Journal of Great Lakes Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

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

Concentration and biochemical gradients of seston in Lake Ontario

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ARTICLE INFO

Article history:
Received 3 November 2016
7 February 2017
Accepted 13 February 2017
Available online xxxx

Keywords:
Lake Ontario
Chlorophyll
C:P stoichiometry
Essential fatty acids
Spatial and temporal variability

ABSTRACT

Spatial variability in resource quantity and quality may have important implications for the distribution and productivity of primary consumers. In Lake Ontario, ecosystem characteristics suggest the potential for significant spatial heterogeneity in seston quantity and quality, particularly due to the potential for nearshore-offshore gradients in allochthonous nutrient supply, and the formation of a deep chlorophyll layer (DCL) in July. We assessed total and zooplankton food particle size-fractionated chlorophyll *a* concentrations, as well as carbon-to-phosphorus stoichiometry and essential fatty acid composition of seston across a distance-from-shore and depth transect. We observed time, sampling depth, and distance from shore to be the best predictors of chlorophyll *a* concentration. Resource quality was much more homogenous in space, but there were strong patterns through time, as both stoichiometric and fatty acid qualities in general were greatest in May, and lowest in July/August. We did observe a peak in essential fatty acid concentration near the DCL in during time of formation, possibly due to differences in phytoplankton community composition between the DCL and epilimnion. These results suggest the potential for a spatially and temporally dynamic resource base for consumers in Lake Ontario, which may be important in developing a broader understanding of variable consumer productivity.

Introduction

Heterogeneity in resource availability and resource quality may have important implications for lake primary consumers (Hunter and Price, 1992). While resource quantity can be an important determinant of consumer biomass, there is also evidence that resource quality may exert a stronger influence on consumer biomass than resource availability (Hessen, 1992; Marcarelli et al., 2011). In particular, the elemental stoichiometry (specifically carbon-to-phosphorus ratio; Sterner and Elser, 2002) and composition or concentration of essential fatty acids (Müller-Navarra, 1995; Brett and Müller-Navarra, 1997) have been demonstrated to act as nutritional constraints, and key regulators of consumer biomass across lakes. Therefore, a heterogeneous landscape of resource quantity or quality may have important implications for consumer growth, possibly creating "hot spots" of high quality nutritional composition (DeMott et al., 2004).

Physical and biological factors may drive heterogeneity in seston (zooplankton food resources) quantity and quality in Lake Ontario. Hydrodynamics allow for differentiation of nearshore and offshore habitats in nutrient concentrations as wind-driven coastal boundary layers separate nearshore water from the open lake (Rao and Schwab, 2007). Nearshore areas may also be differentiated in terms of nutrients due to direct loading and plumes from tributaries (Howell et al., 2012; Makarewicz et al., 2012), and in particular the Niagara River, which has strong influence on lake nutrient conditions (Stevens and Nielson, 1987). These dynamics may create gradients of nutrient concentrations and trophic status as distance from shore is increased and connection to nearshore waters is reduced (Wetzel, 2001), thereby altering seston quantity and quality. Alternatively, dreissenid mussels may remove particulate phosphorus from the water column (Idrisi et al., 2001), potentially having consequences for seston carbon-to-phosphorus stoichiometry. Densities of dreissenids as of 2008 were approximately 700–7000 individuals per m^2, peaking in density at locations 30–90 m in depth, and lowest in locations >90 m (Birkett et al., 2015). Despite lower densities in shallower water compared to deeper sites, it's possible that mussels may have a larger effect on seston quality due to the reduction in water column depth, and a possibility to impact a greater proportion of the water column. Therefore, high densities of dreissenid mussels in Lake Ontario may filter out a significant amount of particles and nutrients nearshore, creating the potential for reduced seston quantity and quality (Hecky et al., 2004; Naddafi et al., 2008; Holeck et al.,

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http://dx.doi.org/10.1016/j.jglr.2017.03.007
0380-1330/

Please cite this article as: Kelly, P.T., et al., Concentration and biochemical gradients of seston in Lake Ontario, J. Great Lakes Res. (2017), http://dx.doi.org/10.1016/j.jglr.2017.03.007

2015) in nearshore areas compared to deep, offshore areas (Hall et al., 2003).

In addition to the potential for "horizontal", or distance-from-shore gradients in seston quantity and quality in Lake Ontario, there exists a possibility for vertical gradients due to the formation of a deep chlorophyll layer (DCL). Multiple mechanisms that contribute to the formation of a DCL may influence seston quality in that layer including physiological shade adaptation by metalimnetic phytoplankton that to lead to lower carbon-to-chlorophyll ratios (Barbiero and Tuchman, 2004). Alternatively Twiss et al. (2012) identified higher phytoplankton growth rates within the DCL compared to the epilimnion, and therefore the potential for greater phytoplankton availability for consumers within the DCL. The same mechanisms that produce reduced carbon-to-chlorophyll in phytoplankton under reduced light conditions may also improve seston quality. Low light reduces phytoplankton carbon-to-phosphorus (C:P) ratios (Sterner et al., 1997), and increases the concentration of essential fatty acids (EFAs; Thompson et al., 2004). Twiss et al. (2012) also identified a high proportion of DCL phytoplankton in Lake Ontario as Heterokontophyta and Pyrrophyta, which may contain a higher concentration of EFAs compared to other taxa (Arts et al., 2001).

Our study quantifies spatial and temporal variation in Lake Ontario seston quantity and quality. We predict an increase in seston quantity (chlorophyll concentration) and quality (seston carbon-to-phosphorus ratios and EFA concentration) below the thermocline during the formation of a deep chlorophyll layer. We also predict a general pattern of increasing seston quantity and quality with increased distance from shore due to reductions in interaction with dreissenid mussels. Our results quantify variability in seston quantity and quality and can potentially identify habitats that serve as food web "hot spots" with greater potential for zooplankton growth in Lake Ontario.

Methods

Sample collection

Seston concentration (chlorophyll *a*, size-fractionated chlorophyll *a*) and quality (carbon-to-phosphorus ratio, total fatty acids) were measured throughout the water column, from April through October 2013, at sampling sites along a transect extending offshore (distance from shore = 0.5, 3, 5, 8, and 14 km) into Lake Ontario at depth of 5, 20, 50, 100, and 200 m (Fig. 1). Samples for seston quality were collected less frequently than for chlorophyll concentration (five times for C:P from May through September; eight times for fatty acid composition from July through October). Temperature and fluorometer-based chlorophyll *a* profiles from a water profile logger were used to delineate sampling based on thermocline and DCL depths. Water was collected at 2–8 specific depths, depending on station depth, using a pump or Van Dorn sampler. Specific sampling depth varied with thermocline depth but generally included multiple epilimnetic samples (1 m and 3–10 m water depth), multiple metalimnetic samples (12–25 m) and multiple hypolimnetic samples (30–60 m).

Chlorophyll a analysis

Water samples (0.1–0.5 L) for chlorophyll *a* concentration were vacuum filtered through different filter types: Whatman ® 47 mm glass fiber filters (GF/F, pore size 0.7 μm; 934-AH, pore size 1.4 μm) and Sterlitech ® polycarbonate membrane filters (pore sizes 0.2 μm, 2.0 μm and 20 μm). Vacuum pressure did not exceed 10 mmHg and was shut off immediately when filtration was complete. Filters were folded, wrapped in aluminum foil and stored frozen. Within 3 weeks of collection, chlorophyll was extracted by adding a filter and 10 mL of buffered acetone (100 mL saturated $MgCO_3$ solution per 900 mL acetone) to a clean glass vial, ensuring that filters were submerged in the acetone. Vials were sonicated in an ice bath (20 min) then wrapped in foil and stored in a freezer for 16 to 24 h. Following the extraction period, vials were brought to room temperature. Vials were decanted into a disposable glass culture tube and placed into a Turner Designs Trilogy® Laboratory Fluorometer to measure chlorophyll *a* fluorescence in RFU (Raw Fluorescence Units). A solid red blank was run in the fluorometer twice each time samples were run to maintain a record of instrument accuracy. An equation to calculate chlorophyll *a* concentrations (μg L^{-1}) was derived from a measured value of a buffered acetone blank (0.53 RFU) and a measured value for a certified standard (21.3 μg L^{-1} standard measured at 313.05 RFU), where V is the volume of water (mL) filtered during sample processing and F is the measured fluorescence (RFU). $[\text{chlorophyll } a] = (F - 0.53) / 14.672 * 10/V$.

Seston C:P stoichiometry

Samples for C:N:P ratio analysis were filtered onto 0.2 μm filters, scraped and transferred to a glass slide and dried at 60 °C. Dried seston was later scraped and tinned for analysis. For the determination of seston phosphorus content, dried and pre-weighed seston samples were combusted at 450 °C for approximately 2 h before analysis to remove excess organic carbon. Samples were then combined with 30 mL reverse osmosis water, and analyzed colorimetrically following persulfate digestion (Menzel and Corwin, 1965). For seston carbon and nitrogen content, dried seston samples were analyzed with a Carlo Erba elemental analyzer (Carlo Erba, Val-de-Reuil, France).

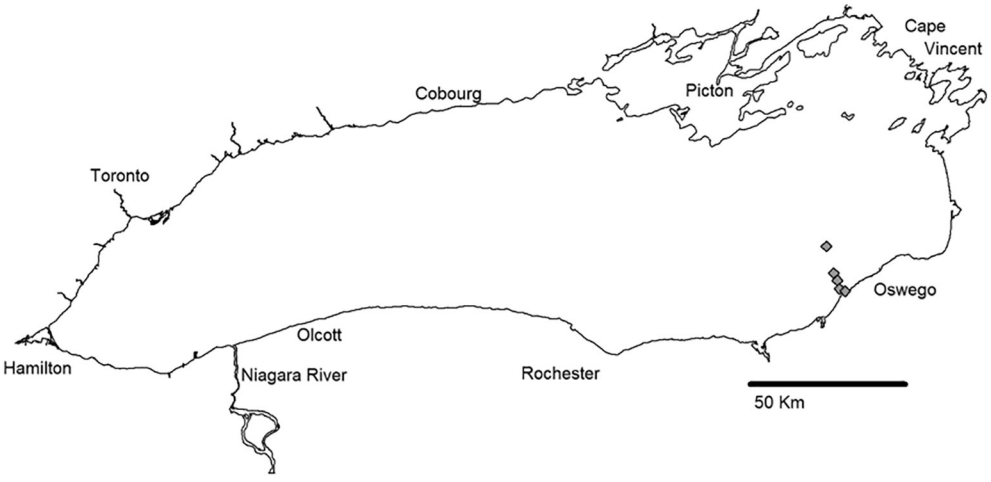

Fig. 1. Sampling locations along a transect extending from nearshore to offshore in Lake Ontario, just west of Oswego NY, 2013. The five sampling stations were located at depths of 5, 20, 50, 100, and 200 m.

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