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Introduction

The ecology and conservation biology of freshwater mussels (superfamily Unionoidea) has been the subject of a rapidly increasing number of field studies over the past two decades. Among the factors explaining this level of interest is the realization that freshwater mussels are among the most endangered and threatened fauna (WILLIAMS et al. 1992). North America supports the largest variety of freshwater mussels on the planet with over 300 recognized species and subspecies belonging to either the family Unionidae or Margaritiferidae (WILLIAMS et al. 1992). In addition, aquatic biologists and conservation biologists recognize that, especially in flowing waters, freshwater mussels can play a significant functional role in filtering suspended particles and recycling nutrients (e.g. VAUGHN et al. 2004). Moreover, the host fish involved in the dispersal of mussel larvae, as well as the conservation status of the species, are not well known for the majority of taxa.

In a separate study of the water quality of the Raisin River system, Eastern Ontario, Canada, freshwater mussels were often found in riffle zones. A more detailed sampling was subsequently conducted to determine the structure (abundance, diversity, and distribution) of the mussel communities and whether this structure could be explained by environmental factors. The specific objectives were to: (1) determine the species richness and quantify mussel abundance at a range of riffle sites, (2) investigate their spatial distribution (within tributaries and between-tributaries or main branches) in relation to stream environmental factors, (3) determine relationships with habitat characteristics and environmental factors, and finally (4) examine the relationship between mussel and fish community structure.

Key words: biodiversity, freshwater mussels, quantitative sampling, riffle zones, rivers

Study area and methods

The Raisin River watershed covers part of Eastern Ontario (546 km^2); the river drains south into Lake Saint Francis on the St. Lawrence River near Lancaster, Ontario (45°11'N, 74°52'W; Fig. 1). The entire watershed has low topography, and agriculture is the main land use. Forty riffle areas were sampled during summer base flow (Jul–Aug 2006). The survey method for mussels consisted of two techniques, both using a viewing box. The quantitative method (1 m^2 quadrat randomly placed into the river) provided characteristics of the community including species relative abundance, spatial distribution, density, and size structure of the populations. The semiquantitative method consisted of a time search (2-person, 30 min total) throughout the riffle zone to estimate mussel abundance. Mussels visible at the substrate surface and under flat rocks were handpicked. All live or empty shells were identified, measured, and returned to the substrate.

In situ physical and chemical variables were measured with a Multiprobe-Hydrolab® Surveyor 3, and included temperature (°C; which affects the reproduction, survivorship, and oxygen consumption of mussels), conductivity (which in streams is often used as a surrogate of productivity), pH (which can affect species distributions), and oxygen levels (which affect mussel metabolism). Turbidity (which affects light penetration and photosynthesis) was estimated by using a transparency tube (units are in mm height of water in the tube). Current velocities within the riffle zone and the overall discharge were estimated using a Swoffer c-140 wading rod and the velocity-area method, respectively. These physical variables, related to flow, affect larval settlement and the supply of food particles. Additional samples were analyzed during the previous summer 2005 for water chemistry (total phosphorus, soluble reactive phosphorus, nitrate, ammonium) and for suspended and periphyton chlorophyll a (Chl-*a*). Adjacent macrohabitat (e.g., percentage of forested or agricultural riparian, width of riparian zone) and microhabitat variables (type of substrate) were noted on site. Land use in the riparian zone can influence water temperature and in-stream nutrient and particle concentrations. Substrate characteristics can affect the distribution and abundance of invertebrates.

Fish community structure data were obtained from the fish survey conducted by the Raisin River Conservation

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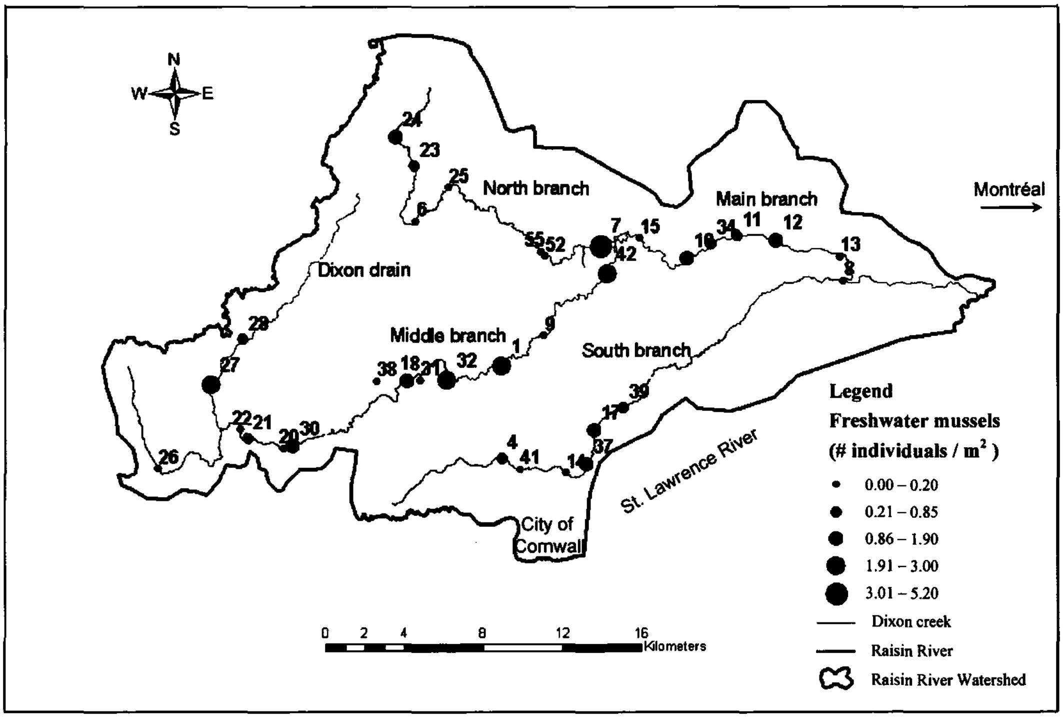

Fig. 1. Raisin River Watershed (45°11'N; 74°52'W) of Eastern Ontario, Canada. Total number of live mussels collected at each riffle site (number of individuals/ m^2)

Authority (RRCA) from 2000 to 2003. Electro fishing and fish seining were used by RRCA, depending on the water depth. We analyzed only fish sampling sites neighbouring those where mussels were encountered.

Results and discussion

Mussels were present at 63 % of the 40 riffle sites sampled (Fig. 1). One site in particular, Site 7, had a much higher mussel density than the others, reaching 5.20 live mussels per m^2. Also, two main branches of the river had higher densities (Middle and North Branch; many sites with densities over 1 individual per m^2) and species diversities than the other branches (South and Main Branch; Fig. 2). These densities are comparable to those reported for other rivers in Ontario (e.g., Grand, Thames, and Rideau; Mackie 1996, Metcalfe-Smith et al. 1998).

In terms of the chemical and physical characteristics of the river, overall the Raisin is characterized by relatively high specific conductivity (mean 505 µS/cm), moderate periphyton biomass in the riffle zones (mean Chl-*a* 61 mg/m^2) and low suspended algal biomass (mean Chl-*a* 8 mg/m^3). Variables such as temperature, pH, dissolved oxygen, oxido-reduction potential were similar across sites (Table 1). In contrast, total phosphorus varied considerably (5–132 µg/L), as did discharge. Good oxygenation and light penetration were observed at all sites. The latter factor influences directly periphyton and suspended chlorophyll production, both important food sources for unionids (e.g., Dillon 2000). At present, the Raisin River water quality would appear to be moderately good based on Ontario provincial water quality guidelines; however, an investigation of water quality through the entire year is required, because it may be the extremes of these variables at other times of the year or at critical points in mussel life history that are important.

Six species were found: *Elliptio complanata* (n = 384), *Pyganodon grandis* (n = 71), *Lasmigona compressa* (n = 25), *Anodontoides ferussacianus* (n = 20), *Lampsilis radiata* (n = 1) and *Lampsilis siliquoidea* (n = 2). At one site on the South Branch a shell of the non-native bibalve *Dreissena polymorpha* was noted. *Elliptio complanata* and *P. grandis* were dominant in terms of the total abundance (Fig. 2). *Elliptio complanata* was broadly distributed and found on all types of substrate including boulder, cobble, gravel, sand, clay, and mud, and from low to high current velocities. This species is known to occur in a range of lentic and lotic habitats (Metcalfe-Smith et al. 2005) so this was not unexpected. Multiple regression analyses showed that the substrate rank had a slight positive correlation with total abundance, but this was not statistically significant (data not presented). Previous

Table 1. Physical, chemical, and macrohabitat variables at sites on the Raisin River main branches (Fig. 1). DO = dissolved oxygen, ORP = redox, SpC = specific conductivity, TP = total phosphorus, Peri Chl-*a* = periphyton chlorophyll a, Susp Chl-*a* = suspended chlorophyll a.

	Mean (range)							
Variable	North		South		Middle		North+Middle	
Temperature (C)	24.6	(21.78–25.83)	23.5	(19.23–26.71)	23.5	(17.84–31.33)	23.5	(21.8–25.34)
pH	7.7	(7.35–7.86)	7.5	(7.45–7.82)	7.5	(7.11–8.22)	7.8	(7.44–8.87)
Turbidity (mm)	56.3	(56.00–58.00)	52.7	(42.7–58)	52.7	(41.5–59)	46.3	(33.4–56)
DO (mg/L)	8.4	(6.15–10.70)	7.9	(6.635–11.36)	7.9	(5.54–11.66)	7.5	(4.94–9.97)
% DO	111	(75.60–142.20)	99.7	(81.5–137.2)	99.7	(72.1–162)	95.3	(64.8–124.4)
ORP	475	(466.00–514.00)	503	(444.5–628)	503	(435–563)	537	(482–616)
SpC (μS/cm)	479	(445.30–517.70)	620	(558.40–672.60)	439	(254.80–585.90)	486	(440.00–510.50)
TP (μg/L)	60	(25.06–91.61)	50	(32.24–72.08)	56	(5.39–131.79)	58	(44.64–63.69)
Peri Chl-*a* (mg/m^2)	59	(39.93–98.41)	70	(25.85–141.43)	46	(12.99–106.94)	68	(30.34–170.07)
Susp Chl-*a* (mg/m^3)	13	(2.22–56.74)	4	(1.89–6.04)	6	(2.71–11.23)	10	(4.80–14.72)
Nitrate (μg/L)	0.35	(0.00–1.36)	0.07	(0.01–0.24)	0.11	(0.00–0.30)	0.05	(0.01–0.11)
Total discharge (L/sec)	30	(0.30–70.68)	58	(34.33–94.34)	71	(0.64–412.22)	492	(60.74–709.33)
Current velocity (m/sec)	0.08	(0.04–0.14)	0.27	(0.17–0.61)	0.27	(0.00–0.65)	0.53	(0.39–0.70)
River width (m)	9.3	(21.78–25.83)	9.8	(19.23–26.71)	9.8	(17.84–31.33)	15.0	(21.8–25.34)
Depth (m)	0.7	(0.60–0.90)	0.8	(0.80–1.00)	0.8	(0.60–1.10)	0.8	(0.60–0.90)
Riparian zone (m)	8.7	(2.00–15.00)	5.1	(0.00–30.00)	5.1	(0.00–15.00)	5.5	(3.00–15.00)

published studies have shown that substrate composition was unable to statistically explain unionid distribution and abundance (STRAYER et al. 1994); however, substrate type may have influenced the species composition in that slow-moving sites with clay, silt, and/or mud substrate seemed to be the preferred habitat of anodontine species (*Pyganodon grandis*, *Anodontoides ferussacianus*). In the case of lampsiline species (*Lampsilis radiata* and *L. siliquoidea*), too few individuals were found to determine its habitat associations, although they, too, tended to be found in more sandy to silty riffle zones. As suggested by MACKIE (1996) for the Grand River, Ontario, the lampsiline subfamily may also be the most at risk in the Raisin River.

The environmental factors considered, including water quality and habitat variables (Table 1), did not correlate significantly with mussel abundance, diversity, or distribution in riffle zones of the Raisin River drainage network. No multiple regression model was found that could explain a significant percentage of the observed variation (data not presented). There were several riffle sites where mussels (live or dead) were completely absent. One possible explanation could be predation by the muskrat (*Ondatra zibethicus*), a common mammal in the area recognized as a primary predator of unionids (HANSON et al. 1989). Further research is required to evaluate its role.

This study only examined site level characteristics and did not examine characteristics at the subcatchment or regional scale; these scales are important when considering the water quality and hydrological regime of rivers (BROADMEADOW & NISBET 2004) and are likely also important to mussel ecology (POOLE & DOWNING 2004). During the last century, the Raisin River basin was highly disturbed by agricultural activities and urbanization. Both removed a considerable number of habitats through deforestation of the riparian zone, an important buffer for flowing waters. Agriculture and a disturbed riparian zone were more typical of the sites along North, South, and Middle branches, whereas the Main branch of the Raisin River was more impacted by urbanization (City of Cornwall). The lack of historical information on the Raisin River, prior to the construction of small dams (e.g., at Martintown in the early 1840s) makes interpretation of present day patterns difficult.

Riparian forest coverage was only coarsely assessed, and a better examination of the vegetation composition and structure over the entire river system may have provided more useful information. The riparian zone provides shading (cooler and more stable temperatures) and indirectly contributes to habitat heterogeneity via woody debris and a more stable hydrological regime. Studies on the Rideau River have revealed positive effects of riparian plant abundance on native mussel abundance (SPOONER 1998). Qualitative observations suggested that in the Raisin River *Elliptio complanata* was particularly abundant in areas with a wide and densely vegetated riparian.

The hydrological regimes of rivers seem important to the ecology of mussels in part through effects on particle

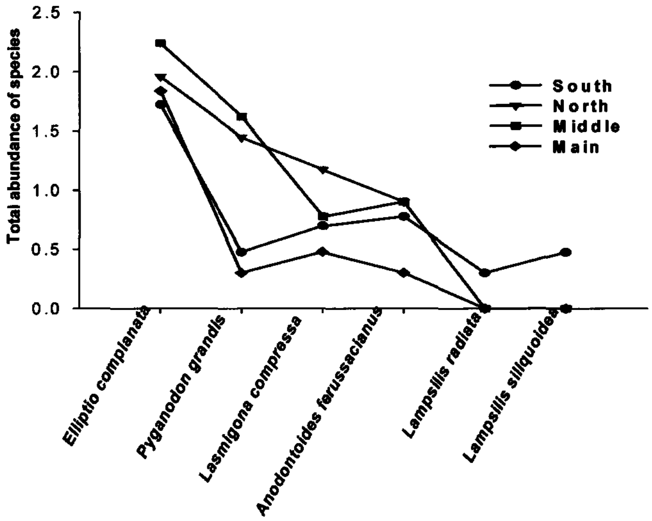

Fig. 2. Rank abundance diagrams of total abundance (log transformed number of individuals encountered in a 30 min time search) of mussel species encountered along the main branches of the Raisin River.

sedimentation (WATTERS et al. 1999). MORALES et al. (2006) showed that the hydrologic regime, controlled in part by the riparian buffer zone, can influence recruitment of young individuals. Mussel reproduction is dependent on temperature, and if fluctuations occur too frequently mussel gametogenesis will not occur. At present the river is continuously gauged only at one location so that the possible effect of the hydrological regime could not be assessed.

Our study could also not detect any relationship between the fish community composition and mussel abundance or diversity; however, evaluating only fish communities neighbouring the mussel sites made establishing linkages problematic. Had we observed fish communities at a larger spatial and temporal scale, we may have found correlations with the mussel community and its spatial distribution. According to BALDIGO et al. (2004), host-fish distributions could be important predictors of mussel communities.

Conclusion

This study examined factors, such as water quality, macro- and microhabitat and fish communities, which could affect abundance, diversity, and distribution of freshwater mussel communities. These factors could not explain the variation in either abundance or diversity of the mussel community at riffle sites within the Raisin River. The river seems to support a modest number of mussel species (although a survey of other habitats such as pools would provide a more complete estimate of diversity); however, some sites had very high densities that could be considered "hotspots" worthy of protection. From a water quality standpoint, the river, despite its location in a largely agricultural watershed, is not severely degraded. The observation of a zebra mussel is of concern considering that the Raisin River flows into the St. Lawrence where this invasive species is already well established. We conclude that abundance, diversity, and distribution of unionids in the Raisin River are not the result of a single factor but multiple factors, some of which may be historical.

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