



Dreissena population status in nearshore Lake Ontario

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ARTICLE INFO

Article history:

Received 17 May 2011

Accepted 17 April 2012

Available online 24 May 2012

Communicated by David Barton

Keywords:

Zebra mussel

Quagga mussel

Benthic correlates

Lake Ontario

ABSTRACT

Dreissenid mussels are ecosystem engineers in the Great Lakes, affecting benthic and water column communities and production. We surveyed mussel populations at four Canadian and three U.S. locations in summer 2008 to update population status and examine correlations with water column data. We measured mussel length, density, shell-free dry mass (SFDM), condition index, and phosphorus content of both shells and mussel tissue. The water column variables of chlorophyll *a*, turbidity, and total phosphorus (TP) were correlated with each other lake-wide, but exhibited only a few correlations with mussel metrics within seasons or shorelines. Quagga mussels (*Dreissena rostriformis bugensis*) represented ~99% of the mussel community in nearshore collections. Mussel length declined in a west-to-east direction and increased with depth in both U.S. and Canadian nearshore waters. Mussel density declined west-to-east in U.S. water, but exhibited no difference among sites in Canadian waters. Mussel condition index and phosphorus concentrations were correlated and increased west-to-east within the U.S. nearshore. There were significant declines in both tissue and shell P content with season in U.S. mussels, but no clear patterns in Canadian mussels. We estimated there were 9.7×10^{12} mussels (mean = 3402.9/m²) in the Lake Ontario nearshore totalling 1.2×10^5 mT of mussel tissue which could filter the entire Lake Ontario nearshore volume (0–20 m depth = 30.9 km³) in roughly 1 to 7 days. It appears that mussel density has declined since the last large surveys of 5 or 10 years ago (Canadian nearshore or U.S. nearshore, respectively), however the data were either only slightly supportive of, or showed no support for, food limitation or goby predation as the most parsimonious explanation for the decline in mussel abundance.

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Introduction

Dreissenid mussels [zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. rostriformis bugensis*)] function as ecosystem engineers in the Great Lakes. Since their arrival in the mid 1980s, these mussels have been implicated in altering substrate habitat conditions (Botts et al., 1996; Ricciardi et al., 1997; Vanderploeg et al., 2002), increasing water clarity via their filtering capacity (Barbiero et al., 2006; Strayer et al., 1999), facilitating the invasion success of subsequent Ponto-Caspian invaders (Ricciardi, 2001), altering the composition of the benthic community (Barton et al., 2005; Haynes et al., 2005; Kuhns and Berg, 1999; Lederer et al., 2006), and redirecting pelagic nutrients to the nearshore benthic zone (Hecky et al., 2004). Recent survey data from across the Great Lakes suggest that *Dreissena* populations may have reached their

peak densities in some locations, but expansion continues into deeper waters in others (Nalepa et al., 2010). Additionally, data indicate quagga mussels have nearly replaced zebra mussels in most locations throughout the Great Lakes (Barton et al., 2005; Jarvis et al., 2000; Mills et al., 1999; Nalepa et al., 2010; Wilson et al., 2006). In particular, Wilson et al. (2006) surveyed the north shore of Lake Ontario in 2003 and reported a nearly 100% quagga mussel community, representing a 50% change in the percent composition of dreissenids in just 8 years (Kilgour et al., 2000). Thus, although dreissenids remain an important structuring force of the benthic zones of the Great Lakes, there are still community changes occurring, and sometimes on a rapid time scale.

As part of a large, coordinated international sampling effort, the water quality and benthic community of the Lake Ontario nearshore zone was assessed in summer 2008 (Makarewicz et al., 2012a). In particular, dreissenid mussel community composition, density, size distribution, and biomass were determined across both the north and south shores for comparison with 2003 and 1995 collections, respectively. In 1995, zebra and quagga mussels each represented about 50% of the mussel community along the north shore (Marvin et al., 2000), whereas by 2000, quagga mussels accounted for nearly 100% of the mussels in the southern nearshore zone (Haynes et al.,

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Table 1
Water column characteristics of sampling polygons. Values are means (1st. err.) from a combination of CTD profiles (Makarewicz et al., 2012c) and fluoroprobe tows (Pavlac et al., 2012) throughout each polygon in the U.S. nearshore, and as described in Howell et al. (2012) in the Canadian nearshore.

Date	Site	Surf temp (°C) ^a	Bott temp (°C) ^b	Turbidity (NTU) ^c	TP (µg/L) ^d	Chl <i>a</i> (µg/L) ^c
May/June	Oak Orchard	12.3 (0.67)	8.2 (2.68)	2.7 (0.72)	12.8 (1.4)	3.2 (0.3)
	Rochester	12.9 (1.66)	12.0 (0.31)	4.3 (0.86)	17.1 (4.0)	10.0 (5.2)
	Mexico Bay	18.2 (1.02)	16.1 (0.24)	3.5 (0.91)	15.7 (2.3)	11.7 (8.5)
	Grimsby	13.2 (0.8)	12.0 (2.6)	1.2 (1.1)	7.1 (9.8)	1.3 (1.2)
	Toronto ^e	10.4 (1.1)	7.1 (1.8)	1.9 (1.6)	10.4 (15.3)	2.2 (0.75)
	Ajax	10.0 (1.7)	6.8 (2.6)	2.0 (3.1)	8.0 (7.3)	1.6 (1.0)
	Cobourg	8.7 (1.2)	6.4 (1.4)	0.9 (0.4)	5.2 (1.0)	0.6 (0.3)
July/August	Oak Orchard	22.8 (0.59)	22.7 (0.69)	2.2 (0.12)	5.6 (0.7)	2.8 (0.2)
	Rochester	23.5 (0.36)	22.9 (0.17)	4.0 (1.04)	12.3 (1.4)	3.4 (0.9)
	Mexico Bay	24.8 (0.65)	24.3 (0.82)	4.1 (0.70)	13.2 (2.2)	6.4 (2.2)
	Grimsby	20.2 (0.7)	14.5 (4.5)	2.0 (1.6)	7.9 (4.1)	1.2 (0.7)
	Toronto ^e	19.0 (0.6)	13.1 (4.6)	2.3 (2.9)	16.1 (18.0)	4.7 (0.6)
	Ajax	16.3 (1.6)	11.4 (3.6)	3.4 (7.2)	7.8 (1.4)	2.3 (0.6)
	Cobourg	21.6 (0.1)	18.7 (4.5)	1.6 (1.8)	7.1 (4.3)	2.9 (1.1)

^a Surface temperature, turbidity and chl *a* total are for full polygons extending from a depth of ~3 m to 5 km offshore. Estimates are means over the area derived from kriged surface-interpolated from field surface measurements over survey tracks.

^b Bottom temp is the average of the minimum temperatures over profiles (averaged over profiles collected during a survey).

^c The May/June values are for a single survey (CA water quality survey 2) collected in early June; estimates for July/August are for (CA water quality survey 3) conducted in late July/early August.

^d TP is average concentration among discrete surface samples collected over the full polygon.

^e The Toronto polygon is split between two sub-polygons over the Greater Toronto area (GTA Centre and GTA West: refer to 6). The reported values are the averages over the two polygons.

2005). This transition in dominance is similar to observations made in southern Lake Michigan by Nalepa et al. (2010) and has been attributed to differences in filtering efficiency at low food levels (Baldwin et al., 2002; Diggins, 2001), lower respiration requirements (Stoekmann, 2003), greater tolerance for cold water by *D. r. bugensis* (Diggins, 2001; Vanderploeg et al., 2010), or a slightly larger size attained by quagga mussels relative to zebra mussels (Patterson et al., 2005; Wilson et al., 2006). Regardless of the mechanism(s) which have allowed *D. r. bugensis* to displace *D. polymorpha*, mussel populations are still very large and management decisions linked to ecosystem changes require up-to-date assessments of population size, size structure, and distribution. Large spatial scale assessments of dreissenid distribution and abundance, coupled with information on chemical and biological properties (e.g., phosphorus concentrations and seston abundance) may provide new insights into mechanisms important in regulating mussel populations.

Predation by round gobies (*Neogobius melanostomus*), food limitation, and possibly upwelling events were all proposed by Wilson et al. (2006) as likely mechanisms controlling mussel populations in Lake Ontario. Multiple lines of evidence, both manipulative and correlative, indicate that round gobies are capable of altering the local size distribution of mussels via direct predation (Barton et al., 2005; Campbell et al., 2009; Djuricich and Janssen, 2001; Johnson et al., 2005; Lederer et al., 2006; Ray and Corkum, 1997). This benthic-feeding fish exhibits a shift to nearly strict molluscivory somewhere between 7 and 10 cm TL (Barton et al., 2005; Campbell et al., 2009; Ghedotti et al., 1995; Janssen and Jude, 2001; Lederer et al., 2006; Ray and Corkum, 1997), as evidenced by gut content and stable isotope analyses. The preferred prey is dreissenid mussels. In contrast, there is little evidence for lake-wide control of mussels by round gobies. Bunnell et al. (2005) and Johnson et al. (2005) have suggested that round gobies consume a very small fraction of available mussel tissue in Lake Erie, and Pennuto et al. (2012) indicated there were only weak correlations between round goby abundance or size and dreissenid mussel benthic density, valve length, or biomass across the nearshore of Lake Ontario.

Dreissenid mussels have been implicated in whole lake nutrient dynamics. Nearshore and offshore nutrient environments are linked by lake hydrodynamics and biological interactions like fish movements, and possibly mussel activity. Hecky et al. (2004) proposed a nearshore shunt hypothesis to explain the redirection of

water column nutrients to the benthic zone as a function of dreissenid mussel filtering and recycling. This hypothesis provides a mechanism to explain why nearshore nutrient levels have not declined as rapidly as offshore nutrient levels, while also providing a mechanism for a recent resurgence in the abundance and coverage of the benthic alga *Cladophora* sp. in the Great Lakes (Depew et al., 2011; Higgins et al., 2008). Several authors have indicated that dreissenid mussels effectively increase light penetration depth as a result of their feeding activity (Barbiero et al., 2006; Strayer et al., 1999), provide new attachment site substrate for algae (Botts et al., 1996; Hecky et al., 2004), and excrete high levels of dissolved nutrients (Arnott and Vanni, 1996; Ozersky et al., 2009), all contributing to conditions favorable for *Cladophora* growth. The combination of mussels and benthic algae might serve to intercept nutrients prior to their reaching open waters.

The nearshore shunt hypothesis presumes that waters and nutrients entering a lake get mixed evenly with waters throughout the lake (Hecky et al., 2004). If so, it suggests a nearshore-offshore gradient in water column conditions should result since particulates and nutrients arrive to the lake via tributaries and erosion in the nearshore and then they are removed via dreissenid mussel filtering before mixing with offshore waters. In particular, total phosphorus (TP), turbidity, and chlorophyll *a* should decline in an offshore direction due to mussel filtering (from assumptions 1–5 in Table 1 of Hecky et al., 2004). However, even in the absence of mussel filtering, at some scale a nearshore-to-offshore gradient in water column nutrients and particulates should be expected since they do arrive to the lake near shore before mixing with offshore waters. If lake hydrodynamics or nearshore-offshore density differences create along-shore currents or otherwise prevent or reduce nearshore waters from mixing with the offshore, there will still be a nearshore-to-offshore gradient in nutrients and particulates (e.g., Makarewicz and Howell, 2009; Neilson and Stevens, 1987; Rao et al., 2004).

Hecky et al. (2004) also suggest it is possible for mussel populations to self-control at high densities as a result of food limitation because of their high filtration efficiency. Thus, as one moves offshore mussels might exhibit signs of food limitation, potentially manifested as a reduction in body mass or condition index. Collectively, we expect to see some correlative evidence of round goby predation or food limitation effects on mussel populations in the nearshore zone of Lake Ontario. Here we quantify

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