, in conjunction with algal nutrient stoichiometry, in describing seasonal nutrient fluctuations, define carbon and nitrogen point sources, and determine if varying shoreline landscape is influential to adjacent littoral zone nutrient dynamics. It is believed that ^{13}C fractionation dependent on carbon limited photosynthesis can be identified in *C. glomerata* beds during periods of rapid production, specifically in late spring and early summer before nutrients become depleted. It is also hypothesized that $\delta^{15}N$ of *C. glomerata* would respond to nitrogen sources dominated by animal wastes or artificial N fertilizers which each can have rather distinctive $\delta^{15}N$ signatures and therefore may be indicative of anthropogenic nutrient enrichment.

Table 4.2: Published $\delta^{15}N$ values for sources of particulate and dissolved nitrogen to lakes

Source	$\delta^{15}N$ (‰)	Reference	Notes
Terrestrial Plants	-10 to +10	Kendall et al. 2001	-
Soil	-10 to +15	Kendall 1998	-
Synthetic Fertilizer	-3 to +3	Kendall 1998	-
Animal Manure	+10 to +20	Kendall et al. 2001	Compiled from various sources
Sewage	-10 to +32	Kendall 1998	Compiled from various sources
Aquatic Macrophytes	-10 to +11	Talbot 2001 Thorp et al. 1998	Partly for the Ohio River
Phytoplankton	0 to +11	Cloern et al. 2002	For freshwater areas of San Francisco Bay estuarine system
Bacteria	+1 to +4	Embury 2000	For water column of Lake 164, ELA in northern Ontario
Dissolved Inorganic Nitrogen	+3.5 to +6	Leggett 2000	Offshore lake signal in Lake Ontario, 1997

4.3 Methods

4.3.1 Survey Sites and Sampling: Temporal and Spatial Observation

In 2006, several surveys were performed along a 12 km stretch of the Halton Region shoreline in western Lake Ontario was performed. Four transects perpendicular to shore, three or more kilometres apart in order to reduce pseudoreplication (Palmer 1968), were each sampled at 2, 5, and 10 m depth (Fig. 2.1). As well, a 35 m offshore station was sampled to define offshore nutrient conditions and potential influences on the coastal zone. A broad-scale spatial survey in 2005 was extended to several urban and non urban shorelines across Lake Erie and Ontario and sampling followed the same routine as described for the Halton shoreline, with the exception that only three transects were used at each site. Sample sites for 2005 are listed in Table 4.3 and were selected based on historical records (Painter & Kamaitis 1987, Higgins et al. 2005a) for consistency or

Table 4.3. 2005 nearshore sampling sites on the Great Lakes.

Lake	Site	Site Type	Spring	Summer
Erie	Peacock Pt	Rural	May-05	Jul-12
	Nanticoke Shoal	Offshore	May-05	Jul-15
	Grand River	Rural	May-11	Jul-15
Ontario	Halton	Urban	Jun-01	Jul-25
	Credit River	Urban	Jun-02	Jul-21
	Presqu'ile Park	Rural	Jun-08	Jul-27
	Dobb's Bank	Offshore	Jun-08	Jul-27

appropriate physical characteristics (if not surveyed in any prior literature). All sites consist of shallow slope, with a combination of exposed bedrock and boulder substrate.

Temperatures in mid summer within the eastern basin of Lake Erie are historically warmer (up to 25^{o}C in 2005) than in Lake Ontario (up to 20^{o}C in 2005 and 2006) as thermal upwelling is more common in the latter.

4.3.2 Physical Measurements

Temperature and conductivity profiles were performed using a CTD profiler. As well, photosynthetically active radiation (PAR) was measured using a Li-Cor radiometer. Using PAR measurements versus depth, the PAR attenuation coefficient (K_d) was calculated and subsequently used to determine PAR at depth. Video was also collected on most boat-based surveys (when equipment was available) for benthic substrate verification and mussel abundance (unpublished data, T. Ozersky, University of Waterloo) in deeper waters.

4.3.3 Water Column Nutrient Chemistry

Nutrient concentrations of the water column were determined from the collected water samples. At each site sampled in 2005 and at Lake Simcoe in 2006, water samples were collected midway through the mixed layer. If thermal structure was present at the 5 and 10 m stations, then one sample was collected mid-epilimnion and an additional sample was collected 1 m off bottom. During the snorkel survey in 2006, water samples were collected midway in the water column at the 1.5 m depth contour. All water collections were performed using a Niskin bottle. Samples were stored in dark coolers for transport at lake temperature for transport to the laboratory. Laboratory measurement of total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus

(SRP), and particulate phosphorus concentrations (Table 2.1) were then performed according to a method from Stainton et al. (1977) using an Ultraspec 3100 Pro UV/Visible Spectrophotometer and a 10 cm cuvette. TP samples were unfiltered, TDP and SRP were both filtered using 0.2 µm polycarbonate filters, and PP samples were filtered on glass fibre filters using a pore size of 0.8 µm. Additional ions, including nitrate, chloride, and sulphate were measured using ion chromatography (Dionex DX 500, Dionex AS17, and AG17 guard column, respectively). Ammonium was determined by fluorometry (Holmes et al. 1999). Total suspended solids were measured by filtering 2-3 L of lake water onto pre-combusted (500^{o}C for 4 hr) and pre-weighed glass fibre filters (GF/F), drying for 24 hrs at 65^{o}C and reweighing. Chlorophyll-*a* concentrations were measured by fluorometry (Smith et al. 1999). Particulate nutrients, carbon (C) and nitrogen (N), were filtered on pre-combusted GF/F, pore size 0.8 µm. Nutrient status indicators for phytoplankton were determined using the molar particulate nutrient ratios of (C:N), (C:P), and (N:P). C:P, C:N, and N:P values greater than 129, 8.3, and 22 are indicative of P, N and P deficiency respectively (Healey & Hendzel 1979, 1980).

4.3.4 Internal *C. glomerata* Nutrient Chemistry

Cladophora glomerata samples were collected by use of a sampling rake. This instrument is a standard rigid flat rake affixed to a chain and rope that connects to the sampling vessel. The method involved tossing the rake overboard and dragging it along the substrate in order to collect sufficient algal biomass for sampling. Algal tissue samples were then stored in dark coolers at lake temperature until laboratory analysis. Tissue samples were subsequently washed in deionized water, freeze-dried, and stored (-

4^{o}C) until internal tissue nutrients (carbon, nitrogen, and phosphorus) were measured. For phosphorus content analysis, ground tissue samples were combusted, autoclaved with saturated potassium persulfate for acid digestion, and measured on an Ultraspec 3100 Pro UV/Visible Spectrophotometer using a 5 cm cuvette according to a modified protocol from Stainton et al. (1977). *C. glomerata* carbon and nitrogen concentrations were determined using a CE-440 Elemental Analyzer (Exeter Analytical, Inc.). Chlorophyll-*a* concentrations were measured via fluorometry using acetone extraction from ground tissue samples (Krause & Weis 1991; Maxwell & Johnson 2000; Hagerthey et al. 2006). Four internal algal nutrient ratios were measured, including C:N, C:P, N:P (molar) and C:Chl-*a*.(μmole/μg).

During each survey, benthic hydro-acoustic measurements were performed by cruising the vessel at transect intervals of 75 m between and at each station on a continuous basis in order to estimate areal coverage and biomass of *C. glomerata* (unpublished data, D. Depew, University of Waterloo).

4.3.5 Stable Isotope Analyses

Carbon (^{13}C) and nitrogen (^{15}N) stable isotopes in *Cladophora glomerata* tissue were measured in dried, ground tissue samples submitted to the Environmental Isotope Laboratory (EIL) at the University of Waterloo, Ontario. Subsamples were run for nitrogen and carbon isotope analysis on an Isochrom Continuous Flow Stable Isotope Mass Spectrometer (Micromass) coupled to a Carlo Erba Elemental Analyzer (CHNS-O EA1108). Results were corrected to nitrogen standards IAEA-N1 and IAEA-N2 (both

Ammonium Sulphate) and carbon standards IAEA-CH6 (sugar), EIL-72 (cellulose) and EIL-32 (graphite). EIL-70b is a lipid extracted/ball-milled fish material and, along with several NIST organic materials, is often used as a monitoring standard ('EIL' denotes internal lab reference materials with values calculated using International Standards). The error for clean ball-milled standard material is +/- 0.2‰ for carbon and +/- 0.3‰ for nitrogen. This error can be expected to change depending on the homogeneity, type, and amount of sample used in analysis. Standards are placed throughout each run at a range of weights to allow for an additional linearity correction, when necessary, due to machine fluctuations or samples of varying signal peak areas. Nitrogen and carbon compositions are calculated based on Carlo Erba Elemental Standards B2005, B2035 and B2036 with an error of +/- 1%.

4.3.6 Statistical Analyses

Statistical analyses of data were performed using Systat 10.2 (Wilkinson 1996). Shorelines were contrasted to determine if varying shoreline impacts affect benthic algal growth and to determine if local point sources were influential on this growth. A three-way ANOVA factoring depth, season, and landscape was designed to interpret potential impacts between varying shorelines. Data were log transformed if necessary to achieve a normal distribution.

4.4 Results

4.4.1 Case Study: The Urbanized Halton Shoreline, 2006

By surveying the Halton shoreline throughout the growing season of 2006, spatial and temporal changes of $\delta^{13}C$ within the dissolved inorganic carbon (DIC) pool and within *C. glomerata* tissue were determined. $\delta^{15}N$ was measured within *C. glomerata* tissue over the same period (Table 4.4).

Table 4.4: 2006 daily means of chemical and physical variables, and internal *Cladophora* stable isotope values at the Halton shoreline. DIC = dissolved inorganic carbon; kPAR = extinction coefficient of photosynthetically active radiation; $\delta^{13}C$ and $\delta^{15}N$ values measured as ‰ from applicable standards.

	Spring	Summer				Fall			ANOVA
	April	May-08	Jun-08	Jun-23	Jul-11	Aug-01	Sep-14	Oct-19	Seasonal
Chemical									
Alkalinity (meq)	na	1.77	1.84	1.78	1.82	1.77	1.73	1.81	0.001
$\delta^{13}C$-DIC (‰)	na	-1.96	-1.54	-1.21	-1.33	-1.29	-0.52	-1.75	0.000
Physical									
Temp. (°C)	na	9.86	17.61	11.12	10.49	16.38	18.75	6.86	
k_{PAR} (m^{-1})	na	0.391	0.388	0.260	0.447	0.357	0.341	0.661	0.034
Cladophora internal nutrient stoichiometry									
$\delta^{13}C$ (‰)									
2 m		-21.73	-18.41	-18.20	-19.77	-17.20	-16.01**	-17.43	0.000
5 m		-19.34**	-16.94	-17.17	-17.58	-16.37			0.011
10 m		-20.36**	-19.38	-18.69	-18.62				0.037
ANOVA-Depth			0.006	0.009	0.004	0.236			
$\delta^{15}N$ (‰)									
2 m		7.27	7.80	7.24	7.28	7.70	6.48**	6.88	0.039
5 m		6.82**	6.66	6.57	6.78	6.22			0.623
10 m		6.35**	5.77	5.40	6.44				0.538
ANOVA-Depth			0.016	0.002	0.195	0.011			

NB: "ANOVA-Seasonal" tests seasonal variation of Spring, Summer, and Autumn data, whereas "ANOVA-Depth" tests variation between 2, 5, and 10 m stations on each survey date; * - Summer and Autumn data tested only; ** - n = 1.

Within the DIC pool, samples were found to be similar (paired t-Test, df = 14, t = 0.121, p = 0.905) in $\delta^{13}C$ values among both the mixed layer and the hypolimnion (Table 4.5). This is likely due to the low stability of the shallow inshore water column, leading to frequent vertical mixing, and persistent upwelling seen throughout much of the summer as observed in the temperature pattern (Fig. 2.2).

Table 4.5: Data for ^{13}C-DIC paired t-Test contrasting differences between hypolimnetic results and the overlying epilimnion samples. t = 0.121, p = 0.905.

		Station		$\delta^{13}DIC$	
Date	Season	#	Depth (m)	Epilimnion	Hypolimnion
8-Jun	Su	607	10.0	-1.91	-1.54
23-Jun	Su	605	5.0	-1.09	-1.49
11-Jul	Su	603	5.0	-1.86	-0.52
11-Jul	Su	604	5.0	-1.68	-1.70
11-Jul	Su	605	5.0	-1.04	-1.16
11-Jul	Su	632	5.0	-1.12	-1.01
11-Jul	Su	606	10.0	-1.05	-2.37
11-Jul	Su	607	10.0	-2.13	-1.59
11-Jul	Su	608	10.0	-0.89	-0.89
11-Jul	Su	633	10.0	-1.04	-1.43
1-Aug	Su	603	5.0	-0.95	-1.14
1-Aug	Su	632	5.0	-0.95	-1.12
1-Aug	Su	607	10.0	-1.62	-1.21
1-Aug	Su	608	10.0	-1.36	-1.15
1-Aug	Su	633	10.0	-0.86	-1.51

Spatial variation in $\delta^{13}C$-DIC was then tested in order to determine if point sources or depth relationships existed. A 2-way ANOVA testing depth and transect (Fig. 2.1) during the summer surveys from June 8 to August 1 was performed:

Source	Type III SS	df	Mean Squares	F	P
Transect	0.504	3	0.168	1.11	0.354
Depth	0.482	2	0.241	1.59	0.213
Tran*Dep	0.688	6	0.115	0.76	0.606
Error	7.563	50	0.151		

From this test it was evident that no individual station was a potential point source ($p = 0.606$) with a different δ^{13}C-DIC , as well, no depth relationship over the peak growing period of June to August, 2006, existed.

Seasonal variation (Fig. 4.1), on the other hand, was much more pronounced. During the spring at all depths and stations, the DIC δ^{13}C value was relatively depleted at all depths before increasing in the ^{13}C fraction during early summer. The δ^{13}C maintained this early summer fractionation value throughout the remainder of the summer before again increasing substantially for the September 14 survey. Subsequently, values varied more but declined overall on the final survey on October 19. As well, the 35 m offshore station was much more variable throughout 2006 being generally lighter during the summer and heavier during our Sept. 14 and Oct. 19 surveys than the nearshore stations. (Fig. 4.1)

A similar seasonal pattern for δ^{13}C in *C. glomerata* tissue samples was also evident (Fig. 4.2a). However, as the onset of rapid *C. glomerata* growth induced a photosynthetic fractionation that increased the δ^{13}C in growing material relative to ambient DIC a decoupling in the rate of change in δ^{13}C values was noticed between the light saturated (2 and 5 m stations) plants and light limited plants (10 m stations). The seasonal pattern in organic tissue is a result of this fractionation (Fig. 4.3), which can vary depending on the

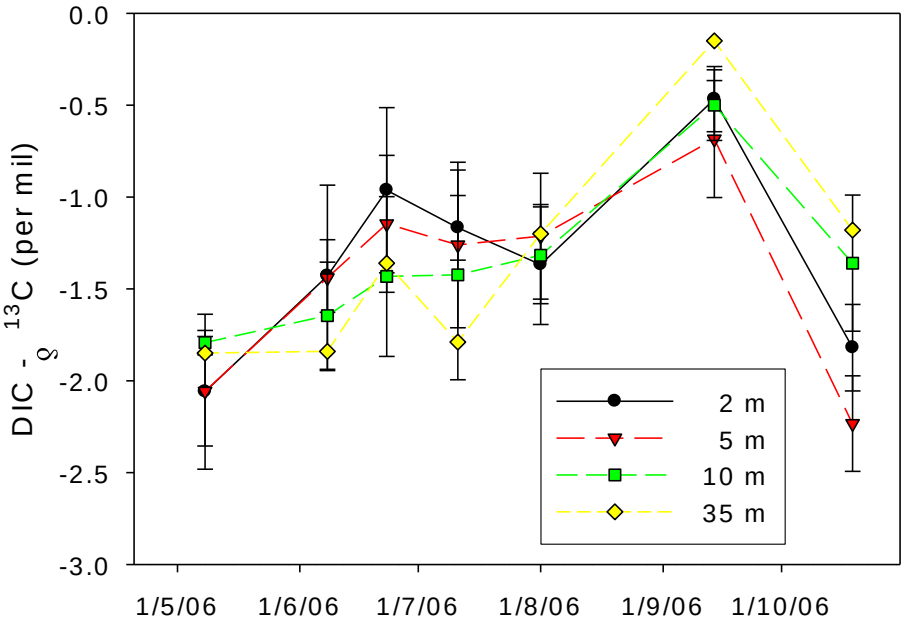

Figure 4.1: Halton shoreline seasonal trends in dissolved inorganic carbon $\delta^{13}C$ values in water at 2, 5, and 10 m nearshore stations, as well as a 35 m offshore station, all collected within the mixed layer. Error bars are one standard deviation.

rate of growth (Hecky & Hesslein 1995), stagnant boundary layer thickness of over dense stands and along individual filaments and the changing $\delta^{13}C$ in the DIC, which is also affected by the high rate of carbon withdrawal, by both *Cladophora* filaments and phytoplankton, selectively removing the lighter isotope. As algal growth maintained its high pace throughout the early summer, $\delta^{13}C$ values in both DIC and *Cladophora* tissue became heavier. However, as late summer die-off and sloughing of algal material began, only samples from 2 m stations were collected throughout the latter two surveys. A relatively slight increase in the $\delta^{13}C$ value was apparent in September before declining in October in tissue samples (Fig. 4.2a), while DIC became much lighter due to CO_2 regeneration from the lighter algal material (Fig. 4.1).

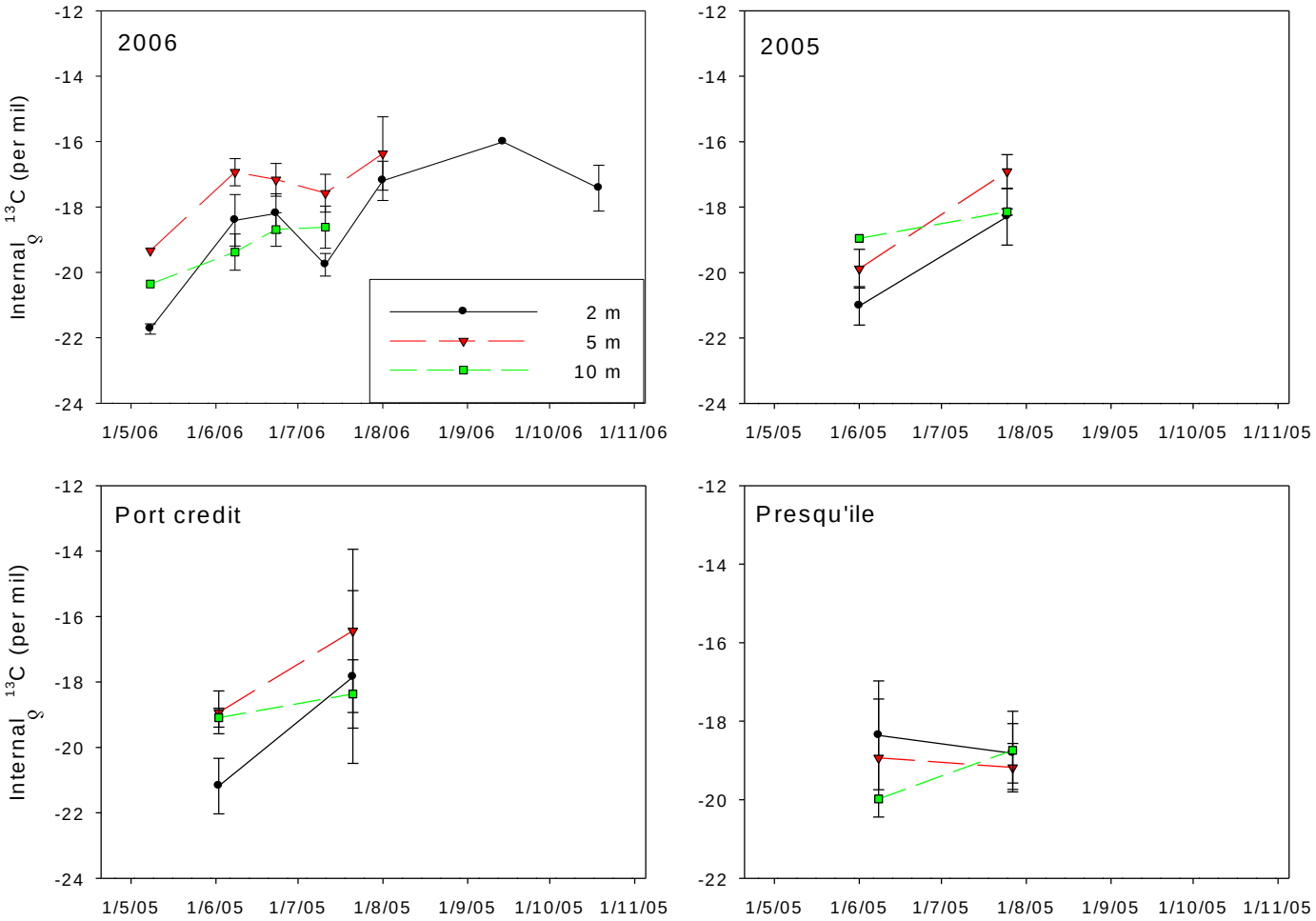

Figure 4.2: a) *C. glomerata* internal $\delta^{13}C$ values along the Halton shoreline, 2006 and b) 2005, c) Port Credit, 2005, and d) Presqu'ile Provincial Park, 2005. Only samples at 2 m were abundant in biomass for collection throughout the full survey period, 2006.

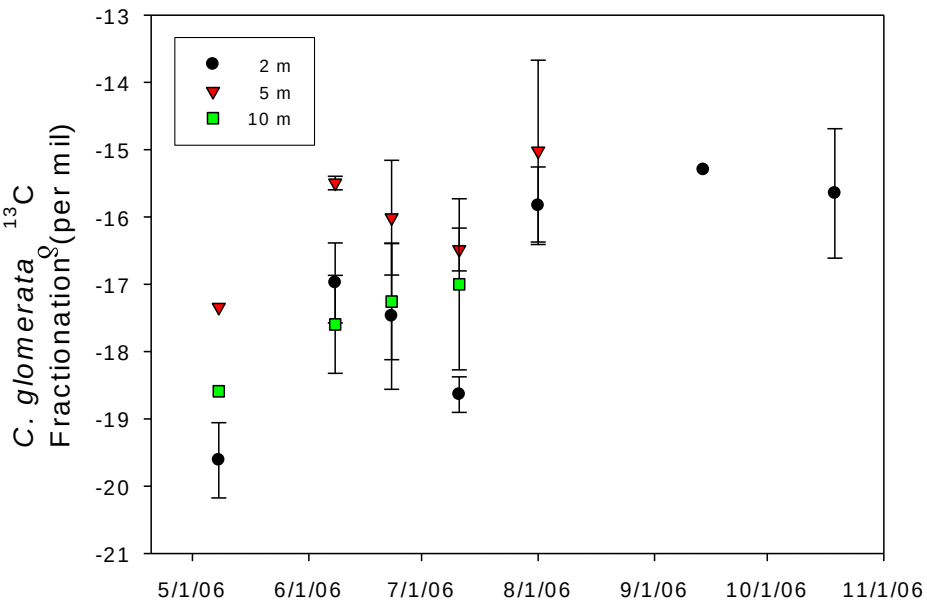

Figure 4.3: Fractionation patterns of *C. glomerata* internal $\delta^{13}C$ values from $\delta^{13}C$-DIC values at Halton, 2006, by depth. Errors bars are one standard deviation.

Fractionation (Fig. 4.3) of ^{13}C in *C. glomerata* tissue samples (calculated as the difference between ambient $\delta^{13}C$-DIC and tissue $\delta^{13}C$) indicated the greatest increase in $\delta^{13}C$ values in early spring from May 8 to June 8, and in midsummer from July 11 to August 1. Tissue $\delta^{13}C$ was consistently most enriched and the lowest fractionation factors were observed at 5 m depth up until sloughing occurred in August. Lowest absolute values for fractionation occurred at 2 m after sloughing. The late June and early July fractionation factors increased slightly coincident with the upwelling events that likely reduced photosynthetic demand. On average, fractionation at 2 m stations on May 8, was -19.62‰ before decreasing to -16.98‰ on June 8. This change in fractionation was 2.64‰ for an estimated daily rate of change in ^{13}C fractionation within *C. glomerata* tissue of 0.085‰ (Table 4.6). Similarly, the daily increase rate of change in fractionation

at 5 and 10 m stations was 0.060‰ and 0.032‰, respectively (Table 4.6). Over the next two sample dates, fractionation at 2 and 5 m stations declined, while 10 m *C. glomerata* samples maintained a decelerating increase in $\delta^{13}C$ values. Fractionation factors for 2 and 5 m samples were observed to increase by 2.81‰ and 1.46‰, respectively, from July 11 to August 1. 10 m samples were not available on this date. Samples were only available at 2 m stations for the remaining two surveys and remained somewhat constant at approximately -15.50‰ from August 1 to October 19 (Fig. 4.3).

Table 4.6: Fractionation (f) patterns in 13C values of*C. glomerata* along the Halton shoreline, 2006. Δ is difference in f between dates.

Date 1	Date 2	Depth (m)	Δ in f (‰)	Δ in f * day^{-1} (‰)
8-May-06	8-Jun-06	2	2.64	0.085
		5	1.85	0.060
		10	1.00	0.032
8-Jun-06	23-Jun-06	2	-0.17	-0.011
		5	-0.51	-0.034
		10	0.34	0.022
23-Jun-06	11-Jul-06	2	-1.49	-0.083
		5	-0.47	-0.026
		10	0.26	0.014
11-Jul-06	1-Aug-06	2	2.81	0.134
		5	1.46	0.070
		10		
1-Aug-06	14-Sep-06	2	0.53	0.012
		5		
		10		
14-Sep-06	19-Oct-06	2	-0.35	-0.010
		5		
		10		

A similar trend in the early summer during the onset of rapid algal growth was also evident at Halton in 2005 (Fig. 4.2b) and at Port Credit (Fig. 4.2c), with the greatest increase in heavy isotope concentration occurring at 2 m stations and sometimes also at 5 m. During this period 10 m stations were much less affected. In comparison seasonal trends for *C. glomerata* $\delta^{15}N$ (Fig. 4.4) were negligible throughout the sampling season.

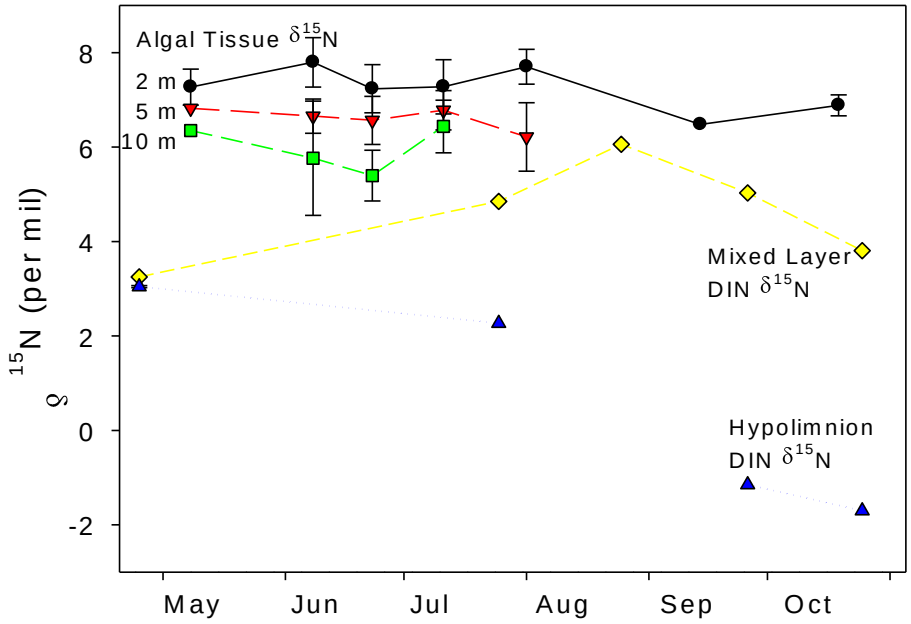

Figure 4.4: *C. glomerata* internal $\delta^{15}N$ values at 2, 5, and 10 m depths along the Halton shoreline, 2006. Only samples at 2 m were abundant in biomass for collection throughout the full survey period. Dissolved inorganic nitrogen (DIN) $\delta^{15}N$ values were measured at 3 m in the mixed layer and at 75 m in the hypolimnion at a central offshore station in Lake Ontario, 1997, which are from Leggett et al. (2000).

Cladophora glomerata $\delta^{13}C$ values (Table 4.4) were tested in a 2-way ANOVA (below) to determine if spatial variation was related to isotopic fractionation. Depth and transect were tested (Fig. 2.1) for significance and potential point sources would be identified through a significant interaction:

Source	Type III SS	df	Mean Squares	F	p
Transect	1.315	3	0.438	0.75	0.533
Depth	16.085	2	8.043	13.82	0.000
Tran*Dep	0.989	6	0.165	0.28	0.938
Error	11.640	20	0.582		

A non-linear depth relationship during the spring and summer was observed as 5 m stations were consistently more enriched in the heavy carbon isotope in 2005 (Fig. 4.5), as well as 2006. No distinct point source influencing $\delta^{13}C$ fractionation in *C. glomerata* was evident.

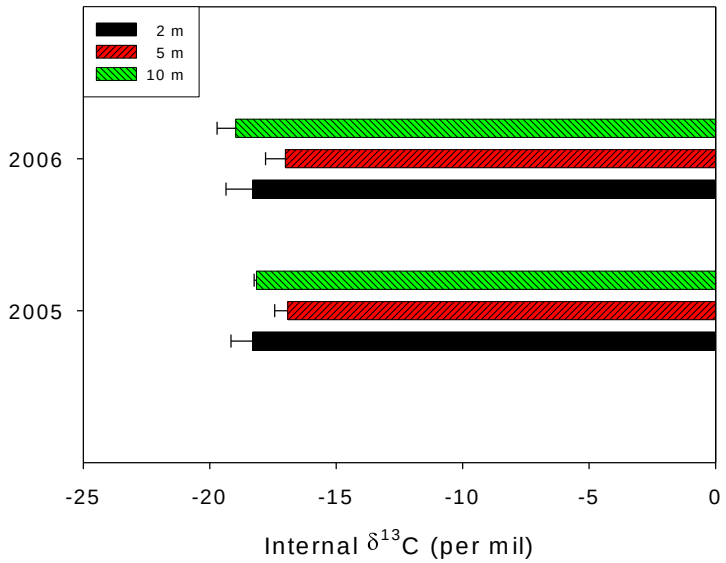

Figure 4.5: Inter year variation in *C. glomerata* internal $\delta^{13}C$ values along the Halton shoreline during peak biomass.

Similarly, a 2-way ANOVA tested spatial variation in *C. glomerata* internal $\delta^{15}N$ values:

Source	Type III SS	df	Mean Squares	F	p
TRAN$	1.499	3	0.500	1.49	0.248
D	14.374	2	7.187	21.43	0.000
TRAN$*D	1.864	6	0.311	0.93	0.497
Error	6.708	20	0.335		

A significant depth relationship exists for *C. glomerata* $\delta^{15}N$ values during the peak growth period as 2 m stations are heavier in ^{15}N relative to 5 and 10 m stations (Fig. 4.4), however no individual station was observed to have a significant ($p = 0.497$) influence on *C. glomerata* $\delta^{15}N$ values. A similar depth trend is present for both $\delta^{13}C$ and $\delta^{15}N$ from 2005 to 2006 at Halton, however 2 and 10 m stations are lighter in ^{15}N isotopes in 2005 (Fig. 4.6).

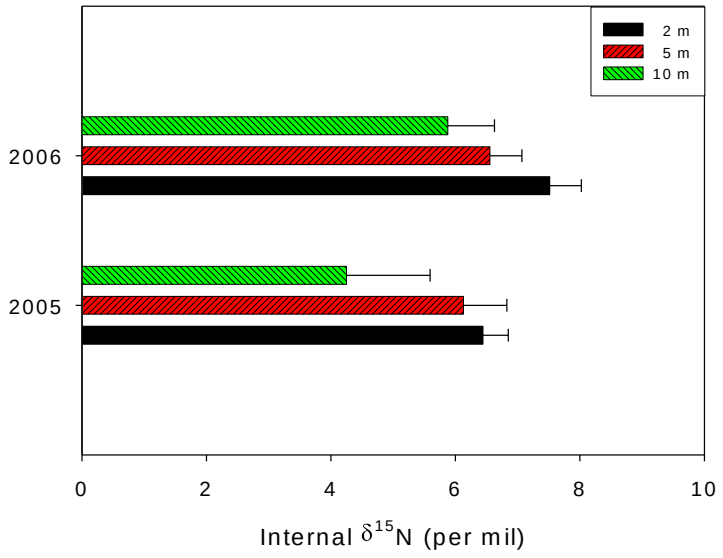

Figure 4.6: Inter year variation in *C. glomerata* internal $\delta^{15}N$ values along the Halton shoreline during peak growth.

4.4.2 Spatial Analyses of ^{13}C and ^{15}N in *C. glomerata*, 2005

Several sites in Lake Erie and Ontario were surveyed in 2005 (Table 4.7) for stable isotope relationships with *C. glomerata* nutritional status. Tissue samples were only successfully collected at all sites during the summer peak biomass period. With the exception of the non-urban site at the mouth of the Grand River, Lake Erie, the only significant (Table 4.7) trend in $\delta^{13}C$ values relative to shoreline use is at 5 m stations (Fig. 4.7). Here, urban sites are enriched in ^{13}C compared to non-urban sites.

Table 4.7: Internal *Cladophora* stable isotope values for 2005. C = carbon, N = nitrogen; $\delta^{13}C$ and $\delta^{15}N$ values measured as ‰. Lake sites as follows, Huron: Ch = Cape Chin, So = Southampton; Erie: Gr = Grand River, Pe = Peacock Point; Ontario: Pr = Presqu'ile Provincial Park, Ha = Halton, Cr = Port Credit. ANOVA-Site tests for variation between sites at each depth. ANOVA-Depth tests for variation in depth at each site.

	Depth	Site							ANOVA -Site	
	(m)	Ch	So	Gr	Pe	Pr	Ha	Cr	F	p
$\delta^{13}C$	2			-16.2	-17.1	-18.8	-18.3	-17.9	2.17	0.000
	5			-16.6	-18.7	-19.2	-16.9	-16.4	5.93	0.000
	10				-18.4	-18.7	-18.2	-18.4	0.21	0.000
ANOVA	F			0.38	3.77	0.26	5.03	0.63		
Depth	p			0.580	0.100	0.782	0.052	0.566		
$\delta^{15}N$	2			8.6	7.8	5.3	6.4	4.2	12.55	0.000
	5			8.2	7.7	5.5	6.1	4.3	24.07	0.000
	10				7.4	5.3	4.3	2.2	13.04	0.000
ANOVA	F			1.18	0.52	0.09	5.15	2.24		
Depth	p			0.357	0.626	0.914	0.050	0.187		

Alternatively, it appears that *C. glomerata* tissue samples in Lake Erie sites are heavier in ^{13}C at 2 m stations, and no relationship to urban land use can be observed. At 10 m stations, there are no clear trends (Fig. 4.7). The exception of the Grand River site may be

related to the large riverine influence, if indeed an urban – non-urban relationship does exist. The heavier $\delta^{13}C$ values at 5 m on urban shorelines are consistent with higher growth rates and reduced selectivity for ^{12}C during photosynthetic fractionation. This may be a combination of a optimum light and nutrient environments as light at depth is still intense enough for optimum rates of photosynthesis (Graham et al. 1982). The lower fractionation factors at 2m depth suggest greater C stress during photosynthesis and may reflect thicker boundary layers under lower turbulence at depth and/or denser stands of Cladophora resulting in more stagnant conditions within the stands at 5 m.

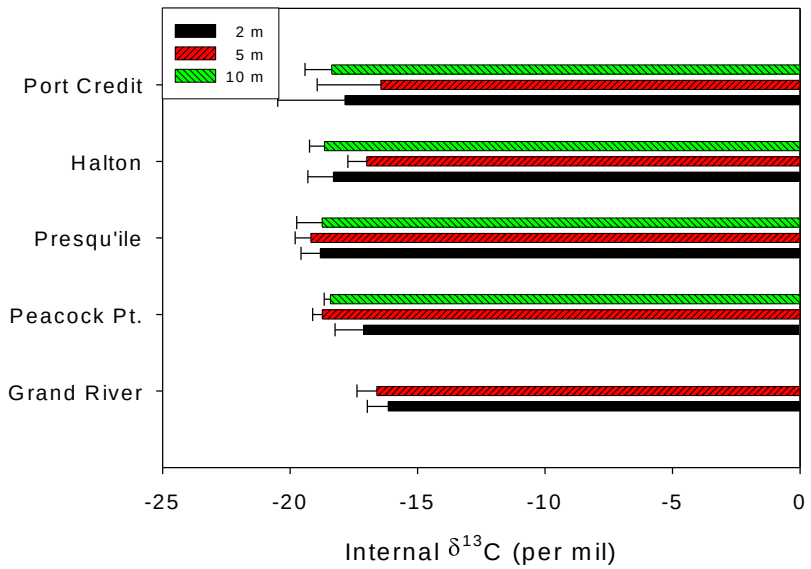

Figure 4.7: Shoreline contrasts of *C. glomerata* $\delta^{13}C$ values. The highly urbanized sites in Lake Ontario (Port Credit and Halton) show only significant enrichment in ^{13}C at 5 m stations (ANOVA, F=5.934, p=0.002) over the non urban sites at Presqu'ile Park (L. Ont) and Peacock Pt. (L. Erie).

A similar analysis of *C. glomerata* tissue $\delta^{15}N$ signatures illustrated that no relationship with urban land use was observed (Table 4.7), though lake-wide trends were observed as algal samples in Lake Ontario sites had lighter in $\delta^{15}N$ at all depths compared

to Lake Erie (Fig. 4.8). Even within Lake Ontario it was also observed that *C. glomerata* $\delta^{15}N$ values are not indicative of varying shoreline use as the non-urban site at Presqu'ile Provincial Park is intermediate in nitrogen isotopic composition with respect to the urban sites at Port Credit and Halton (Fig. 4.8). Also, the same linear depth relationship that is significant along the Halton shoreline in 2006, where 2 and/or 5 m stations are more enriched in $\delta^{15}N$ than at 10 m (Fig. 4.4), was observed at all sites (Fig. 4.8).

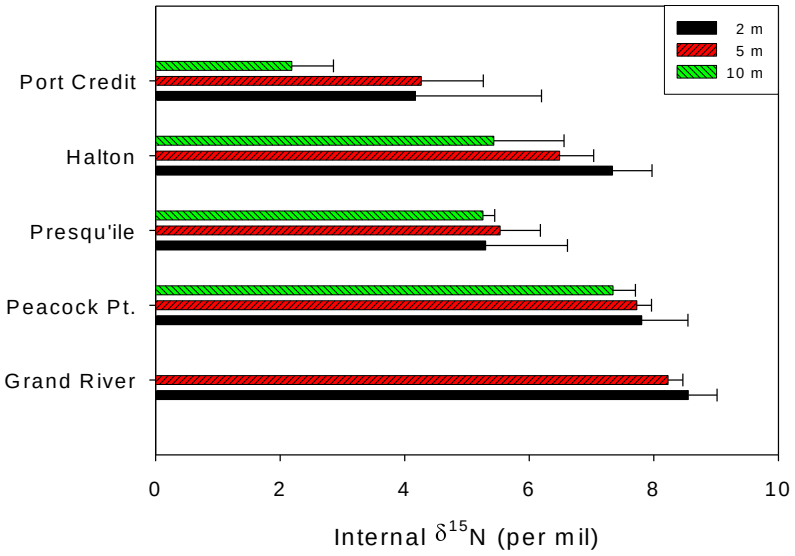

Figure 4.8: Shoreline contrasts of *C. glomerata* tissue $\delta^{15}N$ values in Lake Ontario (Port Credit, Halton, Presqu'ile) and Erie (Peacock Pt., Grand River) during peak biomass in 2005. The highly urbanized shoreline at Port Credit is significantly lower in ^{15}N at 10 m stations (ANOVA, F=13.113, p=0.001). At shallower depths, the Halton shoreline is only significantly enriched when interannual data is incorporated, indicating interannual variation in $\delta^{15}N$ values.

4.5 Discussion

Dissolved inorganic $\delta^{13}C$ signatures over the 2006 growing year displayed strong seasonal trends (Fig. 4.1). It is evident that the light saturated zone, of up to 5 m depths, was lighter in ^{13}C on May 8 compared to the offshore station at a depth of 35 m. This can be typical of the influence that isotopically lighter DIC in spring runoff can have on nearshore regions of lakes after the winter thaw (Upsdell 2005) prior to the onset of algal growth. As spring growth of *C. glomerata* begins to increase rapidly between the May 8 and June 8 surveys, the stations within the light saturated zone (2 and 5 m depths) increase dramatically in $\delta^{13}C$ values (Fig. 4.2), indicative of photosynthetically driven isotopic fractionation (Hecky & Hesslein 1995), whereas the 10 m stations, which are light limited and thus only capable of lower photosynthetic rates, increase modestly in the heavy carbon isotope fraction as it may be also more influenced by offshore waters, similar to station 635. The trend at station 635 is broadly similar to that reported by Leggett et al. (1999), a gradual increase in the heavier carbon isotope as photosynthetic planktonic production gradually increases throughout the summer before reaching a peak in September and then declining rapidly, shifting correspondingly with the decline in water temperature and available light. DIC-$\delta^{13}C$ declines in response to reduced photosynthetic rates and a shift to net respiration which returns lighter DIC-$\delta^{13}C$ in the mixed layer in the fall (Fig. 4.1). Variation between the light saturated (2 and 5 m stations) and light limited (10 and 35 m stations) DIC-$\delta^{13}C$ values along the Halton shoreline consequently decoupled somewhat throughout the surveys from May to early July when benthic algal growth was most rapid. On August 1, 2006, the large sloughing period had begun which resulted in a decline in DIC-$\delta^{13}C$ values at 2 and 5 m depths

(Fig. 4.2) due to degradation of the isotopically light. No samples were available at 10 m stations after our July 11 survey. Also, the 2‰ increase in DIC-$\delta^{13}C$ values in early summer was hypothesized to be a decline in the available offshore $CO_{2(aq)}$ pool (Leggett 1999); a similar mechanism would apply to the inshore waters but be even more extreme because of higher rates of $CO_{2(aq)}$ withdrawal from the DIC pool due to high rates of *Cladophora* growth in shallow waters. The sharp decline in DIC-$\delta^{13}C$ decline observed between September 14 and the October survey may be the result of little *C. glomerata* biomass and photosynthetic activity as only one station was observed to have any algal biomass for analysis and the lake-wide shift to net respiration in the fall period (Fig. 4.1). The lake wide shift to net respiration is a result of reduced photoperiods and deeper mixing imposing light limitation on both benthic and phytoplankton growth. This is especially apparent the closer to shore samples were collected as the greatest declines occurred at the 2 and 5 m stations which had formerly had the most positive values for DIC-$\delta^{13}C$.

C. glomerata internal tissue values for $\delta^{13}C$ follows the DIC trend with remarkable similarity but were relatively depleted because of photosynthetic fractionation (nominally -20‰ when CO_2 is in excess of photosynthetic demand), suggesting that the nearshore seasonal photosynthetic withdrawal from the DIC pool is the driving force for isotopic change both in the water and within the alga. It is clear that the nearshore samples at 2 and 5 m depths were influenced much than the light limited samples at 10 m during early summer as the rates of decreasing absolute ^{13}C fractionation were most evident in the light saturated zone where photosynthetic demand was the greatest. Thus in the early summer, June to July, slopes in $\delta^{13}C$ values over time are indicative of high

photosynthetic demand, whereas the overall trend may be modulated by the DIC-$\delta^{13}C$ values from offshore inputs and cooling by upwelling. Furthermore, the early summer response in algal $\delta^{13}C$ values to increasing photosynthetic demand is observed along the Halton shoreline in the year prior, 2005 (Fig. 4.2b), suggesting that interannual variation in $\delta^{13}C$ values is insignificant at the Halton shoreline (Fig. 4.5) and reinforces the idea that higher demand for carbon at the most productive, light saturated stations is repeated each growing season. As well, along the neighbouring urbanized Port Credit shoreline (Fig. 4.2c), 2005, almost an identical spatio-temporal pattern was observed. However, within Lake Ontario, the non urban shoreline along Presqu'ile Provincial Park (Fig. 4.2d) displays almost the reverse pattern in results with the 2 and 5 m stations declining in the heavy isotope fraction while 10 m stations increase. There is no discernible explanation for this contrast in results other then the potential for a strong respiration effect along this non urban shoreline or potentially an unknown influence such as elevated avian fecal input from the bird colony on the adjacent island. A strong respiratory source would reduce the effect of photosynthetic withdrawal of the lighter isotope on the signature of the DIC pool.

The ^{13}C fractionation in *C. glomerata* algal tissue samples (Fig. 4.3) had the largest change in fractionation the first sample date, May 8, and June 8. The fractionation of ^{13}C between *C. glomerata* and DIC decreased the most at 2 m stations followed by 5 m stations during this interval. This suggests a high photosynthetic capacity on May 8 as *C. glomerata* growth began once lake temperatures began rising (Fig. 2.2) and nutrients, specifically SRP (Fig. 2.5), were at favourable concentrations following winter turnover and spring runoff. Aqueous carbon dioxide concentrations are also generally at sufficient

levels for algal growth following winter turnover as on May 8 prior to the spring bloom in *C. glomerata* filaments. Thus, as *C. glomerata* growth begins accelerating at shallower, light saturated stations (2 and 5 m stations) where available PAR is within optimum ranges (300 – 600 μmol/m^2/s Table 1.1) of more than 15% of surface PAR (Fig. 2.13), there may be a large demand in CO_2. This can lead to carbon stress within the growing algal beds, which reduces fractionation shifting the *C. glomerata* ^{13}C isotopic signature to a heavier value by June 8 as ^{12}C selectivity is reduced with the depletion of CO_2 sources. Conversely, at the 10 m stations a gradual decrease in ^{13}C fractionation occurs as the photoperiod and solar elevation increase through June 21 (Fig. 4.3). This is consistent with light limitation (only 7.5% of average surface PAR, Fig. 2.13) at 10 m reducing the demand and selectivity on ^{12}C-CO_2 and bicarbonate sources. However, fractionation increases somewhat at 2 and 5 m stations after June 8 until June 23. This may be in part to declining SRP concentrations (Fig. 2.5) as they are now low enough to potentially cause severe phosphorus limitation over carbon limitation as *C. glomerata* internal P concentrations are generally below 1.0 μg-P/mg dw during this period (Fig. 2.11). As well, major upwelling events were observed on June 23 and July 11 as water temperatures declined (Fig. 2.2) along with planktonic chlorophyll-*a* concentrations (Fig 2.10). Offshore upwelling may have replenished the CO_2 concentrations while cooler temperatures reduced photosynthetic demand resulting in lower fractionation rates observed earlier in May,. Further, the decreased planktonic chlorophyll-*a* concentrations on June 23 may suggest that *C. glomerata* competition for CO_2 with phytoplankton is relaxed. On August 1, we see that water temperatures have again increased (Fig. 2.2 re-establishing aquatic conditions similar to June 8. Samples at 10 m continue the gradual

decrease in fractionation of 13C during this period, which suggests that light limitation is still the key factor in growth at this depth and that the cooler waters from the upwelling event had little impact. As well, the absolute value of the ^{13}C fraction within *C. glomerata* samples again decreased by 2.81‰ at 2 m and 1.46‰ at 5 m (Table 4.6) from June 23 to August 1. From August on until October 19, a constant rate of fractionation in ^{13}C at 2 m stations, was observed as opposed to a continuation of the June 23 to August 1 trend. The ambient DIC-$\delta^{13}C$ and water temperatures both reached their maximum values on 14 September while alkalinity remained little changed over the season. These observations together suggest that CO_2 concentrations remain low in Lake Ontario until fall cooling leads to mixing with the lake's hypolimnion, thus reducing photosynthetic demand on the carbon pool.

Over this same period in 2006, along the Halton shoreline, corresponding samples were also measured for $\delta^{15}N$ values within *C. glomerata* tissue (Fig. 4.4). These algal results have a $\delta^{15}N$ range from +5‰ to +8‰ with 2 m stations being heavier than 5 m stations, followed by 10 m stations. A statistically significant relationship between *C. glomerata* tissue $\delta^{15}N$ values and station depth was observed on 3 out of 4 possible dates (Table 4.4) throughout the summer before *C. glomerata* sloughing at deeper stations occurred leaving too little biomass for sample collection at 5 and 10 m stations (Fig. 2.12). Several possibilities for this depth trend may be working in combination. First, heavier dissolved inorganic nitrogen (DIN) from coastal runoff may create an offshore gradient in the $\delta^{15}N$ of DIN relative to the offshore DIN. This riverine-nearshore enrichment in ^{15}N is evident in Upsdell's (2005) study of suspended matter as Grand River and stream inflows to Lake Erie had $\delta^{15}N$ values ranging from 7.87 – 10.10‰

while midlake and outflow values ranged from 3.51 – 8.14‰ and typically decreased nearer to the Lake Erie outflow point. Data from Leggett et al. (2000) at a central Lake Ontario offshore station indicated that $\delta^{15}N$ values in DIN samples were approximately +3‰ in late April, and slowly increased to approximately +5‰ by mid July. If the Ontario offshore waters had similar values in 2006, they would be consistently lighter than the values recorded in *Cladophora* nearshore. This would support the possibility of a persistent gradient at the Halton shoreline. Surprisingly, the $\delta^{15}N$ of *Cladophora* along the transect nearest to the Oakville SE WWTP where significantly higher ammonia was observed was not significantly different from other transects along the Halton shoreline. This ammonia if arising from a waste water stream would be expected to be significantly heavier than ambient ammonia yet there is no detectable interaction effect between depth and transect suggesting the depth effect on $\delta^{15}N$ of *Cladophora* is not a nitrogen source effect but may be related to depth dependent photosynthesis which would be evident throughout all the study sites.

Another possible explanation for the depth effect on $\delta^{15}N$ of *Cladophora* is that it is a consequence of the high growth rates, as observed at 2 and 5 m stations inferred from ambient DIC- $\delta^{13}C$ values (Fig. 4.2) and reduced fractionation between DIC and tissue. High growth rates at shallower depths may also reduce the fractionation of N isotopes as DIN concentrations are drawn down. Ammonia would be the preferred DIN source for algal growth. Ammonia is regenerated from degradation of organic matter and from animal excretion and generally measurable at all the stations even in midsummer. The preferential uptake of the isotopically lighter ammonia would decrease at shallower depths where demand reduced ammonia concentrations especially in boundary layers

over Cladophora stands and along filaments. Dreissenids may play a role in the observed depth effect as they are least abundant at depths of 2 m and less because of ice scour and achieve highest densities beyond 5 m depth. Dreissenids are a major ammonia source and may impose a gradient in the isotopic signature of ammonia between ammonia arising from surface runoff and ammonia from dreissenid excretion. Further research is necessary to determine which of these possibilities best explains the observed depth effect on $\delta^{15}N$ of *Cladophora*

After comparing shorelines in both Lake Erie and Ontario, it was evident that there was no consistent relationship between urban and non-urban land use and *C. glomerata* $\delta^{13}C$ values over all depths (Fig. 4.7). Samples however, were only compared during peak biomass, mid July, when phosphorus-limited photosynthetic activity at the shallower, light saturated stations may be comparable to light limited photosynthesis at 10 m stations. This may mask the actual influence of shoreline usage as it was evident, during the temporal survey along the Halton shoreline in 2006, that prior to potentially severe phosphorus limitation of *C. glomerata* photosynthetic activity in July and August (Fig. 2.11), greater variation between $\delta^{13}C$ values of light saturated and light limited stations existed. It could be suggested that a response to light availability in $\delta^{13}C$ values would be most evident during the initial onset of rapid algal growth from mid May to early June within Lake Ontario.

After measuring $\delta^{15}N$ values at varying shorelines in Lake Erie and Ontario, it was clear that this depth relationship was present in the nearshore zones regardless of lake or shoreline landscape (Fig. 4.8), with 2 m stations having a heavier signal relative to 10 m

stations. Although, shorelines varied in absolute $\delta^{15}N$ values; e.g. Lake Erie sites were heavier at all depths relative to Lake Ontario sites the depth effect persisted in both lakes. Within Lake Ontario, it was observed that shoreline use, whether urban or non urban, was not the determining factor for the variation in ^{15}N among shorelines. As Leggett et al. (2000) determined that the overall lake signal was approximately +5‰ during mid July, our non-urban site, at Presqu'ile Provincial Park matched this value at all depths, as virtually no depth relationship existed and the average in $\delta^{15}N$ values from all three depths was +5.16‰ in mid July, 2005. However, along the Halton shoreline, $\delta^{15}N$ values were heavier averaging +5.61‰ in 2005, and +6.77‰ in 2006, while results at Port Credit indicated that *C. glomerata* tissue samples were lighter in ^{15}N during 2005, +3.54‰. Interannual variation along the Halton shoreline (Fig. 4.6) was significant at 2 and 10 m stations, indicating that potential runoff inputs, perhaps due to climatic conditions being wetter or drier from year to year, may alter $\delta^{15}N$ values. Again this is likely mediated through the availability of ammonia with runoff tending to increase ammonia availability.

The differences in $\delta^{15}N$ values in *C. glomerata* tissue between Lake Erie and Ontario may be due to variation in overall lake signals from offshore influences, or Lake Erie potentially being influenced by runoff and riverine inputs as these sites were located near agriculture regions and the large input of the Grand River. These may have introduced nitrogen species that are heavier in ^{15}N from animal wastes as $\delta^{15}N$ values from these sources typically range from +10 to +20‰ (Kendall et al. 2001). Also lakes vary in their productivity, which affects the N cycle, and denitrification losses, which can also remove

isotopically light N as gas resulting in a net increase in the remaining of $\delta^{15}N$ of the cycling nitrogen.

4.6 Conclusion

The significant results from this chapter indicate that carbon limited photosynthetic rates may be potentially measured in *C. glomerata* tissue $\delta^{13}C$ values especially in the spring during the onset of rapid growth at depths where light saturation and relatively high P cell quota is allowing optimal growth. This was observed along the Halton shoreline in late spring and early summer. This occurred prior to phosphorus depletion and growth limitation. However, the overall trend in internal $\delta^{13}C$ values of *C. glomerata* was also correlated with the DIC-$\delta^{13}C$ within the offshore dissolved inorganic carbon pool as well as being driven by near shore photosynthesis. The influence of varying shoreline use was not evident from samples collected across the Great Lakes. However, it was observed that differential fractionation of $\delta^{13}C$ values between *C. glomerata* and DIC was evident during the early summer between light saturated and light limited stations was present during early summer along the Halton shoreline before soluble phosphorus concentrations were depleted, suggesting that future stable isotope work targeting this period may best discern any potential relationship with depth and light availability.

The results from the tissue ^{15}N analyses along the Halton shoreline, 2006, did not identify any point source pollution as had been hypothesized for from such sources as 16 Mile Creek and the Oakville Southeast WWTP outfall. However, a significant depth relationship was present in *C. glomerata*. The same trend was also observed at most sites

in Lake Ontario and Lake Erie (Fig. 4.8) Filaments growing closer to shore had heavier $\delta^{15}N$ values compared to filaments further offshore, and this was consistent throughout the year, with little to no seasonal variation. This finding may have implications for using ^{15}N stable isotope measurements as a tracer for determining origins of sloughed *C. glomerata* filaments. However, as inter-annual variation and inter-shoreline variation is significant across Lake Erie and Ontario, baseline measurements during spring or early summer growth periods will likely be needed for calibration. As well, it is clear that overall lake signals for Lake Erie and Ontario are significantly different, as Lake Erie sites along the northern shore of the east basin were heavier in ^{15}N with respect to Lake Ontario.

Chapter 5: Overall Summary and Conclusions

5.1 General Comments

In this field survey of the lower Great Lakes and Lake Simcoe, several aspects of *Cladophora glomerata* nutrient stoichiometry were observed in order to determine seasonal variation, impacts of localized point sources, the influence of urbanized shorelines and lake effects, and the potential for the stable isotopes, ^{13}C and ^{15}N, to trace nutrient sources and algal production. *C. glomerata* tissue parameters were determined for a great diversity of sites, at large shoreline scales (up to 12 km linear sections of shoreline per site), and to greater depths, than has previously been accomplished. This study was also performed over a greater time frame than typical, elucidating the natural variability of early autumn and greater resolution of influences of solar irradiance.

5.2 Chapter 2 Summary

The objectives of this survey were to determine the localized spatial and seasonal variation in *Cladophora glomerata* nutritional composition along the Halton Region shoreline in the urbanized western end of Lake Ontario. Impacts related to both depth and potential nutrient point sources were analyzed throughout the growing period from April to October, 2006. A localized temporal survey of the Halton region shoreline at the western end of Lake Ontario revealed that the benthic alga, *Cladophora glomerata*, is largely phosphorus limited at light saturated depths which extend out to 5 m depths at most surveyed locations, throughout the spring and summer. Strong seasonal variation is present in both total and soluble reactive phosphorus concentrations in water and internal

algal phosphorus concentrations. Also, a strong depth relationship with internal P exists, with light limited samples exhibiting greater concentrations in P due to less than optimal growth and accumulation of surplus P. Once seasonal and light relationships were determined, it was clear that no significant specific nutrient point source, (i.e. 16 Mile Creek, WWTP outfall,) existed, as no individual station varied from others at similar depths and seasons. Further, it was observed that an offshore station had similar chemical concentrations and seasonality as the shallower nearshore stations. These results, also suggest that dreissenid mussels as a non-point source of regenerated nutrients may account for the homogeneity of the near shore regime despite the expected influence of identifiable nutrient inputs, such as moderately sized rivers and WWTP effluents. A depth relationship was also established relating internal algal P concentrations to light. In all, the three objectives of this survey were answered as seasonal and depth/light related variation was established and local point sources were determined to be negligible on a shoreline extending over 12 km in length.

5.3 Chapter 3 Summary

A similar study template as in Chapter 2 was performed on a larger scale to determine if varying shoreline uses and/or inter-lake variability played a pivotal role in *Cladophora glomerata* nutrient stoichiometry. Several shorelines in both Lake Ontario and Erie were selected based on being either urban shores or non urban shores; the key variable being that greater human impact should impose alterations to the coastal nutrient dynamics. Several trends emerged. Urban regions within Lake Ontario may be enriched in nutrients evident in higher nutrient concentrations in light limited Cladophora (at 10 m depth)

relative to non urban shorelines as demonstrated by the comparison between Halton (urban) and Presqu'ile (non urban) shorelines, and further between Halton and the urban shoreline at Peacock Point in Lake Erie. However, large riverine influences such as the Grand River may an equivalent if not greater impact, though sampling results were inconclusive. Phosphorus limitation of *C. glomerata* was also determined with nutritional status ratios as empirical evidence from all sites displayed that P was the main nutrient limiting growth. Zero positive growth due to P concentrations and the onset of P limitation were determined to be 1246 and 505.1, for C:P atomic ratios, respectively, and 73.6 and 41.6, for N:P atomic ratios, respectively, based on related values for internal P concentrations. In regards to land use, field observations suggest that urban landscapes may have a minor role in nutrient, specifically P, enrichment along the nearshores.

5.4 Chapter 4 Summary

In this final data chapter, the utility of natural stable isotope abundances, ^{13}C and ^{15}N, investigated to determine if they could provide evidence of relative rates of benthic algal production and used as tracers for point source or shoreline-scale pollution. The expected results varied as $\delta^{13}C$ values from *C. glomerata* tissue samples were indeed indicative of high growth rates during the early summer rapid growth period at depths within the light saturated zone, approximately up to the 5 m depth contour. Though, overall ^{13}C signals were a function of offshore DIC-$\delta^{13}C$ patterns throughout the year. This trend was evident along most shorelines and from year to year, verifying the use of ^{13}C stable isotope practices to define periods of potentially carbon-limited production. The use of ^{13}C and ^{15}N stable isotopes to delineate urban shoreline influences was not as clearly

demonstrated. No obvious relationship between stable isotopes and type of land use was measured. Similarly, this method was inconclusive in measuring local point source impacts, though, point sources were also not apparent after measuring water chemistry and *C. glomerata* tissue parameters (Chapter 2). However, the use of ^{15}N isotopes in tracing *C. glomerata* filament origins may be of merit as depth relationships were observed at most sites.

5.5 Summary and Recommendations

The research performed over 2005-2006 aimed to characterize *Cladophora glomerata* tissue nutrient stoichiometry in relation to temporal and spatial patterns along the nearshore zones of the Great Lakes. Seasonal patterns, localized spatial variation, and potential point source influences were investigated. In general depth was the primary factor affecting the variability of *Cladophora* nutrient and stable isotope stoichiometry. There was no demonstrable point source influence on *Cladophora* stoichiometry within shoreline reaches up to 12 km in length. Similarly, no significant effect of coastal land use on tissue nutrient stoichiometry and stable isotope composition was observed. The apparent similarity of Cladophora growth and composition within the nearshore zones despite substantial point source inputs is perhaps best explained by the hypothesis proposed by Hecky et al. (2004) that dreissenid mussels have altered the nearshore zone of the lower Great Lakes and may now dominant nutrient cycling. The characterization of seasonal patterns will aid in delineating mussel influence throughout the growing season, and the lack of influence of several point sources relative to background nutrient environments and offshore results suggests that mussels are indeed capable of

reengineering the environment in which *C. glomerata* lives through a combination of increasing water clarity to deeper depths, extending habitat, and supplying a greater nutrient load to the nearshore zones.

Throughout this research several recommendations for future work have become apparent in order to strengthen and clarify some of these results, as well as extend research into new areas.

- Greater sample frequency during late spring/early summer for stable isotope measurement to verify that increasing $\delta^{13}C$ values in algal tissue are indeed indicative of high growth rates and inorganic carbon drawdown. As well, this would enable greater resolution of $\delta^{13}C$ measurements to determine if urban shorelines do have measurable stable isotope patterns, as much of the data was collected when P limitation at shallow stations may match light limitation at 10 m stations, thereby limiting the separation of potential land use influences in the shallower stations.

- Measurement of the stable isotope composition of river inputs and waste water treatment plant (WWTP) outfalls should be considered in order to contrast potential source nutrient concentrations and stable isotope values. Also the hypotheses developed here to explain the persistent effect of depth on $\delta^{15}N$ of *Cladophora* should be further investigated to determine if the isotopic composition can be used as a tracer for catchment DIN effects in the nearshore.

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Appendix

Table A.1: Legend for column headings for Tables A.3 - A. Continued on page153.

LabID	Identification #
Date	Date of sampling
Year	Year of sampling
Seas	Season: Sp = spring; Su = summer; Au = Autumn
Lake	GB= Georgian Bay; H = Huron; E = Erie; O = Ontario; S = Simcoe
Site	Site name
Pop	Population of adjacent settlement(s)
LU	Land Use: U = Urban; NU = Non-Urban; OS = Offshore Shoal
Stn	Station #
Lat	Latitude
Long	Longitude
Tran	Transect ID: A-D (See Fig. 2.1) & O = offshore at Halton, 2006; A-C respective figures in 2005
dP	Stations linear distance from Primary shoreline input (if applicable) (km)
dS	Stations linear distance from Secondary shoreline input (if applicable) (km)
D	Water Column Depth (m)
SD	Water Sample Depth (m)
TL	Thermal Layer: E = epilimnion; H = hypolimnion
Str	Stratified: Y = yes; N = no
ST	Water surface tempurature (^{o}C)
DT	Water tempurature (^{o}C) at depth of sample
Secc	Secchi Depth (m)
PAR	Surface Photosynthetically Active Radiation (µmole m^{-2} s^{-1})
K_d	Light attenuation coefficient (m^{-1})
I_z	Irradiance(PAR) at depth Z(m) in µmole m^{-2} s^{-1}
$\%I_o$	Percent of surface irradiance(PAR) at I_z
pH	Potential of hydrogen
Alk	Alkalinity (mEq L^{-1})
TSS	Total Suspended Solids (mg L^{-1})
AFDW	Ash free dry weight (mg L^{-1})
Chl	Chlorophyll *a* (µg L^{-1})
PC	Particulate Carbon (µg L^{-1})
PN	Particulate Nitrogen (µg L^{-1})
PP	Particulate Phosphorus (µg L^{-1})
TP	Total Phosphorus (µg L^{-1})
TDP	Total Dissolved Phosphorus (µg L^{-1})
SRP	Soluble Reactive Phosphorus (µg L^{-1})
NO_3^-	Nitrate (µg L^{-1})
NO_2^-	Nitrite (µg L^{-1})
NH_3	Ammonia (µM)
TN	Total Nitrogen (µg L^{-1})
F	Fluorine (µg L^{-1})
Cl	Chlorine (µg L^{-1})
SO_4^{2-}	Sulfate (µg L^{-1})
PSi	Particulate Silicon (µg L^{-1})
SRSi	Soluble Reactive Silicon (µg L^{-1})

Table A.1: Continued from page 152.

δ^{13}DIC	Carbon 13 isotope value in Dissolved Inorganic Carbon pool (‰)
Bact.	Bacterial presence: Y = yes; N = no
Phyto.	Phytoplankton presence: Y = yes; N = no
PhyY	Phytoplankton fluorescence yield, measured with PAM (F_v F_m^{-1})
IChl	Algal Internal Chlorophyll *a* (µg mg^{-1}dw)
IC	Algal Internal Carbon (µg mg^{-1}dw)
IN	Algal Internal Nitrogen (µg mg^{-1}dw)
IP	Algal Internal Phosphorus (µg mg^{-1}dw)
IPAF	Algal Internal ash free Phosphorus (µg mg^{-1}dw)
δ^{13} IC	Carbon 13 isotope value in algal Internal C (‰)
δ^{15} IN	Nitrogen 15 isotope value in algal Internal N (‰)

Table A.2: Site locations from 2005 - 2006. From pages 154-156.

Lake	Site	Site Type	Station	Lat	Long
Erie	Grand	Rural	518	42.83267	-79.63869
Erie	Grand	Rural	519	42.83883	-79.54508
Erie	Grand	Rural	520	42.84419	-79.50000
Erie	Grand	Rural	521	42.82909	-79.64830
Erie	Grand	Rural	522	42.83803	-79.54525
Erie	Grand	Rural	523	42.84008	-79.50145
Erie	Grand	Rural	524	42.82364	-79.65205
Erie	Grand	Rural	525	42.83511	-79.54705
Erie	Grand	Rural	526	42.83181	-79.49875
Erie	Peacock	Rural	502	42.77054	-79.96908
Erie	Peacock	Rural	503	42.78531	-79.97922
Erie	Peacock	Rural	504	42.78808	-79.98381
Erie	Peacock	Rural	507	42.80397	-79.89197
Erie	Peacock	Rural	509	42.80778	-79.93971
Erie	Peacock	Rural	510	42.81369	-79.89297
Erie	Peacock	Rural	511	42.80544	-79.94003
Erie	Peacock	Rural	512	42.80247	-79.93292
Erie	Peacock	Rural	513	42.80061	-79.89420
Erie	Rathfon	Rural		42.87481	-79.30776
Huron	Cape Chin	Rural	800	45.11850	-81.27990
Huron	Cape Chin	Rural	801	45.09106	-81.26570
Huron	Cape Chin	Rural	802	45.08996	-81.26629
Huron	Cape Chin	Rural	803	45.08975	-81.26736
Huron	Cape Chin	Rural	804	45.11855	-81.28071
Huron	Cape Chin	Rural	805	45.11888	-81.28207
Huron	Cape Chin	Rural	806	45.16716	-81.33530
Huron	Cape Chin	Rural	807	45.16700	-81.33605
Huron	Cape Chin	Rural	808	45.16723	-81.33634
Huron	Inverhuron	Rural		44.29557	-81.60242
Huron	Pike	Rural	700	44.85310	-81.37425
Huron	Pike	Rural	701	44.87826	-81.39116
Huron	Pike	Rural	702	44.90179	-81.40820
Huron	Pike	Rural	703	44.91011	-81.39104
Huron	Pike	Rural	704	44.91252	-81.38432
Huron	Pike	Rural	705	44.88536	-81.37852
Huron	Pike	Rural	706	44.89206	-81.36875
Huron	Pike	Rural	707	44.86110	-81.35778
Huron	Pike	Rural	708	44.86414	-81.35468
Huron	Pt. Farms	Rural		43.80418	-81.72783
Huron	Southamp	Rural	709	44.40831	-81.50649
Huron	Southamp	Rural	710	44.41046	-81.51098
Huron	Southamp	Rural	711	44.41266	-81.51234
Huron	Southamp	Rural	712	44.43873	-81.46479
Huron	Southamp	Rural	713	44.42677	-81.45621
Huron	Southamp	Rural	714	44.42450	-81.45501
Huron	Southamp	Rural	715	44.51783	-81.38063
Huron	Southamp	Rural	716	44.51766	-81.37754
Huron	Southamp	Rural	717	44.51204	-81.36566
Huron	Southamp	Rural		44.51379	-81.36205
Ontario	Bath	Rural		44.18200	-76.77452
Ontario	Cobourg	Urban		43.95165	-78.16648

Table A.2: Continued from page 154

Ontario	Credit	Urban	609	43.53944	-79.58828
Ontario	Credit	Urban	610	43.56266	-79.56556
Ontario	Credit	Urban	611	43.58710	-79.53415
Ontario	Credit	Urban	612	43.53797	-79.58492
Ontario	Credit	Urban	613	43.56051	-79.56186
Ontario	Credit	Urban	614	43.58463	-79.53446
Ontario	Credit	Urban	615	43.53584	-79.57908
Ontario	Credit	Urban	616	43.55501	-79.55317
Ontario	Credit	Urban	617	43.57843	-79.52158
Ontario	Emeric	Rural		44.10379	-76.69988
Ontario	Halton	Urban	600	43.41802	-79.68422
Ontario	Halton	Urban	601	43.44424	-79.66366
Ontario	Halton	Urban	602	43.46759	-79.64030
Ontario	Halton	Urban	603	43.41780	-79.68287
Ontario	Halton	Urban	604	43.44356	-79.66151
Ontario	Halton	Urban	605	43.46588	-79.63815
Ontario	Halton	Urban	606	43.41695	-79.67938
Ontario	Halton	Urban	607	43.44129	-79.65640
Ontario	Halton	Urban	608	43.46171	-79.63257
Ontario	Halton	Urban	631	43.48410	-79.61897
Ontario	Halton	Urban	632	43.48318	-79.61727
Ontario	Halton	Urban	633	43.48065	-79.61447
Ontario	Halton	Urban	635	43.44380	-79.62658
Ontario	Halton	Urban	L11	43.44467	-79.65833
Ontario	Halton	Urban	L12	43.44333	-79.65583
Ontario	Halton	Urban	L13	43.44167	-79.65250
Ontario	Halton	Urban	L21	43.47450	-79.62167
Ontario	Halton	Urban	L22	43.47333	-79.61833
Ontario	Halton	Urban	L23	43.47333	-79.61250
Ontario	Halton	Urban	L31	43.48833	-79.60583
Ontario	Halton	Urban	L32	43.48750	-79.60250
Ontario	Halton	Urban	L33	43.48667	-79.59883
Ontario	Halton	Urban		43.45004	-79.65742
Ontario	Presqu'ile	Rural	618	43.97288	-77.74369
Ontario	Presqu'ile	Rural	619	43.98672	-77.70955
Ontario	Presqu'ile	Rural	620	43.99518	-77.67828
Ontario	Presqu'ile	Rural	621	43.97199	-77.74245
Ontario	Presqu'ile	Rural	622	43.98562	-77.70825
Ontario	Presqu'ile	Rural	623	43.99372	-77.67532
Ontario	Presqu'ile	Rural	624	43.97152	-77.74015
Ontario	Presqu'ile	Rural	625	43.98338	-77.70504
Ontario	Presqu'ile	Rural	626	43.99257	-77.67412
Ontario	Presqu'ile	Rural		43.99015	-77.72249
Ontario	Pt. Petre	Rural		43.83942	-77.15103
Ontario	Whitby	Urban		43.51024	-78.53496
Simcoe	Central		E51	44.50951	-79.25854
Simcoe	Central		K39	44.38432	-79.64666
Simcoe	Central		K42	44.39499	-79.58376
Simcoe	Central		K45	44.46065	-79.43793
Simcoe	Cook's	Rural	S15	44.34264	-79.39032
Simcoe	Cook's	Rural	C1	44.21262	-79.50865
Simcoe	Cook's	Rural	C6	44.25759	-79.51215
Simcoe	Cook's	Rural	C9	44.28953	-79.51385

Table A.2: Continued from page 154.

Simcoe	Georgina	Rural	901	44.39058	-79.27395
Simcoe	Georgina	Rural	902	44.39041	-79.28195
Simcoe	Georgina	Rural	903	44.39438	-79.27711
Simcoe	Pefferlaw	Rural	907	44.38852	-79.19988
Simcoe	Pefferlaw	Rural	908	44.37906	-79.18577
Simcoe	Pefferlaw	Rural	909	44.37761	-79.18478
Simcoe	Thorah	Rural	904	44.44563	-79.24425
Simcoe	Thorah	Rural	905	44.43844	-79.25127
Simcoe	Thorah	Rural	906	44.43140	-79.26324

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. From pages 157-163

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
O6002	11-Apr	Sp	603	a	5.7	16.3	5.0	2.0	E	N													
O6003	11-Apr	Sp	604	b	1.1	9.5	5.0	2.0	E	N													
O6004	11-Apr	Sp	605	c	7.2	3.3	5.0	2.0	E	N													
O6005	13-Apr	Sp	600	a	5.7	16.3	2.0	1.0	E	N													
O6006	13-Apr	Sp	603	a	5.7	16.3	5.0	2.0	E	N													
O6007	13-Apr	Sp	606	a	5.7	16.0	10.0	5.0	E	N													
O6008	13-Apr	Sp	NA				0.0	0.0	E	N													
O6009	13-Apr	Sp	NA				0.0	0.0	E	N													
O6010	13-Apr	Sp	NA				0.0	0.0	E	N													
O6011	13-Apr	Sp	NA				0.0	0.0	E	N													
O6012	13-Apr	Sp	NA				0.0	0.0	E	N													
O6013	13-Apr	Sp	L11				4.0	2.0	E	N													
O6014	13-Apr	Sp	L12				10.0	5.0	E	N													
O6015	13-Apr	Sp	L13				0.0	5.0	E	N													
O6016	13-Apr	Sp	L23				0.0	5.0	E	N													
O6017	13-Apr	Sp	L22				10.0	5.0	E	N													
O6018	13-Apr	Sp	L21				5.0	2.0	E	N													
O6019	13-Apr	Sp	NA				0.0	0.0	E	N													
O6020	13-Apr	Sp	NA				0.0	0.0	E	N													
O6021	13-Apr	Sp	L31				5.0	2.0	E	N													
O6022	13-Apr	Sp	L32				10.0	5.0	E	N													
O6023	13-Apr	Sp	L33				0.0	5.0	E	N													
O6024	13-Apr	Sp	NA				0.0	0.0	E	N													
O6025	13-Apr	Sp	NA				0.0	0.0	E	N													
O6026	13-Apr	Sp	NA				0.0	0.0	E	N													
O6027	13-Apr	Sp	NA				0.0	0.0	E	N													
O6028	13-Apr	Sp	NA				0.0	0.0	E	N													
O6029	13-Apr	Sp	NA				0.0	0.0	E	N													
O6030	13-Apr	Sp	NA				0.0	0.0	E	N													
O6031	13-Apr	Sp	NA				0.0	0.0	E	N													
O6032	13-Apr	Sp	NA				0.0	0.0	E	N													
O6033	13-Apr	Sp	NA				0.0	0.0	E	N													
O6034	13-Apr	Sp	NA				0.0	0.0	E	N													
O6038	20-Apr	Sp	L33				15.0	5.0	E	N													

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. Continued from page 157.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
O6039	20-Apr	Sp	L31				8.0	2.0	E	N													
O6040	20-Apr	Sp	L32				11.0	5.0	E	N													
O6041	20-Apr	Sp	L23				15.0	6.0	E	N													
O6042	20-Apr	Sp	L11				5.0	2.0	E	N													
O6043	20-Apr	Sp	603	a	5.7	16.3	5.0	2.0	E	N													
O6044	20-Apr	Sp	L12				10.0	5.0	E	N													
O6045	20-Apr	Sp	606	a	5.7	16.0	10.0	5.0	E	N													
O6046	20-Apr	Sp	600	a	5.7	16.3	2.0	1.0	E	N													
O6047	20-Apr	Sp	L22				12.0	5.0	E	N													
O6048	20-Apr	Sp	L21				8.0	2.0	E	N													
O6049	20-Apr	Sp	L13				15.0	6.0	E	N													
O6050	20-Apr	Sp	NA				0.0	0.0	E	N													
O6051	20-Apr	Sp	NA				0.0	0.0	E	N													
O6052	20-Apr	Sp	NA				0.0	0.0	E	N													
O6053	20-Apr	Sp	NA				0.0	0.0	E	N													
O6054	20-Apr	Sp	NA				0.0	0.0	E	N													
O6055	20-Apr	Sp	NA				0.0	0.0	E	N													
O6056	20-Apr	Sp	NA				0.0	0.0	E	N													
O6057	20-Apr	Sp	NA				0.0	0.0	E	N													
O6058	20-Apr	Sp	NA				0.0	0.0	E	N													
O6059	20-Apr	Sp	NA				0.0	0.0	E	N													
O6060	20-Apr	Sp	NA				0.0	0.0	E	N													
O6061	20-Apr	Sp	NA				0.0	0.0	E	N													
O6062	20-Apr	Sp	NA				0.0	0.0	E	N													
O6063	20-Apr	Sp	NA				0.0	0.0	E	N													
O6064	20-Apr	Sp	NA				0.0	0.0	E	N													
O6065	20-Apr	Sp	NA				0.0	0.0	E	N													
O6066	20-Apr	Sp	NA				0.0	0.0	E	N													
O6067	20-Apr	Sp	NA				0.0	0.0	E	N													
O6068	20-Apr	Sp	NA				0.0	0.0	E	N													
O6069	27-Apr	Sp	NA				0.0	0.0	E	N													
O6070	27-Apr	Sp	NA				0.0	0.0	E	N													
O6071	27-Apr	Sp	NA				0.0	0.0	E	N													
O6072	27-Apr	Sp	NA				0.0	0.0	E	N													

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. Continued from page 155.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
O6073	27-Apr	Sp	NA				0.0	0.0	E	N													
O6074	27-Apr	Sp	NA				0.0	0.0	E	N													
O6075	27-Apr	Sp	NA				0.0	0.0	E	N													
O6076	27-Apr	Sp	NA				0.0	0.0	E	N													
O6077	27-Apr	Sp	L31				5.0	2.0	E	N													
O6078	27-Apr	Sp	L32				10.0	5.0	E	N													
O6079	27-Apr	Sp	L33				15.0	5.0	E	N													
O6080	27-Apr	Sp	NA				0.0	0.0	E	N													
O6081	27-Apr	Sp	NA				0.0	0.0	E	N													
O6082	27-Apr	Sp	NA				0.0	0.0	E	N													
O6083	27-Apr	Sp	L21				5.0	2.0	E	N													
O6084	27-Apr	Sp	L22				10.0	5.0	E	N													
O6085	27-Apr	Sp	L23				15.0	5.0	E	N													
O6086	27-Apr	Sp	NA				0.0	0.0	E	N													
O6087	27-Apr	Sp	NA				0.0	0.0	E	N													
O6088	27-Apr	Sp	NA				0.0	0.0	E	N													
O6089	27-Apr	Sp	NA				0.0	0.0	E	N													
O6090	27-Apr	Sp	L11				5.0	2.0	E	N													
O6091	27-Apr	Sp	L12				10.0	5.0	E	N													
O6092	27-Apr	Sp	L13				15.0	5.0	E	N													
O6093	27-Apr	Sp	600	a	5.7	16.3	2.0	1.0	E	N													
O6094	27-Apr	Sp	603	a	5.7	16.3	5.0	2.0	E	N													
O6095	27-Apr	Sp	606	a	5.7	16.0	10.0	5.0	E	N													
O6121	8-May	Sp	631	d	12.2	1.6	2.0	1.0	E	N	7.6	8.5	0.69	25	8.1	1.77							
O6122	8-May	Sp	632	d	12.2	1.6	5.0	2.0	E	N	8.4	8.5	0.29	24	8.2	1.70							
O6123	8-May	Sp	633	d	12.2	1.6	10.0	5.0	E	N	8.6	8.4	0.38	2	8.2	1.77							
O6124	8-May	Sp	602	c	7.4	3.3	2.0	1.0	E	N	9.9	9.4	0.30	55	8.2	1.77							
O6125	8-May	Sp	605	c	7.2	3.3	5.0	2.0	E	N	9.2	8.7	0.38	15	8.2	1.77							
O6126	8-May	Sp	608	c	7.3	3.8	10.0	5.0	E	N	9.3	8.4	0.28	6	8.2	1.76		318	31.0	2.0	5.0	-20.36	6.35
O6127	8-May	Sp	635	O	6.5	7.5	35.0	5.0	E	N	9.7	7.0	0.22	0		1.77							
O6128	8-May	Sp	601	b	0.9	9.7	2.0	1.0	E	N	11.3	11.2	0.69	25	8.7	1.77	0.66	332	30.0	1.4	3.0	-21.62	7.00
O6129	8-May	Sp	604	b	1.1	9.5	5.0	2.0	E	N	10.8	9.5	0.32	20	8.4	1.77		334	32.4	1.4	2.9	-19.34	6.82
O6130	8-May	Sp	607	b	1.6	9.5	10.0	5.0	E	N	10.8	8.5	0.24	9	8.2	1.77							
O6131	8-May	Sp	600	a	5.7	16.3	2.0	1.0	E	N	11.3	10.7	0.61	30	8.5	1.77		327	27.5	1.4	3.4	-21.84	7.54

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. Continued from page 157.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13} IC	δ^{15} IN
O6132	8-May	Sp	603	a	5.7	16.3	5.0	2.0	E	N	10.7	10.0	0.42	12	8.3	1.88							
O6133	8-May	Sp	606	a	5.7	16.0	10.0	5.0	E	N	10.6	8.6	0.26	7	8.4	1.77							
O6155	8-Jun	Su	633	d	12.2	1.6	10.0	9.0	H	Y	17.0		0.41	2	8.4	1.84							
O6156	8-Jun	Su	633	d	12.2	1.6	10.0	3.0	E	Y			0.41	2	8.6	1.92							
O6157	8-Jun	Su	602	c	7.4	3.3	2.0	1.0	E	N	17.1	16.5	0.52	35	8.6	1.80	1.19	310	23.3	0.9	2.3	-17.32	8.34
O6158	8-Jun	Su	608	c	7.3	3.8	10.0	2.0	E	Y	17.5	11.3	0.37	3	8.5	1.85							
O6159	8-Jun	Su	608	c	7.3	3.8	10.0	9.0	H	Y		11.3	0.37	3	8.4	1.81	3.87	316	42.0	2.9	7.8	-18.99	4.91
O6160	8-Jun	Su	635	O	6.5	7.5	35.0	5.0	E	Y	17.1	6.4	0.30	0	8.5	1.86							
O6161	8-Jun	Su	603	a	5.7	16.3	5.0	2.0	E	N	17.4	17.0	0.26	27	8.5	1.83	1.61	297	27.0	1.2	2.7	-16.47	6.86
O6162	8-Jun	Su	605	c	7.2	3.3	5.0	2.0	E	N	17.5	15.1	0.39	14	8.6	1.78	1.70	305	29.1	1.1	2.8	-16.85	6.17
O6163	8-Jun	Su	600	a	5.7	16.3	2.0	1.0	E	N	18.0		0.39	46	8.5	1.78	0.97	322	25.1	0.9	2.3	-18.37	8.14
O6164	8-Jun	Su	606	a	5.7	16.0	10.0	9.0	H	Y	18.0		0.26	8	8.3	1.86	0.97	320	31.3	1.4	4.2	-19.77	6.62
O6165	8-Jun	Su	606	a	5.7	16.0	10.0	3.0	E	Y		11.0	0.26	8									
O6166	8-Jun	Su	607	b	1.6	9.5	10.0	3.0	E	Y	18.0		0.30	5	8.4	1.86							
O6167	8-Jun	Su	607	b	1.6	9.5	10.0	9.0	H	Y		10.1	0.30	5	8.4	1.80							
O6168	8-Jun	Su	632	d	12.2	1.6	5.0	2.0	E	N	17.7	16.0	0.46	10	8.5	1.97	0.58	305	31.5	1.3	3.9	-17.48	6.60
O6169	8-Jun	Su	631	d	12.2	1.6	2.0	1.0	E	N	17.3	16.5	0.46	40	8.5	1.81	1.17	324	26.8	1.3	3.1	-18.86	7.42
O6170	8-Jun	Su	601	b	0.9	9.7	2.0	1.0	E	N	18.4	18.0	0.80	20	8.4	1.86	2.38	323	26.9	0.7	2.1	-19.09	7.28
O6171	8-Jun	Su	604	b	1.1	9.5	5.0	2.0	E	N	18.0	17.7	0.33	19	8.5	1.84	1.24	306	24.9	1.0	2.5	-16.94	6.99
O6219	23-Jun	Su	606	a	5.7	16.0	10.0	2.0	E	Y	16.0		0.22	11									
O6220	23-Jun	Su	603	a	5.7	16.3	5.0	2.0	E	N	16.6	7.8	0.28	24	8.1	1.79	1.48	306	21.1	0.6	1.6	-17.65	6.26
O6221	23-Jun	Su	601	b	0.9	9.7	2.0	1.0	E	N	11.3	8.3	0.52	35	8.1	1.80	1.17	310	21.7	0.6	1.7	-17.42	7.69
O6222	23-Jun	Su	604	b	1.1	9.5	5.0	4.0	H	N		6.9	0.30	22	8.0	1.76	1.50	318	22.6	0.8	2.4	-17.54	6.26
O6223	23-Jun	Su	600	a	5.7	16.3	2.0	1.0	E	N			0.35	50	8.0	1.78	0.80	298	21.3	0.7	2.3	-18.83	7.65
O6224	23-Jun	Su	606	a	5.7	16.0	10.0	9.0	H	Y		5.8	0.22	11	8.0	1.79	0.97	293	28.1	1.4	5.5	-18.88	5.22
O6225	23-Jun	Su	632	d	12.2	1.6	5.0	4.0	H	N		7.5	0.27	26	8.1	1.78	1.91	308	26.8	1.3	3.4	-16.65	7.32
O6226	23-Jun	Su	632	d	12.2	1.6	5.0	2.0	E	N	9.0		0.27	26									
O6227	23-Jun	Su	631	d	12.2	1.6	2.0	1.0	E	N	9.9	7.9					1.08	312	26.3	0.9	3.1	-18.45	6.70
O6228	23-Jun	Su	605	c	7.2	3.3	5.0	2.0	E	N	9.0		0.22	32	8.2	1.78							
O6229	23-Jun	Su	608	c	7.3	3.8	10.0	9.0	H	Y		5.6	0.18	17	8.1	1.80	2.10	308	32.7	2.0	5.6	-18.30	5.50
O6230	23-Jun	Su	604	b	1.1	9.5	5.0	2.0	E	N	10.0		0.30	22									
O6231	23-Jun	Su	602	c	7.4	3.3	2.0	1.0	E	N	11.0	9.0	0.41	44	8.2	1.76	0.73	306	21.1	0.7	1.8	-18.09	6.90
O6232	23-Jun	Su	605	c	7.2	3.3	5.0	4.0	H	N		7.0	0.22	32	8.1	1.79	1.65	315	22.3	0.5	1.4	-16.84	6.42
O6233	23-Jun	Su	633	d	12.2	1.6	10.0	9.0	H	Y		5.7	0.14	25	8.0	1.76	2.01	292	32.7	1.8	4.4	-18.25	4.79

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. Continued from page 157.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13} IC	δ^{15} IN
O6234	23-Jun	Su	607	b	1.6	9.5	10.0	9.0	H	Y		5.5	0.20	13	8.0	1.78	2.87	319	40.7	3.1	15.3	-19.33	6.07
O6235	23-Jun	Su	608	c	7.3	3.8	10.0	5.0	E	Y	9.1		0.18	17									
O6236	23-Jun	Su	633	d	12.2	1.6	10.0	5.0	E	Y	9.5		0.14	25									
O6237	23-Jun	Su	607	b	1.6	9.5	10.0	5.0	E	Y	11.0		0.20	13									
O6238	23-Jun	Su	635	O	6.5	7.5	35.0	5.0	E	Y			0.31	0	8.0	1.78							
O6252	11-Jul	Su	600	a	5.7	16.3	2.0	1.0	E	N	11.6	11.4	0.57	32	8.2	1.85							
O6253	11-Jul	Su	631	d	12.2	1.6	2.0	1.0	E	N	10.1	8.7	0.75	22	8.1	1.85	1.63	318	27.9	0.9	2.3	-19.67	7.94
O6254	11-Jul	Su	633	d	12.2	1.6	10.0	9.0	H	Y		7.5	0.51	1	8.0	1.87							
O6255	11-Jul	Su	633	d	12.2	1.6	10.0	5.0	E	Y	10.5		0.51	1	8.1	1.86							
O6256	11-Jul	Su	632	d	12.2	1.6	5.0	2.0	E	Y	10.0		0.45	11	8.1	1.82							
O6257	11-Jul	Su	632	d	12.2	1.6	5.0	4.0	H	Y		7.5	0.45	11	7.7	1.72	1.76	309	25.0	0.5	1.6	-17.02	6.62
O6258	11-Jul	Su	602	c	7.4	3.3	2.0	1.0	E	N	11.1	10.3	0.52	35	8.1	1.84	0.55	318	24.5	0.8	2.7	-19.48	6.93
O6259	11-Jul	Su	605	c	7.2	3.3	5.0	4.0	H	Y		7.9	0.26	27	8.1	1.83	1.03	320	23.9	0.9	2.7	-17.83	7.25
O6260	11-Jul	Su	605	c	7.2	3.3	5.0	2.0	E	Y	10.5		0.26	27	8.1	1.81							
O6261	11-Jul	Su	608	c	7.3	3.8	10.0	9.0	H	Y		6.5	0.29	5	8.1	1.82	2.40	330	34.5	1.6	7.1	-18.76	6.10
O6262	11-Jul	Su	608	c	7.3	3.8	10.0	5.0	E	Y	8.8		0.29	5	8.2	1.81							
O6263	11-Jul	Su	601	b	0.9	9.7	2.0	1.0	E	N	11.7	10.5	0.63	28	8.1	1.83	0.78	309	22.7	0.7	2.2	-20.15	6.96
O6264	11-Jul	Su	604	b	1.1	9.5	5.0	2.0	E	Y	10.6		0.40	14	8.1	1.82							
O6265	11-Jul	Su	604	b	1.1	9.5	5.0	4.0	H	Y		8.0	0.40	14	8.1	1.84	1.49	317	23.3	1.1	3.7	-18.27	6.29
O6266	11-Jul	Su	607	b	1.6	9.5	10.0	9.0	H	Y		7.0	0.71	0	8.1	1.77	2.78	329	33.7	1.6	6.2	-19.18	6.13
O6267	11-Jul	Su	607	b	1.6	9.5	10.0	5.0	E	Y	11.5		0.71	0	8.1	1.86							
O6268	11-Jul	Su	635	O	6.5	7.5	35.0	5.0	E	Y					8.1	1.85							
O6269	11-Jul	Su	603	a	5.7	16.3	5.0	4.0	H	Y		7.9	0.37	15	8.0	1.81	1.19	308	24.3	1.0	3.1	-17.20	6.96
O6270	11-Jul	Su	603	a	5.7	16.3	5.0	2.0	E	Y	10.5		0.37	15	8.0	1.78							
O6271	11-Jul	Su	606	a	5.7	16.0	10.0	9.0	H	Y		7.0	0.24	9	8.0	1.83	1.99	281	24.0	2.1	3.8	-17.91	7.08
O6272	11-Jul	Su	606	a	5.7	16.0	10.0	5.0	E	Y	9.0		0.24	9	8.0	1.81							
O6288	1-Aug	Su	633	d	12.2	1.6	10.0	9.0	H	Y		11.1	0.37	2	8.2	1.77							
O6289	1-Aug	Su	633	d	12.2	1.6	10.0	5.0	E	Y	18.5		0.37	2	8.4	1.77							
O6290	1-Aug	Su	632	d	12.2	1.6	5.0	4.0	H	Y		13.5	0.40	13	8.3	1.78	2.15	316	31.3	1.9	5.2	-15.62	6.78
O6291	1-Aug	Su	632	d	12.2	1.6	5.0	2.0	E	Y	19.5		0.40	13	8.4	1.76							
O6292	1-Aug	Su	631	d	12.2	1.6	2.0	1.0	E	N	19.0	16.2	0.49	38	8.5	1.77	0.40	227	15.5	0.5	0.8	-16.48	8.24
O6293	1-Aug	Su	602	c	7.4	3.3	2.0	1.0	E	N	18.7	11.5	0.32	53	8.4	1.78	0.93	316	23.5	0.6	1.7	-16.94	7.62
O6294	1-Aug	Su	605	c	7.2	3.3	5.0	4.0	H	Y		12.2	0.29	23	8.3	1.79	1.10	307	25.8	1.1	2.5	-15.24	6.88
O6295	1-Aug	Su	605	c	7.2	3.3	5.0	2.5	E	Y	18.8		0.29	23									

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. Continued from page 157.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13} IC	δ^{15} IN
O6296	1-Aug	Su	608	c	7.3	3.8	10.0	9.0	H	Y		10.0	0.29	6	8.2	1.78							
O6297	1-Aug	Su	608	c	7.3	3.8	10.0	5.0	E	Y	16.8		0.29	6	8.3	1.77							
O6298	1-Aug	Su	601	b	0.9	9.7	2.0	1.0	E	N	15.5	15.5	0.39	45	8.1	1.73	0.88	323	22.6	0.8	1.8	-17.75	7.52
O6299	1-Aug	Su	604	b	1.1	9.5	5.0	4.0	H	Y		12.7	0.34	18	8.3	1.85	1.77	320	29.3	1.1	3.1	-17.61	5.77
O6300	1-Aug	Su	604	b	1.1	9.5	5.0	2.5	E	Y	15.5		0.34	18									
O6301	1-Aug	Su	607	b	1.6	9.5	10.0	9.0	H	Y		9.4	0.32	4	8.2	1.77							
O6302	1-Aug	Su	607	b	1.6	9.5	10.0	5.0	E	Y	15.5		0.32	4	8.3	1.75							
O6303	1-Aug	Su	635	O	6.5	7.5	35.0	5.0	E	Y	16.6		0.29	0	8.1	1.79							
O6304	1-Aug	Su	606	a	5.7	16.0	10.0	9.0	H	Y		8.7	0.34	3	8.2	1.77							
O6305	1-Aug	Su	606	a	5.7	16.0	10.0	5.0	E	Y	12.4		0.34	3									
O6306	1-Aug	Su	603	a	5.7	16.3	5.0	4.0	H	Y		10.0	0.38	15	8.3	1.76	1.26	332	27.6	0.8	3.2	-16.99	5.43
O6307	1-Aug	Su	603	a	5.7	16.3	5.0	2.5	E	Y	13.9		0.38	15	8.4	1.77							
O6308	1-Aug	Su	600	a	5.7	16.3	2.0	1.0	E	N	12.3	11.7	0.54	34	8.5	1.77	1.79	330	23.8	0.8	2.5	-17.63	7.42
O6365	14-Sep	Au	606	a	5.7	16.0	10.0	5.0	E														
O6366	14-Sep	Au	632	d	12.2	1.6	5.0	2.5	E		18.7		0.32	20									
O6367	14-Sep	Au	632	d	12.2	1.6	5.0	4.0	H				0.32	20	8.2	1.72							
O6368	14-Sep	Au	633	d	12.2	1.6	10.0	9.0	H				0.20	14	8.1	1.73							
O6369	14-Sep	Au	604	b	1.1	9.5	5.0	2.5	E				0.28	24									
O6370	14-Sep	Au	600	a	5.7	16.3	2.0	1.0	E		18.8		0.59	31	8.3	1.74							
O6371	14-Sep	Au	608	c	7.3	3.8	10.0	9.0	H				0.32	4	8.2	1.75							
O6372	14-Sep	Au	605	c	7.2	3.3	5.0	2.5	E		18.9		0.25	28									
O6373	14-Sep	Au	605	c	7.2	3.3	5.0	4.0	H				0.25	28	8.2	1.73							
O6374	14-Sep	Au	608	c	7.3	3.8	10.0	5.0	E		18.5		0.32	4									
O6375	14-Sep	Au	631	d	12.2	1.6	2.0	1.0	E		18.5		0.52	35	8.2	1.73	6.46	302	43.4	5.1	10.5	-16.01	6.48
O6376	14-Sep	Au	602	c	7.4	3.3	2.0	1.0	E		18.9		0.51	36	8.2	1.73							
O6377	14-Sep	Au	633	d	12.2	1.6	10.0	5.0	E		18.8		0.20	14									
O6378	14-Sep	Au	635	O	6.5	7.5	35.0	5.0	E		19.0	18.2			8.2	1.74							
O6379	14-Sep	Au	606	a	5.7	16.0	10.0	9.0	H						8.2	1.74							
O6380	14-Sep	Au	603	a	5.7	16.3	5.0	2.5	E														
O6381	14-Sep	Au	601	b	0.9	9.7	2.0	1.0	E				0.44	42	8.2	1.71							
O6382	14-Sep	Au	604	b	1.1	9.5	5.0	4.0	H				0.28	24	8.2	1.72							
O6383	14-Sep	Au	607	b	1.6	9.5	10.0	5.0	E				0.32	4									
O6384	14-Sep	Au	607	b	1.6	9.5	10.0	9.0	H				0.32	4	8.2	1.73							
O6385	14-Sep	Au	603	a	5.7	16.3	5.0	4.0	H						8.1	1.71							

Table A.3: Halton, 2006, Physical and *C. glomerata* chemistry. Continued from page 157.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Strat	ST	DT	K_d	$\%I_o$	pH	Alk	IChl	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
O6700	19-Oct	Au	607	b	1.6	9.5	10.0	2.5	E	N	7.7		0.93	0									
O6701	19-Oct	Au	607	b	1.6	9.5	10.0	9.0	H	N		4.0	0.93	0									
O6702	19-Oct	Au	608	c	7.3	3.8	10.0	2.5	E	N				100									
O6703	19-Oct	Au	601	b	0.9	9.7	2.0	1.0	E	N	6.3	6.0	1.38	6	8.2	1.74							
O6704	19-Oct	Au	635	O	6.5	7.5	35.0	5.0	E	N			0.19	0	8.1	1.81							
O6705	19-Oct	Au	604	b	1.1	9.5	5.0	4.0	H	N		5.4	0.84	1	8.2	1.86							
O6706	19-Oct	Au	604	b	1.1	9.5	5.0	2.5	E	N	6.7		0.84	1									
O6707	19-Oct	Au	633	d	12.2	1.6	10.0	9.0	H	N		5.0	0.14	25	8.1	1.80							
O6708	19-Oct	Au	632	d	12.2	1.6	5.0	4.0	H	N		5.0	0.34	18									
O6709	19-Oct	Au	600	a	5.7	16.3	2.0	1.0	E	N	8.3	5.0	2.10	1	8.1	1.81		196	26.8	3.6	6.8	-16.62	6.63
O6710	19-Oct	Au	632	d	12.2	1.6	5.0	2.5	E	N	6.1		0.34	18									
O6711	19-Oct	Au	603	a	5.7	16.3	5.0	1.0	E	N	8.4		1.50	0									
O6712	19-Oct	Au	605	c	7.2	3.3	5.0	4.0	H	N		5.0	0.33	19	8.1	1.81							
O6713	19-Oct	Au	605	c	7.2	3.3	5.0	2.5	E	N	5.0		0.33	19									
O6714	19-Oct	Au	608	c	7.3	3.8	10.0	9.0	H	N					8.0	1.80							
O6715	19-Oct	Au	606	a	5.7	16.0	10.0	2.5	E	N	8.5		0.64	0									
O6716	19-Oct	Au	631	d	12.2	1.6	2.0	1.0	E	N	6.2	6.2	0.70	25	8.2	1.84	2.21	263	34.4	3.5	7.1	-17.78	6.97
O6717	19-Oct	Au	602	c	7.4	3.3	2.0	1.0	E	N	6.0	5.5	0.60	30	8.1	1.83	1.53	196	24.2	2.8	4.1	-17.88	7.05
O6718	19-Oct	Au	633	d	12.2	1.6	10.0	2.5	E	N	6.3		0.14	25									
O6719	19-Oct	Au	603	a	5.7	16.3	5.0	4.0	H	N		4.9	0.15	48	8.0	1.85							
O6720	19-Oct	Au	606	a	5.7	16.0	10.0	9.0	H	N		4.8	0.16	20	8.1	1.79							

Table A.4: Halton, 2006, water chemistry, pages 164-170..

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6002	11-Apr	Sp	603	a	5.0	2.0	0.90	0.70	3.73	363	59.7	3.7	6.8	3.9	2.2	491	6.6		17.8	534	
O6003	11-Apr	Sp	604	b	5.0	2.0	0.80	0.50	3.75	330	60.0	4.6	6.5	3.6	2.7	464	8.5		18.6	504	
O6004	11-Apr	Sp	605	c	5.0	2.0			3.29	428	66.1	4.0	6.8	3.9	3.3	466	11.1		19.3	308	
O6005	13-Apr	Sp	600	a	2.0	1.0	1.85	1.00	3.66	594	84.4	4.4	7.2	3.8	3.5	515			21.4	446	
O6006	13-Apr	Sp	603	a	5.0	2.0	0.80	0.50	2.94	346	57.5	3.4	6.5	4.4	4.1	398	22.3		17.3	419	
O6007	13-Apr	Sp	606	a	10.0	5.0	0.70	0.35	3.20	519	59.7	3.5	5.7	2.3	2.7	406	24.4		17.2	654	
O6008	13-Apr	Sp	NA		0.0	0.0	2.24	0.96	3.47				9.6			477			22.4		
O6009	13-Apr	Sp	NA		0.0	0.0	0.70	0.65	3.95				8.4			365			15.6		
O6010	13-Apr	Sp	NA		0.0	0.0	1.58	0.95	3.12				13.2			429			18.5		
O6011	13-Apr	Sp	NA		0.0	0.0	1.17	0.97	3.35				8.7			447			20.1		
O6012	13-Apr	Sp	NA		0.0	0.0	1.40	0.65	3.34				7.8			332			15.4		
O6013	13-Apr	Sp	L11		4.0	2.0	1.85	0.90		474	66.4	3.0	5.7	3.2	2.7	391	18.4		19.8	358	
O6014	13-Apr	Sp	L12		10.0	5.0	0.85	0.65	3.14	338	57.2	4.4	9.1	3.0	3.0	369	20.9		15.8	504	
O6015	13-Apr	Sp	L13		0.0	5.0	0.75	0.60	3.27	360	63.1	4.8	9.7	5.1	3.0	323	22.0		13.3	211	
O6016	13-Apr	Sp	L23		0.0	5.0	0.60	0.70	3.39	370	63.6	4.6	9.1	4.2	2.4	336	31.6		13.9	625	
O6017	13-Apr	Sp	L22		10.0	5.0	0.65	0.60	3.24	359	63.1	5.5	10.3	4.8	3.0	387	37.6		16.5	446	
O6018	13-Apr	Sp	L21		5.0	2.0	0.90	0.60	2.38	374	64.2	4.2	9.7	3.3	1.6	375	38.6		15.5	299	
O6019	13-Apr	Sp	NA		0.0	0.0	1.07	0.93	2.45				10.9			342			13.9		
O6020	13-Apr	Sp	NA		0.0	0.0	0.53	0.53	2.91				10.6			446			20.7		
O6021	13-Apr	Sp	L31		5.0	2.0			3.72	397	70.7	5.4	11.5	4.2	3.0	429	49.7		18.3	507	
O6022	13-Apr	Sp	L32		10.0	5.0	1.58	0.73		421	63.1	6.1	10.9	4.8	3.0	422	52.5		17.5	607	
O6023	13-Apr	Sp	L33		0.0	5.0	0.75	0.61	2.38	435	76.8	12.0		8.4	4.9		148.5			648	
O6024	13-Apr	Sp	NA		0.0	0.0	0.60	0.60	2.50				7.9			382			18.0		
O6025	13-Apr	Sp	NA		0.0	0.0	1.00	0.47	2.24				8.5			481			24.0		
O6026	13-Apr	Sp	NA		0.0	0.0	0.60	0.55	3.12				8.2			434			19.7		
O6027	13-Apr	Sp	NA		0.0	0.0	2.07	1.20	2.13				6.5			478			30.6		
O6028	13-Apr	Sp	NA		0.0	0.0	0.95	0.45	3.02				6.8			440			21.7		
O6029	13-Apr	Sp	NA		0.0	0.0	3.10	0.90	2.39				7.1			531			33.1		
O6030	13-Apr	Sp	NA		0.0	0.0	4.40	1.40	1.85				12.9			407			22.4		
O6031	13-Apr	Sp	NA		0.0	0.0	0.80	0.74	3.10				8.8			385			19.0		
O6032	13-Apr	Sp	NA		0.0	0.0	0.87	0.67	1.98				6.8			354			16.5		
O6033	13-Apr	Sp	NA		0.0	0.0	2.10	0.40	2.08				7.3			453			26.2		
O6034	13-Apr	Sp	NA		0.0	0.0	11.83	2.33	2.11				7.1			469			38.8		

Table A.4: Halton, 2006, water chemistry. Continued from page 164.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6038	20-Apr	Sp	L33		15.0	5.0			2.18	462	76.2	4.1	8.9	5.9	3.3	432	31.3		20.5	645	
O6039	20-Apr	Sp	L31		8.0	2.0			2.92	354	57.0	3.7	9.8	5.3	3.3	238	50.5		10.8	639	
O6040	20-Apr	Sp	L32		11.0	5.0			2.00	381	60.5	5.3	10.1	5.6	3.3	438	39.6		21.3	431	
O6041	20-Apr	Sp	L23		15.0	6.0	0.95	0.80	2.72	369	62.0	6.6	9.8	5.0	3.0	438	72.7		18.8	513	
O6042	20-Apr	Sp	L11		5.0	2.0	0.95	0.90	2.26	356	62.6	5.5	8.6	4.1	3.3	379	23.5		15.5	598	
O6043	20-Apr	Sp	603	a	5.0	2.0	0.40	0.35	2.23	466	80.1	4.1	7.7	3.5	3.5	327	24.8		14.2	323	
O6044	20-Apr	Sp	L12		10.0	5.0	0.85	0.75	2.17	393	64.3	4.0	7.7	4.7	3.0	354	20.5		15.9	282	
O6045	20-Apr	Sp	606	a	10.0	5.0	0.70	0.85	2.59	464	75.8	2.1	9.8	5.9	3.8	324	22.6		14.2	331	
O6046	20-Apr	Sp	600	a	2.0	1.0	1.00	1.00	1.92	284	41.1	1.9	9.2	5.9	4.1	331	21.8		15.7	238	
O6047	20-Apr	Sp	L22		12.0	5.0	0.85	0.85	2.13	386	63.8	4.3	9.2	4.7	3.8	412	36.9		16.7	680	
O6048	20-Apr	Sp	L21		8.0	2.0	1.15	1.15	2.43	506	79.1	6.0	11.0	5.9	3.3	499	82.5		18.2	522	
O6049	20-Apr	Sp	L13		15.0	6.0	1.74	1.24	2.19	352	56.4	3.4	8.0	5.6	3.3	73	28.8		2.2	367	
O6050	20-Apr	Sp	NA		0.0	0.0	1.05	0.80					7.1			456			21.4		
O6051	20-Apr	Sp	NA		0.0	0.0	0.70	0.80					9.2			362			16.6		
O6052	20-Apr	Sp	NA		0.0	0.0	0.47	0.93	2.40				9.5			458			22.2		
O6053	20-Apr	Sp	NA		0.0	0.0	1.13	0.67	1.64				10.7			510			22.2		
O6054	20-Apr	Sp	NA		0.0	0.0	0.65	0.35					8.3			451			21.6		
O6055	20-Apr	Sp	NA		0.0	0.0	1.10	0.90	1.86				7.4			441			20.8		
O6056	20-Apr	Sp	NA		0.0	0.0	0.70	0.70	1.15				10.1			430			20.3		
O6057	20-Apr	Sp	NA		0.0	0.0	0.70	0.60					11.3			421			21.0		
O6058	20-Apr	Sp	NA		0.0	0.0	0.80	0.65	1.17				7.7			444			22.1		
O6059	20-Apr	Sp	NA		0.0	0.0	1.25	0.50	1.91				10.4			421			22.1		
O6060	20-Apr	Sp	NA		0.0	0.0			2.76				8.3			449			22.1		
O6061	20-Apr	Sp	NA		0.0	0.0	1.00	0.45					8.0			459			22.3		
O6062	20-Apr	Sp	NA		0.0	0.0	0.73	0.73	2.20				10.1			424			21.9		
O6063	20-Apr	Sp	NA		0.0	0.0	1.15	0.90					6.8						44.6		
O6064	20-Apr	Sp	NA		0.0	0.0	0.81	0.59	2.61				7.8						20.4		
O6065	20-Apr	Sp	NA		0.0	0.0	3.14	0.97					9.3						19.3		
O6066	20-Apr	Sp	NA		0.0	0.0	0.90	0.55					8.7						21.6		
O6067	20-Apr	Sp	NA		0.0	0.0	1.00	0.65	1.41				11.7						84.8		
O6068	20-Apr	Sp	NA		0.0	0.0	0.88	0.39	1.53				10.5			924			97.6		
O6069	27-Apr	Sp	NA		0.0	0.0	10.13	2.27	3.72				13.7			1			85.7		
O6070	27-Apr	Sp	NA		0.0	0.0	13.27	1.82	1.35				9.3			577			35.8		

Table A.4: Halton, 2006, water chemistry. Continued from page 164.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6071	27-Apr	Sp	NA		0.0	0.0	7.26	1.79	0.81				6.3			437			23.0		
O6072	27-Apr	Sp	NA		0.0	0.0	5.75	1.00					7.2			524			27.2		
O6073	27-Apr	Sp	NA		0.0	0.0	2.70	1.30					6.9			451			21.8		
O6074	27-Apr	Sp	NA		0.0	0.0	2.27	0.87					6.9						15.5		
O6075	27-Apr	Sp	NA		0.0	0.0	1.50	0.50					7.8						22.2		
O6076	27-Apr	Sp	NA		0.0	0.0	2.37	1.56					7.8						25.3		
O6077	27-Apr	Sp	L31		5.0	2.0	0.65	0.55	0.52	257	35.9	3.2	8.5	3.9	4.9		95.2		19.4	531	
O6078	27-Apr	Sp	L32		10.0	5.0	0.80	0.45	0.52	223	29.0	2.8	6.0	6.2	4.0		72.9		19.0	663	
O6079	27-Apr	Sp	L33		15.0	5.0	1.45	0.75													
O6080	27-Apr	Sp	NA		0.0	0.0	1.35	0.85					4.0			293			12.5		
O6081	27-Apr	Sp	NA		0.0	0.0			0.58				5.7			377			16.5		
O6082	27-Apr	Sp	NA		0.0	0.0	0.65	0.52	0.65				8.4			608			28.4		
O6083	27-Apr	Sp	L21		5.0	2.0	1.35	0.55	0.45	199	22.3	2.6	6.0	5.3	2.5	356	91.6		15.9		
O6084	27-Apr	Sp	L22		10.0	5.0	5.00	2.33	0.43	168	20.5	2.7	6.7	4.2	3.4	292	62.2		12.3	557	
O6085	27-Apr	Sp	L23		15.0	5.0	0.77	0.40	0.44	153	14.1	2.1	7.3	3.9	3.1	460	45.0		21.5	496	
O6086	27-Apr	Sp	NA		0.0	0.0	0.90	0.70					7.2			417			17.2		
O6087	27-Apr	Sp	NA		0.0	0.0							4.3			375			19.7		
O6088	27-Apr	Sp	NA		0.0	0.0							4.9			428			18.6		
O6089	27-Apr	Sp	NA		0.0	0.0	1.05	0.65					4.9			229			9.7		
O6090	27-Apr	Sp	L11		5.0	2.0	0.70	0.45	0.51	242	25.9	2.4	8.5	4.2	4.0	447	54.8		20.7	537	
O6091	27-Apr	Sp	L12		10.0	5.0	1.70	0.60	0.35	167	18.7	2.3	6.3	3.2	3.7	285	53.5		12.9	677	
O6092	27-Apr	Sp	L13		15.0	5.0	1.20	0.30	0.43	153	16.9	1.9	6.4	4.5	3.7	290	44.6		12.9	672	
O6093	27-Apr	Sp	600	a	2.0	1.0	0.70	0.50	0.53	241	30.6	3.1	8.5	6.4	2.8	433	44.9		12.4	836	
O6094	27-Apr	Sp	603	a	5.0	2.0	0.82	0.36	0.35	153	18.7	1.9	7.9	4.8	3.4	304	58.0		13.4	616	
O6095	27-Apr	Sp	606	a	10.0	5.0	1.10	0.37	0.58	209	32.1	3.5	7.6	4.8	2.8		53.7		14.8	698	
O6121	8-May	Sp	631	d	2.0	1.0	6.50	2.50	0.62	392	52.6	2.8	6.6	3.8	2.1	380	23.2	975	15.6	171	-1.93
O6122	8-May	Sp	632	d	5.0	2.0	3.00	1.45	0.93	278	39.9	3.8	7.2	3.8	1.8	350	56.5	665	16.0	445	-1.78
O6123	8-May	Sp	633	d	10.0	5.0	3.43	1.27	1.22	382	53.7	5.0	9.3	6.6	2.1	362	73.0	937	15.9	437	-1.71
O6124	8-May	Sp	602	c	2.0	1.0			0.39	415	54.4	3.1	7.5	2.6	0.9	379	29.4	1098	17.0	139	-2.08
O6125	8-May	Sp	605	c	5.0	2.0	1.42	0.55	0.70	221	33.6	3.6	7.2	4.1	3.0	379	80.2	683	16.4	232	-1.97
O6126	8-May	Sp	608	c	10.0	5.0	2.80	1.29	3.37	483	87.5	8.7	15.5	6.9	2.7	371	75.8	804	16.0	390	-1.77
O6127	8-May	Sp	635	O	35.0	5.0	1.73	1.07	2.50	435	61.4	3.6	8.1	3.2	2.4	320	33.0	626	15.2	451	-1.85
O6128	8-May	Sp	601	b	2.0	1.0	1.33	0.70	0.24	179	26.7	1.4	7.8	2.6	0.6	279	14.2	687	15.5	110	-1.61

Table A.4: Halton, 2006, water chemistry. Continued from page 164.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6129	8-May	Sp	604	b	5.0	2.0	1.40	0.90	0.25	198	26.8	2.0	6.3	3.8		322	10.4	617	16.2	142	-2.00
O6130	8-May	Sp	607	b	10.0	5.0	2.00	1.67	0.90	284	43.1	3.6	9.8	4.7	2.1	342	38.2	704	15.8	375	-1.83
O6131	8-May	Sp	600	a	2.0	1.0	2.10	1.30	0.34	196	28.0	1.9	6.6	3.8	0.9	318	6.7	596	18.2	89	-2.62
O6132	8-May	Sp	603	a	5.0	2.0	1.00	1.00	1.33	330	48.8	3.1	7.7	5.0	1.2	320	20.6	722	16.5	247	-2.48
O6133	8-May	Sp	606	a	10.0	5.0	1.26	0.74	0.90	327	49.5	2.2	8.1	3.8	1.2	282	38.9	757	13.0	332	-1.86
O6155	8-Jun	Su	633	d	10.0	9.0	2.11	1.44	3.65	762	128.8	6.9	11.5	4.7	1.0	297	99.7	774	16.1	338	-1.21
O6156	8-Jun	Su	633	d	10.0	3.0			2.56	575	97.8	5.8	10.9	5.6	1.0	302	50.1	731	18.2	507	
O6157	8-Jun	Su	602	c	2.0	1.0	1.15	0.85	1.34	495	71.3	2.9	5.3	3.5	0.3	311	44.9	770	16.9	367	-1.14
O6158	8-Jun	Su	608	c	10.0	2.0	1.87	1.13	2.66	831	112.7	6.9	12.1	2.3	1.0	329	95.8	831	18.4	424	
O6159	8-Jun	Su	608	c	10.0	9.0	1.71	0.88	2.45	534	86.2	6.4	9.7	5.0	0.8	338	43.4	726	16.4	315	-1.91
O6160	8-Jun	Su	635	O	35.0	5.0	1.63	1.11	2.21	584	86.4	4.9	8.5	4.1	0.5	291	26.2	631	16.9	324	-1.84
O6161	8-Jun	Su	603	a	5.0	2.0	1.24	0.64	1.08	481	84.2	5.0	8.6	3.2	1.3	277	26.9		16.6	404	-0.90
O6162	8-Jun	Su	605	c	5.0	2.0	1.55	0.95	2.11	539	91.7	5.5	10.3	3.5	0.8	282	38.2	731	16.3	516	-1.37
O6163	8-Jun	Su	600	a	2.0	1.0	1.53	0.84	1.65	525	84.4	6.0	9.8	4.1	0.5	281	26.1	727	17.4	312	-1.48
O6164	8-Jun	Su	606	a	10.0	9.0	2.35	1.29	2.82	531	87.7	4.8	9.4	3.5	0.8	304	27.4	872	17.9	470	-1.66
O6165	8-Jun	Su	606	a	10.0	3.0	1.76	1.03	1.78	523	90.8	6.3	10.0	3.2	0.8	366	22.8	817	16.5	594	
O6166	8-Jun	Su	607	b	10.0	3.0	1.44	0.94	2.10	606	99.8	6.3	13.0	4.7	1.3	265	45.8	763	16.0	387	-1.91
O6167	8-Jun	Su	607	b	10.0	9.0	1.53	1.13	3.34	620	102.1	5.2	9.4	3.5	0.8	303	36.9	763	17.7	281	-1.54
O6168	8-Jun	Su	632	d	5.0	2.0	2.06	1.00	2.03	589	93.8	4.1	7.4	2.9	0.8	303	52.2	833	16.0	335	-2.12
O6169	8-Jun	Su	631	d	2.0	1.0	1.71	1.00	1.70	468	83.4	5.7	9.4	3.8	0.8	357	43.9	937	20.2	283	-1.52
O6170	8-Jun	Su	601	b	2.0	1.0	1.21	0.53	1.09	423	70.0	5.3	10.0	5.0	0.8	357	28.1	904	18.7	120	-1.58
O6171	8-Jun	Su	604	b	5.0	2.0	1.64	1.09	1.20	421	71.7	6.6	10.9	3.5	1.0	301	38.8	1310	17.8	372	-1.37
O6219	23-Jun	Su	606	a	10.0	2.0	0.80	0.47	0.52	286	40.0	2.6	6.1	2.5	0.6	242	25.1		15.5	274	
O6220	23-Jun	Su	603	a	5.0	2.0	0.56	0.52	0.46	249	36.2	3.2	7.0	3.4	0.9	282	15.1	789	15.5	368	-0.53
O6221	23-Jun	Su	601	b	2.0	1.0	1.16	0.84	0.31	322	51.8	2.3	7.9	2.5	1.2	293	36.1	734	14.7	340	-1.07
O6222	23-Jun	Su	604	b	5.0	4.0	0.92	0.36	0.93	374	58.1	3.1	5.2	2.8	0.9	612	27.0		18.4	848	-1.30
O6223	23-Jun	Su	600	a	2.0	1.0	1.04	0.68	0.65	243	35.2	2.3	4.9	2.5	0.6	264	34.3	824	15.6	318	-0.47
O6224	23-Jun	Su	606	a	10.0	9.0	0.68	0.52	0.52	206	28.1	2.4	4.9	2.8	0.9	324	55.8	1036	14.6	795	-1.02
O6225	23-Jun	Su	632	d	5.0	4.0	1.00	0.48	0.54	280	42.8	3.9	7.3	3.7	0.9	311	17.8	863	14.5	413	-1.32
O6226	23-Jun	Su	632	d	5.0	2.0	0.68	0.48	0.57	295	47.4	4.3	7.6	3.4	1.5	325	20.2	764	14.7	454	
O6227	23-Jun	Su	631	d	2.0	1.0	0.80	0.40	0.46	246	41.1	3.8	4.9	3.7	0.9	327	54.2	868	14.7	451	
O6228	23-Jun	Su	605	c	5.0	2.0	0.72	0.36	0.38	175	29.6	2.4	4.9	2.8	1.2	316	14.1	744	14.6	420	-1.09
O6229	23-Jun	Su	608	c	10.0	9.0	0.76	0.64	0.55	203	27.0	1.2	5.8	2.5	0.9	329	23.5	695	14.5	928	-1.40

Table A.4: Halton, 2006, water chemistry. Continued from page 164.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6230	23-Jun	Su	604	b	5.0	2.0	0.88	0.56	0.26	195	28.6	1.8	4.3	2.5	0.9	318	22.7	720	14.5	678	
O6231	23-Jun	Su	602	c	2.0	1.0	0.69	0.49	0.15	242	36.7	3.3	5.8	3.4	1.2	372	14.6	769	15.1	436	-1.35
O6232	23-Jun	Su	605	c	5.0	4.0	0.60	0.49	0.93	274	44.1	3.3	5.8	3.1	1.5	305	26.8	799	14.5	540	-1.49
O6233	23-Jun	Su	633	d	10.0	9.0	0.46	0.29	0.40	195	34.7	2.3	5.2	3.1	0.9	299	62.0	704	12.9	924	-2.04
O6234	23-Jun	Su	607	b	10.0	9.0	0.63	0.49	0.39	216	37.5	2.4	4.6	2.8	1.2	329	67.2	743	14.5	854	-1.27
O6235	23-Jun	Su	608	c	10.0	5.0	0.43	0.31	0.70	213	30.6	2.7	5.2	3.1	0.3	242	26.3	712	10.6	771	
O6236	23-Jun	Su	633	d	10.0	5.0	0.70	0.53	0.60	236	38.3	3.0	5.5	2.8	0.9	315	47.4	716	14.5	660	
O6237	23-Jun	Su	607	b	10.0	5.0	0.69	0.54	0.44	301	54.6	2.7	6.4	3.1	0.6	310		864	13.5	737	
O6238	23-Jun	Su	635	O	35.0	5.0	0.83	0.57	0.65	338	61.5	3.7	7.0	3.7	0.9	306	49.6	731	15.1	389	-1.36
O6252	11-Jul	Su	600	a	2.0	1.0	1.00	0.40	0.85	300	45.8	2.8	9.0	4.9	1.9	276	80.4	542	12.3	417	-1.29
O6253	11-Jul	Su	631	d	2.0	1.0	2.30	0.75	1.71	417	65.5	4.2	8.7	3.7	1.1	267	28.6	832	12.3	280	-0.93
O6254	11-Jul	Su	633	d	10.0	9.0	0.60	0.30	0.64	210	31.7	2.3	6.4	3.4	1.4	321	33.1	499	13.9	543	-1.43
O6255	11-Jul	Su	633	d	10.0	5.0	1.50	0.70	1.84	389	62.0	4.9	9.0	4.0	1.6	329	65.9	858	12.2	428	-1.04
O6256	11-Jul	Su	632	d	5.0	2.0	2.20	0.90	1.88	341	54.7	4.2	7.9	3.4	1.9	301		585	13.8	305	-1.12
O6257	11-Jul	Su	632	d	5.0	4.0	1.16	0.79	2.14	389	59.4	4.8	9.3	4.9	1.6	318	88.1	538	14.0	385	-1.01
O6258	11-Jul	Su	602	c	2.0	1.0	1.95	0.45	1.98	442	73.0	4.3	8.5	4.0	0.5	310	23.2	816	14.6	202	-1.14
O6259	11-Jul	Su	605	c	5.0	4.0	0.90	0.75	2.49	378	63.0	3.6	7.7	4.0	1.6	286	10.8	542	13.4	328	-1.16
O6260	11-Jul	Su	605	c	5.0	2.0	1.05	0.80	2.24	402	63.3	3.1	6.7	3.4	1.9	250	12.0	480	11.6	322	-1.04
O6261	11-Jul	Su	608	c	10.0	9.0	1.40	0.90	2.03	376	59.7	2.9	6.7	2.9	0.5	336	17.0	791	12.3	483	-0.89
O6262	11-Jul	Su	608	c	10.0	5.0	1.35	0.85	3.52	432	74.2	3.0	7.9	3.4	1.4	286	12.6	879	13.4	391	-0.89
O6263	11-Jul	Su	601	b	2.0	1.0	1.70	0.90	1.08	350	56.3	4.3	7.7	3.7	0.8	208	11.7	428	9.9	245	-1.31
O6264	11-Jul	Su	604	b	5.0	2.0	1.45	0.55	1.40	382	56.0	3.8	6.9	3.4	0.8	277	29.9	1233	13.2	414	-1.68
O6265	11-Jul	Su	604	b	5.0	4.0	1.70	0.85	2.25	389	66.5	3.9	7.1	3.1	1.1	221	22.1	770	13.7	451	-1.70
O6266	11-Jul	Su	607	b	10.0	9.0	1.65	0.85	2.68	435	72.2	3.4	8.6	3.4	0.5	231	14.9	761	9.9	460	-1.59
O6267	11-Jul	Su	607	b	10.0	5.0			2.10	413	65.0	5.0	8.0	3.4	0.5	327	14.4	614	15.7	365	-2.13
O6268	11-Jul	Su	635	O	35.0	5.0	2.50	0.95	4.27	631	99.0	4.9	9.4	4.0	1.4	211	10.1	476	14.1	162	-1.79
O6269	11-Jul	Su	603	a	5.0	4.0	2.45	1.75	1.93	360	55.2	3.8	7.1	3.7	0.5	224	12.1	761	14.2	274	-0.52
O6270	11-Jul	Su	603	a	5.0	2.0	1.00	0.80	1.26	340	50.1	5.1	7.7	3.1	0.5	225	17.3		13.2	274	-1.86
O6271	11-Jul	Su	606	a	10.0	9.0	1.45	0.65	2.66	480	87.2	4.2	8.6	4.6	0.2	228	13.8		10.0	526	-2.37
O6272	11-Jul	Su	606	a	10.0	5.0	1.45	1.25	1.98	440	69.2	3.2	6.9	3.7	0.8	257	10.7		11.4	408	-1.05
O6288	1-Aug	Su	633	d	10.0	9.0	0.93	0.67	1.26	513	85.2	4.7	8.6	4.4	0.5	272	83.7		14.1	333	-1.51
O6289	1-Aug	Su	633	d	10.0	5.0	1.50	0.97	1.35	399	69.2	5.4	10.4	3.8	0.5	270	54.8		15.2	132	-0.86
O6290	1-Aug	Su	632	d	5.0	4.0	1.30	0.77	1.15	428	63.8	5.1	10.4	3.9	0.2	250	37.2		10.6	112	-1.12

Table A.4: Halton, 2006, water chemistry. Continued from page 164.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6291	1-Aug	Su	632	d	5.0	2.0	1.20	0.77	1.02	416	62.2	5.1	8.9	3.5	0.2	249	32.6		15.0	174	-0.95
O6292	1-Aug	Su	631	d	2.0	1.0	1.30	0.80	1.14	392	68.9	6.7	10.7	4.1		249	38.6	437	14.9	86	-0.96
O6293	1-Aug	Su	602	c	2.0	1.0	1.48	1.03	1.53	524	91.9	7.9	11.9	3.5	0.5	252	36.0		14.8	114	-1.75
O6294	1-Aug	Su	605	c	5.0	4.0	1.95	1.14	2.09	470	87.2		12.2	3.5		284	41.5	471	14.4	322	-1.87
O6295	1-Aug	Su	605	c	5.0	2.5	1.40	0.90	1.99	436	77.9	6.4	11.6	4.2	0.2	247	36.4		13.7	205	
O6296	1-Aug	Su	608	c	10.0	9.0	0.77	0.57	1.28	305	50.7	4.1	9.5	3.8	0.7	273	39.8	1019	10.4	322	-1.15
O6297	1-Aug	Su	608	c	10.0	5.0	1.32	1.04	2.50	550	104.4	13.6	11.6	5.0	1.6	221	31.0	566	12.8	747	-1.36
O6298	1-Aug	Su	601	b	2.0	1.0	2.00	1.40	1.52	516	92.7	6.8	10.1	9.5	0.7	248	40.0		13.7	705	-1.32
O6299	1-Aug	Su	604	b	5.0	4.0	1.52	1.00	1.90	472	84.3	6.9	12.2	5.0	0.7	267	33.1	599	14.1	251	-1.25
O6300	1-Aug	Su	604	b	5.0	2.5	1.30	1.00	1.18	440	72.9	7.0	10.4	4.4	0.5	258	38.4	390	14.5	205	
O6301	1-Aug	Su	607	b	10.0	9.0	0.77	0.57	1.29	260	43.5	4.1	7.4	3.8	0.5	274	35.5	395	13.6	415	-1.21
O6302	1-Aug	Su	607	b	10.0	5.0	1.33	1.02	2.26	495	88.4	5.5	8.6	4.1	0.7	246	23.8	433	7.4	188	-1.62
O6303	1-Aug	Su	635	O	35.0	5.0	1.64	1.20	2.48	427	67.2	5.1	9.5	3.5	1.0	187	20.6	466	10.4	214	-1.20
O6304	1-Aug	Su	606	a	10.0	9.0	1.15	0.75		448	66.3	5.8	8.0	3.9	0.7	268	23.8	471	13.6	259	-1.51
O6305	1-Aug	Su	606	a	10.0	5.0	2.14	1.21	2.53	421	74.8	6.0	10.1	4.4	1.0	213	28.5	490	10.8	202	
O6306	1-Aug	Su	603	a	5.0	4.0	0.80	0.53	1.07	326	48.7	4.0	7.7	3.5	0.5	259	33.3	423	13.9	350	-1.14
O6307	1-Aug	Su	603	a	5.0	2.5	1.27	0.97	1.77	462	78.7	6.9	9.2	3.9	0.7	252	35.2	514	13.5	222	-0.95
O6308	1-Aug	Su	600	a	2.0	1.0	0.93	0.80	1.43	312	52.5	4.7	7.4	4.1	0.2	25	24.6	437	14.0	222	-1.44
O6365	14-Sep	Au	606	a	10.0	5.0	0.79	0.55	0.45	235	32.8	2.9	16.4	10.4	7.5	221	187.4		13.7	481	
O6366	14-Sep	Au	632	d	5.0	2.5	0.88	0.55	0.27	305	49.4	4.2	27.9	14.4	10.1	231	88.2		9.9	449	
O6367	14-Sep	Au	632	d	5.0	4.0	1.20	0.57	0.32	248	36.7	7.6	20.2	13.8	12.4	327	67.3		15.7	359	-1.04
O6368	14-Sep	Au	633	d	10.0	9.0	0.85	0.58	0.31	205	33.5	4.5	20.4	9.8	9.0	211	78.6		14.1	540	-0.51
O6369	14-Sep	Au	604	b	5.0	2.5	0.52	0.42	0.41	185	26.2	3.8	12.4	9.2	7.1	224	188.3		14.2	461	
O6370	14-Sep	Au	600	a	2.0	1.0	0.78	0.43	0.59	210	31.2	4.0	11.8	9.2	7.0	225	91.5		13.2	915	-0.38
O6371	14-Sep	Au	608	c	10.0	9.0	0.80	0.48	0.26	200	28.5	3.4	15.8	9.5	7.2	205	98.9		14.1	1037	-0.48
O6372	14-Sep	Au	605	c	5.0	2.5	0.72	0.50	0.33	234	34.5	4.4	11.8	9.2	7.8	294	81.0		15.7	518	
O6373	14-Sep	Au	605	c	5.0	4.0	0.85	0.55	0.16	201	31.2	3.7	10.9	10.9	8.4	268	64.5		14.4	773	-0.79
O6374	14-Sep	Au	608	c	10.0	5.0	0.25	0.30	0.41	218	31.5	3.6	13.8	9.5	7.8	203	73.0		14.1	847	
O6375	14-Sep	Au	631	d	2.0	1.0	1.13	0.52	0.39	196	28.2	4.6	26.4	18.9	12.2	324	81.9	537	14.8	390	-0.71
O6376	14-Sep	Au	602	c	2.0	1.0	1.00	0.70	0.32	297	54.9	7.7	18.6	12.2	8.1	272	76.0	493	14.2	958	-0.48
O6377	14-Sep	Au	633	d	10.0	5.0	0.60	0.43	0.29	181	29.5	4.1	23.7	10.1	7.2	208	85.6	348	13.9	844	
O6378	14-Sep	Au	635	O	35.0	5.0	1.37	1.00	0.72	412	76.9	9.8	20.6	8.7	7.5	177	71.3	305	13.8	779	-0.15
O6379	14-Sep	Au	606	a	10.0	9.0	0.70	0.48	0.40	212	32.0	3.0	17.7	10.3	7.1	223	155.1	399	14.4	960	-0.74

Table A.4: Halton, 2006, water chemistry. Continued from page 164.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi	δ^{13}DIC
O6380	14-Sep	Au	603	a	5.0	2.5	0.75	0.45	0.55	197	30.2	3.5	14.0	8.4	7.1	218	80.1	414	14.1	1026	
O6381	14-Sep	Au	601	b	2.0	1.0	0.75	0.52	0.55	230	34.5	6.3	17.5	9.0	5.7	248	66.7	370	14.9	733	-0.30
O6382	14-Sep	Au	604	b	5.0	4.0	0.65	0.40	0.23	254	37.2	4.5	22.1	13.4	7.1	256	72.7	384	15.0	1000	-0.63
O6383	14-Sep	Au	607	b	10.0	5.0	0.47	0.53	0.67	291	46.1	4.3	18.3	6.2	3.0	187	65.8	312	13.7	895	
O6384	14-Sep	Au	607	b	10.0	9.0	0.43	0.47	0.63	214	31.2	4.9	21.7	13.5	5.0	191	75.5	754	13.9	858	-0.27
O6385	14-Sep	Au	603	a	5.0	4.0	0.57	0.60	0.75	224	35.3	4.0	23.9	14.3	6.1	216	77.2		14.1	940	-0.28
O6700	19-Oct	Au	607	b	10.0	2.5	1.88	0.42	0.60	190	27.2	3.8	17.3	7.5	3.4	331		580	13.1	1162	
O6701	19-Oct	Au	607	b	10.0	9.0	0.16	0.20	0.08	119	12.2	2.9	8.9	7.1	3.9	268		442	12.6	1290	
O6702	19-Oct	Au	608	c	10.0	2.5	1.00	0.60	0.93	202	28.9	5.8	9.6	6.5	3.2	284		514	12.2	1006	
O6703	19-Oct	Au	601	b	2.0	1.0	1.03	0.50	0.36	160	21.2	2.6	14.5	5.1	5.6	190		457	14.9	481	-1.95
O6704	19-Oct	Au	635	O	35.0	5.0	0.42	0.42	1.63	227	39.1	4.8	7.6	3.6	0.6	192		376	13.5	472	-1.18
O6705	19-Oct	Au	604	b	5.0	4.0	1.40	0.46	0.24	178	25.7	3.9	10.5	7.7	5.6	314		452	13.3	1233	-1.97
O6706	19-Oct	Au	604	b	5.0	2.5	2.68	0.59	0.39	239	32.6	5.4	20.6	10.2	7.0	401		530	15.8	1290	
O6707	19-Oct	Au	633	d	10.0	9.0	0.26	0.20	0.10	121	14.5	1.8	10.6	6.5	3.9	349	10.9	544	13.2	1136	-0.94
O6708	19-Oct	Au	632	d	5.0	4.0	0.50	0.30	0.21	150	19.2	2.2	13.1	8.4	4.1	381	30.0	530	14.9	1392	
O6709	19-Oct	Au	600	a	2.0	1.0	5.31	1.06	0.64	285	43.6	5.9	24.7	18.0	10.7	436	28.7	595	16.6	1866	-2.08
O6710	19-Oct	Au	632	d	5.0	2.5	1.22	0.41	0.24	165	19.7	3.3	12.7	8.3	3.8	375	34.8	551	14.8	1463	
O6711	19-Oct	Au	603	a	5.0	1.0	3.92	1.31	0.91	294	42.6	5.7	22.2	15.8	8.1	402	24.6	595	15.3	1412	
O6712	19-Oct	Au	605	c	5.0	4.0	0.70	0.35	0.24	140	17.6	1.8	10.3	7.2	3.8	348	3.9		14.8	1261	-2.49
O6713	19-Oct	Au	605	c	5.0	2.5	0.65	0.30	0.25	116	14.9	3.1	14.0	7.8	4.1	371	8.3	559	14.3	1446	
O6714	19-Oct	Au	608	c	10.0	9.0	0.52	0.35	0.13	137	13.1	1.5	13.4	6.5	2.9	279	8.7	479	13.2	1210	-1.50
O6715	19-Oct	Au	606	a	10.0	2.5	1.36	0.77	1.34	268	43.3	7.7	9.6	5.1	2.1	323	15.7	791	13.9	889	
O6716	19-Oct	Au	631	d	2.0	1.0	1.70	0.73	0.40	224	31.9	2.7	10.8	9.7	4.1	345		899	14.8	1040	-1.57
O6717	19-Oct	Au	602	c	2.0	1.0	0.70	0.37	0.74	185	41.1		10.3	5.3	2.4	330	11.2	827	13.5	1389	-1.68
O6718	19-Oct	Au	633	d	10.0	2.5	0.43	0.25	0.27	125	16.4	1.4	10.3	7.3	3.8	318	26.5	827	12.5	1026	
O6719	19-Oct	Au	603	a	5.0	4.0			0.19	117	15.4	2.0	10.0	6.7	3.2	296	13.6	820	11.2	1233	-2.24
O6720	19-Oct	Au	606	a	10.0	9.0	0.65	0.48	0.17	216	26.9		6.5	5.3	1.5	328	5.8	725	13.9	1264	-1.64

Table A.5: Halton, Lake Ontario, 2005, Physical and *C. glomerata* chemistry.

LabID	Date	Seas	Stn	Tran	dP	dS	D	SD	TL	Str	ST	DT	K_d	$\%I_o$	IChl	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
O5030	1-Jun	Sp	606	A	5.7	16.0	10.0	9.0	H	N	11.3	7.5	0.20	14.1		351	29.0	1.0	3.8	-18.96	5.74
O5031	1-Jun	Sp	606	A	5.7	16.0	10.0	5.0	E	N	11.3	9.0	0.20	14.1							
O5032	1-Jun	Sp	603	A	5.7	16.3	5.0	2.5	E	N	11.1	10.3	0.29	24.0		331	24.5	0.6	1.3	-20.31	4.20
O5033	1-Jun	Sp	607	B	1.6	9.5	10.0	5.0	E	N	12.8	8.5	0.36	2.8							
O5034	1-Jun	Sp	607	B	1.6	9.5	10.0	9.0	H	N	12.8	8.3	0.36	2.8							
O5035	1-Jun	Sp	600	A	5.7	16.3	2.0	1.0	E	N	11.2	11.2	0.41	43.8		346	22.6	0.7	2.7	-21.25	4.51
O5036	1-Jun	Sp	602	C	7.4	3.3	2.0	1.0	E	N	11.2	10.9	0.36	49.1		334	22.6	0.8	2.4	-20.35	4.27
O5037	1-Jun	Sp	605	C	7.2	3.3	5.0	2.5	E	N	10.6	9.9	0.29	23.6		330	26.6	0.8	1.8	-20.13	2.26
O5038	1-Jun	Sp	608	C	7.3	3.8	10.0	5.0	E	N	11.1	8.8	0.26	7.4							
O5039	1-Jun	Sp	608	C	7.3	3.8	10.0	9.0	H	N	11.1	8.5	0.26	7.4							
O5040	1-Jun	Sp	601	B	0.9	9.7	2.0	1.0	E	N	11.1	11.1	0.29	55.6		308	23.0			-21.46	4.75
O5041	1-Jun	Sp	604	B	1.1	9.5	5.0	2.5	E	N	11.0	10.3	0.30	22.6	0.12	317	23.8	0.8	2.6	-19.21	4.14
O5163	25-Jul	Su	608	C	7.3	3.8	10.0	1.5	E	Y	18.5	18.0	0.41	1.7							
O5164	25-Jul	Su	605	C	7.2	3.3	5.0	1.5	E	Y	15.5	15.5	0.31	20.8							
O5165	25-Jul	Su	608	C	7.3	3.8	10.0	8.0	H	Y	18.5	13.2	0.41	1.7		307	36.4	1.7	4.8	-18.25	2.70
O5166	25-Jul	Su	601	B	0.9	9.7	2.0	1.0	E	N	17.6	16.4	1.07	11.7	0.16	185	13.0	0.6	1.6	-18.89	6.05
O5167	25-Jul	Su	604	B	1.1	9.5	5.0	4.0	H	Y	17.2	12.9	0.36	16.7	0.49	326	27.5	0.9	3.8	-17.49	6.01
O5168	25-Jul	Su	607	B	1.6	9.5	10.0	2.0	E	Y	17.0	14.3	0.37	2.5							
O5169	25-Jul	Su	604	B	1.1	9.5	5.0	1.5	E	Y	17.2	16.2	0.36	16.7							
O5170	25-Jul	Su	600	A	5.7	16.3	2.0	1.0	E	N	16.9	10.8	0.55	33.1		303	18.0	0.5	1.9	-18.69	6.86
O5171	25-Jul	Su	603	A	5.7	16.3	5.0	2.5	E	N	13.1	9.6	0.54	6.7		293	22.1	0.8	1.8	-16.48	6.88
O5172	25-Jul	Su	606	A	5.7	16.0	10.0	1.0	E	Y	15.0	12.3	0.46	1.0							
O5173	25-Jul	Su	606	A	5.7	16.0	10.0	9.0	H	Y	15.0	7.8	0.46	1.0		306	35.4	2.5	7.4	-18.14	5.09
O5174	25-Jul	Su	607	B	1.6	9.5	10.0	9.0	H	Y	17.0	10.1	0.37	2.5	0.96	308	37.6	2.5	7.2	-18.06	4.96
O5175	25-Jul	Su	602	C	7.4	3.3	2.0	1.0	E	N	16.6	14.0	0.42	43.3		290	19.4	0.6	1.4	-17.30	6.42
O5176	25-Jul	Su	605	C	7.2	3.3	5.0	4.0	H	Y	15.5	13.3	0.31	20.8		324	29.1	1.4	3.6	-16.77	5.50

Table A.6: Halton, Lake Ontario, 2005, water chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
O5030	1-Jun	Sp	606	A	10.0	9.0			2.07	387	54	1.7	4.6	2.8	0.86	499	5.2	819	10.6	247
O5031	1-Jun	Sp	606	A	10.0	5.0			1.87	381	58	2.1	5.5	3.3	1.13	498	5.6	952	14.1	183
O5032	1-Jun	Sp	603	A	5.0	2.5			1.57	307	46	2.1	4.3	3.1	0.98	501	3.1		14.3	293
O5033	1-Jun	Sp	607	B	10.0	5.0			1.95	346	55	2.3	4.4	3.6	0.36	463	3.8	2357	25.0	192
O5034	1-Jun	Sp	607	B	10.0	9.0			1.51	272	43	1.3	3.2	2.1	0.31	409	11.5	1372	28.4	163
O5035	1-Jun	Sp	600	A	2.0	1.0			1.11	314	44	1.9	5.4	3.7	0.13		5.1			231
O5036	1-Jun	Sp	602	C	2.0	1.0			1.20	314	49	3.1	6.3	3.0	0.03	1218	9.3	1072	18.3	245
O5037	1-Jun	Sp	605	C	5.0	2.5			1.91	368	57	2.8	5.9	3.0	0.51		7.3	959	3.4	205
O5038	1-Jun	Sp	608	C	10.0	5.0			2.70	369	59	2.9	8.2	4.1	0.69	718	14.5	1129	29.0	243
O5039	1-Jun	Sp	608	C	10.0	9.0			1.43	267	35	3.0	8.2	3.9	0.64	556	9.1		9.5	192
O5040	1-Jun	Sp	601	B	2.0	1.0			1.12	329	54	2.9	8.2	2.6	0.37	603	6.1	979	17.6	214
O5041	1-Jun	Sp	604	B	5.0	2.5			1.25	354	54	4.5	8.2	3.4	0.69	536	4.7	3522	6.7	305
O5163	25-Jul	Su	608	C	10.0	1.5	1.24	0.84	1.86	469	77	4.8	7.8	1.9	0.80	363	15.0	1143	10.8	60
O5164	25-Jul	Su	605	C	5.0	1.5	0.92	0.76	0.90	377	60	4.7	5.8	2.7	0.23	599	89.6	1765	24.4	75
O5165	25-Jul	Su	608	C	10.0	8.0	1.40	1.16	2.35	674	118	8.1	9.2	4.1	1.25	389	82.7	1562	11.3	146
O5166	25-Jul	Su	601	B	2.0	1.0	0.88	1.00	1.62	430	65	4.6	11.4	1.9	0.95	354	112.5	1429	20.2	63
O5167	25-Jul	Su	604	B	5.0	4.0	1.00	0.96	2.25	508	90	7.6	6.5	3.3	0.52	480	7.6	1348	8.9	49
O5168	25-Jul	Su	607	B	10.0	2.0	1.28		2.75	503	91	6.5	5.9	2.8	0.89	514	47.3	1043	16.1	40
O5169	25-Jul	Su	604	B	5.0	1.5	0.88	0.92	1.96	443	73	5.0	6.1	3.0	0.61	519	105.1	1357	18.4	40
O5170	25-Jul	Su	600	A	2.0	1.0	1.08	1.04	2.03	497	84	6.1	7.1	4.9	0.58	366	84.2	1465	12.1	89
O5171	25-Jul	Su	603	A	5.0	2.5	0.96		2.79	558	91	7.2	7.0	3.5	1.27	420	75.1	2350	23.0	169
O5172	25-Jul	Su	606	A	10.0	1.0	1.16	1.12	2.65	540	89	6.0	7.6	3.3	0.91	145	77.9	816	19.8	115
O5173	25-Jul	Su	606	A	10.0	9.0	0.76	0.60	2.20	453	60	4.2	6.0	2.9	1.11	751	22.9	1216	15.2	318
O5174	25-Jul	Su	607	B	10.0	9.0	1.28	1.20	2.59	538	97	4.7	6.1	3.5	1.06	540	93.6	821	21.6	129
O5175	25-Jul	Su	602	C	2.0	1.0	0.96	0.88	2.29	367	66	6.9	6.6	3.2	0.69	251	6.4	865	13.8	34
O5176	25-Jul	Su	605	C	5.0	4.0	0.92		1.63	363	63	5.9	7.2	3.5	0.67	649	10.4	2752		100

Table A.7: Port Credit, Lake Ontario, 2005, Physical and *C. glomerata* chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TL	Str	ST	DT	K_d	$\%I_o$	IC	IN	IP	IPAF	δ^{13} IC	δ^{15} IN
O5047	2-Jun	Sp	609	A	2.0	1.0	E						356	27.5	1.2	4.4	-20.25	2.70
O5051	2-Jun	Sp	612	A	5.0	2.5	E						371	31.3	1.3	5.4	-19.66	2.07
O5052	2-Jun	Sp	615	A	10.0	5.0	E											
O5053	2-Jun	Sp	615	A	10.0	9.0	H						383	44.6	2.3	4.0	-19.30	3.14
O5043	2-Jun	Sp	610	B	2.0	1.0	E						346	23.6	0.9	3.8	-21.38	3.53
O5042	2-Jun	Sp	613	B	5.0	4.0	E						345	31.4	1.3	4.0	-18.39	0.80
O5044	2-Jun	Sp	616	B	10.0	9.0	H						383	47.4	4.1	10.5	-18.89	3.12
O5050	2-Jun	Sp	616	B	10.0	5.0	E											
O5049	2-Jun	Sp	611	C	2.0	1.0	E						276	20.1	0.7	1.5	-21.91	3.35
O5048	2-Jun	Sp	614	C	5.0	2.5	E						306	24.3	1.5	6.6	-18.75	3.54
O5045	2-Jun	Sp	617	C	10.0	9.0	H											
O5046	2-Jun	Sp	617	C	10.0	5.0	E											
O5152	21-Jul	Su	609	A	2.0	1.0	E	N	25.9	23.8	0.41	43.8	339	29.7	1.2	4.8	-14.86	5.81
O5150	21-Jul	Su	612	A	5.0	0.7	E	Y	23.0	22.9	0.45	10.6						
O5161	21-Jul	Su	612	A	5.0	4.0	H	Y	23.0	17.2	0.45	10.6	359	35.4	2.0	6.1	-14.05	5.25
O5160	21-Jul	Su	615	A	10.0	1.5	E	Y	22.8	21.8	0.33	3.8						
O5162	21-Jul	Su	615	A	10.0	9.0	H	Y	22.8	12.4	0.33	3.8	341	41.6	2.5	4.7	-18.16	2.96
O5154	21-Jul	Su	610	B	2.0	1.0	E	N	24.8	23.8	0.52	35.0	347	39.0	2.9	10.3	-19.85	1.91
O5149	21-Jul	Su	613	B	5.0	4.0	H	N	23.2	20.5	0.52	7.5	363	34.3	1.3	4.5	-16.24	4.29
O5151	21-Jul	Su	613	B	5.0	1.5	E	N	23.2	22.9	0.52	7.5						
O5148	21-Jul	Su	616	B	10.0	2.0	E	Y	23.1	22.1	0.42	1.5						
O5153	21-Jul	Su	616	B	10.0	9.0	H	Y	23.1	12.0	0.42	1.5	351	36.3	0.9	2.3	-17.44	1.83
O5158	21-Jul	Su	611	C	2.0	1.0	E	N	21.2	19.7	0.55	33.3	329	22.6	0.7	2.6	-18.84	4.80
O5157	21-Jul	Su	614	C	5.0	4.0	H	Y	20.6	16.3	0.46	9.8	343	26.2	0.9	2.3	-19.03	3.26
O5159	21-Jul	Su	614	C	5.0	2.0	E	Y	20.6	18.8	0.46	9.8						
O5155	21-Jul	Su	617	C	10.0	9.0	H	Y	21.8	19.9	0.49	0.7	334	39.9	0.9	2.7	-19.50	1.77
O5156	21-Jul	Su	617	C	10.0	2.0	E	Y	21.8	11.9	0.49	0.7						

Table A.8: Port Credit, Lake Ontario, 2005, water chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
O5047	2-Jun	Sp	609	A	2.0	1.0			1.89	462	80	2.4	5.0	3.7	0.7	795	2.7	1451	36.56	530
O5051	2-Jun	Sp	612	A	5.0	2.5			2.35	245	41	2.2	5.3	3.4	0.6	563		2137	32.48	271
O5052	2-Jun	Sp	615	A	10.0	5.0			1.87	303	54	5.0	8.1	1.9	0.3	455		1112	10.60	234
O5053	2-Jun	Sp	615	A	10.0	9.0			2.03	272	44	2.0	6.9	3.8	0.6	516		1398	15.85	125
O5043	2-Jun	Sp	610	B	2.0	1.0			1.67	320	45	2.2	6.4	3.5	0.4	467	1.9	1604		119
O5042	2-Jun	Sp	613	B	5.0	4.0			1.73	322	51	2.2	6.4	3.3	0.4	561	7.6	1245	25.82	344
O5044	2-Jun	Sp	616	B	10.0	9.0			2.51	361	54	2.4	6.5	3.0	0.6	450	2.3	1472		150
O5050	2-Jun	Sp	616	B	10.0	5.0			1.99	355	58	2.4	6.8	4.9	0.1	537	4.4	1129	24.34	251
O5049	2-Jun	Sp	611	C	2.0	1.0			2.08	338	55	2.6	7.5	3.2	0.9	471		1378	20.97	265
O5048	2-Jun	Sp	614	C	5.0	2.5			2.19	329	52	2.1	6.4	3.1	0.5	475		1184	15.74	223
O5045	2-Jun	Sp	617	C	10.0	9.0			2.65	468	76	4.6	11.6	4.8	1.0	582	92.4	1684	24.37	309
O5046	2-Jun	Sp	617	C	10.0	5.0			2.07	463	70	3.6	9.3	3.5	1.7	659	95.5	1715	17.41	333
O5152	21-Jul	Su	609	A	2.0	1.0	1.33	5.87	1.22	461	84	6.0	9.2	2.8	0.7	309	51.4	885		235
O5150	21-Jul	Su	612	A	5.0	0.7	0.60	0.85	1.05	373	56	3.9	6.0	2.3	1.3	362	8.6	931	21.64	77
O5161	21-Jul	Su	612	A	5.0	4.0	0.76	0.68	0.77	295	43	4.3	5.2	2.4	0.5	431	99.5	1398	23.69	115
O5160	21-Jul	Su	615	A	10.0	1.5	0.72	0.76	1.25	416	64	4.4	8.4	3.0	0.4	375	181.5	1887	13.64	103
O5162	21-Jul	Su	615	A	10.0	9.0	1.00	0.95	1.59	400	69	5.8	6.8	3.1	0.7	472	70.5	897	13.45	166
O5154	21-Jul	Su	610	B	2.0	1.0	2.68		0.96	379	61	6.2	7.0	3.4	0.5	188	5.1	907	22.48	55
O5149	21-Jul	Su	613	B	5.0	4.0	0.77	0.63	0.96	434	64	5.4	7.3	3.4	0.7	567	52.9	1296	12.42	49
O5151	21-Jul	Su	613	B	5.0	1.5	0.69	0.62	0.82	360	51	4.4	5.8	1.4	0.6	496	45.5	944	14.48	98
O5148	21-Jul	Su	616	B	10.0	2.0	0.56	0.68	0.58	369	47	3.4	6.7	3.2	1.0	308	81.8	1138	16.99	124
O5153	21-Jul	Su	616	B	10.0	9.0	0.96		0.88	334	53	6.5	10.7	2.4	0.7	572	4.1	968		109
O5158	21-Jul	Su	611	C	2.0	1.0	0.64		0.89	326	54	5.8	7.2	2.3	0.5	576	151.0	1154	13.80	75
O5157	21-Jul	Su	614	C	5.0	4.0	0.88		1.31	468	82	6.7	11.9	2.8	0.5	635	9.4	2403	21.97	155
O5159	21-Jul	Su	614	C	5.0	2.0	2.08	0.80	1.14	418	79	7.5	9.9	3.2	0.7	375	9.7	1467		109
O5155	21-Jul	Su	617	C	10.0	9.0	0.84	0.80	1.00	396	74	8.5	11.2	6.7	0.8	406	26.5	2433	14.14	149
O5156	21-Jul	Su	617	C	10.0	2.0	1.00	0.95	1.23	435	79	7.5	7.2	2.8	0.7	356	140.8	1136	24.17	103

Table A.9: Presqu'ile Provincial Park, Lake Ontario, 2005, physical and *C. glomerata* chemistry.

LabID	Date	Seas	LU	Stn	Tran	D	SD	TL	Str	ST	DT	K_d	$\%I_o$	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
O5056	8-Jun	Sp	NU	620	C	2.0	1.0		N	13.0	12.4	0.55	33.1	281	18.8	0.4	1.1	-19.68	5.18
O5058	7-Jun	Sp	NU	624	A	10.0	9.0		N	9.9	8.0	0.28	5.8						
O5059	7-Jun	Sp	NU	624	A	10.0	5.0		N	9.9	8.8	0.28	5.8						
O5061	8-Jun	Sp	NU	625	B	10.0	5.0		N	11.6	9.0	0.35	3.1						
O5062	8-Jun	Sp	NU	623	C	5.0	2.5		N	15.3	11.2	0.43	11.6	290	21.2	0.9	2.5	-19.05	3.97
O5063	8-Jun	Sp	NU	625	B	10.0	9.0		N	11.6	8.1	0.35	3.1	280	22.9	1.2	3.9	-19.98	5.19
O5064	8-Jun	Sp	NU	618	A	2.0	1.0		N	13.6	13.5	0.49	37.6	293	20.0	1.3	3.9	-16.92	5.11
O5066	8-Jun	Sp	NU	621	A	5.0	2.5		N	13.4	11.1	0.27	26.2	310	23.4	0.8	1.9	-20.38	4.52
O5068	8-Jun	Sp	NU	626	C	10.0	9.0		N	10.5	9.3	0.32	4.3						
O5070	8-Jun	Sp	NU	626	C	10.0	5.0		N	10.5	9.6	0.32	4.3						
O5071	8-Jun	Sp	NU	619	B	2.0	1.0		N	12.7	12.5	0.27	58.5	309	21.5	0.8	3.2	-18.48	5.07
O5072	8-Jun	Sp	NU	622	B	5.0	2.5		N	13.3	10.4	0.38	15.0	338	26.5	1.1	3.4	-17.38	5.23
O5246	27-Jul	Su	NU	621	A	5.0	2.5		N	20.1	20.1			293	22.6	1.0	2.5	-19.88	4.79
O5247	27-Jul	Su	NU	624	A	10.0	9.0		N	20.3	17.1			277	19.5	0.7	1.6	-19.84	5.39
O5248	27-Jul	Su	NU	624	A	10.0	4.0		N	20.3	20.2								
O5249	27-Jul	Su	NU	625	B	10.0	3.0		Y	18.4	18.0								
O5250	27-Jul	Su	NU	625	B	10.0	9.0		Y	18.4	13.1			295	24.6	0.7	1.7	-18.50	5.04
O5251	27-Jul	Su	NU	620	C	2.0	1.0		N	20.9	20.2			302	18.8	0.6	2.8	-19.65	5.20
O5252	27-Jul	Su	NU	626	C	10.0	9.0		Y	19.7	14.4			298	33.7	2.0	6.2	-17.89	5.34
O5253	27-Jul	Su	NU	623	C	5.0	2.5		N	20.0	17.6			297	27.4	1.2	3.1	-18.71	5.94
O5254	27-Jul	Su	NU	626	C	10.0	2.5		Y	19.7	18.9								
O5256	27-Jul	Su	NU	619	B	2.0	1.0		N	17.8	17.5			304	18.5	0.7	2.1	-18.63	4.04
O5258	27-Jul	Su	NU	618	A	2.0	1.0		N	20.2	20.2			339	22.6	0.8	1.8	-18.17	6.66
O5259	27-Jul	Su	NU	622	B	5.0	2.5		N	18.0	18.0			293	19.0	0.6	1.2	-18.96	5.87

Table A.10: Presqu'ile Provincial Park, Lake Ontario, 2005, water chemistry.

LabID	Date	Seas	LU	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
O5056	8-Jun	Sp	NU	620	C	2.0	1.0			2.27	598	71	4.2	7.9	4.1	0.4	394		808	12.8	255
O5058	7-Jun	Sp	NU	624	A	10.0	9.0			5.44	657	90	5.6	10.9	4.5	0.9	375	6.5	526	5.5	304
O5059	7-Jun	Sp	NU	624	A	10.0	5.0			4.31	576	85	2.2	7.8	5.6	1.3	367	33.8	1458	12.1	278
O5061	8-Jun	Sp	NU	625	B	10.0	5.0			4.57	647	87	3.2	9.4	3.7	1.4	390		1558	9.0	297
O5062	8-Jun	Sp	NU	623	C	5.0	2.5			3.17	608	80	2.2	6.6	4.5	0.8	342	18.4	609	16.0	252
O5063	8-Jun	Sp	NU	625	B	10.0	9.0			6.51	810	108	1.6	8.9	6.3	1.3	376		826		341
O5064	8-Jun	Sp	NU	618	A	2.0	1.0			2.37	412	55	1.4	7.7	5.5	0.9	325	7.1	819		238
O5066	8-Jun	Sp	NU	621	A	5.0	2.5			3.15	453	60	1.3	5.9	4.0	0.7	365	3.3	907		222
O5068	8-Jun	Sp	NU	626	C	10.0	9.0			3.46	571	77	2.8	7.4	2.7	0.6	381	8.2	1090		241
O5070	8-Jun	Sp	NU	626	C	10.0	5.0			3.28	538	71	2.7	7.0	2.5	2.9	366	8.3	758		231
O5071	8-Jun	Sp	NU	619	B	2.0	1.0			2.10	423	57	1.1	4.5	2.7	1.5	340	9.4	1105		264
O5072	8-Jun	Sp	NU	622	B	5.0	2.5			3.61	474	64	1.5	5.2	3.4	0.6	358	10.3	852		243
O5246	27-Jul	Su	NU	621	A	5.0	2.5	0.92	0.84	1.32	447	64	4.3	5.7	4.1	1.8	349	50.3	1277	9.3	90
O5247	27-Jul	Su	NU	624	A	10.0	9.0	0.57	0.57	1.67	322	45	4.4	6.1	4.0	2.8	151	8.2	1666	23.2	96
O5248	27-Jul	Su	NU	624	A	10.0	4.0	0.87	0.83	1.59	407	62	3.8	6.5	2.4	2.0	217	5.5	703	17.6	135
O5249	27-Jul	Su	NU	625	B	10.0	3.0	0.70	0.83	1.60	377	61	4.6	4.9	2.2	1.8	331	7.2	1512	6.8	119
O5250	27-Jul	Su	NU	625	B	10.0	9.0	0.53	0.53	0.98	322	46	3.5	4.1	1.6	1.5	322	4.3	1607	15.5	99
O5251	27-Jul	Su	NU	620	C	2.0	1.0	1.57		1.20	351	53	4.6	4.8	2.6	2.0	480	15.0	784	3.3	128
O5252	27-Jul	Su	NU	626	C	10.0	9.0	0.70	0.73	1.24	416	60	3.7	4.5	2.3	1.7	537	6.3	1087	20.3	115
O5253	27-Jul	Su	NU	623	C	5.0	2.5	1.00		1.12	447	76	3.8	4.6	1.3	1.7	286	7.5	1678	15.0	64
O5254	27-Jul	Su	NU	626	C	10.0	2.5	1.30	0.10	1.18	376	56	3.5	4.1	1.4	0.9	339	4.3	1689	2.3	106
O5256	27-Jul	Su	NU	619	B	2.0	1.0	1.30		0.68	317	45	3.1	5.1	3.0	1.4	236	8.5	1277	23.0	67
O5258	27-Jul	Su	NU	618	A	2.0	1.0	0.83	1.07	1.51	357	57	4.4	4.9	2.0	1.4	266	4.9	1482	10.2	167
O5259	27-Jul	Su	NU	622	B	5.0	2.5	1.00	0.64	1.54	363	68	4.5	5.2	1.9	0.8	353	87.8	1628	15.4	125

Table A.11: Grand River, Lake Erie, 2005, physical and *C. glomerata* chemistry.

LabID	Date	Seas	Stn	Tran	dP	D	SD	TL	Str	ST	DT	K_d	$\%I_o$	IC	IN	IP	IPAF	δ^{13}IC	δ^{15}IN
E5017	11-May	Sp	518	A	5.5	2.0	1.0	E	Y	11.89	6.48	0.38	46.6						
E5018	11-May	Sp	521	A	5.5	5.0	2.5	E	N	11.38	10.00	0.24	30.5						
E5019	11-May	Sp	524	A	5.6	10.0	2.5	E	Y	11.32	10.94	0.28	6.1						
E5020	11-May	Sp	524	A	5.6	10.0	9.0	H	Y	11.32	5.70	0.28	6.1						
E5021	11-May	Sp	525	B	3.7	10.0	8.5	H	Y	11.66	5.65	0.71	0.1						
E5022	11-May	Sp	525	B	3.7	10.0	1.5	E	Y	11.66	11.70	0.71	0.1						
E5023	11-May	Sp	522	B	3.5	5.0	4.0	H	Y	13.04	5.73	0.54	6.7						
E5024	11-May	Sp	522	B	3.5	5.0	1.5	E	Y	13.04	11.60	0.54	6.7						
E5025	11-May	Sp	519	B	3.3	2.0	1.0	E	N	13.88	13.88	0.97	14.4						
E5026	19-May	Sp	520	C	8.0	2.0	1.5	E	N	11.65	11.58	0.38	46.8						
E5027	19-May	Sp	523	C	8.0	5.0	2.5	E	N	11.21	10.91	0.34	18.6						
E5028	19-May	Sp	526	C	8.1	10.0	5.0	E	Y	10.40	9.62	0.31	4.7						
E5029	19-May	Sp	526	C	8.1	10.0	8.0	H	Y	10.40	7.90	0.31	4.7						
E5130	15-Jul	Su	522	B	3.5	5.0	2.5	E	N	24.10	23.80	0.54	6.9	344	39.5	1.7	6.9	-16.50	8.48
E5131	15-Jul	Su	525	B	3.7	10.0	9.0	H	Y	25.73	20.72	0.23	9.9						
E5132	15-Jul	Su	525	B	3.7	10.0	5.0	E	Y	25.73	23.30	0.23	9.9						
E5133	15-Jul	Su	520	C	8.0	2.0	1.0	E	N	24.71	24.62	0.26	59.9						
E5134	15-Jul	Su	526	C	8.1	10.0	9.0	H	N	24.45	20.62	0.33	3.7						
E5135	15-Jul	Su	523	C	8.0	5.0	2.5	E	N	24.16	23.80	0.29	23.2	292	29.9	1.5	2.6	-17.42	8.20
E5136	15-Jul	Su	526	C	8.1	10.0	3.0	E	N	24.45	23.79	0.33	3.7						
E5137	16-Jul	Su	524	A	5.6	10.0	9.0	H	Y	24.46	19.17	0.23	9.7						
E5138	16-Jul	Su	521	A	5.5	5.0	2.5	E	N	24.96	24.60	0.49	8.8	295	21.5	0.8	0.9	-15.88	8.01
E5139	16-Jul	Su	524	A	5.6	10.0	4.0	E	Y	24.46	24.23	0.23	9.7						
E5140	16-Jul	Su	519	B	3.3	2.0	1.0	E	N	24.10	24.10	0.69	25.1	332	27.1	0.9	2.3	-15.58	8.88
E5141	16-Jul	Su	518	A	5.5	2.0	1.0	E	N	25.17	24.89	0.55	33.5	318	25.7	0.6	2.0	-16.73	8.23

Table A.12: Grand River, Lake Erie, 2005, water chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
E5017	11-May	Sp	518	A	2.0	1.0	0.87	0.63	1.24	244	35	1.2	6.7	5.2	3.0	178	6.4	963	24.9	253
E5018	11-May	Sp	521	A	5.0	2.5			0.48	255	33	1.6	6.8	4.5	4.8	298	6.4	766		174
E5019	11-May	Sp	524	A	10.0	2.5	0.43	0.40	0.31	238	35	0.8	8.0	6.0	4.3	305	6.9	1092		110
E5020	11-May	Sp	524	A	10.0	9.0	0.47	0.37	1.15	282	42	1.3	6.1	3.9	5.3	189	5.9	730	13.8	256
E5021	11-May	Sp	525	B	10.0	8.5			2.08	241	37	3.2	11.2	3.7	4.2	279	23.5	1085	19.2	277
E5022	11-May	Sp	525	B	10.0	1.5	6.00	2.60	12.59	1000	146	6.5	12.1	5.8	4.7	1366	10.9	2119		143
E5023	11-May	Sp	522	B	5.0	4.0			3.07	454	73	2.4	7.7	4.2	6.3	543	8.8	1085		233
E5024	11-May	Sp	522	B	5.0	1.5			9.25	943	136	9.2	15.1	4.6	3.6	1344	8.4	2484		61
E5025	11-May	Sp	519	B	2.0	1.0	4.51	2.50	8.56	978	137	4.6	11.2	7.3	4.9	1649	7.6	2743		159
E5026	19-May	Sp	520	C	2.0	1.5	0.97	0.60	1.34	232	37	2.0	6.2	4.2	2.0	508	2.2	1510		126
E5027	19-May	Sp	523	C	5.0	2.5	0.87	0.51	1.27	221	36	1.9	5.1	2.9	7.2	628	2.0	1891		134
E5028	19-May	Sp	526	C	10.0	5.0	0.64	0.58	1.75	277	46	2.4	7.6	4.0	0.9	555		1250		143
E5029	19-May	Sp	526	C	10.0	8.0	0.64	0.68	1.47	244	39	2.0	6.3	3.5	0.7	396		1059		171
E5130	15-Jul	Su	522	B	5.0	2.5	0.73	0.73	3.20	477	71	5.2	5.5	3.2	0.4	148	81.8	2665	18.7	88
E5131	15-Jul	Su	525	B	10.0	9.0	1.83		0.82	423	79	6.6	6.1	0.4	0.4	685	42.7	747	15.0	117
E5132	15-Jul	Su	525	B	10.0	5.0	0.77		2.81	427	70	2.3	1.7	0.6	0.4	223	9.6	1315	15.6	125
E5133	15-Jul	Su	520	C	2.0	1.0	0.60	0.27	1.05	348	43	2.1	1.0	0.4	0.4	193	14.9	3061	14.4	162
E5134	15-Jul	Su	526	C	10.0	9.0	1.20	0.73	0.85	410	63	3.5	1.8	0.4	0.4	430	25.7	1093	16.1	114
E5135	15-Jul	Su	523	C	5.0	2.5	0.67	0.57	1.85	348	48	2.1	3.4	0.5	0.4	140	19.5	905	12.8	97
E5136	15-Jul	Su	526	C	10.0	3.0	0.73		1.17	343	61	3.5	2.6	0.4	0.4	290	27.7	1499	14.9	74
E5137	16-Jul	Su	524	A	10.0	9.0	0.93	0.70	1.58	382	70	4.2	5.2	0.0	0.4	315	66.4	1679		119
E5138	16-Jul	Su	521	A	5.0	2.5	2.07	1.67	4.95	832	131	5.3	6.3	0.4	0.4	164	17.1	1315	23.5	407
E5139	16-Jul	Su	524	A	10.0	4.0	0.60	1.00	2.26	469	83	2.1	1.5	0.4	0.4	358	10.2	2542	12.4	46
E5140	16-Jul	Su	519	B	2.0	1.0	1.80	1.13	2.77	796	116	5.0	4.5	1.2	0.4	154	26.6	2309	13.5	165
E5141	16-Jul	Su	518	A	2.0	1.0	2.40	1.47	4.86	893	142	7.0	7.2	1.1	0.4	173	26.5	876	19.0	284

A. 13: Peacock Point, Lake Erie, 2005, physical and *C. glomerata* chemistry.

LabID	Date	Seas	LU	Stn	Tran	D	SD	TL	Str	ST	DT	K_d	$\%I_o$	IC	IN	IP	IPAF	δ^{13} IC	δ^{15} IN
E5000	29-Apr	Sp	NU	504	A	2.0	1.0	E	N	8.7	8.7	0.73	23.1						
E5001	29-Apr	Sp	NU	509	B	2.0	1.0	E	N			1.09	11.4						
E5002	29-Apr	Sp	NU	510	C	2.0	1.0	E	N	8.7	8.7	1.25	8.1						
E5003	29-Apr	Sp	NU	507	C	5.0	2.5	E	N	8.4	8.4	0.34	18.3						
E5004	29-Apr	Sp	NU	513	C	10.0	5.0	E	N	7.7	7.2	0.26	7.1						
E5005	29-Apr	Sp	NU	513	C	10.0	9.0	H	N	7.7	6.4	0.26	7.1						
E5006	29-Apr	Sp	NU	512	B	10.0	5.0	E	N	7.3	7.2	0.33	3.6						
E5007	29-Apr	Sp	NU	512	B	10.0	9.0	H	N	7.3	7.1	0.33	3.6						
E5008	29-Apr	Sp	NU	511	B	5.0	2.5	E	N	8.5	8.6	0.43	11.5						
E5009	29-Apr	Sp	NU	502	A	10.0	5.0	E	N	7.2	6.9	0.18	17.2						
E5010	29-Apr	Sp	NU	502	A	10.0	9.0	H	N	7.2	6.8	0.18	17.2						
E5011	29-Apr	Sp	NU	503	A	5.0	2.5	E	N	8.9	8.9	0.50	8.1						
E5111	12-Jul	Su	NU	504	A	2.0	1.0	E	N	24.1	23.3	0.26	59.0	319	23.3	0.5	1.5	-18.21	7.63
E5113	12-Jul	Su	NU	510	C	2.0	1.0	E	N	23.5	23.0	0.36	48.8	303	21.1	0.8	1.7	-15.97	7.17
E5114	12-Jul	Su	NU	512	B	10.0	9.0	H	Y	22.7	16.4	0.27	6.7						
E5115	12-Jul	Su	NU	512	B	10.0	2.5	E	Y	22.7	20.5	0.27	6.7						
E5116	12-Jul	Su	NU	507	C	5.0	2.5	E	N	22.7	22.1	0.32	20.2	314	17.3	0.4	1.0	-18.50	7.91
E5117	12-Jul	Su	NU	513	C	10.0	8.0	H	Y	22.8	16.9	0.35	3.0	290	25.6	0.9	2.3	-18.59	7.09
E5120	12-Jul	Su	NU	511	B	5.0	1.5	E	Y	23.1	22.4	0.34	18.2						
E5121	12-Jul	Su	NU	511	B	5.0	3.5	H	Y	23.1	19.4	0.34	18.2	320	20.4	0.7	1.1	-18.54	7.81
E5122	12-Jul	Su	NU	513	C	10.0	3.0	E	Y	22.8	22.0	0.35	3.0						
E5123	12-Jul	Su	NU	509	B	2.0	1.0	E	N	23.6	23.6	0.17	71.1	342	26.7	0.9	4.1	-17.17	8.62
E5124	12-Jul	Su	NU	503	A	5.0	2.5	E	N	23.3	21.5	0.25	28.5	269	19.9	0.6	1.4	-19.17	7.46
E5128	12-Jul	Su	NU	502	A	10.0	9.0	H	Y	23.2	17.9	0.28	6.0	308	24.4	0.7	1.5	-18.25	7.60
E5129	12-Jul	Su	NU	502	A	10.0	3.0	E	Y	23.2	22.4	0.28	6.0						

Table A.14: Peacock Point, Lake Erie, 2005 water chemistry.

LabID	Date	Seas	LU	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
E5000	29-Apr	Sp	NU	504	A	2.0	1.0	2.47	0.89	1.83	266	41	2.8	7.9	6.1	0.7		18.5		19.2	183
E5001	29-Apr	Sp	NU	509	B	2.0	1.0	5.90	1.33	1.87	448	67	3.2	15.5	11.0	6.4	1110	55.4	2481	24.4	326
E5002	29-Apr	Sp	NU	510	C	2.0	1.0	6.21	1.21	1.75	443	63	13.5	29.1	17.2	7.9		52.1	4833	25.4	489
E5003	29-Apr	Sp	NU	507	C	5.0	2.5	1.40	0.70	2.42	306	48	2.5	7.2	2.8	1.9	360	5.3		26.4	120
E5004	29-Apr	Sp	NU	513	C	10.0	5.0	2.25	1.65	1.70	342	56	1.7	11.6	5.8	3.1	330	5.7		33.4	198
E5005	29-Apr	Sp	NU	513	C	10.0	9.0	0.60	0.60	1.69	242	41	1.3	7.2	6.3	3.9		6.9	1444	17.8	213
E5006	29-Apr	Sp	NU	512	B	10.0	5.0	1.07	0.87	1.55	288	44	2.1	8.5	4.0	4.2	450	3.6		32.1	187
E5007	29-Apr	Sp	NU	512	B	10.0	9.0	1.40	0.57	1.46	288	46	2.8	8.7	5.8	1.2	337	3.5	2326	18.6	273
E5008	29-Apr	Sp	NU	511	B	5.0	2.5	1.13	0.60	1.89	294	51	3.1	9.9	4.8	2.4	463	6.2	1306	27.4	175
E5009	29-Apr	Sp	NU	502	A	10.0	5.0	0.73	0.53	1.42	259	39	1.6	10.3	6.9	2.7		7.7	925	23.4	165
E5010	29-Apr	Sp	NU	502	A	10.0	9.0	0.57	0.40	1.19	226	35	1.0	8.3	6.3	2.4		5.5	659	21.8	168
E5011	29-Apr	Sp	NU	503	A	5.0	2.5	1.84	0.72	2.15	277	41	2.3	9.2	8.5	3.9	389	5.3	2110	18.9	168
E5111	12-Jul	Su	NU	504	A	2.0	1.0	0.92		0.38	302	45	3.9	5.2	1.6	0.4	323	50.4	2074	15.3	77
E5113	12-Jul	Su	NU	510	C	2.0	1.0	1.28	0.72	1.85	410	60	5.6	7.3	2.0	0.4	122	26.8	11411	11.6	60
E5114	12-Jul	Su	NU	512	B	10.0	9.0	1.12	0.72	1.79	354	49	3.3	5.2	1.0	0.4	188		1821	5.8	122
E5115	12-Jul	Su	NU	512	B	10.0	2.5	1.17		1.05	337	51	3.6	5.2	1.0	0.4	128	18.4	833	9.1	65
E5116	12-Jul	Su	NU	507	C	5.0	2.5	1.24	0.72	1.01	349	51	3.6	4.8	1.0	0.4	163	36.2	2701	14.1	173
E5117	12-Jul	Su	NU	513	C	10.0	8.0	1.00		1.57	353	56	4.0	5.5	1.1	0.4	140	32.8	1770	10.5	199
E5120	12-Jul	Su	NU	511	B	5.0	1.5	1.08	0.68	1.04	424	61	3.9	7.2	2.3	0.4	433	37.6	1912	9.0	77
E5121	12-Jul	Su	NU	511	B	5.0	3.5	2.12	1.32	3.14	538	94	4.8	6.8	1.9	0.4	114	42.8	889	17.0	122
E5122	12-Jul	Su	NU	513	C	10.0	3.0	1.00	0.72	1.30	420	69	4.5	5.0	2.5	0.4	394	39.8	1340	12.8	65
E5123	12-Jul	Su	NU	509	B	2.0	1.0	1.28	0.76	0.69	416	64	3.5	5.3	2.3	0.4	332	29.1	2114	7.6	51
E5124	12-Jul	Su	NU	503	A	5.0	2.5	0.72	0.64	0.96	346	49	3.9	5.1	2.4	0.4	158	22.7	1173	18.2	74
E5128	12-Jul	Su	NU	502	A	10.0	9.0	1.35	0.71	1.35	356	53	3.6	6.8	3.2	0.4	388	38.6	1617	11.2	97
E5129	12-Jul	Su	NU	502	A	10.0	3.0	1.30	0.80	1.32	335	44	2.9	5.5	3.6	0.4	206	48.3	1520	8.7	105

Table A.15: Southampton, Lake Huron, 2005, physical chemistry.

LabID	Date	Seas	Stn	Tran	dP	D	SD	TL	Str	ST	DT	K_d	$\%I_o$
H5280	8-Aug	Su	709	C	14.7	2.0	1.0	E	N	24.4	24.4	0.27	58.1
H5287	8-Aug	Su	710	C	14.8	5.0	2.5	E	N	23.9	23.7	0.18	40.7
H5281	8-Aug	Su	711	C	14.7	10.0	5.0	E	N	23.8	23.2	0.17	17.5
H5283	8-Aug	Su	711	C	14.7	10.0	9.0	H	N	23.8	23.2	0.17	17.5
H5285	8-Aug	Su	712	B	9.9	10.0	5.0	E	N	23.7	23.7	0.18	16.7
H5288	8-Aug	Su	712	B	9.9	10.0	9.0	H	N	23.7	23.7	0.18	16.7
H5279	8-Aug	Su	713	B	10.5	5.0	2.5	E	N	24.6	24.8	0.26	27.3
H5284	8-Aug	Su	714	B	10.6	2.0	1.0	E	N	25.0	25.0	0.33	51.6
H5278	8-Aug	Su	715	A	1.9	10.0	9.0	H	N	23.8	23.7	0.17	17.7
H5282	8-Aug	Su	715	A	1.9	10.0	5.0	E	N	23.8	23.8	0.17	17.7
H5289	8-Aug	Su	716	A	1.8	5.0	2.5	E	N	23.8	23.8	0.32	20.5
H5286	8-Aug	Su	717	A	1.5	2.0	1.0	E	N	26.1	26.0	0.17	71.7

Table A. 16: Southampton, Lake Huron, 2005, water chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
H5278	8-Aug	Su	715	A	10.0	9.0	0.56	0.42	0.56	266	42	3.1	9.7	2.9	1.23	359	4.7	430	4.6	804
H5279	8-Aug	Su	713	B	5.0	2.5	0.55	0.48	0.71	222	33	3.2	8.8	2.8	1.07	321	1.6	278	4.0	1089
H5280	8-Aug	Su	709	C	2.0	1.0	0.63	0.43	0.34	223	31	3.4	9.3	2.8	1.23	269	2.9	506	2.6	1269
H5281	8-Aug	Su	711	C	10.0	5.0	0.50	0.40	0.30			3.1	9.0	2.8	1.07	292	9.4	555	5.6	836
H5282	8-Aug	Su	715	A	10.0	5.0	0.50	0.40	0.65	177	25	3.3	9.7	2.2	1.23	299	10.3	536	2.8	849
H5283	8-Aug	Su	711	C	10.0	9.0	0.50	0.35	0.32	163	22	3.6	9.0	2.0	1.07	337	4.9	623	5.3	1016
H5284	8-Aug	Su	714	B	2.0	1.0	0.78	0.48	0.71	214	29	5.6	10.6	3.8	0.92	310	41.1	744	5.7	1134
H5285	8-Aug	Su	712	B	10.0	5.0	0.43	0.30	0.32	115	18	6.0	10.9	3.8	1.69	411	77.1	617	5.7	907
H5286	8-Aug	Su	717	A	2.0	1.0			0.67	264	40	6.3	11.6	4.1	1.54	436	3.6	855	7.5	2361
H5287	8-Aug	Su	710	C	5.0	2.5	0.25	0.23	0.31	118	18	7.2	13.9	5.2	1.07	392	59.7	586	4.9	1086
H5288	8-Aug	Su	712	B	10.0	9.0	0.40	0.33	0.32	129	21	5.5	9.3	3.2	0.92	388	25.4	597	3.9	955
H5289	8-Aug	Su	716	A	5.0	2.5	0.50	0.33	0.56	234	36	5.1	9.7	3.6	1.54	284	2.9	667	4.6	21082

Table A. 17: Cape Chin, Georgian Bay, Lake Huron, 2005, physical chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TL	Str	ST	DT	K_d	$\%I_o$
H5086	15-Jun	Sp	805	B	2.0	1.0	E	N	15.5	15.4	0.17	71.8
H5087	15-Jun	Sp	804	B	5.0	2.5	E	N	15.3	15.2	0.24	30.6
H5088	15-Jun	Sp	807	A	5.0	3.0	H	N	14.2	12.5	0.23	32.3
H5089	15-Jun	Sp	800	B	10.0	5.0	E	Weak	15.3	15.1	0.07	47.9
H5090	15-Jun	Sp	803	C	2.0	1.0	E	N	15.1	15.1	0.30	55.1
H5091	15-Jun	Sp	802	C	5.0	2.5	E	N	15.3	14.8	0.09	63.5
H5092	15-Jun	Sp	806	A	10.0	9.0	H	N	14.2	11.2	0.08	47.2
H5093	15-Jun	Sp	808	A	2.0	1.0	E	N	14.2	14.2	0.06	88.7
H5094	15-Jun	Sp	807	A	5.0	1.5	E	N	14.2	14.1	0.23	32.3
H5095	15-Jun	Sp	800	B	10.0	9.0	H	Weak	15.3	13.7	0.07	47.9
H5096	15-Jun	Sp	806	A	10.0	5.0	E	N	14.2	11.7	0.08	47.2
H5097	15-Jun	Sp	801	C	12.0	5.0	E	N	15.4	14.6	0.05	55.1
H5098	15-Jun	Sp	801	C	12.0	11.0	H	N	15.4	11.5	0.05	55.1
H5260	4-Aug	Su	806	A	10.0	2.0	E					
H5261	4-Aug	Su	806	A	10.0	9.0	H					
H5262	4-Aug	Su	800	B	10.0	2.5	E					
H5263	4-Aug	Su	800	B	10.0	9.0	H					
H5264	4-Aug	Su	802	C	5.0	2.5	E				0.20	37.2
H5265	4-Aug	Su	804	B	5.0	2.5	E					
H5266	4-Aug	Su	805	B	2.0	1.0	E				0.39	45.8
H5267	4-Aug	Su	808	A	2.0	1.0	E					
H5268	4-Aug	Su	801	C	10.0	3.5	E				0.16	19.9
H5269	4-Aug	Su	801	C	10.0	9.0	H				0.16	19.9
H5270	4-Aug	Su	803	C	2.0	1.0	E				0.49	37.5
H5271	4-Aug	Su	807	A	5.0	1.5	E					
H5272	4-Aug	Su	807	A	5.0	4.0	H					

Table A. 18: Cape Chin, Georgian Bay, Lake Huron, water chemistry.

LabID	Date	Seas	Stn	Tran	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
H5086	15-Jun	Sp	805	B	2.0	1.0			0.55	223	31	1.3	3.5	1.8	1.95	361	27.3	354		1012
H5087	15-Jun	Sp	804	B	5.0	2.5			0.55	184	23	1.6	3.2	1.3	1.10	375	5.0	273		1170
H5088	15-Jun	Sp	807	A	5.0	3.0			0.40	147	19	0.5	2.6	1.4	1.13	375	5.6	243		1112
H5089	15-Jun	Sp	800	B	10.0	5.0			0.68	185	23	0.9	2.5	1.2	1.13	375	2.7	659		1119
H5090	15-Jun	Sp	803	C	2.0	1.0			0.48	187	25	0.6	3.5	1.4	1.19	379	2.2	171		1158
H5091	15-Jun	Sp	802	C	5.0	2.5			0.47	203	29	1.3	2.7	1.8	0.75	367	3.5	879		1224
H5092	15-Jun	Sp	806	A	10.0	9.0			0.36			0.7	8.2	2.5	0.98	297	5.4	188		1231
H5093	15-Jun	Sp	808	A	2.0	1.0			0.36	169	21	0.5	2.9	1.9	1.13	347	4.9	732		1177
H5094	15-Jun	Sp	807	A	5.0	1.5			0.44	159	20	1.5	4.2	1.8	0.59	362	4.4	282		1140
H5095	15-Jun	Sp	800	B	10.0	9.0			0.42	167	22	0.9	9.4	1.9	0.89	379	8.3	586		1117
H5096	15-Jun	Sp	806	A	10.0	5.0			0.37	145	19	1.7	9.2	3.1	0.80	451	12.8	293		1165
H5097	15-Jun	Sp	801	C	12.0	5.0			0.41	163	19	0.9	4.5	1.9	1.23	375	18.4	879		1140
H5098	15-Jun	Sp	801	C	12.0	11.0			0.43	159	25	0.0	4.3	2.3	0.89	375	27.3	205		1140
H5260	4-Aug	Su	806	A	10.0	2.0	0.32		0.52	169	22	1.8	3.6	1.3	1.23	312	15.4	1361	4.08	647
H5261	4-Aug	Su	806	A	10.0	9.0	0.47	0.43	0.40	153	18	1.5	4.1	2.2	1.54	387	5.2	698	3.29	1054
H5262	4-Aug	Su	800	B	10.0	2.5	0.43	0.43	0.49	169	21	2.5	6.8	3.5	0.92	267	51.2	778	4.02	731
H5263	4-Aug	Su	800	B	10.0	9.0	0.57	0.37	0.59	158	23	1.8	5.7	4.1	1.38	277	12.4	668	4.71	663
H5264	4-Aug	Su	802	C	5.0	2.5	0.40	0.43	0.53	138	25	2.7	5.8	4.2	1.54	337	1.7	728	2.65	638
H5265	4-Aug	Su	804	B	5.0	2.5	0.80	0.43	0.44	149	21	3.8	7.5	5.1	1.07	232	11.4	1416	4.11	1016
H5266	4-Aug	Su	805	B	2.0	1.0	0.29	0.35	0.42	140	23	2.8	6.5	3.8	1.38	329	5.9	802	5.06	650
H5267	4-Aug	Su	808	A	2.0	1.0	0.45	0.73	0.34	113	17	2.9	6.7	3.6	1.23	337	90.8	890	2.37	791
H5268	4-Aug	Su	801	C	10.0	3.5	0.34	0.60	0.56			6.6	15.4	7.0	1.54	311	1.1	975	3.69	663
H5269	4-Aug	Su	801	C	10.0	9.0	0.13	0.13	0.47	159	22	3.8	9.0	6.1	1.23	221	0.8	546	5.03	791
H5270	4-Aug	Su	803	C	2.0	1.0	0.27	0.30	0.45	151	24	2.9	7.0	3.8	1.69	326	2.7	846	4.83	849
H5271	4-Aug	Su	807	A	5.0	1.5	0.13	0.70	0.40	128	19	4.2	13.5	5.4	1.69	352	3.0	551	4.39	807
H5272	4-Aug	Su	807	A	5.0	4.0	0.20	0.50	0.25	105	16	2.7	7.0	3.3	1.23	270	6.6	728	5.18	686

Table A.19: 2006 snorkel survey physical and *C. glomerata* chemistry.

LabID	Date	Seas	Lake	Site	LU	Lat	Long	D	IC	IN	IP	IPAF
Snk01	22-Jun	Su	E	Peacock	NU	42.79185	-79.98289	0.5	312	22.4	1.1	4.0
Snk02	22-Jun	Su	E	Peacock	NU	42.79185	-79.98289	1.0	294	18.5	0.5	1.5
Snk03	22-Jun	Su	E	Peacock	NU	42.79185	-79.98289	1.5	304	23.3	1.3	4.3
Snk04	22-Jun	Su	E	Peacock	NU	42.79185	-79.98289	2.0	308	20.6	0.7	4.3
Snk05	22-Jun	Su	E	Grand R.	NU	42.84055	-79.62509	0.5	256	15.1	0.3	0.7
Snk06	22-Jun	Su	E	Grand R.	NU	42.84055	-79.62509	1.0	247	13.0	0.6	1.3
Snk07	22-Jun	Su	E	Grand R.	NU	42.84055	-79.62509	1.5	294	20.6	0.9	4.3
Snk08	22-Jun	Su	E	Grand R.	NU	42.84055	-79.62509	2.0	308	20.8	1.1	3.7
Snk09	22-Jun	Su	E	Grand R.	NU	42.84115	-79.55080	0.5	304	22.2	0.7	2.3
Snk10	22-Jun	Su	E	Grand R.	NU	42.84115	-79.55080	1.0	316	22.8	0.7	2.6
Snk11	22-Jun	Su	E	Grand R.	NU	42.84115	-79.55080	1.5	339	31.6	1.5	8.7
Snk12	22-Jun	Su	E	Grand R.	NU	42.84115	-79.55080	2.0	335	28.3	1.2	5.4
Snk13	22-Jun	Su	E	Rathfon	NU	42.87481	-79.30776	0.5	267	14.8	0.3	1.0
Snk14	22-Jun	Su	E	Rathfon	NU	42.87481	-79.30776	1.0	312	19.0	0.4	1.6
Snk15	22-Jun	Su	E	Rathfon	NU	42.87481	-79.30776	1.5	274	16.1	0.5	1.5
Snk16	22-Jun	Su	E	Rathfon	NU	42.87481	-79.30776	2.0	329	18.4	0.5	2.5
Snk17	29-Jun	Su	O	Halton	U	43.45004	-79.65742	0.5	320	28.3	1.3	4.8
Snk18	29-Jun	Su	O	Halton	U	43.45004	-79.65742	1.5	285	21.1	0.9	2.3
Snk19	29-Jun	Su	O	Halton	U	43.45004	-79.65742	3.0	281	18.7	0.8	2.0
Snk20	29-Jun	Su	O	Whitby	U	43.51024	-78.53496	0.5	256	18.6	0.6	1.5
Snk21	29-Jun	Su	O	Whitby	U	43.51024	-78.53496	1.5	252	9.8	1.0	2.2
Snk22	29-Jun	Su	O	Whitby	U	43.51024	-78.53496	3.0	267	19.1	0.7	1.8
Snk23	29-Jun	Su	O	Cobourg	U	43.95165	-78.16648	0.5	292	28.9	0.8	2.4
Snk24	29-Jun	Su	O	Cobourg	U	43.95165	-78.16648	1.5	283	21.7	0.6	1.6
Snk25	29-Jun	Su	O	Cobourg	U	43.95165	-78.16648	3.0	260	20.5	0.3	0.7
Snk26	29-Jun	Su	O	Presqu'ile	NU	43.99015	-77.72249	1.5	272	17.8	0.6	1.5
Snk27	29-Jun	Su	O	Presqu'ile	NU	43.99015	-77.72249	3.0	278	15.1	0.6	1.6
Snk28	29-Jun	Su	O	Pt. Petre	NU	43.83942	-77.15103	1.5	314	17.1	0.5	2.3
Snk29	29-Jun	Su	O	Pt. Petre	NU	43.83942	-77.15103	3.0	286	18.1	0.5	1.8
Snk30	29-Jun	Su	O	Bath	NU	44.18200	-76.77452	0.5	269	19.2	0.6	1.6
Snk31	29-Jun	Su	O	Bath	NU	44.18200	-76.77452	1.5	322	26.7	1.1	3.2
Snk32	29-Jun	Su	O	Bath	NU	44.18200	-76.77452	3.0	293	23.0	1.5	4.3
Snk33	29-Jun	Su	O	Emeric Pt.	NU	44.10379	-76.69988	1.5	319	21.4	0.4	1.1
Snk34	29-Jun	Su	O	Emeric Pt.	NU	44.10379	-76.69988	3.0	242	14.6	0.4	1.1
Snk35	29-Jun	Su	O	Emeric Pt.	NU	44.10379	-76.69988	5.0	309	20.3	0.4	1.1
Snk36	25-Aug	Su	H	Pt. Farms	NU	43.80418	-81.72783	2.0	117	7.7	0.3	0.6
Snk37	25-Aug	Su	H	Pt. Farms	NU	43.80418	-81.72783	3.0	211	15.3	0.4	0.9
Snk38	25-Aug	Su	H	Inverhuron	NU	44.29557	-81.60242	1.5	107	7.7	0.6	1.7
Snk39	25-Aug	Su	H	Inverhuron	NU	44.29557	-81.60242	2.0	215	15.1	0.8	1.8
Snk40	25-Aug	Su	H	Southamp.	NU	44.51379	-81.36205	0.5	284	29.7	1.2	4.9
Snk41	25-Aug	Su	H	Southamp.	NU	44.51379	-81.36205	2.0	224	15.6	0.4	0.8

Table A.20: 2006 snorkel survey water chemistry.

LabID	Date	Seas	Lake	Site	LU	D	pH	Alk	TSS	PP	SRP	NO_3^-	NO_2^-	NH_3	TN	SRSi	δ^{13}DIC
Snork03	22-Jun	Su	E	Peacock	NU	1.5	8.4	1.93	5.90	1.2	0.50	172	5.0	2.0	250	20	-1.05
Snork07	22-Jun	Su	E	Grand R.	NU	1.5	8.4	2.06	3.90	1.1	0.50	356	7.0	2.0	280	20	-1.70
Snork11	22-Jun	Su	E	Grand R.	NU	1.5	8.5	2.06	4.10	2.3	0.50	411	7.0	2.0	270	20	-1.98
Snork15	22-Jun	Su	E	Rathfon	NU	1.5	8.6	1.78	2.60	2.2	0.50	152	5.0	2.0	380	20	0.04
Snork17	29-Jun	Su	O	Halton	U	0.5	8.4	1.92	1.40	6.0	0.50	384	3.0	3.0	200	100	
Snork20	29-Jun	Su	O	Whitby	U	0.5	8.3	1.92	1.20	14.0	0.50	584	12.0	2.0	320	200	
Snork23	29-Jun	Su	O	Cobourg	U	0.5	8.3	1.90	1.00	8.0	0.50	278	4.0	23.0	220	80	
Snork26	29-Jun	Su	O	Presqu'ile	NU	1.5	8.4	1.86	1.50	7.0	0.50	219	5.0	31.0	240	40	
Snork28	29-Jun	Su	O	Pt. Petre	NU	1.5	8.3	1.88	0.80	19.0	0.50	297	4.0	32.0	230	20	
Snork30	29-Jun	Su	O	Bath	NU	0.5	8.2	2.02	0.90	8.0	2.50	211	4.0	35.0	270	240	
Snork33	29-Jun	Su	O	Emeric Pt.	NU	1.5	8.3	1.90	1.10	9.0	0.50	235	4.0	25.0	230	100	
Snork36	25-Aug	Su	H	Pt. Farms	NU	2.0	8.4	2.06	12.80	11.0	0.50	402	7.0	13.0	240	700	
Snork38	25-Aug	Su	H	Inverhuron	NU	1.5	8.3	1.67	0.80	3.0	0.50	317	4.0	43.0	150	600	
Snork40	25-Aug	Su	H	Southamp.	NU	0.5	8.4	1.96	11.40	11.0	0.50	310	4.0	18.0	240	840	

Table A.21: Lake Simcoe, 2006, physical and *C. glomerata* chemistry

LabID	Date	Seas	Site	LU	Stn	D	SD	K_d	$\%I_o$	pH	Alk	IC	IN	IP	IPAF
S6134	16-May	Su	Offshore	O	900	20.0	5.0	0.30	0.24	8.3	2.22				
S6135	16-May	Su	Georgina	NU	901	5.0	2.0	0.25	29.38	8.3	2.21				
S6136	16-May	Su	Georgina	NU	902	2.0	1.0	0.37	47.74	8.3	2.19				
S6137	16-May	Su	Georgina	NU	903	10.0	5.0	0.29	5.56	8.3	2.21				
S6138	16-May	Su	Pefferlaw Creek	NU	907	10.0	5.0	0.31	4.35	8.2	2.19				
S6139	16-May	Su	Thorah	NU	906	10.0	5.0	0.45	1.13	8.3	2.20				
S6140	16-May	Su	Thorah	NU	905	5.0	2.0	0.31	21.06	8.3	2.22				
S6141	16-May	Su	Pefferlaw Creek	NU	909	2.0	1.0	0.75	22.26	8.3	2.22				
S6142	16-May	Su	Thorah	NU	904	2.0	1.0	0.38	46.34	8.3	2.20				
S6143	16-May	Su	Pefferlaw Creek	NU	908	5.0	2.0	0.35	17.15	8.3	2.20				
S6309	8-Aug	Su	Central		K45	30.0	5.0	0.31	0.01						
S6310	8-Aug	Su	Central		K42	40.0	2.0	0.40	0.00						
S6311	8-Aug	Su	Central		K42	40.0	10.0	0.40	0.00						
S6312	8-Aug	Su	Central		K39	35.0	2.0	0.33	0.00						
S6313	8-Aug	Su	Central		E51	10.0	2.0	0.33	3.70						
S6314	8-Aug	Su	Central		K42	40.0	20.0	0.40	0.00						
S6315	8-Aug	Su	Central		K45	30.0	10.0	0.31	0.01						
S6316	8-Aug	Su	Central		K45	30.0	20.0	0.31	0.01						
S6317	9-Aug	Su	Offshore	O	900	20.0	5.0			8.4	2.12				
S6319	9-Aug	Su	Thorah	NU	906	10.0	5.0	0.27	6.77	8.2	2.13				
S6320	9-Aug	Su	Thorah	NU	905	5.0	2.0	0.36	16.54	8.1	2.07				
S6321	9-Aug	Su	Thorah	NU	904	2.0	1.0	0.60	30.19	8.4	2.14	360	35.3	2.48	15.21
S6322	9-Aug	Su	Georgina	NU	903	10.0	5.0	0.37	2.57	8.4	2.12				
S6323	9-Aug	Su	Georgina	NU	902	2.0	2.0	0.41	44.36	8.4	2.14	312	26.5	1.86	7.69
S6324	9-Aug	Su	Georgina	NU	901	5.0	4.0	0.38	15.29	8.3	2.12				
S6325	9-Aug	Su	Pefferlaw Creek	NU	908	5.0	2.0	0.54	6.61	8.4	2.12				
S6326	9-Aug	Su	Cook's Bay	NU	S15	20.0	5.0	0.37	0.07	8.5	2.18				
S6327	9-Aug	Su	Pefferlaw Creek	NU	907	10.0	5.0	0.43	1.34	8.4	2.12				
S6328	9-Aug	Su	Pefferlaw Creek	NU	909	2.0	1.0	0.75	22.50	8.4	2.14	288	21.5	1.81	5.25
S6329	10-Aug	Su	Cook's Bay	NU	C9	18.0	5.0	0.41	0.06	8.6	2.18				
S6330	10-Aug	Su	Cook's Bay	NU	C6	14.0	5.0	0.35	0.79	8.5	2.12				
S6331	10-Aug	Su	Cook's Bay	NU	C1	2.0	1.0	0.31	53.32	8.3	1.98				

Table A.22: Lake Simcoe, 2006, water chemistry

LabID	Date	Seas	Site	LU	Stn	D	SD	TSS	AFDW	Chl	PC	PN	PP	TP	TDP	SRP	NO_3^-	NH_3	TN	Cl	SRSi
S6134	16-May	Su	Offshore	O	900	20.0	5.0	1.28	0.74	1.27	500	73	5.2	9.2	4.7	1.66	319	74.3	508	23.3	1137
S6135	16-May	Su	Georgina	NU	901	5.0	2.0	1.13	1.40	0.65	391	58	1.2	6.2	4.1	1.04	47	34.2	465	19.2	1090
S6136	16-May	Su	Georgina	NU	902	2.0	1.0	1.27	0.64	0.42	298	43	1.2	7.1	4.8	1.66	26	46.6	575	12.4	1023
S6137	16-May	Su	Georgina	NU	903	10.0	5.0	1.12	0.73	0.94	398	56	2.3	6.8	4.7	0.73	43	33.6	465	24.8	1145
S6138	16-May	Su	Pefferlaw	NU	907	10.0	5.0	1.23	0.80	0.68	351	47	1.6	6.2	3.4	1.35	42	31.2	556	25.5	1008
S6139	16-May	Su	Thorah	NU	906	10.0	5.0	0.80	0.68	0.58	313	42	1.3	6.8	6.3	1.04	28	23.8	660	16.2	1069
S6140	16-May	Su	Thorah	NU	905	5.0	2.0			0.33	287	41	1.3	6.8	4.7		24	21.7	541	14.5	880
S6141	16-May	Su	Pefferlaw	NU	909	2.0	1.0	0.82	0.53	0.21	222	31	1.9	5.3	3.0	1.66	40	82.9	489	25.5	1026
S6142	16-May	Su	Thorah	NU	904	2.0	1.0	1.44	0.73	0.17	247	34	2.0	6.8	3.8	1.66	26	32.3	460	19.7	976
S6143	16-May	Su	Pefferlaw	NU	908	5.0	2.0	1.62	1.26	0.40	318	41	4.0	6.8	3.0	1.97	37	138.4	522	25.0	1154
S6309	8-Aug	Su	Central	O	K45	30.0	5.0			2.59	536	80	11.5	13.2	7.0	0.91	6	25.2	110	8.1	1310
S6310	8-Aug	Su	Central	O	K42	40.0	2.0	1.87	1.27	3.32	637	93	5.7	10.0	3.8	0.48	3	5.5	40	18.1	1366
S6311	8-Aug	Su	Central	O	K42	40.0	10.0	1.40	1.20	4.55	555	96	7.7	10.3	9.9	1.35	28	10.9	51	24.4	1511
S6312	8-Aug	Su	Central	O	K39	35.0	2.0	0.44	0.75	3.52	592	97	5.5	9.1	6.4	1.64	18	14.6	110	26.6	1187
S6313	8-Aug	Su	Central	O	E51	10.0	2.0	0.60	0.64	0.98	288	56	14.0	9.1	5.6	1.20	16	36.5	75	24.0	1644
S6314	8-Aug	Su	Central	O	K42	40.0	20.0	1.40	1.20	0.71	336	53	4.3	9.7	4.7	1.06	38	31.6	107	16.2	1258
S6315	8-Aug	Su	Central	O	K45	30.0	10.0	0.75	0.80	3.14	544	87	7.8	10.6	6.2	2.50	5	23.6	152	23.5	1028
S6316	8-Aug	Su	Central	O	K45	30.0	20.0	0.67	0.67	0.63	410	63	9.1	8.0	5.6	0.77	51	65.5	530	24.4	2652
S6317	9-Aug	Su	Offshore	O	900	20.0	5.0	1.50	1.05	0.27	249	45	7.1	9.7	5.9	1.06	8	69.3	110	24.2	1534
S6318	9-Aug	Su	Offshore	O	900	20.0	15.0	1.80	1.33	1.76	471	78	16.6	10.0	4.7	0.63	5	14.9	129	26.0	2121
S6319	9-Aug	Su	Thorah	NU	906	10.0	5.0	1.00	0.90	2.08	404	73	7.8	13.4	3.8	0.63	10	24.4	74	27.1	1977
S6320	9-Aug	Su	Thorah	NU	905	5.0	2.0	0.95	1.20	1.38	417	66	6.4	11.7	5.0	0.48		27.6	40	23.9	2334
S6321	9-Aug	Su	Thorah	NU	904	2.0	1.0	1.20	0.90	1.00	392	48	8.3	9.7	6.0	0.77	13	21.3	29	17.8	2150
S6322	9-Aug	Su	Georgina	NU	903	10.0	5.0	2.00	1.40	0.90	328	56	18.8	10.0	6.0	0.91	7	22.4	71	23.7	2292
S6323	9-Aug	Su	Georgina	NU	902	2.0	2.0	0.60	0.53	0.59	300	45	8.1	18.6	6.0	0.48	18	17.2	60	27.1	2292
S6324	9-Aug	Su	Georgina	NU	901	5.0	4.0	1.67	1.27	0.74	353	57	16.1	12.6	7.5	1.49	14	30.9	85	23.0	1906
S6325	9-Aug	Su	Pefferlaw	NU	908	5.0	2.0	1.73	1.20	0.35	342	70	15.6	8.5	5.0	0.91	14	193.4	51	22.7	1650
S6326	9-Aug	Su	Cook's	NU	S15	20.0	5.0	0.95	0.80	2.80	549	81	11.9	9.1	3.8	0.48	75	74.4	152	12.1	1696
S6327	9-Aug	Su	Pefferlaw	NU	907	10.0	5.0	1.96	1.46	1.02	423	67	8.4	12.3	4.4	1.20	10	70.5	128	24.4	2363
S6328	9-Aug	Su	Pefferlaw	NU	909	2.0	1.0	2.45	1.86	0.67	332	51	9.6	10.3	4.1	1.06	8	63.6	352	24.0	1917
S6329	10-Aug	Su	Cook's	NU	C9	18.0	5.0	1.42	0.94	3.26	499	73	8.4	12.9	4.4	1.20	13	78.8	464	17.3	1625
S6330	10-Aug	Su	Cook's	NU	C6	14.0	5.0	1.05	0.75	3.06	513	73	2.3	13.4	8.5	1.64		159.2	80	20.5	1006
S6331	10-Aug	Su	Cook's	NU	C1	2.0	1.0			0.51	306	48	2.4	13.4	11.3	2.07	5	94.0	40	25.2	1917