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Freshwater mussel community response to warm water discharge in western Lake Erie

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ABSTRACT

Native unionid mussels are endangered in the Laurentian Great Lakes due to habitat degradation and biofouling by invasive dreissenids. However, a robust community was discovered living within the thermal discharge of a power plant at Oregon, Ohio, on the south shore of Lake Erie. Our study compared this community to nearby communities outside the thermal plume, and examined habitat characteristics that may affect unionids. Unionids were sampled from the exposed lake bed at three sites during a seiche in 2011: (1) within the thermal plume, (2) at Bayshore Park (2.0 km east of the plant), and (3) at the University of Toledo's Lake Erie Center (4.0 km east). In 2010, sediment samples were collected along a 2 km transect extending east from the plant discharge roughly parallel to the south shore of Lake Erie. Results indicated that the community within the thermal plume had higher densities, higher diversity (H'), more small individuals but overall larger sizes than communities outside the plume. Both the rate and intensity of fouling by dreissenids were lower within the plume. Dry mass of coarse surface sediment and sediment organic matter content were negatively related to distance from the plant ($R^2 = 0.497$, and 0.479, respectively). An unexpected discovery was that the bulk of the coarse sediment was comprised of shell material from Asian clams and dreissenid mussels, suggesting a contribution of these exotic species to sediment accumulation. In total, our results suggest that several habitat characteristics close to the power plant are favorable to unionids.

Introduction

North America hosts the most diverse group of unionids (Bivalvia: Unionidae) in the world with over 300 documented species (Bogan, 1993). Historically, the western basin of Lake Erie had the largest populations of unionids within the Laurentian Great Lakes, probably due to relatively warm temperatures, shallow depths, and high flushing rates (Nalepa et al., 1991). However, unionid abundances in western Lake Erie have been declining since the 1960s (Nalepa et al., 1991) due to pollution and habitat alteration (Stevens and Neilson, 1989; Nalepa et al., 1991; Morang et al., 2011). When Eurasian dreissenid mussels (Bivalvia: Dreissenidae) invaded Lake Erie in 1986 (Schloesser et al., 1996), they exacerbated unionid declines by fouling their shells and possibly competing for food and oxygen (Schloesser and Nalepa, 1994; Parker et al., 1998). Ricciardi et al. (1998) reported that all unionid species were extirpated within 4–8 years in many areas that developed high dreissenid populations.

Although habitat degradation and dreissenid mussels have reduced unionid distributions and abundances in western Lake Erie, some habitats still support abundant populations and diverse communities (Crail et al., 2011). Habitat characteristics that allow coexistence of unionids with dreissenids are unclear (Bowers and de Szalay, 2003), but understanding these characteristics may be important for the conservation and management of unionids. Recent studies suggest several reasons why certain habitats have low dreissenid fouling rates. Strong currents reduce the likelihood that dreissenid pediveligers will settle out of the water column and attach to unionids (Bowers and de Szalay, 2003). Deep layers of unconsolidated sediments allow unionids to burrow, thus escaping colonization and possibly even "shedding" attached dreissenids (Nichols and Wilcox, 1997). Also, dreissenid predators may remove attached dreissenids from the shells of unionids (Bowers et al., 2005). The reason why dreissenid colonization rates are relatively low in some habitats is almost certainly multi-factorial, so that habitats offering a combination of key features may be most likely to allow coexistence of exotic and native mussels.

A seiche in October, 2011, along the southern shore of the western basin of Lake Erie revealed a diverse community of unionids living within the discharge plume of First Energy's Bayshore Power Plant (BPP) at Oregon, Ohio. The plant takes water from the Maumee River as it enters the western basin (Ager, 2009) and discharges it into a small bay partially separated from the larger basin by an island of sediments dredged from the Toledo shipping channel (Fig. 1). Herein, we present field data from unionid sampling we completed in the vicinity of the power plant's thermal plume. We also present data from three additional studies done within and adjacent to this thermal plume. Using these data, we elucidated the likely factors contributing to unionid success in this

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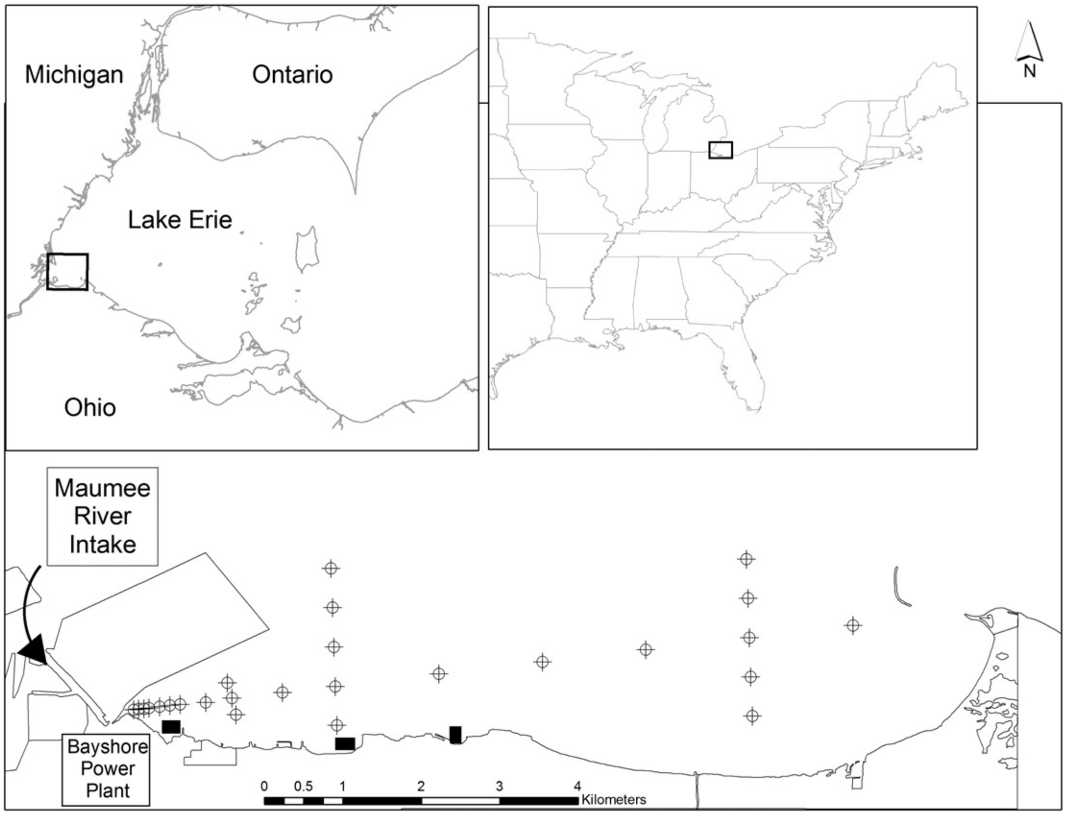

Fig. 1. Location of study area within the United States and Great Lakes region. The lower panel shows the location of the three 0.5 ha plots (black squares) and sampling sites (bullseyes).

habitat. The goal of this study was to identify the key habitat characteristics and positive feedbacks among bivalves that allow native unionids to coexist with two exotic taxa (*Dreissena* spp. and *Corbicula fluminea*). Our findings may be important for unionid conservation in western Lake Erie.

Methods

Study area

Our study area was located in the shallow (<2 m depth) waters within 200 m of the southern shoreline of Lake Erie, within the Maumee Bay (Fig. 1). This included sites (1) within the power plant's thermal plume (ca. 0.4 km east of the BPP), (2) at Bayshore Park (2.0 km east of BPP), and (3) at the University of Toledo's Lake Erie Center (4.0 km east of BPP). The BPP receives cooling water from an intake canal connected to the east side of the mouth of the Maumee River. Heated water is discharged eastward from the plant at 8–33 m^3 sec^{-1} (Lawler et al., 2003), into a partial embayment created by a rectangular dredge-spoil island located to the north of the plant outflow. Water depths range from 0.6 m to 1.5 m LWD. The substratum is variable, with areas of silt-clay, silt, silt-sand, and sand. All of these substrate types include *Corbicula* and dreissenid shells and in some areas these shells form a gravel-like substrate. The discharge water coming from the BPP ranges from 3 to 6 °C above ambient (Tetra Tech, 2009). Water temperature at Bayshore Park is usually about 2–3 °C cooler and water near the Lake Erie Center is about 3–4 °C cooler than in the plume of the power plant.

Unionid collections

We collected unionids during two separate wind-driven seiche events. In October of 2011, they were collected by hand from the exposed lakebed from a 0.5 ha plot at each of the three sampling sites along the south shoreline of Maumee Bay (Fig. 1). Each plot was sampled for 2 person hours. All visible unionids on the sediment surface were identified to species, their lengths were measured, and all were examined for presence of attached dreissenids or their byssal threads. If dreissenids were present, the number attached was recorded. An additional 0.01 ha quadrant (10 × 10 m) within the thermal plume (0.4 km east of the BPP) was thoroughly searched during the seiche. All unionids at the sediment surface within the plot were identified, measured, and examined for dreissenids and their byssal threads. The purpose of this 0.01 ha plot was to estimate unionid density within the thermal plume for comparison to densities found at Bay Shore Park during a similar seiche in 2009 (Crail et al., 2011). During the 2009 seiche, unionids were collected by hand from the exposed lakebed in four 0.01 ha plots. Each plot was thoroughly searched so that all visible unionids were retrieved. Unionids were identified and measured before being returned to the substrate (Crail et al., 2011).

Dreissenid and corbiculid sampling

We collected benthic samples in the summer of 2010 with four, 23 × 23 cm ponar grabs at each of 23 sites located within the study area (Fig. 1, bottom). All living bivalves, including dreissenids and corbiculids, were removed from each sample, identified to species and returned to the site.

We also examined dreissenid and corbiculid densities reported by Ager (2009) from an environmental impact study completed during August of 2008. Ager (2009) took ponar grabs at 23 locations (4 replicates per location) within the study area: 20 within 3.0 km of the BPP and three reference sites located in the more distant, open waters of Maumee Bay.

Sediments

After all bivalves were removed by hand from our benthic samples collected in 2010 (described above), the sediments were poured into a sieve bucket and rinsed with water to remove all material less than 2.0 mm. Remaining material was divided into 4 size classes (2.0–6.4 mm, 6.4–12.7 mm, 12.7–25.4 mm, >25.4 mm). These fractions were then dried to a constant mass at 100 °C and weighed.

One sediment core was collected from each of the same 23 sampling sites using a hand held sediment corer (7 cm diameter). The corer was pushed through the loose sediments on the surface into the underlying glacial lake clay. The loose surface sediments were decanted and the remaining core contents were saved in plastic bags and taken to the lab for processing. A fine particle size fraction (0.075–0.6 mm) was isolated from each sample using a wet sieve. Approximately 2 cm^3 of each fine particle sample was placed in a crucible, dried to a constant mass at 100 °C, and weighed. The crucibles were then held at 500 °C for 8 h in a muffle furnace and the organic matter content of samples estimated as weight loss on combustion.

Sediment grain size data for Maumee Bay were also obtained from the Army Corps of Engineers. Their sampling was done in 2002 and reported mean sediment grain size (phi) for a wide range of locations in the area.

Statistical methods

Unionids

The Shannon diversity index (H') was calculated for each of the 0.5 ha sample plots in 2011. However, the single plot sampled at each site does not permit statistical comparisons between sites. In contrast, the 95% confidence intervals about the means for density and H' of the four 0.01 ha plots collected at Bayshore Park in 2009 were compared to the density and diversity of the community found in the 0.01 ha plot within the thermal plume of the power plant in 2011.

Only *Leptodea fragilis* was abundant in all 0.5 ha plots, and size distributions showed a break between two relatively distinct size groups (small and large individuals) at each site (Fig. 2). We used a Mann–Whitney U test ($\alpha = 0.05$) to compare mean shell length between sites for all individuals and for both size groups of this species. There were so few individuals of the small size group in the Lake Erie Center plot (N = 4), that only the power plant and Bayshore Park plots were compared in this statistical analysis. A Mann–Whitney U test ($\alpha = 0.05$) evaluated differences in the size distributions between the three plots.

A Chi-Square test ($\alpha = 0.05$) was also used to compare the ratio of infested:non-infested unionids at each site. A single factor ANOVA

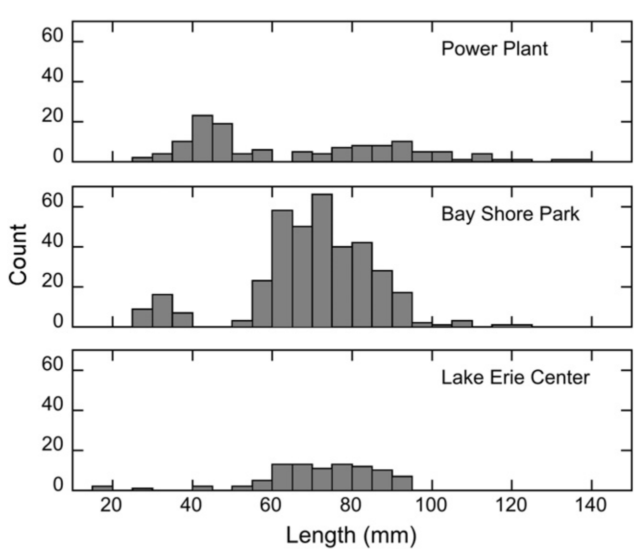

Fig. 2. *L. fragilis* size distributions adjacent to the Power Plant (top), Bayshore Park (middle), and the Lake Erie Center (bottom).

($\alpha = 0.05$) was then performed to determine if there was a significant difference in the mean number of attached dreissenids per unionid between sites (only infested unionids were included in this analysis). Finally, t-tests were used to compare the average length of infested and non-infested unionids in the three 0.5 ha plots and the 0.01 ha plot from the 2011 seiche. Observations were sufficient to permit tests for differences in lengths for *L. fragilis* in all four plots, *Amblema plicata* in all plots except the Lake Erie Center, and *Truncilla donaciformis* in only the 0.01 ha plot at the power plant.

Dreissenids and corbiculids

To determine if dreissenids and corbiculids responded to the thermal plume, we used multiple linear regressions to examine the relationships between mussel density and distance from both the power plant and south shoreline ($\alpha = 0.05$). For dreissenids, we used data from Ager (2009) and for corbiculids, we used data from both Ager (2009) and our summer 2010 study.

Sediments

Data from our summer, 2010 study were used to determine the relationship between total unconsolidated surface sediment dry mass (from ponar grabs) and distance from both the power plant and south shoreline (multiple linear regression, $\alpha = 0.05$). The dry mass of each of the four, particle size classes making up the total (<6.4 mm, 6.4–12.7 mm, 12.7–25.4 mm, >25.4 mm) were analyzed using the same method. A multiple linear regression was also used to determine if a relationship existed between organic matter content of sediments and distance from both the power plant and south shoreline. Finally, the sediment grain size data (phi) from the Army Corps of Engineers (2002) were analyzed to determine the relationship between grain size and distance from both the power plant and south shoreline (multiple linear regression, $\alpha = 0.05$).

Results

Unionids

We found 2657 unionids representing 13 species during the 2011 seiche. There were 715 unionids in the 0.01 ha plot representing 11 species, and 1942 unionids representing 11 species in the three 0.5 ha plots (Table 1). This includes 3 species listed in Ohio as threatened or as species of concern (Ohio Department of Natural Resources). For the 0.5 ha plots (2011), the thermal plume had 598 individuals, Bayshore Park had 531, and Lake Erie Center had 97. The density of unionids in the 0.01 ha plot within the thermal plume in 2011 (7.16 unionids/m^2) was much higher than at Bayshore Park in 2009 (N = 4, 0.09 ± 0.06 unionids/m^2). The 95% confidence interval from the 2009 plots (0.06–0.12 unionids/m^2) suggests that unionid density was greater in the thermal plume.

Shannon's index for the 0.5 ha plots (2011) was highest within the thermal plume ($H = 1.51$) and declined with distance from the plant ($H = 0.96$ for Bayshore Park, $H = 0.35$ for Lake Erie Center). The 95% confidence interval from the 2009 plots (0.11–0.63) suggests that unionid diversity was greater ($H = 1.15$) within the thermal plume.

The percentage of small individuals in the total population of *L. fragilis* was highest within the plume (51.9%), lower at Bayshore Park (8.7%), and lowest at Lake Erie Center (2.1%). Mann–Whitney U tests showed that the overall size distribution of *L. fragilis* within the plume was significantly different than the size distributions at both Bayshore Park and the Lake Erie Center (N = 496 and 458 respectively, $p < 0.0001$ and $p = 0.025$ respectively), but there was no significant difference between Bayshore Park and Lake Erie Center ($p = 0.246$). Small *L. fragilis* had longer shells in the thermal plume than at Bayshore Park (Mann–Whitney U test, N = 94, $p < 0.0001$).

Table 1
Mean ± sd shell length (mm) and numbers (N) of unionids sampled in 0.01 and 0.5 ha plots at Maumee bay, Ohio.

Species	Power Plant (0.01 ha)	Power Plant (0.5 ha)	Bay Shore Park (0.5 ha)	Lake Erie Center (0.5 ha)
Amblema plicata	56.4 ± 23.2 (374)	26.4 ± 15.6 (273)	21.0 ± 4.8 (127)	15.0 ± 1.0 (3)
Fusconaia flava	46 (1)			
Lasmigona complanata	25 (1)			
Lampsilis siliqudia		31 (1)		
Leptodea fragilis	87.1 ± 18.5 (249)	65.3 ± 26.1 (129)	69.3 ± 16.0 (367)	71.2 ± 14.7 (91)
Obliquaria reflexa[a]	31 (1)		20 (1)	
Potamilus alatus	79 ± 10.8 (3)			44 (1)
Pyganodon grandis	99 (1)	64.3 ± 13.1 (56)		
Quadrula quadrula	47.7 ± 8.5 (10)	13.9 ± 15.9 (47)	21.0 ± 3.6 (3)	
Quadrula pustulosa	32.3 ± 7.1 (3)		20 (1)	
Toxolasma parvus		15.6 ± 4.0 (40)		
Truncilla donaciformis[a]	29.6 ± 5.2 (45)	14.7 ± 6.7 (52)	24.6 ± 3.1 (29)	20.5 ± 6.4 (2)
Truncilla truncate[b]	34.6 ± 5.8 (28)		31.0 ± 7.9 (3)	

[a] Ohio threatened species.
[b] Ohio species of concern.

Large *L. fragilis* also were significantly longer within the plume than at Bayshore Park or Lake Erie Center (single factor ANOVA with Tukey pos-hoc, $\alpha = 0.05$, N = 465, $p < 0.0001$). There was no difference in the sizes of large individuals between Bayshore Park and Lake Erie Center.

Fewer unionids were fouled with dreissenids at the power plant (13%) than at the other sites (71% and 79% at Bayshore Park and Lake Erie Center, respectively, Chi-Square test, N = 959, $p < 0.0001$) but there was no significant difference between the two latter sites. The following means are accompanied by standard deviations. The mean number of attached dreissenids on infested unionids within the plume (1.76 ± 1.73) was significantly lower than at the other sites (single factor ANOVA with post-hoc Tukey HSD, N = 297, $p < 0.0001$), but the intensity of infestation at Bayshore Park (5.71 ± 7.06) was not significantly different from the Lake Erie Center (3.50 ± 3.56).

Unionids infested with dreissenids were larger than non-infested unionids. Infested *L. fragilis* (97.9 ± 12.6 mm), *A. plicata* (73.1 ± 22.0 mm), and *T. donaciformis* (32.7 ± 4.9 mm) from the 0.01 ha plot at the power plant were all significantly larger (N = 100, 99, and 45 respectively; $p = 0.048$, 0.003, and 0.001 respectively), than non-infested *L. fragilis* (92.6 ± 10.5 mm), *A. plicata* (59.2 ± 20.7 mm), and *T. donaciformis* (27.6 ± 4.4 mm). No significant differences in size were found between infested and non-infested unionids in the 0.5 ha plot at the power plant. Infested *L. fragilis* (70.7 ± 16.0 mm) from the 0.5 ha plot at Bayshore Park were significantly larger ($p = 0.003$, N = 100) than non-infested *L. fragilis* (49.8 ± 16.9 mm). Finally, infested *L. fragilis* (74.4 ± 10.8 mm) from the 0.5 ha plot at Lake Erie Center were significantly larger ($p = 0.013$, N = 91) than non-infested *L. fragilis* (64.4 ± 19.2 mm).

Dreissenids and corbiculids

There was a positive relationship between live dreissenid density and distance from the power plant (Fig. 3a; N = 22, $p = 0.0002$) based on data in Ager (2009). Conversely, data from our samples collected in 2010 showed that corbiculids (*C. fluminea*) had high densities close to the plant and decreased with distance (Fig. 3a). Also, both studies showed that almost all sites with *C. fluminea* densities >200/ m^2 were within 1500 m of the power plant, which roughly corresponds to a partial embayment of the outflow area created by the island located to the north of the power plant discharge (Fig. 1).

Sediments

The mass of coarse surface sediments overlaying a compact lacustrine clay layer (Fig. 3b) showed a significant, negative relationship with distance from the power plant (N = 85, $R^2 = 0.551$, $p < 0.0001$). Of the four size fractions examined, both the 6.4–12.7 mm and 12.7–25.4 mm size classes also showed significant negative relationships with distance from the plant (Fig. 3c; N = 85 and $p < 0.0001$ for both analyses, $R^2 = 0.286$ and 0.497 respectively). Shells and shell fragments of *C. fluminea* were the primary components of the 6.4–25.4 mm sediment size class within 1200 m of the plant, again falling within the partial embayment of the power plant discharge plume (Fig. 1).

The organic matter content in fine sediments (Fig. 3e) also showed a negative relationship with distance from the discharge (N = 20, $R^2 = 0.479$, $p = 0.0007$). In contrast, the Army Corps of Engineers sediment data (2002) from Maumee Bay showed a significant

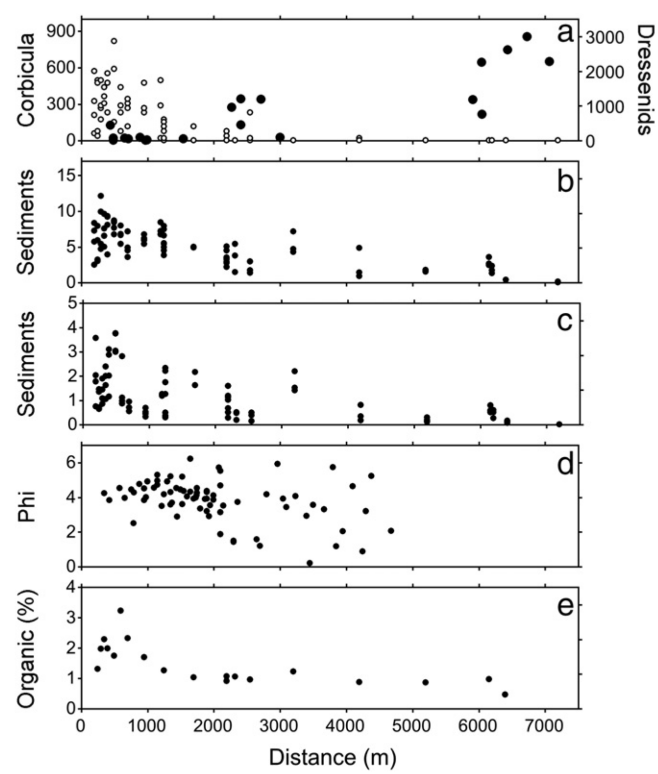

Fig. 3. Gradients of environmental variables (a) corbiculid (open circles) and dreissenid (filled circles) densities (Ager, 2009), (b) total sediment mass (mg), (c) coarse sediment (12.7–25.0 mm) mass (mg), (d) mean phi grain-size value, (e) percent organic matter in fine sediments (0.075–0.60 mm).

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positive relationship between mean grain size and distance from the power plant (Fig. 3d; N = 76, $R^2 = 0.1145$, $p = 0.0028$).

Discussion

Our results indicate a larger, more diverse community of unionids living within the thermal plume of the Bayshore Power Plant than at other more exposed locations along the southwest shore of Lake Erie. Clearly unionids have not been extirpated by dreissenids, despite concerns by Ricciardi et al. (1998). The low rate of dreissenid infestation within the discharge embayment is probably one of the reasons why unionids are thriving in this habitat. Positive flow from the power plant may reduce both the likelihood of veligers settling out of the water column (Horvath and Lamberti, 1999) and the chance of their entering the embayment from the open lake (Zanatta et al., 2002; McGoldrick et al., 2009). Greater shell surface area and siphoning capacity almost certainly makes larger unionids more susceptible to infestation, and small unionids have been shown to burrow deeper than large unionids (Schwalb and Pusch, 2007), which might reduce infestation for those living in the deeper sediments within the plume.

We found a higher number of small *L. fragilis* living within the plume and our data suggest that for this species (and possibly *A. plicata*, not shown), the thermal plume may support breeding populations. However, we did not test any females for fecundity. Another possibility is that the plume is a gathering area for species of host fish that are infected with glochidia at other locales and drop them at this location. Finally, elevated temperature has been shown to increase growth rates of marine bivalves (Shpigel et al., 1992; Gangnery et al., 2003) and our results showed that unionids within the thermal plume were larger than their counterparts outside the plume. In particular, both small and large individuals of *L. fragilis* were significantly larger within the plume. However, we have no data to relate age to size.

We found a dense *Corbicula* population within about 1500 m of the BPP (Fig. 3), largely within the embayment created by the dredge-spoil island. Scott-Wasilk et al. (1983) also showed that *C. fluminea* develop dense populations in thermal effluents along the western Lake Erie coast. These populations can generate large volumes of shell material, which we found contributed to the development of a deeper substrate inside the embayment. Finally, temperature may also help explain why dreissenid densities and fouling rates are low close to the plant. Dreissenid veligers may be killed by heat shock as they pass through the cooling system, creating a veliger shadow, and effluent temperatures may approach the upper limit of adult dreissenid thermal tolerance (McMahon and Ussery, 1995).

Sediments within the thermal plume provided a greater volume of potential unionid habitat (Fig. 3). Sediment composition and distribution is reported to be extremely important to the distribution and abundance of unionids (Box and Mossa, 1999). We found that unconsolidated sediment mass declined with distance from the power plant and almost all of the gravel-size sediment consisted of *C. fluminea* shell debris. We speculate that the shell material acted as a gravel bed, which trapped fine particles. The result was a substrate comprised of coarse and fine particles that is both friable enough for unionids and stable enough to resist erosion. Asiatic clams are a common component of the benthic community in thermally impacted waters of western Lake Erie (Scott-Wasilk et al., 1983), so it's likely they have engineered substrates that are beneficial to unionids in other thermal plumes. In western Lake Erie refuges, Nichols and Wilcox (1997) and Bowers et al. (2005) also report that unionids in deeper substrate tend to have a lower infestation rate of dreissenids.

Sediments within the plume also had higher organic matter content than sediments outside the plume. Unionids pedal feed on organic material in sediment (Yeager and Cherry, 1994; Raikow and Hamilton, 2001), although the relative importance of pedal feeding is uncertain. Nonetheless, mussels close to the power plant had both more habitat (sediment) and potentially access to more organic matter in sediments than at the other sites. Further study would be needed to determine the source of the sediment organic matter, however, we observed high concentrations of fish and birds near the BPP (personal observations), which probably contribute fecal input. Also, the lower Maumee River, from which water is drawn to cool the power plant, is very productive (Bridgeman et al., 2012) and has a high sediment load (Richards et al., 2010), so that it is likely an organic matter source.

The south shore of Lake Erie is the most altered shoreline segment of the Great Lakes. The shoreline is 83% armored, so the lakebed is severely sand starved compared with conditions that existed 200 years ago (Morang et al., 2011). The decline in unionids that was already occurring before the dreissenid mussel invasion (Nalepa et al., 1991) was due in part to shoreline alteration (which reduced land/lake sediment exchange) and pollution. When dreissenids invaded, they exacerbated the negative effect that habitat degradation was already causing. Increasing sources of coarse sediment (sand/gravel) may be important to the conservation of unionids in western Lake Erie.

Conclusion

The thermal plume at the Bayshore Power Plant provided favorable habitat for unionids due to a combination of interacting factors. Dreissenid density was low, sediment and potential food availability (sediment organic matter) was high, and temperature and flow (plant discharge = 8–33 $m^3 s^{-1}$) were elevated within the embayment. All of these factors may individually and synergistically contribute to the greater sizes, density, and diversity of the unionid community in the thermal plume. Despite concerns of extirpation from the Great Lakes, robust communities continue to persist in protected nearshore habitats that accumulate sediments.

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