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Freshwater mussels in an urban watershed: Impacts of anthropogenic inputs and habitat alterations on populations

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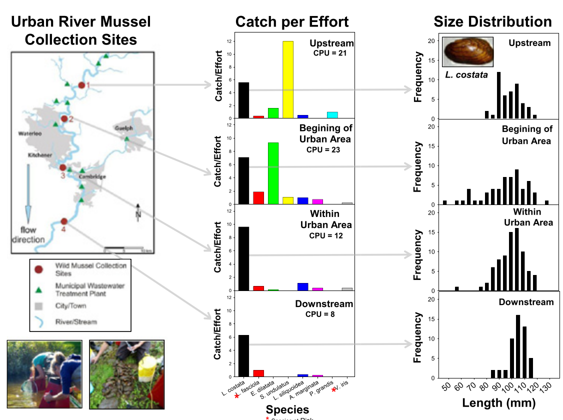
HIGHLIGHTS

- Mussel abundance was 60% lower downstream of an urban area compared to upstream.
- Mussels downstream of the cities were dominated by larger size classes.
- 98% drop in abundance immediately downstream of wastewater treatment plant outfall
- *Lasmigona costata* was the dominant species even at urban-impacted sites.
- Population effects correspond to negative impacts at lower levels of organization.

GRAPHICAL ABSTRACT



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ABSTRACT

The substantial increase in urbanization worldwide has resulted in higher emissions of wastewater to riverine systems near urban centers, which often impairs aquatic populations and communities. This study examined the effect of urbanization on freshwater mussel populations, including Species at Risk in two rivers receiving wastewater. The influence of anthropogenic activities was assessed in a watershed in the Laurentian Great Lakes basin, one that historically supported one of the most diverse mussel faunas in Canada. In the Grand River (ON), four sites along a 60 km reach spanning from an upstream reference site to an urban-impacted downstream area were examined. In the Speed River, mussel populations at six sites along a 10 km reach, selected to bracket specific anthropogenic inputs and structures were assessed. A semi-quantitative visual search method revealed that catch per unit effort in the Grand River declined by >60% from the upstream reference site to the area downstream of an urban center. The size (length) frequency distribution of the most abundant species, *Lasmigona costata*, was significantly ($p \leq 0.008$) different upstream of the majority of urban inputs (45–130 mm) compared to downstream of the cities (85–115 mm). In the Speed River, impoundments and wastewater treatment plants (WWTP) reduced both the diversity and catch per effort. Most striking were 84 and 95% changes in the number of mussels found on either side of two impoundments, and a 98% drop in mussels immediately downstream of a WWTP outfall. These population level effects of decreased abundance and

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underrepresentation of smaller mussels downstream of the urban area correspond to previously documented impacts at the biochemical and whole organism level of biological organization in wild mussels at this location. Our results demonstrate that poor water quality and physical barriers in urban environments continue to impair susceptible populations and communities of aquatic animals.

1. Introduction

Rapid urbanization is occurring in many areas of the world, causing a huge shift in land use from previously natural or agricultural landscapes to highly dense urban environments (Mouri, 2015). The human densification has changed not only the natural nutrient cycle process, but also as a result of the waste generated by larger and increasingly urbanized human populations, wastewater emissions are predicted to increase rapidly in the next 40 years (Van Drecht et al., 2009). An assessment of the 100 largest cities worldwide over a 20 year period has found that water quality has degraded in numerous urban watersheds throughout the world (Duh et al., 2008). Municipal Wastewater Treatment Plants (WWTPs) have been identified as point sources of a broad suite of substances including metals, pharmaceuticals and personal care products, macronutrients such as ammonia, nitrates and phosphorus, and endocrine disrupting compounds to freshwater ecosystems (Ternes et al., 1999; Servos et al., 2005; Metcalfe et al., 2010). Poor water quality in surface water receiving effluents from WWTPs can impair populations of aquatic organisms, including feminization of male fish (Tetreault et al., 2011), reduced fertilization success and egg survival (Fuzzen et al., 2015), reduced survivorship and body condition (Gillis, 2012), and alterations in fish populations and community structure (Brown et al., 2011; Tetreault et al., 2013; Robinson et al., 2016). Furthermore, physical structures associated with urbanization may reduce population density and species richness of aquatic animals in affected riverine systems (Wang et al., 2001). Improvements made to the treatment of the effluents from WWTPs, however, not only can lead to improved water quality, but also to restoration of aquatic community structure and species richness (Azimi and Rocher, 2016). Hence, mitigation of the effects of urbanization on water quality and physical impairments may allow affected populations to recover.

In this study, we focus upon a watershed that is heavily influenced by both chemical and physical influences of urbanization, with a history of impairment of aquatic communities. The Grand River watershed is an example of an anthropogenically-impacted watershed with a population of nearly one million people (Grand River Conservation Authority (GRCA), 2008, 2014), and which receives effluent from 30 municipal WWTPs, 11 of those have outfalls in the study area. At various locations in both the main stem of the Grand River and its tributaries, long-term water quality monitoring data demonstrate that total phosphorus, nitrates, ammonia and some metals (Al, Fe, Pb) can periodically exceed the Canadian Water Quality Guidelines for the Protection of Aquatic Life (Cooke, 2006). In addition, a wide variety of pharmaceuticals and agricultural chemicals have been reported in this watershed (Arlos et al., 2014; de Solla et al., 2016; Frank and Logan, 1988; Fuzzen et al., 2015; Gillis et al., 2014a; Lissemore et al., 2006; Metcalfe et al., 2010; Tanna et al., 2013; Tetreault et al., 2011), though water quality guidelines are available for very few of these compounds. In addition, the input of WWTP-derived organic material has led to localized eutrophication (Chambers et al., 1997; Cooke, 2006), to the extent where downstream of the largest (Kitchener) WWTP in the watershed, dissolved oxygen sometimes falls below the 4 mg/L Canadian Water Quality Guideline during the summer season (Cooke, 2006; Rosamond et al., 2011, 2012).

Freshwater mussels are particularly sensitive to habitat alterations and water quality plays a key role in their distribution (Strayer et al., 2004). They are known to be among the most endangered groups of animals (Biggins et al., 1995), with nearly 70% of North American species designated as either threatened, endangered or in decline (Haag and Williams, 2014; Lydeard et al., 2004; Neves et al., 1997; Williams et al., 1993). Historically, the lower Laurentian Great Lakes drainage basin has supported a rich and abundant population of freshwater mussels, with 40 of Canada's 53 species occurring in this area (Clarke, 1981). However, there has been substantial species loss and changes in community structure since historical times (late 1800's) with recent assessments (late 1990s) revealing a pattern of species loss and changes in community structure throughout the Great Lakes basin. Thirty-four freshwater mussel species have, at one time, been found in this watershed, nine of which are Species at Risk (SAR) (Department of Fisheries and Oceans, 2010; Metcalfe-Smith et al., 2000b). While 31 (live) mussel species were identified in the Grand River watershed between 1885 and 1969, only 17 were found in the 1970's (Kidd, 1973). Similarly, Mackie (1996) and Metcalfe-Smith et al. (1998a) documented a loss of 11 species (33%) compared to historical records. Much of these reductions in mussel diversity are believed to be linked to poor water quality due to urbanization and local land use.

In urban-impacted regions of this watershed impairments from poor water quality and aquatic contaminants have been demonstrated across multiple levels of biological organization from induction of stress biomarkers at the sub-cellular (Gillis et al., 2014a, 2014b; Machado et al., 2014) and tissue levels (Bahamonde et al., 2014, 2015; Fuzzen et al., 2015; Tanna et al., 2013; Tetreault et al., 2011) to alterations in population structure (Brown et al., 2011; Tetreault et al., 2013) in both fish and invertebrates. With respect to freshwater mussels those living within and downstream of the large urban area exhibited evidence of oxidative stress (Gillis et al., 2014b; Machado et al., 2014), as well as reduced condition factor (Gillis, 2012) in comparison to mussels living upstream of cities. Furthermore, although only a semi-quantitative observation, Gillis (2012) reported it took much longer (20 h of searching) to collect a designated number of live *Lasmigona costata* downstream of the urban area than it did (8 h) upstream of the cities, indicating that there may also be population level effects in the urbanized region of the watershed. To determine if the negative effects observed at lower levels of biological organization were evident in mussel populations, this study examined the distribution of freshwater mussels in an urban-impacted area. The effect of anthropogenic activities including WWTPs and the effect of habitat fragmentation from impoundments (dams) on the distribution of freshwater mussels, including SAR was assessed through semi-quantitative population surveys (timed searches).

2. Materials and methods

2.1. Study area

A comprehensive knowledge base that includes both historical and current information on aquatic communities, comprehensive studies on the impacts of urban-derived stressors across phyla and across multiple levels of biological organization, and well characterized water quality make the Grand River watershed an ideal system to investigate the impacts of urbanization on sentinel species, particularly ones that are imperiled worldwide. To assess the effect of urbanization on populations of freshwater mussels, four study sites on the central Grand River and six study sites on the lower Speed River (tributary) were selected. The Grand River study sites have been used previously by our