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Quagga mussels (*Dreissena bugensis*) as biomonitors of metal contamination: A case study in the upper St. Lawrence River

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ABSTRACT

In this study, the utility of quagga mussels (*Dreissena bugensis*) as biomonitors was investigated by measuring total concentrations of three trace metals, cadmium, copper, and zinc, in soft tissues. Quagga mussels were sampled from five sites along the upper St. Lawrence River, including one industrially influenced site, from 1999 through 2007. Mussels were collected from near-shore areas, divided into 5 size classes based on maximum shell length, and tissues were pooled for analysis of each size group. Two-way analysis of variance and a posteriori range tests were used to test for differences among sites along a distance gradient from the outflow of Lake Ontario and to examine inter-annual variability within and among sites. Cadmium concentrations were higher nearer the outflow of the lake. Copper concentrations varied among sites and years, but were generally highest near the industrial site. Zinc concentrations were relatively uniform, possibly reflecting internal regulation. Animal size measured as shell length was not an important factor in this section of the river, but warrants further consideration in a wider range of ecosystems and contaminant exposure levels. In general, concentrations of the three metals were not high compared to reports in the published literature for dreissenid mussels in contaminated environments. However, few studies have utilized quagga mussels rather than zebra mussels. The two species may differ in bioaccumulation patterns and may not be interchangeable as biomonitors. Further studies of bioaccumulation of contaminants by quagga mussels in a wider range of contaminant exposures would be useful particularly as quagga mussels displace zebra mussels in the Laurentian Great Lakes and the St. Lawrence River.

Introduction

Benthic macro-invertebrates have played a major role in evaluating contamination of both marine and freshwater ecosystems worldwide. Mussels, especially, have been used to delineate spatial distribution patterns of organo-chlorine and metal contaminants and to monitor changes in conjunction with remediation activities (Brown and Luoma, 1995; Metcalfe and Charlton, 1990; Rainbow et al., 2002; Richman and Somers, 2010; Tessier et al., 1984; Wang et al., 2002). These organisms assimilate a proportion of contaminants available in dissolved, particulate, biotic (prey), or sedimentary forms, depending on their particular microhabitats, diet, metabolism, and life histories (Luoma and Rainbow, 2005, 2008). Many species in these groups are useful as biomonitoring organisms as they are relatively long-lived and sedentary, are widespread and easy to collect, accumulate contaminants in proportion to length and level of exposure yet are relatively tolerant of these contaminants, and are large enough to provide suffi cient tissue to analyze easily (Phillips and Rainbow, 1994). Dreissenid mussels in North America fulfill many of these requirements for biological monitoring organisms.

Quagga mussels (*Dreissena bugensis*) were first found in Lake Erie in 1989, a year after the zebra mussels (*D. polymorpha*) had been identified in Lake St. Clair (Mills et al., 1999; New York Sea Grant, 2002). A highly invasive species, by 1993 quagga mussels had spread eastward to Quebec City along the St. Lawrence River and by 1995 had become more abundant in many areas of Lake Ontario than the zebra mussel (Mills et al., 1996, 1999). While very similar to the zebra mussel in terms of ecological niche, the quagga mussel may better tolerate lower temperatures and may be able to outcompete the zebra mussel in shallow waters even during summer months (Stoeckmann, 2003; Vanderploeg et al., 2002). Zebra mussels function as ecosystem engineers in shallow waters by selectively grazing, altering nutrient cycles, contributing organic matter in the form of feces and pseudofeces to benthic areas, increasing water clarity, and changing the physical habitat by producing clumps of shells in their colonies or druses (Limburg et al., 2010; Vanderploeg et al., 2002). Presumably, as quagga mussels increase in numbers in shallow waters, their role will be similar. Zebra mussels bioaccumulate various contaminants, including PCBs and metals, through their extensive filter feeding (Comba et al., 1996; Kwan et al., 2003; Kraak et al., 1991; Mills et al.,

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1993). Because quagga mussels feed in a similar manner and on similar food items, they are also likely to bioaccumulate contaminants in their tissues. Compared to zebra mussels, only a few studies have been published on bioaccumulation by quaggas and their potential as biomonitors of contaminants (Johns and Timmerman, 1998; Richman and Somers, 2005, 2010; Roseman et al., 1994; Rutzke et al., 2000). Given their increasing prevalence in the Laurentian Great Lakes and across North America (e.g., into Arizona, Nevada and California; Stokstad, 2007), more understanding of the quaggas' ability for bioaccumulation would be useful to environmental managers.

The overall goal of this study is to examine bioaccumulation of selected trace metals by quagga mussels using the international section of the St. Lawrence River (SLR) as a case study. The upper SLR is an understudied ecosystem compared to Lake Ontario or to the river downstream of Cornwall, Ontario (Twiss, 2007). In this section, most of the river's water is from the outflow of Lake Ontario with few major point discharges until the Cornwall-Massena Area of Concern below the Moses Saunders Power Dam (Fig. 1). Clean-up activities over the past decades, required by the Great Lakes Water Quality Agreement (International Joint Commission (1978)) have improved water quality in Lake Ontario and the St. Lawrence River by reducing inputs of phosphorus and toxic contaminants (Stevens and Neilson, 1987). Previous work at Cape Vincent, NY, near the outflow of the lake, found elevated concentrations of cadmium, copper and zinc in both zebra and quagga mussels sampled in 1993 from May to October (Johns and Timmerman, 1998). Subsequently, zebra mussels showed spatially variable tissue concentrations of these metals at six sites along the international portion of the river with higher bioaccumulation near the outflow of Lake Ontario and near an industrialized site (Johns, 2001). Numbers of quagga mussels began increasing in the upper SLR in the mid-1990s. Beginning in 1999, quagga mussels were sampled at five of these same sites. In this study quagga mussels are hypothesized to bioaccumulate metals in the upper SLR corresponding to proximity to Lake Ontario and to show declines over time as water quality has improved in the lake. Specific objectives of this study are to (1) delineate spatial variability in bioaccumulation of three metals: copper, cadmium, and zinc, (2) examine trends in inter-annual variability of metal concentrations, and (3) elucidate any influence of size of the mussels on extent of bioaccumulation.

Methods

Study area, water characteristics and sample sites

The St. Lawrence River (SLR) has the second largest discharge of rivers in North America (Hudon and Carignan, 2008) with a mean flow of 7500–9200 m^3/s at the Moses Saunders hydropower dam spanning the river at Cornwall, Ontario, the lower end of the study area, 110 km downstream of Lake Ontario (Basu et al., 2000; Hudon, 2000; Morin et al., 2003). Approximately 95–99% of the flow at the hydropower dam consists of outflow from the lake. The SLR is a hard-water river with calcium carbonate buffering; alkalinity is approximately 90 mg/L $CaCO_3$ (Kleinschmidt Assoc. 1996). Water hardness ranged from 110 to 130 mg/L $CaCO_3$ from 1990 to 1996 and from 2007 to 2008 (USGS NWIS). River waters are slightly basic with pH averaging 7.5–8.19 (USGS NWIS). The SLR contains unusually clear and low nutrient waters for a river of its magnitude (Hudon and Carignan, 2008). Levels of dissolved organic carbon in the upper river averaged 5.5 ± 0.2 mg/L in 1997 with no spatial trend in concentrations between Lake Ontario and Trois Rivieres, Quebec (Basu et al., 2000). Dissolved oxygen, measured at the power dam during the ice free months, reached 12–14.1 mg/L in March, decreased to approximately 8 mg/L in summer months and rose to approximately 10 mg/L in October and November. Water temperatures range from 0.2 °C in February to 22–23 °C in July and August (USGS NWIS).

Sample sites were established in an earlier biomonitoring study of zebra mussels (Johns, 2001) in shallow, littoral areas. Mussels could be accessed by wading in less than 1-m depth of water when river levels decreased by 0.3–0.5 m in fall months. Sites are designated 1–5 in this study (Fig. 1), corresponding to sites 1, 3, 6, 8, and 10 from the previous study (Johns, 2001). Site 5 is adjacent to an industrial site and landfill located within the IJC's Massena-Cornwall Area of Concern. While

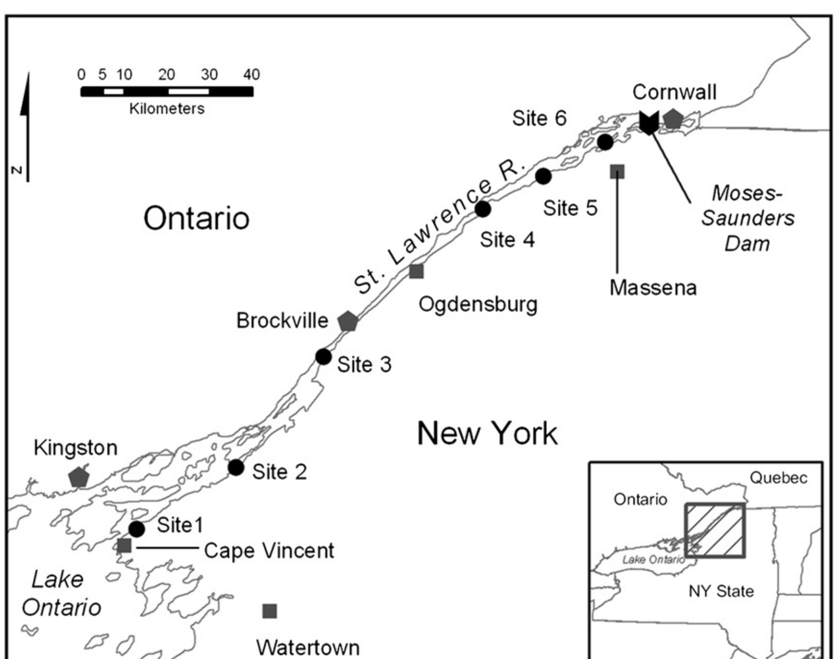

Fig. 1. Map of the international section of the St. Lawrence River and locations of quagga mussel sampling sites.