ARTICLE IN PRESS

JGLR-01091; No. of pages: 11; 4C:

Journal of Great Lakes Research xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Bi-weekly Changes in Phytoplankton Abundance in 25 Tributaries of Lake St. Francis, Canada: Evaluating the Occurrence of Nuisance and Harmful Algae

MacKenzie E. Waller [a,b,*], Andrew J. Bramburger [a,b,1], Brian F. Cumming [a,c]

[a] School of Environmental Studies, Queen's University, Kingston, Ontario, Canada K7L 3J9

[b] St. Lawrence River Institute of Environmental Sciences, Cornwall, Ontario, Canada K6H 4Z1

[c] Paleoecological Environmental Assessment and Research Laboratory, Department of Biology, Queen's University, Kingston, Ontario, Canada K7L 3J9

ARTICLE INFO

Article history:
Received 28 January 2016
Accepted 14 June 2016
Available online xxxx

Communicated by R. Michael McKay

Index words:
Cultural eutrophication
phytoplankton
algal blooms
tributaries
eastern Ontario

ABSTRACT

Eutrophication and undesirable algae growth remain listed as beneficial use impairments in 14 Great Lakes areas of concern, including the Cornwall/St. Lawrence region. However, there is currently a lack of information regarding the distribution and frequency of undesirable algae occurrences, particularly in lotic systems influencing this region. Here, we examine phytoplankton assemblages in 25 tributaries of Lake St. Francis (St. Lawrence River) between the months of May and September (2013 and 2014) in order to evaluate abundance and taxonomic composition. Phytoplankton in the tributaries were dominated by diatoms, followed by chlorophytes, and on average only ~1% of overall composition were cyanobacteria. The low proportion of chlorophytes and cyanobacteria was surprising, given that these tributaries are located in watersheds dominated by agricultural activities. Stream order was not related to total phytoplankton abundance, potentially due to the highly disturbed nature of the catchments. Multiple linear regression models were developed to better understand possible chemical and physical factors contributing to phytoplankton abundance and cyanobacteria occurrence across all sites. Water temperature, total phosphorus and day of year were identified as the best predictors of phytoplankton abundance, and water temperature and depth were identified as predictors for cyanobacteria occurrence. While these models were significant, they only accounted for a low amount of the variability (between 8 and 12%) of total phytoplankton and cyanobacteria abundance. Year-to-year variation between mean phytoplankton abundances was also high, which was reflected in the low correlation between the rank order of sites between 2013 and 2014 ($\rho = 0.16$).

Introduction

Algae are an important component of aquatic ecosystems, including streams and rivers, where they serve as primary producers (Lamberti and Steinman, 1997). Within lakes, rivers and streams, phosphorus and nitrogen are widely considered to be the most important limiting nutrients for algal growth (Biggs, 2000; Bothwell, 1989; Dodds et al., 1997; Francoeur, 2001; Rier and Stevenson, 2006). Cultural eutrophication has been well demonstrated in lakes, with a strong positive relationship between nutrient concentrations and algal production (e.g. Schindler and Fee, 1974; Schindler et al., 2008). However, the relationship between anthropogenic nutrient additions and algal production in rivers has not been as intensely studied and does not exhibit as clear a relationship, due to the greater seasonal and inter-annual variation in rivers and streams (Basu and Pick, 1995; Dodds and Smith, 2016; Søballe and Kimmel, 1987; van Nieuwenhuyse and Jones, 1996), as well as spatial lags associated with downstream transport of nutrient loadings (Dent and Grimm, 1999).

Increases in the cultural eutrophication of surface waters due to human activities, such as intensive agriculture and urbanization, as well as the effects of climate change, have resulted in an increase in reports of algal blooms worldwide (Taranu et al., 2015), including blooms containing cyanobacteria that can pose hazards to human and animal health (O'Neil et al., 2012; Paerl, 2014; Paerl et al., 2011; Qu et al., 2014; Taranu et al., 2012). Occurrences of cyanobacteria at high abundances are often referred to as harmful algal blooms (HABs) (Hallegraeff, 1993), and in the most extreme cases, can release toxins which can cause liver disease, cancers and death in humans (Carmichael, 1997, 2001). Although cyanobacterial blooms receive the majority of public attention within the Great Lakes region (Michalak et al., 2013; Watson et al., 2008), other algal groups can also be problematic when present in high abundances. In freshwater systems, the organisms most often responsible for producing high biomass include filamentous chlorophytes within the genera *Cladophora*, *Rhizoclonium*,

* Corresponding author at: School of Environmental Studies, Queen's University, Kingston, Ontario, Canada K7L 3J9.
E-mail address: m_e_waller@hotmail.com (M.E. Waller).
[1] Present address: Natural Resources Research Institute, University of Minnesota-Duluth, Duluth, Minnesota, USA 55812.

http://dx.doi.org/10.1016/j.jglr.2016.07.003
0380-1330/

and *Oedogonium* (Stevenson et al., 2012). When present in excess amounts, these algae have been referred to as nuisance algal blooms (NABs), and can create unfavorable conditions including unpleasant odours and clogged water intake pipes (Palmer, 1962), leading to impediments to recreational water activities (e.g., fishing, swimming and boating) (Caffrey and Monahan, 1999) and issues related to water supply. Similar to HABs, NABs can affect the structure and function of aquatic ecosystems by causing excessive shading to underwater vegetation, often resulting in oxygen depletion due to a reduction of photosynthesis and increased degradation of both algae and macrophytes, with adverse effects on other aquatic organisms (Ryding and Rast, 1989) as well as impairments to the beneficial use of waters, including human consumption and recreational activities (Chorus and Bartram, 1999; Lévesque et al., 2014).

Within the Laurentian Great Lakes, eutrophication and excessive growth of "undesirable algae" was listed as an initial beneficial use impairment (BUI) at one third (16/48) of all areas of concern (AOCs). By 2015, this BUI had been rehabilitated in two AOCs. Of the 14 AOCs that still have an active eutrophication BUI, 11 are in fluvial systems (Environment and Climate Change Canada, http://www.ec.gc.ca/raps-pas/, 2015; United States Environmental Protection Agency, https://www.epa.gov/great-lakes-aocs#number, 2015). Lake St. Francis, a fluvial lake comprising a section of the St. Lawrence River near Cornwall, Ontario, lies within the Cornwall / St. Lawrence River Area of Concern (AOC) as per the amended Great Lakes Water Quality Agreement of 1978 (International Joint Commission (IJC), 1987). Primary BUIs that were identified included cultural eutrophication and the associated excessive growth of undesirable algae and aquatic macrophytes, as well as industrial contamination of lake sediments and restrictions to fish consumption (Anderson et al., 1992).

Under the ensuing Remedial Action Plan (RAP) (Dreier et al., 1997), ecosystem health within the region has improved considerably since the late 1980′s and the area has made substantial progress towards delisting criteria for many BUIs (IJC, 2003). However, metrics related to trophic status remain impaired (Environment Canada and Ontario Ministry of the Environment, 2010). Several of the nearshore areas in Lake St. Francis have reported persistently high phosphorus concentrations (2008–2013 mean summer TP range = 19–218 μg/L) and toxic cyanobacterial blooms (*Anabaena, Microcystis*, *Oscillatoria* and *Aphanocapsa*) (Bramburger, 2014; Savard et al., 2012, 2015). Continued watershed management programs and monitoring remain in place until the BUI is deemed restored (Environment Canada and Ontario Ministry of the Environment, 2010). To this end, we implemented a high frequency survey of algal community conditions in Lake St. Francis tributaries during the summers of 2013 and 2014 in order to gain insight into occurrences of "undesirable algae," as well as algal densities and community compositions in tributaries associated with the AOC.

Although high levels of nutrients and warmer temperatures have been consistently identified as important drivers of algal growth (Beaulieu et al., 2013; Jöhnk et al., 2008; Kosten et al., 2012; Taranu et al., 2012; Wagner and Adrian, 2009), the relative importance of factors that regulate algal composition and abundance are not as well understood (Anderson et al., 2012; Paerl and Huisman, 2009; Paerl, 2014; Taranu et al., 2012), and studies of fluvial systems across seasons are rare. In eastern Ontario, there is a gap in our knowledge of the frequency and spatial distribution of HABs and NABs in lotic waters. Surface algal conditions are poorly monitored, and our knowledge of temporal trends depends on reports filed to the Ministry of the Environment and Climate Change (MOECC), e.g., if cyanobacteria are found to contaminate drinking water, are noticed by the health unit during beach monitoring, or if a member of the community reports a suspicious bloom (Winter et al., 2011; https://www.ontario.ca/page/blue-green-algae). While detection of suspected HABs could be improved through high-frequency monitoring programs, in situ identification of algae is nearly impossible, and characterization of blooms as "harmful" is rarely done. To help improve monitoring, the identification of easily measurable, quantitative predictors of conditions conducive to bloom formation could help identify potentially hazardous conditions. However, understanding when algal blooms will occur is complicated, and often site-specific (Chorus, 2012; Paerl, 1988), emphasizing the importance of local studies. Here we have evaluated the relationships between phytoplankton density and a suite of physical and chemical water quality variables by employing rapid counting and identification techniques. This allowed for a high throughput of samples in order to better monitor and understand the undesirable algae BUI in the tributaries of Lake St. Francis. The data collected for this study were also part of a larger citizen science project to monitor for HAB- and NAB-forming taxa.

Methods

Study area and sampling design

The study area is located within the drainage basin of Lake St. Francis, near the provincial border between Ontario and Quebec and the international border between Canada and New York, U.S.A., bordering the St. Lawrence River (Fig. 1A, B). It includes nine sub-basins that drain into the Ontario portion of Lake St. Francis, which spans from Cornwall, Ontario to Salaberry de Valleyfield, Quebec (Fig. 1C). This drainage basin is sparsely populated in the more northern regions, with agriculture and forests being important components to the landscape. To the south, closer to Lake St. Francis, the basins are primarily occupied by seasonal cottages and recreational areas, including beaches, campsites, and parks. The city of Cornwall, with a population just above 45,000 (2011 census data, Statistics Canada), is located in the southwest portion of the study area, primarily within the Grays Creek drainage basin and entering into the Raisin River drainage basin (Fig. 1C). The Lake St. Francis region of the St. Lawrence River is an important area for recreation and fishing, and many homeowners along the shoreline of Lake St. Francis draw their drinking water directly from the river. The occurrence of high algal abundance along the shoreline and in recreational areas constitutes a potential public health concern with economic consequences during the summer tourist season.

A total of 25 tributary sites (Fig. 1C) were selected using criteria derived from the sub-basin land use types and stream characteristics that were most strongly associated with high phytoplankton abundances in 2010–2011 (Waller et al. unpublished data), based on the rationale that sites with high overall phytoplankton densities would result in an increased likelihood of having greater abundances of nuisance or harmful algae. The criteria used for site selection included high stream sinuosity, high percent cropland coverage within the drainage basin, and little open water coverage within the basin based on the satellite image pixels. To choose the sites, a network of tessellated hexagons (dimension = 3 m) was overlaid on the study region using ArcGIS v. 10.2.2 software (Environmental Systems Research Institute, 2014) based on shapefiles and raster files obtained from Ontario Land Cover data (OMNR, 2000), Ontario Road Network (OMNR, 2012) and Ontario Hydro Network (OMNR, 2011) (downloaded from Scholars GeoPortal: http://geo2.scholarsportal.info/, 2013) with the constraint that potential sampling locations needed to be within 5 m of roads. Stream sinuosity was determined using the Ontario Hydro Network watercourse shapefile (OMNR, 2011). All land use characteristics were derived using the Ontario Land Cover data (2000) and reclassified into a 7-class raster file using the categories of water, forest, wetland, urban, pasture, cropland and other, in ArcGIS v. 10.2.2 (ESRI, 2014) for land use characteristics for site, drainage basin and sub-basin. Original land use classes included freshwater inland marsh, deciduous swamp, conifer swamp, open fen, dense deciduous forest, dense coniferous forest, mixed forest, mainly deciduous, mixed forest, mainly coniferous, sparse deciduous forest, mine