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Chronic nutrient loading from Lake Erie affecting water quality and nuisance algae on the St. Catharines shores of Lake Ontario

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ABSTRACT

Water quality and lake circulation in the nearshore of Lake Ontario bordering the city of St. Catharines were examined from May to October 2013 to interpret factors impacting water resources and contributing to nuisance algae. Our findings suggest that loadings from eastern Lake Erie via Twelve Mile Creek and the Welland Canal are a primary driver of variability in nearshore water quality, creating mixing areas enriched in particulate and dissolved phosphorus and turbidity. Impingement of the Niagara River plume and regional lake circulation also impact water quality conditions. Quantitative benthic sampling revealed that *Cladophora* was abundant to lake depths of about six meters, which is shallower than other nearshore areas of Lake Ontario. Estimates of PAR intensity at the lakebed interpolated over the study area suggest that light limitation counteracts the stimulation of *Cladophora* growth attributable to elevated dissolved phosphorus over the discharge mixing areas. No evidence was found that the chronic loading of phosphorus in the area resulted in a higher prevalence of *Cladophora* compared with other areas of the lake. The abundance of dreissenid mussels, reaching 4760 individuals/m^2, was not correlated with water chemistry features or biomass of *Cladophora*. Interactions between dreissenids and *Cladophora* may be muted in the area due to overriding physical factors which appear to limit *Cladophora* to shallow depths and mussels to deeper waters.

Introduction

Lake Ontario's southwestern perimeter from St. Catharines to Niagara-on-the-Lake, Ontario, is highly developed with urban, agricultural and industrial lands. Diverse influences on nearshore water quality have been noted over the years. Nearshore water quality surveys conducted annually in the spring 1976 to 1979 over the shores of western Lake Ontario by the Ontario Ministry of the Environment identified elevated levels of total phosphorus (TP), soluble reactive phosphorus (SRP) and nitrate, and reduced water clarity east of the Niagara River mouth centered on the City of St. Catharines (OMOE, 1980). Mapping of sediment contaminants in Lake Ontario by Thomas (1983) demonstrates the influence of Niagara River water to the area. Dynamic water quality in this region is suggested by satellite imagery, which routinely indicates km-scale areas of perturbed water quality as visible plumes along the shoreline (e.g., MODIS image t1.13094.1604. Lake Ontario143.250 m; https://coastwatch.glerl.noaa.gov/modis/modis.html).

Despite some superficial similarity with urban shorelines elsewhere in western Lake Ontario, the drivers of nearshore water quality are more diverse here. A complex network of engineered waterways and diversions bring high and relatively constant inputs of water from eastern Lake Erie to the study area. The Welland Ship Canal discharges to Lake Ontario west of the Niagara River at Port Weller, on the eastern margin of St. Catharines. Some of this water is diverted from the Welland Canal to support a hydroelectric plant on Twelve Mile Creek, which is the largest tributary in the area (NPCA, 2012) and discharges to Lake Ontario at Port Dalhousie in St. Catharines. Hall (2013) suggests that the original flow in Twelve Mile Creek would be 1 to 2% of present day flows without this diversion. The discharge of water from the Welland Canal to Lake Ontario is not measured and is split in varying proportions through the mouths of Port Weller and Port Dalhousie, but the routing to Twelve Mile Creek predominates (International Niagara Commission (INC), 2013).

Unlike most tributaries, where discharge is seasonally-variable and episodic (Dickinson, 1976), discharge from the Welland Canal is persistent throughout the year with relatively constant discharge loaded to the lake on a daily basis (INC, 2013). Past monitoring indicates that concentrations of macro nutrients and suspended solids are elevated in the discharges from Port Weller and Port Dalhousie in comparison with Lake Ontario (Howell, 2004), representing persistent sources of enrichment. This contrasts greatly from other Lake Ontario tributaries, for which the delivery of nutrient and solids to the nearshore is highly variable over time, with loads weighted towards wet weather events and snowmelt (e.g., Long et al., 2015; Eimers and Watmough, 2016).

The discharge from the Niagara River may add to the direct influence of Lake Erie on the area. The mouth of the Niagara River is located 11 km

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to the east of the Welland Canal; this Great Lakes connecting channel represents the largest source of phosphorus to Lake Ontario (Dolan and Chapra, 2012; Makarewicz et al., 2012a). The flow is predominantly easterly, and strong impacts to water quality are observed along the New York State nearshore (Makarewicz and Lewis, 2015). However, periodic circulation also occurs towards the west (Hayashida et al., 1999). The Niagara plume has great potential to affect water quality in the study area by virtue of its elevated levels of turbidity and phosphorus and the sheer volume of discharge (mean daily discharge was 5600 m^3/s in 2013; Environment Canada and Climate Change (ECCC) data); however, the actual spatial and temporal impacts to water quality in the study area are poorly known.

Similar to other urban areas, there is a mixture of loading sources to the shoreline of the City of St. Catharines. The local watershed for Twelve Mile Creek is comprised of rural lands and small communities. The shoreline and nearshore waters are highly valued for their municipal beaches, boating and sport fishing and also for their aesthetics. Fouling of the beaches and residential shoreline by the benthic algae *Cladophora* is a long-standing concern along the St. Catharines waterfront (Howell, 2004; OWRC, 1958), but the causes are unclear. A resurgence of *Cladophora* in Lake Ontario more broadly followed its colonization by dreissenid mussels and has been interpreted to be the result of increased water clarity due to removal of phytoplankton by mussel filtration and their effects on whiting. The increased light availability has allowed an expansion of the depth distribution for *Cladophora* (Kuczynski et al., 2016; Malkin et al., 2008). However, Higgins et al. (2012) observed higher *Cladophora* biomass in urban areas of the lake correlated with water quality features and concluded that problem levels of *Cladophora* were limited to areas impacted by urban development. Further uncertainty as to the controls on *Cladophora* abundance relates to nutrient flux at the lakebed and the degree to which leakage of phosphorus from dreissenid colonized lakebed facilitates *Cladophora* growth as argued by Ozersky et al. (2009).

Here, we seek to distinguish among the three primary factors (Lake Erie diversions, local influences and regional lake circulation) affecting nearshore water quality in the study area and to determine their relative impact to the water resources. We investigated and assessed the spatial patterns of water circulation and the physical regime, water quality using deployed and towed sensors and laboratory analyses, and nearshore biological features including dreissenids and *Cladophora*. These assessments provide insight to the possible controls of *Cladophora* growth for the study area. We hypothesized that the consistent loading of phosphorus to the area via the Welland Canal would sustain *Cladophora* growth, resulting in greater biomass than seen in other regions where phosphorus loading is more temporally variable. The countervailing effect of the turbidity plumes on the availability of light reaching the lakebed was unknown and considered a possible mitigating factor. Light limitation aggravated by elevated turbidity has been found to be a constraint to *Cladophora* growth in other parts of the Great Lakes by Winslow et al. (2014) and Valipour et al. (2016). We further hypothesized a positive correlation of dreissenid mussels with *Cladophora* distribution and biomass.

Methods

Study area

The study area encompasses the nearshore of Lake Ontario adjacent to 15 km of shoreline centered on the City of St. Catharines (population of 131,400; 2011 Census Canada) and the embayments at Port Dalhousie and Port Weller, located at the mouths of Twelve Mile Creek and the Welland Ship Canal, respectively (Fig. 1). The combined phosphorus loading from the Welland Canal and Twelve Mile Creek in 2008 was estimated at 90 metric tonnes, roughly equivalent to the Humber River (93 metric tonnes), the largest Canadian tributary source of phosphorus to Lake Ontario (Makarewicz et al., 2012a). The drainage area includes several smaller communities and is a developed rural landscape (NPCA, 2012).

Urbanized land and hardened shoreline front the lake from the west edge of the study area to east of Port Weller; land use then transitions into mostly agricultural land to the east. Areas of parkland with municipal beaches are located directly west of the tributary outlets at Port Dalhousie and Port Weller. Seven additional small tributaries and several storm sewers and drains also discharge to the lake. Wastewater treatment plants discharge to Port Dalhousie and Port Weller near their outlets to Lake Ontario. Total phosphorus loadings from these plants in 2008 were estimated to be 6.1 and 5.4 metric tonnes at Port Dalhousie and Port Weller, respectively (Makarewicz et al., 2012a).

The nearshore lakebed consists of a depth-variable mix of erosional and depositional material consisting of a mix of sand, gravel and various rock sizes at lake depths < 6 m with the exception of east of the Welland Canal and the western edge of the study area where finer material is found (Rukavina, 1969). The substrate transitions to silt-sand and silt-clay at lake depths of 6 to 10 m. Stabilization and capping of soft substrate in the area by dreissenid mussels was reported by Marvin et al. (2000).

Lake circulation and physical measurements

Acoustic Doppler Current Profilers (ADCP; RDI 600 kHz Workhorse) measured current speed and direction from April to November 2013; data were binned at intervals of 0.5 to 1 m and recorded as pulses at 30-minute intervals (Fig. 1). Temperature recorders (Onset Stowaway Tidbits) were also placed at intervals through the water column near the ADCP moorings and at additional sites. Antifouling sensors for measurement of conductivity (ALEC Electronics Compact-CLW) were deployed at selected sites (Fig. 1).

Water quality surveys

Spatial patterns in water quality over a nearshore zone, extending from approximately 3-m depth to 5 km offshore (Fig. 1), were assessed four times between May and October 2013 using field measurements and the collection of water samples for laboratory analysis from the Ontario Ministry of the Environment and Climate Change (OMOECC) vessel *Great Lakes Guardian*. Field measurements were obtained from sensors mounted in flow-through frames connected to ship-board manifold continuously fed by water pumped from approximately 1.5 m below the lake surface and logged with geographic position at intervals of approximately 5 m over a predefined survey track (Fig. 1). The track was navigated moving opposite to the direction of the alongshore lake current at the start of the day, as inferred from wind direction and lake conditions.

A RBR XR-620 probe measured temperature and conductivity, and a Chelsea Technology Group (CTG) UV Aquatracka probe measured UV-stimulated fluorescence of organic matter (in a range optimized for coloured dissolved organic matter or CDOM). The CDOM probe has peak excitation and emission wavelengths at 239 nm and 430 nm, respectively, with full width half maxima of 26 and 110 nm, respectively. Probe output is relative to the concentration of perylene, which is used to calibrate the sensor response (CTG, 1994). The calibrated responses are subsequently referred to as CDOM-fluorescence (CDOM). Chlorophyll *a* fluorescence was measured with a CTG Aquatracka II probe. A Sea Point turbidity sensor attached to a pole mounted on the side of the vessel was used to measure turbidity at a depth of 1.5 m below the lake surface.

Using a second set of sensors mounted on a frame, 30 to 40 depth profiles were collected during each survey at both predesigned locations and in areas of high variability along the survey track. Temperature, pressure, and turbidity profiles were measured by a CTG Aquapac profiler. The profiler was integrated with a CTG Alphatracka transmissometer (660 nm), and a Satlantic photosynthetically active