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A Quantitative Survey of the Freshwater Mussel (Unionidae) Fauna in Honeoye Creek, New York

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A Quantitative Survey of the Freshwater Mussel (Unionidae)

Fauna in Honeoye Creek, New York

by

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Chapter 1: A Survey of the Freshwater Mussel Fauna in Honeoye Creek, New York

Abstract

Contemporary baseline data such as species presence, distribution, abundance, size-class structure, species-habitat relationships, and host species distributions are needed for monitoring the status and health of freshwater mussel communities in Honeoye Creek and other watersheds in New York State in the future.

Quantitative surveys were performed at 20 sampling sites to assess the status of freshwater mussels in Honeoye Creek. Fifteen species were observed throughout the creek, with the highest diversity of nine species at two sites. Mussel abundance ranged from 0 to 3.15 mussels/m^2. Recent recruitment was observed in five species, including *Fusonaia flava, Lampsilis cardium, Lampsilis siliquoidea, Strophitus undulatus,* and *Villosa iris*.

Physical and chemical habitat parameters were assessed at each of the 20 sites sampled for mussels. Instream cover, embeddedness, velocity/depth regime, and frequency of riffles were positively correlated to mussel density. Discriminant analysis produced a single function positively correlated with instream cover and velocity/ depth regime. The analysis was able to correctly classify 95% of sites based on presence/ absence of freshwater mussels.

A survey of host fishes provided additional data regarding the reproductive potential of freshwater mussels. Twenty seven fish species, including 19 known mussel hosts, were caught during the surveys. Host fishes were not collected for

Leptodea fragilis, *Potamilus alatus*, and *Truncilla truncata*, a finding consistent with the low abundances of these three species in Honeoye Creek.

While these data provide a base-line for freshwater mussel diversity, abundance and distribution, additional research is needed to monitor the status and health of freshwater mussel communities in Honeoye Creek. Future research will help identify trends in population health and target sites where management and conservation measures are needed.

General Introduction

Life History of Unionid Mussels

The United States supports the world's greatest diversity of freshwater mussels (Mollusca, Class Bivalva, Family Unionidae), nearly 300 species. However, freshwater mussel declines have been noted by researchers and conservationists (The National Native Mussel Conservation Committee 1998), and nearly 67% of freshwater mussels in the United States are vulnerable to extinction or already extinct (Metcalfe-Smith *et al.* 2000). Currently there is a lack of information on mussel population biology, which hinders the ability of managers to develop and implement conservation and recovery strategies. Estimates of presence, extent, density, or size of freshwater mussel populations are needed to evaluate the status of these imperiled organisms (Strayer and Smith 2003).

Freshwater mussels are long-lived, slow-growing organisms which makes them susceptible to a variety of threats. They have a unique and complex life cycle that is dependent on several factors to be successful. Female mussels filter sperm from the water column as it is released by male mussels. The female then raises eggs in her gills until the larval stage (glochidium) is reached (Nedeau 2008). The glochidia are eventually released into the water column where they must attach to the gills or fins of an often mussel species-specific fish host (Strayer *et al.* 2004).

Freshwater mussels have developed a unique method for increasing the probability that glochidia attach to an appropriate fish host. Once the glochidia have developed the female mussel creates a "lure" out of soft tissue. Lures range from simple to complex, and successfully imitate bait fish or other aquatic organisms. The purpose of the lure is to trick a fish into biting it. When a fish bites the lure the female mussel will release glochidia, giving her offspring a higher probability of attaching to a fish host (Strayer *et al.* 2004). The glochidia will spend two weeks to seven months attached to a fish host, after which they will drop off the fish and bury themselves in the surrounding substrate. Survival of juvenile mussels is dependent on the environment in which they detach themselves from their fish host (Nedeau 2008).

Ecosystem Engineers

Freshwater mussel communities are important components of the freshwater ecosystem (Vaughn and Spooner 2006, Vaughn *et al*. 2008). Due to their benthic existence and filter feeding habit freshwater mussels are sometimes referred to as ecosystem engineers because they can influence the environment around them (Gutierrez *et al.* 2003) and community structure in streams (Vaughn and Spooner 2006). Shell production is another important ecosystem engineering process: both living mussels and spent shells provide or improve habitat for benthic macroinvertebrates and a substrate for periphyton, an important food source for macroinvertebrates (Vaughn and Hakenkamp 2001, Gutierrez *et al*. 2003, Vaughn and Spooner 2006, Vaughn *et al.* 2008).

Freshwater mussels also help oxygenate sediments through bioturbation which provides improved habitat for other macroinvertebrates. As filter feeders, they transfer nutrients from the water column to the benthos (Vaughn and Spooner 2006). The organic matter deposited in the sediment by mussels provides a food source for detritivores such as chironomids (Vaughn and Hakenkamp 2001, Vaughn and Spooner 2006, Vaughn *et al.* 2008). Due to their roles and importance, declines in freshwater mussel populations lead to altered ecological structure and function in freshwater systems (Vaughn and Hakenkamp 2001, Vaughn and Spooner 2006).

Threats

Freshwater mussel species in the United States have experienced sharp declines due to water pollution, dam construction, and the introduction of exotic species (The National Native Mussel Conservation Committee 1998). Dams pose a threat to freshwater mussels by: 1) altering the sediment and substrate composition both upstream and downstream of the dam, 2) creating inconsistent water flows, 3) limiting the availability of host fish for early life stage development, and 4) limiting the ability of host fish to transport glochidia to upstream reaches (Watters 1996, The National Native Mussel Conservation Committee 1998). The introductions of invasive, nonnative mussels, *Dreissena polymorpha* (zebra mussel) and *Dreissena rostriformis bugensis* (quagga mussel), to the Great Lakes and their tributaries threatens the survival of native mussels by interfering with their feeding, growth, locomotion, respiration and reproduction (Ricciardi *et al.* 1998, Nedeau 2008). Freshwater mussels that survived decades of environmental degradation in the upper St. Lawrence River were decimated within a few years after the dreissenid invasion (Ricciardi *et al.* 1998). However, some mussel populations have remained intact despite the numerous threats to their survival.

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Chapter 1: A Survey of the Freshwater Mussel Fauna in Honeoye Creek, New York

Introduction

Honeoye Creek originates as an unregulated outlet from Honeoye Lake in Richmond, New York, flows north through the village of Honeoye Falls and eventually veers westward where it empties in the Genesee River in Golah, New York (Figure 1). The Honeoye Creek watershed covers an area of approximately 691.5 km^2. Land use is dominated by agriculture (43.5%) and forest (38.6%) (Makarewicz *et al*. 2013).

Historical information on the freshwater mussel fauna of Honeoye Creek is limited, making it difficult to determine any trends in freshwater mussel abundance, distribution, and size-class structure. Clarke and Berg (1959) recorded six species in Honeoye Creek at a site two miles west of Rush, New York. Only the three most dominant species were listed: *Lampsilis ovata*, *Villosa iris*, and *Lasmigona costata*. Unpublished data from the Rochester Museum and Science Center (RMSC) identified nine species in Honeoye Creek at the junction of Rt. 15 and Fishell Rd. in Rush, New York. RMSC records dated from 1943 to 1988 and included *Anodontoides ferussacianus*, *Alasmidonta marginata*, *Elliptio dilatata*, *Fusconaia flava*, *Lampsilis siliquoidea*, *Strophitus undulatus*, and the three species reported by Clarke and Berg (1959).

In more recent surveys performed by the New York State Department of Environmental Conservation (NYSDEC), Landry and Mahar (2014) found 16 species of freshwater mussels in Honeoye Creek during qualitative surveys from 2008 to 2010, including nine species not previously reported: *Elliptio complanata*, *Lampsilis cardium*, *Lasmigona compressa*, *Leptodea fragilis*, *Ligumia nasuta*, *Potamilus alatus*, *Pyganodon grandis*, *Truncilla truncata*, and *Toxolasma parvus* (only represented by a spent shell).

While most rivers and creeks in western New York State are experiencing declines in mussel fauna (Strayer and Jirka 1997), based on limited historical data Honeoye Creek seems to be remaining stable. Data on species presence, distribution, abundance, and size-class structure are needed to establish a contemporary baseline for monitoring the status and health of freshwater mussel communities in Honeoye Creek and other watersheds in the future.

The goal of this part of my study was to document current freshwater mussel abundance and distribution at selected sites in Honeoye Creek, New York, and to provide quantitative base-line data for future monitoring programs of the freshwater mussel fauna in the creek. Specific objectives included:

1) Document mussel abundance (mussels/m^2) at selected sites in Honeoye Creek.
2) Document species distribution and percentages of mussel species collected using quantitative sampling methods.

3) Document size-class distributions of mussels collected at the selected sites.
4) Determine if there are statistical differences in abundance or species richness among the three sampling zones, defined by impassable barriers, in Honeoye Creek.
5) Identify areas for long term monitoring and make recommendations for management strategies to protect, maintain and recover mussel populations in Honeoye Creek.

Materials and Methods

Site Selection

In 2012, 20 sites were sampled on Honeoye Creek, from its outlet at the northern end of Honeoye Lake in Richmond, New York to its confluence with the Genesee River (Figure 2, Appendix A). Sampling sites were selected based on the locations of previously documented living mussels identified during qualitative surveys performed by the NYSDEC in 2009, 2010, and 2011 (Landry and Mahar 2014). Additional not-previously-surveyed sites were selected to provide more complete coverage of Honeoye Creek. Sampling site dimensions were determined following a method similar to Villella and Smith (2005); the length of the site sampled was 1.5 times the stream width.

Two impassible barriers on Honeoye Creek served to split the creek into three zones. The first zone (upper) consisted of Honeoye Lake to Honeoye Falls and included sites 15 to 20. The second zone (middle) consisted of the Honeoye Falls to the dam located in the town of Rush, New York and included sites 10 to 14. The third zone (lower) consisted of the dam in the town of Rush to Honeoye Creek's confluence with the Genesee River and included sites 1 to 9 (Figure 2).

Quantitative Sampling

Quantitative surveys were performed by visually searching 0.25 m^2 quadrats placed a calculated (see below) distance apart. Systematic sampling incorporating three random starts was used, as suggested by Smith *et al*. (2000). The level of quantitative sampling varied for each site (Figure 2). All sites in the upper zone (15-20) were sampled using 72 quadrats. Sites in the middle zone (10-14) were sampled using 72 quadrats, with the exception of site 11, where 150 quadrats were searched. Sites in the lower zone (1-9) were sampled using 150 quadrats, with the exception of site 9, where 36 quadrats were searched. The number of quadrats sampled varied based on the likelihood of mussel occurrence as well as time and cost constraints.

Upon arrival at a site, the distance between quadrats was determined using the following equation provided by Smith *et al*. (2001) and Strayer and Smith (2003):

$$d = \sqrt{L * \frac{W}{\frac{n}{k}}}$$

where d is the distance between quadrats, L and W are the length and width of the stream, n is the total number of quadrats, and k is the number of random starts.

After the distance between each quadrat was calculated, the random start points were generated. Each start point began at the lower right edge of the downstream reach of the site. A total of six numbers were randomly generated (two random numbers for each start point) to locate each start point (Strayer and Smith 2003). The range of the random numbers generated was dependent on the distance between each quadrat. Strayer and Smith (2003) provided the example: if the distance between each quadrat is 3 m then the two random numbers generated for each random start will be between zero and three. If the numbers zero and two are generated then the first point would be 0 m from the right edge of the bank and 2 m upstream from the bottom edge of the site. Quadrats were then placed across and upstream from each random start (Strayer and Smith 2003).

Quadrats were visually searched for freshwater mussels at the surface of the substrate using viewing buckets. Mussels located by visual searches were carefully removed from the sediment, identified to species, and measured to the nearest millimeter using calipers. All mussels were immediately returned to the approximate location in the creek where they were collected. Excavation of quadrats to increase chances of finding juvenile mussels was not performed. Smith *et al*. (2000) suggested that excavation may interfere with reproduction and cause increased mortality, especially for juvenile mussels. Not excavating quadrats limited the ability to discover recent recruits, but also reduced disturbance and potentially negative impacts to mussels in Honeoye creek.

Mussel Density

Mussel density (mussels/m^2) was calculated for each site by averaging the abundance of each species in the counting quadrats. Mean mussel density was calculated for each of the three zones by averaging the mussel densities from all sites within a zone. Kruskal-Wallis one-way ANOVA and Tamhane's T2 multiple comparison analysis were used to determine whether significant differences in mussel density existed between the upper, middle, and lower zones (Figure 2). Correlations (r) between mussel density and site number were calculated as well.

Precision, in the form of coefficient of variation, of mussel density was calculated using the formula from Strayer and Smith (2003):

$$n = m^{-0.5} CV^{-2}$$

where, n = number of quadrats sampled, m = mean number of mussels per quadrat, and CV = coefficient of variation (standard error divided by the mean).

Species Distributions

The number of species present at each site was determined from quantitative sampling. Percentages of mussel species collected by zone and in the entire creek were calculated. Kruskal-Wallis one-way ANOVA and Tamhane's T2 multiple comparison analysis were used to determine if differences existed between numbers of species in the three zones. Correlation (r) between number of species collected and site number was calculated as well.

Size-class Structure

For the purpose of this study, size-classes were used to determine recent recruitment. Using guidelines from Ahlstedt *et al*. (2005), mussels less than 40 mm in length generally were considered recent recruits. Due to the smaller maximum lengths of *Fusconaia flava*, *Leptodia fragilis*, *Truncilla truncata*, and *Villosa iris* specimens less than 30 mm in length were considered recent recruits.

Community Similarity

The proportional index of community similarity (Brower and Zar 1984) was calculated as another way of comparing the mussel communities between the upper, middle, and lower zones. For each of the three zones, the percent of each species was calculated by taking the number of individuals of that species and dividing it by the total number of mussels sampled in that zone. Percent similarity was calculated by taking the sum of the lowest percent value for each species between the communities being compared.

Data Analysis

Both mussel density and species diversity data were checked for normality with a Shapiro-Wilk test and for homogeneity of variance with a Levene's test. Mussel density data failed both the Shapiro-Wilk and Levene's test, thus differences in mussel density were tested using Kruskal-Wallis one-way ANOVA. Species diversity data failed the Shapiro-Wilk test and these data also were tested using Kruskal-Wallis one-way ANOVA.

All statistical analyses were performed using IBM SPSS Statistics 20, G*Power 3.1.9.2, and Microsoft Excel 2010. P-values <0.05 were considered significant. Analyses to determine the level of power achieved by the post hoc tests were performed for the comparisons of abundance and species richness among zones. By achieving an appropriate level of power, the likelihood that a statistical test will accept H_0 when H_A is true can be determined. Power levels were calculated using α-levels of 0.05, 0.10, and 0.15.

Results

Mussel Density

Mussel density per sampling site ranged from 0 to 3.15 mussels/m^2 (Table 1). Coefficients of variation associated with mussel density ranged from 0.07 to 0.50 (Table 2). The average density of the lower zone was 1.55 mussels/m^2 compared to

0.048 mussels/m^2 in the middle zone and 0.323 mussels/m^2 in the upper zone. The Kruskal-Wallis one way ANOVA found significant differences between the three river zones (p= 0.002). Tamhane's T2 post hoc analysis determined that mussel density in the lower zone was significantly higher than the upper and middle zones (p= 0.033 for lower to upper; p= 0.010 for lower to middle). No significant differences occurred between the upper and middle zones (p= 0.394) (Table 3). There was a significant correlation between site and mussel density (r= -0.578, p= 0.008) (Figure 3). Post hoc power analysis determined that powers of 0.65, 0.77, and 0.84 were achieved with α-values of 0.05, 0.10, and 0.15 respectively (Table 4).

Species Diversity

Quantitative sampling in Honeoye Creek found 513 mussels of 15 species, including seven species of greatest conservation need (SGCN; NYSDEC 2006) in New York State (Table 5, Appendix B). Kruskal-Wallis one-way ANOVA found significant differences among number of species in each of the three zones ($p \leq 0.001$); the number of species collected in the lower zone was significantly higher than the number collected in the upper and middle zones ($p \leq 0.001$). There was no significant difference between the number of species collected in the upper and middle zones (p= 0.987) (Table 3). There was a significant correlation between site and number of species (r= -0.788, $p \leq 0.001$) (Figure 4). Post hoc power analysis determined that powers of 0.80, 0.89, and 0.93 were achieved with α-values of 0.05, 0.10, and 0.15, respectively (Table 4).

Fusconaia flava (46.8%), *Lampsilis siliquoidea* (16.8%), and *Lampsilis cardium* (10.1%) were the most commonly collected species, and were collected at 9, 10, and 8 sites, respectively. The next most common species, *Elliptio complanata* (6.8%), *Villosa iris* (5.5%), and *Lasmigona costata* (3.5%), were each collected at 6 sites. *Strophitus undulatus* (1.8%) was collected at 9 sites, while *Lasmigona compressa* (1.2%) was collected at 6 sites. *Pyganodon grandis* (1.0%), *Ligumia nasuta* (0.8%), *Truncilla truncata* (0.6%), *Anodontoides ferussacianus* (0.2%), *Alasmidonta marginata* (0.2%), and *Leptodea fragilis* (0.2%) were all collected at 4 or fewer sites (Table 6).

Community Similarity

Only two species were found in the upper zone, *E. complanata* (88.6%) and *L. nasuta* (11.4%). *V. iris* (55.6%), *A. ferussacianus* (11.1%), *A. marginata* (11.1%), *L. siliquoidea* (11.1%), and *L. costata* (11.1%) were the five species recorded in the middle zone. *F. flava* (51.2%), *L. siliquoidea* (18.1%), *L. cardium* (11.1%), *P. alatus* (5.1%), *V. iris* (4.9%), *L. costata* (3.6%), *S. undulatus* (1.9%), *L. compressa* (1.3%), *P. grandis* (1.1%), *E. complanata* (0.9%), *T. truncata* (0.6%), and *L. fragilis* (0.2%) were the 12 species recorded in the lower zone (Table 7). The zones with the highest community similarity were the middle and lower zones at 19.6%. The upper and lower zones had the lowest percent similarity at 0.9%. The upper and middle zones had 11.4% similarity (Table 8).

Size-class Structure

Three species were represented by single individuals: *A. ferussacianus*, *A. marginata*, and *L. fragilis*. The remaining 12 species were all represented by multiple size-classes (Appendix C). Of the 12 species with multiple size-classes, five had mussels below the size representing recent recruitment (< 30 mm or < 40 mm, depending on maximum length). Three species of greatest conservation need, *F. flava*, *L. cardium*, and *V. iris*, were represented by size-classes indicating recent recruitment. *F. flava* had the greatest number of individuals representing recent recruitment (Table 9). All mussels that were determined to have recent recruitment were found in the lower zone of Honeoye Creek.

Discussion

Mussel Diversity, Density and Abundance

While historical records report 18 species of freshwater mussels in Honeoye Creek, during this study 15 species (83%) were collected. The three species not present were *E. dilatata*, *L. ovata*, and *T. parvus*. The RMSC record of *E. dilatata* dates back to 1946, and it should be noted that this species is easily confused with *E. complanata* (Strayer and Jirka 1997). *L. ovata* and *L. cardium* are very similar species that are sometimes grouped as *L. ovata*; however, Strayer and Jirka (1997) indicate that New York records are *L. cardium*. It is possible that historic records misidentified these species. *T. parvis,* the final species not collected has only been recorded as a spent shell (dead individual) collected by Landry and Mahar (2014).

F. flava was the most abundant species followed by *L. siliquoidea* and *L. cardium*, suggesting the populations of these species are stable, and possibly recruiting (recent recruitment was observed for *F. flava* and *L. siliquoidea* and will be discussed below). In contrast the low abundance and percent composition of *A. ferussacianus*, *A. marginata*, *L. fragilis*, *L. nasuta*, *P. grandis*, and *T. truncata* suggest that these species are not recruiting and may become extirpated from Honeoye Creek.

Species Distributions

One of the more interesting findings during this study was the presence of *T. truncata* at site 1. Besides the recent NYSDEC surveys (Landry and Mahar 2014), the only other record of this species in New York was in Tonawanda Creek at North Tonawanda, New York in 1948 (Strayer and Jirka 1997). While unlikely, it is possible that *T. truncata* made its way from Tonawanda Creek to Honeoye Creek, via the Erie Canal and Genesee River. NYSDEC (2006) listed *T. truncata* as historically occurring in the southern Lake Ontario watershed, but believed to be extirpated.

Most of the sites in the middle and upper zones lacked freshwater mussels, and sites with mussels present had relatively low densities. It is possible that these sites are experiencing declines and mussels may soon be extirpated. The causes of the declines were not investigated during this study. Strayer and Jirka (1997) have suggested that human activities are the leading cause of mussel declines in New York. Activities such as agriculture, urban and suburban development, the construction of dams, and pollution are just a few of the threats to mussels. The construction of dams changes the area above the dam from a once running-water habitat, to standing or slow moving water habitat. This often leads to a shift to softer sediment and water level fluctuations. Freshwater mussels cannot tolerate these conditions and species diversity is often reduced or eliminated altogether (Watters 1996, Strayer and Jirka 1997).

Differences in species composition are apparent when compared among the three zones defined by this study. Species diversity in the upper and middle zones was significantly lower than the lower zone. These data suggest that mussels in the middle and upper zones have been subjected to influences leading to the decline of species diversity. Specifically the dam in Rush, NY and the natural waterfall in Honeoye Falls, NY may be restricting the distribution of freshwater mussels in the middle and upper zones. The limited historical records of mussels in Honeoye Creek only contain data in the defined lower zone of this study. The previous status of mussels in the middle and upper zones is unknown.

A source-sink hypothesis has been developed from data on the distribution of mussels in Honeoye Creek. Because mussels rely on a fish host to complete their life cycle, their distribution is limited by the distribution of the host fish (Watters 1996). It is hypothesized that the Genesee River is a source population for the mussels in Honeoye Creek. Fish from the Genesee River could have initially introduced freshwater mussels into Honeoye Creek. The dam located in Rush, New York would have restricted movement of host fish past this point, leading to mussels only being able to establish in the lower zone of Honeoye Creek. This hypothesis is supported by the low abundance and species diversity observed in the middle zone which is isolated by a dam downstream and a natural waterfall upstream. The intermediate abundance and diversity of mussels in the upper zone may be related to its connection with Honeoye Lake. It might be possible to test this hypothesis by exploring the genetics of freshwater mussels in the Genesee River, Honeoye Lake and Honeoye Creek. It is unlikely that freshwater mussels in the lower zone are migrants from Honeoye Lake or other tributaries. If this were the case, it would be expected to see a more similar species composition between the three zones.

Community Similarity

The low percent similarity between all three zones further supports the significant differences in species diversity found between the three zones of Honeoye Creek defined in this study (Table 8). The low similarity between zones suggests that the impassible barriers in Honeoye Creek are restricting the distribution of freshwater mussels by host fishes.

Size-class Structure

The data on size-class structure provide baseline data for Honeoye Creek. Future monitoring will be able to identify shifts in size-class structure of individual freshwater mussel species. Identifying shifts in size-class structure can indicate recent recruitment (a shift to smaller size classes) or recruitment failure (a shift to larger size classes). Although excavation to increase the chance of identifying recent recruits was not performed, recent recruitment was observed in Honeoye Creek for five species: *F. flava, L. cardium, L. siliquoidea, S. undulatus,* and *V. iris*. *F. flava* had the highest percent of recent recruits (12.9%). Observations of recent recruitment demonstrate that Honeoye Creek is able to support natural reproduction of some freshwater mussel species. While the visual surveys found mussels in size-classes representing recent recruitment, more research focused on identifying recent recruitment is necessary. Such surveys would better identify other species that may be recruiting, as well as confirm species that are not.

Sample Size

While no target precision was selected for this study, any long-term monitoring effort should have a target precision. The density estimates from this survey are relatively precise, with coefficients of variation ranging from 0.07 to 0.50 mussels/m^2. Determining the accuracy of these estimates would require significant disturbance to mussel habitat in order to determine true mussel densities. Using the data from this study, the number of quadrats that should be sampled to reach predetermined precision levels was determined (Table 10). Future quantitative sampling should include at least 200 quadrats at each site to reach a precision value of 0.1.

Conclusions

While these data provide a base-line for freshwater mussel diversity, abundance and distribution, additional research is needed to monitor the status and health of freshwater mussel communities in Honeoye Creek. The following are recommendations for future monitoring:

1) The majority of sites sampled in the middle and upper zones (10 through 20) produced no mussels, and those that did had one species with low abundance. Sites 11, 15, 19, and 20 should still be monitored by qualitative sampling to document species or loss recovery in the future.
2) There are still areas in the Honeoye Creek that remain un-sampled which should be targeted for qualitative and quantitative surveys to better document the status of the mussel fauna.
3) Although excavation was not preformed, evidence of recent recruitment of several species of mussel was observed. Future quantitative surveys should incorporate excavation of a subset of quadrats as smaller mussels and juveniles are more likely to be encountered this way. This will provide better data on size-class distributions of mussels in Honeoye Creek, and provide insight on mussel species that are successfully reproducing.
4) A standardized, long-term sampling program needs to be developed to monitor changes in the status of freshwater mussels at selected sites in Honeoye Creek. This program should create standard operating procedures for both qualitative and quantitative surveys, selection of sites to monitor, and creation of monitoring intervals.

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Tables

Table 1. Densities (mussels/m^2) of mussel species collected during quadrat sampling of sites in Honeoye Creek, New York.

	Site Number																			
	Lower Zone									Middle Zone					Upper Zone					
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Anodontoides ferussacianus	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-
Alasmidonta marginata	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-
Elliptio complanata	-	-	-	0.03	-	-	-	0.05	0.11	-	-	-	-	-	0.83	-	-	-	0.56	0.33
Fusconaia flava	0.91	0.08	0.45	2.27	0.51	1.55	0.32	0.13	0.78	-	-	-	-	-	-	-	-	-	-	-
Lampsilis cardium	0.45	0.03	-	0.24	0.21	0.27	0.05	0.05	0.33	-	-	-	-	-	-	-	-	-	-	-
Lampsilis siliquoidea	0.61	0.13	0.21	0.27	0.19	0.48	0.16	0.11	0.56	-	0.03	-	-	-	-	-	-	-	-	-
Lasmigona compressa	-	-	-	-	-	0.11	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Lasmigona costata	0.11	0.05	0.05	0.16	-	0.11	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-

Leptodea fragilis	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ligumia nasuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.22	
Potamilus alatus	0.40	-	0.03	0.05	-	0.11	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyganodon grandis	-	-	-	0.03	-	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strophitus undulatus	-	0.03	0.05	0.03	-	0.05	-	0.05	0.11	-	-	-	-	-	-	-	-	-	-	-
Truncilla truncata	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Villosa iris	-	-	0.13	0.08	0.11	0.19	0.11	-	-	-	0.13	-	-	-	-	-	-	-	-	-
Site Density (mussel/m^2)	2.56	0.35	0.93	3.15	1.01	2.96	0.75	0.40	1.89	0.00	0.24	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.78	0.33
Total Quadrats Sampled	150	150	150	150	150	150	150	150	36	72	150	72	72	72	72	72	72	72	72	72
Total Species	6	6	6	9	4	9	6	5	5	0	5	0	0	0	1	0	0	0	2	0

Table 2. Number of quadrats sampled, total mussel density (mussels/m^2), and coefficient of variation (CV) from samples in Honeoye Creek, New York.

Site	**Number of Quadrats**	**Density (mussels/m^2)**	**CV**
1	150	2.56	0.11
2	150	0.35	0.55
3	150	0.93	0.12
4	150	3.15	0.08
5	150	1.01	0.16
6	150	2.96	0.09
7	150	0.75	0.22
8	150	0.40	0.13
9	36	1.89	0.20
10	72	-	-
11	150	0.24	0.12
12	72	-	-
13	72	-	-
14	72	-	-
15	72	0.83	0.33
16	72	-	-
17	72	-	-
18	72	-	-
19	72	0.78	0.07
20	72	0.33	0.29

Table 3. Differences in species diversity and mussel density (mussel/m^2) within the upper, middle, and lower zones of Honeoye Creek, New York. Sites were divided into zones (Upper: sites 15 to 20; Middle: sites 10-14; Lower: sites 1-9). Like letters indicate no significant difference ($p > 0.05$) per Tukey's HSD and Tamhane's T2 post hoc analysis.

Species Diversity		**Mussel Density (mussel/m^2)**	
Zone	**Mean**	**Zone**	**Mean**
Upper	0.67a	**Upper**	0.323a
Middle	1.00a	**Middle**	0.048a
Lower	6.22b	**Lower**	1.55b

Table 4. Levels of power achieved through post hoc power analysis of ANOVA of mussel density and species diversity within the upper, middle, and lower zones. Higher levels of power show increased ability of a statistical test to detect significant differences between zones.

α	**Mussel Density (mussels/m^2)**	**Species Diversity**
0.05	0.65	0.80
0.10	0.77	0.89
0.15	0.84	0.93

Table 5. Mussel species collected during sampling in Honeoye Creek, New York.

Scientific Name	**Common Name**
Alasmidonta marginata[1]	Elktoe
Anodontoides ferussacianus	Cylindrical papershell
Elliptio complanata	Eastern elliptio
Fusconaia flava[1]	Wabash pigtoe
Lampsilis cardium[1]	Plain pocketbook
Lampsilis siliquoidea	Fatmucket
Lasmigona compressa	Creek heelsplitter
Lasmigona costata	Flutedshell
Leptodea fragilis	Fragile papershell
Ligumia nasuta[1]	Eastern pondmussel
Potamilus alatus[1]	Pink heelsplitter
Pyganodon grandis	Giant floater
Strophitus undulates	Creeper
Truncilla truncata[1]	Deertoe
Villosa iris[1]	Rainbow

[1]Species of greatest conservation need (NYSDEC 2006)

Table 6. Sites present at and percent composition of mussels collected in Honeoye Creek, New York.

Species	**Number of Sites Found**	**Number Collected**	**Percent Composition**
Alasmidonta marginata	1	1	0.19
Anodontoides ferussacianus	1	1	0.19
Elliptio complanata	6	35	6.82
Fusconaia flava	9	240	46.78
Lampsilis cardium	8	52	10.14
Lampsilis siliquoidea	10	86	16.76
Lasmigona compressa	2	6	1.17
Lasmigona costata	6	18	3.51
Leptodea fragilis	1	1	0.19
Ligumia nasuta	1	4	0.78
Potamilus alatus	5	24	4.68
Pyganodon grandis	2	5	0.97
Strophitus undulatus	6	9	1.75
Truncilla truncata	1	3	0.58
Villosa iris	6	28	5.46
	Total	**513**	**100.00**

Table 7. Percent composition of mussels by zone in Honeoye Creek, New York.

	Lower	**Middle**	**Upper**
Alasmidonta marginata	0.0	11.1	0.0
Anodontoides ferussacianus	0.0	11.1	0.0
Elliptio complanata	0.9	0.0	88.6
Fusconaia flava	51.2	0.0	0.0
Lampsilis cardium	11.1	0.0	0.0
Lampsilis siliquoidea	18.1	11.1	0.0
Lasmigona compressa	1.3	0.0	0.0
Lasmigona costata	3.6	11.1	0.0
Leptodea fragilis	0.2	0.0	0.0
Ligumia nasuta	0.0	0.0	11.4
Potamilus alatus	5.1	0.0	0.0
Pyganodon grandis	1.1	0.0	0.0
Strophitus undulatus	1.9	0.0	0.0
Truncilla truncata	0.6	0.0	0.0
Villosa iris	4.9	55.6	0.0

Table 8. Community similarity between zones in Honeoye Creek, New York.

Zones Being Compared	Percent Similarity
Upper and Middle	11.4
Upper and Lower	0.9
Middle and Lower	19.6

Table 9. Percent of individuals collected in size classes suggesting recent recruitment in the lower zone of Honeoye Creek, New York. Individuals less than 40 mm in length were considered recent recruits for *Lampsilis cardium*, *Lampsilis siliquoidea*, and *Strophitus undulates*. Individuals less than 30 mm in length were considered recent recruits for *Fusconia flava* and *Villosa iris*.

Species	**Total Number**	**Recent Recruits**	**Percent Recent Recruits**
Fusconaia flava	240	31	12.9
Lampsilis cardium	52	3	5.8
Lampsilis siliquoidea	85	4	4.7
Strophitus undulatus	14	1	7.1
Villosa iris	23	2	8.7

Table 10. Number of quadrats required to obtain predetermined levels of precision at where mussels were present in Honeoye Creek.

	Precision				
Site	**0.20**	**0.15**	**0.1**	**0.075**	**0.05**
1	16	28	63	111	250
2	42	75	169	300	676
3	26	46	104	184	415
4	14	25	56	100	225
5	25	44	100	177	398
6	15	26	58	103	232
7	29	51	115	205	462
8	40	70	158	281	632
9	18	32	73	129	291
11	51	91	204	363	816
15	27	49	110	195	439
19	28	50	113	201	453
20	44	77	174	309	696

Figures

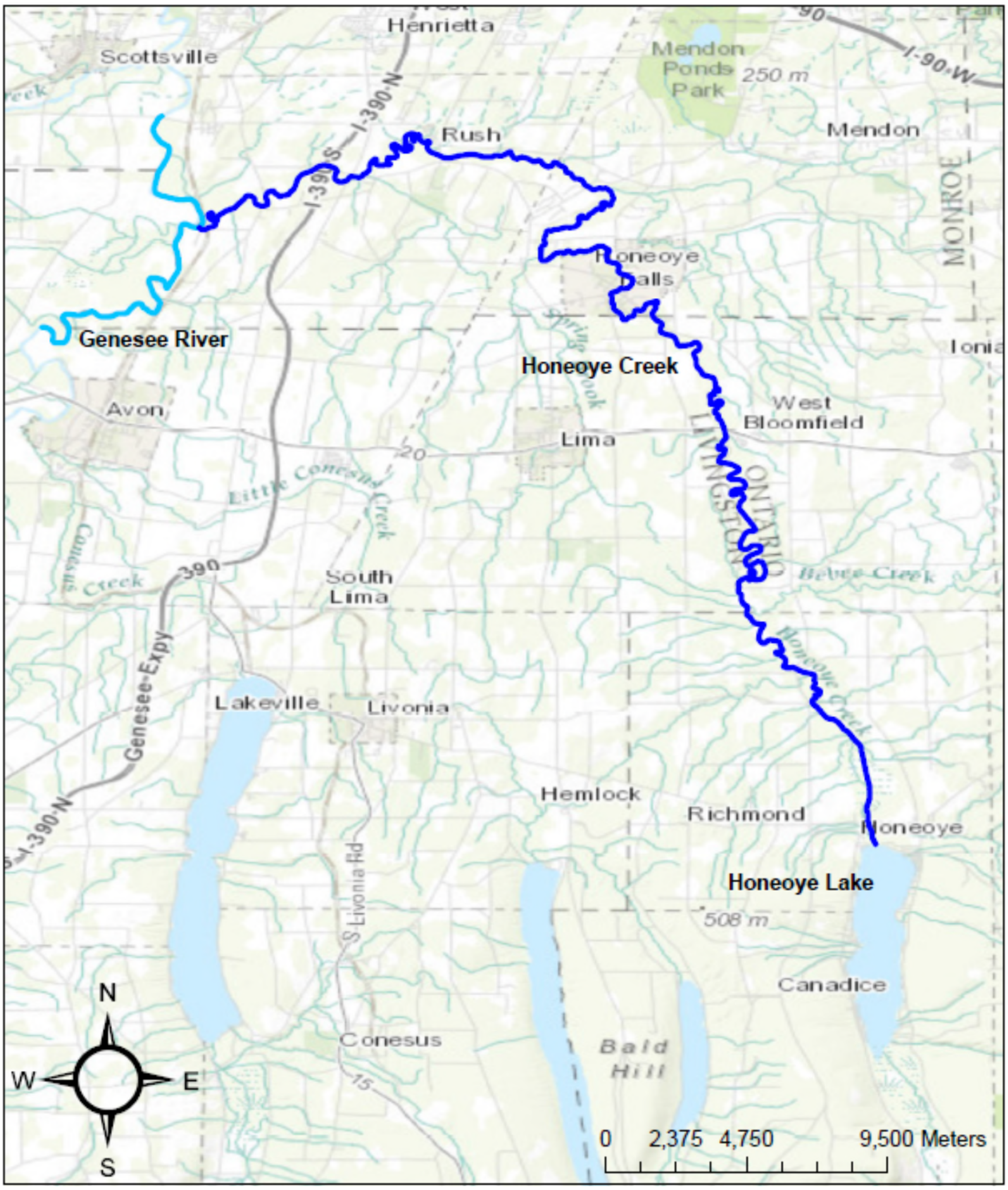


Figure 1. Location of Honeoye Creek in the Finger Lakes region of New York State.

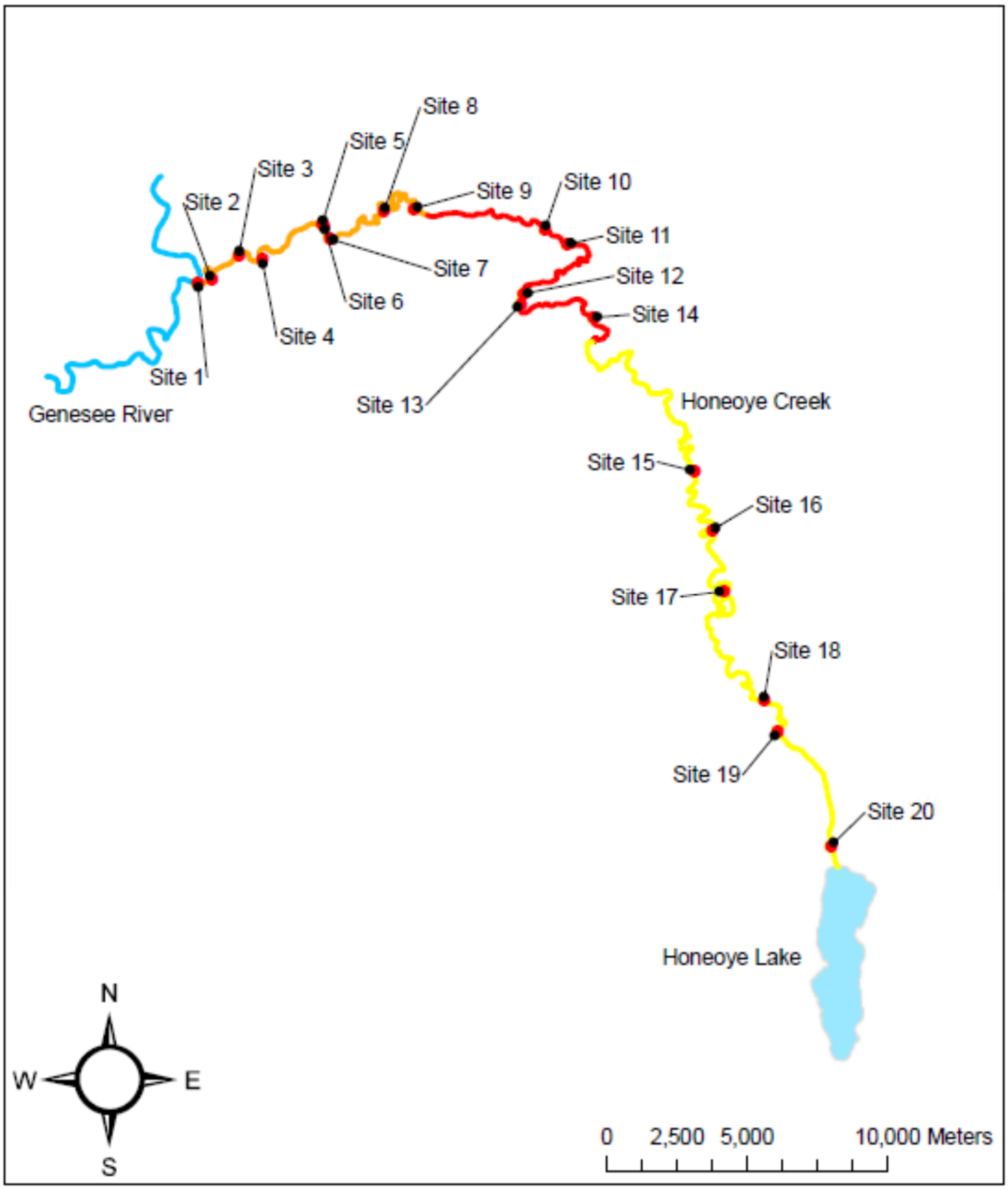


Figure 2. Locations of mussel sampling sites in Honeoye Creek. The orange segment represents the lower zone, red the middle zone, and yellow the upper zone.

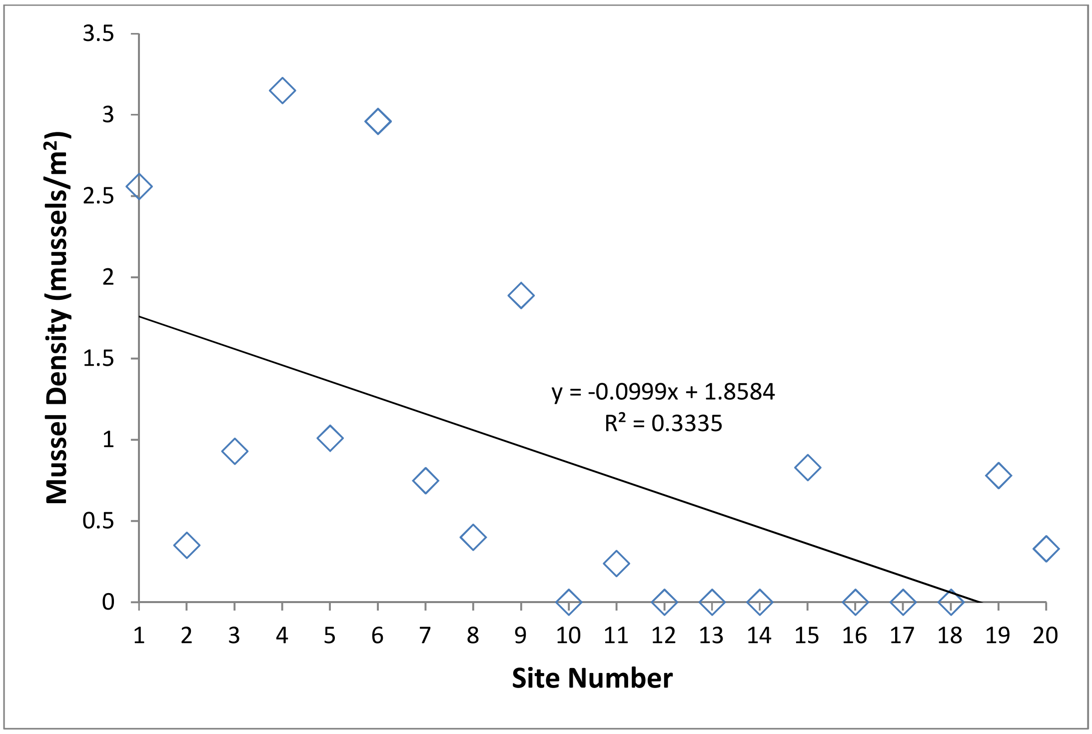


Figure 3. Plot of mussel densities at sites in Honeoye Creek, New York. Correlation between mussel density and site: r= -0.578.

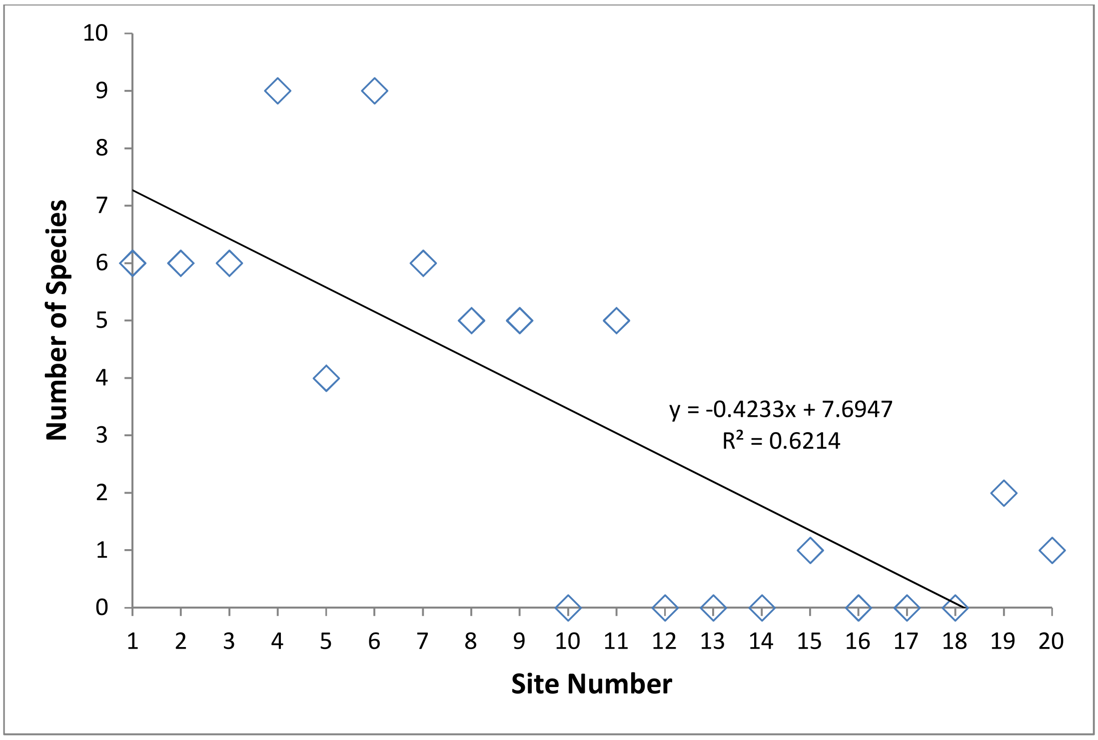


Figure 4. Plot of number of species at sites in Honeoye Creek, New York.

Correlation between number of species and site: r= -0.788.

Appendices

Appendix A. GPS coordinates for the 20 sites sampled in Honeoye Creek.

Site	Latitude	Longitude
1	42.971002°	-77.718366°
2	42.971959°	-77.713860°
3	42.979901°	-77.705199°
4	42.978454°	-77.697722°
5	42.989791°	-77.678356°
6	42.989578°	-77.677792°
7	42.985204°	-77.675926°
8	42.993806°	-77.658563°
9	42.994937°	-77.648866°
10	42.988006°	-77.606892°
11	42.983456°	-77.599801°
12	42.967486°	-77.613643°
13	42.964225°	-77.614554°
14	42.960589°	-77.592244°
15	42.910471°	-77.559029°
16	42.891736°	-77.553196°
17	42.872156°	-77.549466°
18	42.836876°	-77.536451°
19	42.826684°	-77.532073°
20	42.790348°	-77.515069°

Appendix B. Photographic documentation of freshwater mussels in Honeoye Creek.

B-1. Alasmidonta marginata (Elktoe).

B-2. *Anodontoides ferussacianus* (Cylindrical papershell).

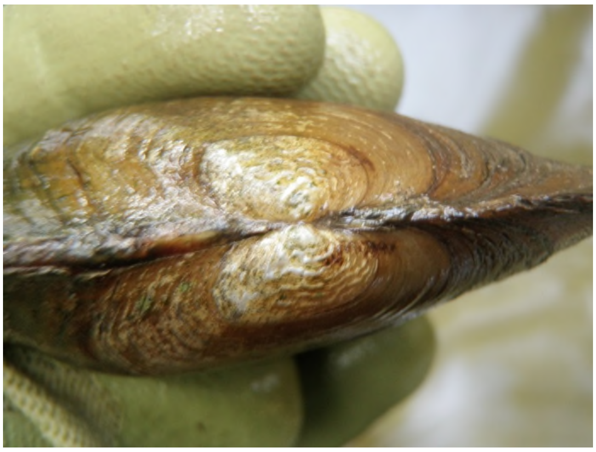
B-3. *Elliptio complanata* (Eastern elliptio).

B-4. *Fusconaia flava* (Wabash pigtoe).

B-5. *Lampsilis cardium* (Plain pocketbook).


B-6. Lampsilis siliquoidea (Fat mucket).


B-7. *Lasmigona compressa* (Creek heelsplitter).



B-8. *Lasmigona costata* (Flutedshell).

B-9. *Leptodea fragilis* (Fragile papershell).

B-10. *Ligumia nasuta* (Eastern pondmussel).

B-11. *Potamilus alatus* (Pink heelsplitter).

B-12. *Pyganodon grandis* (Giant floater).

B-13. Strophitus undulatus (Creeper).

B-14. *Truncilla truncate* (Deertoe).

B-15. *Villosa iris* (Rainbow).

Appendix C. Size class distributions of mussel species collected in Honeoye Creek, New York in 2012.

C-1. Size class distribution of *Alasmidonta marginata*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
11	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Total	0	0	0	0	1	0	0	0	0	0	0	0	0	0

C-2: Size class distribution of *Anodontoides ferussacianus*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
11	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Total	0	0	0	0	1	0	0	0	0	0	0	0	0	0

C-3. Size class distribution of *Elliptio complanata*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
4	-	-	-	-	-	-	-	-	-	-	-	1	-	-
8	-	-	-	-	-	-	1	-	-	1	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	1	-	-
15	-	-	-	-	-	-	2	2	5	3	2	1	-	-
19	-	-	-	-	-	-	2	4	2	1	1	-	-	-
20	-	-	-	-	-	-	1	2	1	1	1	-	-	-
Total	0	0	0	0	0	0	6	8	8	6	4	3	0	0

C-4. Size class distribution of *Fusconaia flava*. Mussels less than 30 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**109-119**	**120-129**	**130-139**
1	-	-	-	2	12	9	4	6	1	-	-	-	-	-
2	-	-	-	2	-	-	1	-	-	-	-	-	-	-
3	-	-	-	2	3	4	1	3	4	-	-	-	-	-
4	-	-	1	11	15	16	24	16	2	-	-	-	-	-
5	-	-	1	4	4	1	5	3	1	-	-	-	-	-
6	-	-	1	6	17	7	9	8	10	-	-	-	-	-
7	-	-	-	-	1	4	1	2	3	1	-	-	-	-
8	-	-	-	-	1	1	1	-	1	1	-	-	-	-
9	-	-	-	1	1	-	-	1	3	1	-	-	-	-
Total	0	0	3	28	54	42	46	39	25	3	0	0	0	0

C-5. Size class distribution of *Lampsilis cardium*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
1	-	-	-	-	-	-	-	-	3	2	2	4	5	1
2	-	-	-	-	-	-	-	1	-	-	-	-	-	-
4	-	-	-	-	-	-	-	1	4	2	1	1	-	-
5	-	-	-	1	1	-	-	1	1	1	2	1	-	-
6	-	-	-	-	-	-	2	2	4	1	-	1	-	-
7	-	-	-	-	1	-	-	-	-	-	-	1	-	-
8	-	-	-	-	-	1		-	-	-	1	-	-	-
9	-	-	-	-	-	-	-	-	2	-	-	1	-	-
Total	0	0	0	1	2	1	2	5	14	6	6	9	5	1

C-6. Size class distribution of *Lampsilis siliquoidea*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
1	-	-	-	2	2	1	1	1	3	4	3	1	-	-
2	-	-	-	-	-	-	-	-	1	4	-	-	-	-
3	-	-	-	-	-	-	-	3	4	-	1	-	-	-
4	-	-	-	-	-	-	2	3	2	3	-	-	-	-
5	-	-	-	-	-	1	1	1	2	-	1	1	-	-
6	-	-	-	-	5	2	1	3	5	2	-	-	-	-
7	-	-	2	-	-	2	-	-	1	-	1	-	-	-
8	-	-	-	-	-	-	1	-	2	-	-	1	-	-
9	-	-	-	-	1	-	-	-	1	-	3	-	-	-
10	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Total	0	0	2	2	8	6	7	11	21	13	9	3	0	0

C-7. Size class distribution of *Lasmigona compressa*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
5	-	-	-	-	1	3	-	-	-	-	-	-	-	-
6	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Total	0	0	0	0	2	4	0	0	0	0	0	0	0	0

C-8. Size class distribution of *Lasmigona costata*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
1	-	-	-	-	-	-	-	-	-	2	-	1	1	-
2	-	-	-	-	-	-	-	-	1	1	-	-	-	-
3	-	-	-	-	-	-	-	1	-	1	-	-	-	-
4	-	-	-	-	-	-	-	2	2	2	-	-	-	-
5	-	-	-	-	1	1	-	-	2	-	-	-	-	-
11	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Total	0	0	0	0	1	1	1	3	5	6	0	1	1	0

C-9. Size class distribution of *Leptodea fragilis*. Mussels less than 30 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
2	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Total	0	0	0	0	0	0	1	0	0	0	0	0	0	0

C-10: Size class distribution of *Ligumia nasuta*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
19	-	-	-	-	-	-	2	1	1	-	-	-	-	-
Total	0	0	0	0	0	0	2	1	1	0	0	0	0	0

C-11. Size class distribution of *Potamilus alatus*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
1	-	-	-	-	2	-	1	-	1	3	-	5	2	1
3	-	-	-	-	-	-	-	1	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	1	-	1	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	1	-	-	1	1	1	-	-	-
7	-	-	-	-	-	-	-	-	1	-	-	1	-	-
Total	0	0	0	0	2	1	1	1	4	4	2	6	2	1

C-12. Size class distribution of *Pyganodon grandis*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
4	-	-	-	-	-	-	-	1	-	-	-	-	-	-
6	-	-	-	-	-	1	1	-	1	1	-	-	-	-
Total	0	0	0	0	0	1	1	1	1	1	0	0	0	0

C-13. Size class distribution of *Strophitus undulatus*. Mussels less than 40 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
2	-	-	-	-	-	-	1	-	-	-	-	-	-	-
3	-	-	-	1	-	-	1	-	-	-	-	-	-	-
4	-	-	-	-	-	1	-	-	-	-	-	-	-	-
6	-	-	-	-	1	1	-	-	-	-	-	-	-	-
8	-	-	-	-	-	1	-	-	1	-	-	-	-	-
9	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Total	0	0	0	1	1	3	2	1	1	0	0	0	0	0

C-14. Size class distribution of *Truncilla truncata*. Mussels less than 30 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
1	-	-	-	-	2	1	-	-	-	-	-	-	-	-
Total	0	0	0	0	2	1	0	0	0	0	0	0	0	0

C-15. Size class distribution of *Villosa iris*. Mussels less than 30 mm were considered recent recruits.

	Size-class (mm)													
Site	**0-09**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-109**	**110-119**	**120-129**	**130-139**
3	-	-	-	2	1	2	-	-	-	-	-	-	-	-
4	1	-	-	1	1	-	-	-	-	-	-	-	-	-
5	-	-	1	-	2	1	-	-	-	-	-	-	-	-
6	-	-	-	2	1	3	1	-	-	-	-	-	-	-
7	-	-	-	-	2	2	-	-	-	-	-	-	-	-
11	-	-	-	-	4	1	-	-	-	-	-	-	-	-
Total	1	0	1	5	11	9	1	0	0	0	0	0	0	0

Chapter 2: Correlating Freshwater Mussel Density with EPA Habitat Assessment Parameters and Predicting Presence/Absence Using Discriminant Analysis

Introduction

Freshwater mussels may be habitat sensitive water quality indicators (Fuller 1974, Strayer and Ralley 1993) but the degree to which physical habitat parameters and water chemistry affect freshwater mussel populations has been unclear to biologists (Gangloff and Feminella 2007). Previous studies have tried to link mussel density to water quality and physical characteristics of streams (Fuller 1974, Strayer and Ralley 1993, Strayer 1999) but there has been no consensus regarding definitive, predictive relationships among any of these factors and mussel density in streams (Nicklin and Balas 2007). As a result, management and conservation efforts have been constrained by a lack of quantitative information regarding species-habitat relationships (Strayer and Smith 2003).

Linking habitat variables to mussel density or even presence/absence would be valuable for the management and conservation of freshwater mussels. In order to understand the status of freshwater mussels, qualitative and quantitative data must be collected, which is costly and time consuming (Strayer and Smith 2003). The development and implementation of a strategy that allows for rapid collection of habitat data that can be used to determine mussel density or presence/absence would be beneficial for the management and conservation of freshwater mussels. Reducing the time spent locating mussels populations would allow conservation efforts to focus on collecting important data such as distribution, abundance, and size- or age-class structures.

The goal of this part of my study was to determine if there is a relationship between freshwater mussels and habitat parameters. Specific objectives included:

1) Assess whether mussel density is correlated with easily obtained measures of stream habitat quality, specifically the U.S. Environmental Protection Agency's (EPA) rapid bioassessment protocols for use in streams (Barbour *et al.* 1999).
2) Use discriminant analysis to determine if habitat variables can be used to predict mussel presence/absence.

Materials and Methods

Site Selection

In 2012, 20 sites were sampled on Honeoye Creek for physical and chemical habitat parameters from its outlet at the northern end of Honeoye Lake in Richmond, New York to its confluence with the Genesee River in Golah, New York (Figure 1). These sites were sampled in conjunction with the quantitative freshwater mussel surveys reported in Chapter 1.

Habitat Characterization

I attempted to develop a relationship between mussel presence/absence and a number of physical habitat and water quality parameters. A YSI multi-meter was used to measure dissolved oxygen, pH, conductivity and temperature. LaMotte water quality test kits were used to test concentrations of nitrate and phosphate, measured as total orthophosphate. To ensure more realistic readings, water quality parameters were measured before sampling for mussels.

Physical habitat was characterized using the EPA's rapid bioassessment protocols for use in wadable waters (Barbour *et al*. 1999). The ten components analyzed were 1) instream cover, 2) embeddedness, 3) velocity/depth regime, 4) sediment deposition, 5) channel flow, 6) channel alteration, 7) frequency of riffles, 8) bank stability, 9) vegetative protection, and 10) riparian vegetative zone width. Each habitat parameter was scored on a scale of 0-20, with 16-20 being optimal habitat (Table 1). Bank stability, vegetative protection, and riparian vegetative zone width were split between left bank and right bank with each bank being scored 0-10. The sum of the individual scores for the 10 physical habitat parameters produced a total Habscore.

Data Analysis

Spearman's correlation was used to determine the relationship between mussel density and each physical habitat and water quality parameter at the sampling locations. Stepwise discriminant analysis was performed using the four variables significantly correlated with mussel density (instream cover, embeddedness, velocity/depth regime, and frequency of riffles), in order to determine their ability to predict sites with and sites without freshwater mussels. The four predictor variables were tested for normality using a Shapiro-Wilks test; all predictor variables were determined to be normal. To prevent misclassification of subjects to groups with the largest variance, equality of covariance matrices is required. To meet this requirement, the sample size of the smallest group must be larger than the number of predictor variables. This assumption was met as the sample size of the smallest group, sites without mussels, was seven and the number of predictor variables was four. A Mann-Whitney U test was used to determine if significant differences existed between total Habscore and sites with or without freshwater mussels. All statistical analysis was performed using IBM SPSS Statistics 20.

Results

Correlations

Temperature ranged from 13.6°C to 22.1°C. Specific conductance was relatively high at three sites, two of which lacked mussels (sites 16 and 17) and one with the fourth highest mussel density (site 9). Dissolved oxygen concentration ranged from 5.89 to 12.1 mg/L, and pH ranged from 6.98 to 8.82. Nitrate levels ranged from 8.8 to 22 ppm, and total orthophosphate concentrations ranged from 0.3 to 0.8 ppm (Table 2). Mussel density was not significantly correlated with any of these variables (Table 3), although total orthophosphate approached significance ($p=0.056$).

Physical habitat variables ranged from poor to optimal for the ten variables measured. Total Habscore ranged from 69 to 161 among the 20 sampling sites (Table 4). Instream cover ($p < 0.001$), embeddedness ($p=0.017$), velocity/depth regime ($p < 0.001$), frequency of riffles ($p=0.017$), and total Habscore ($p=0.008$) were positively correlated with mussel density (Table 3).

Discriminant Analysis

Stepwise discriminant analysis produced a single function, positively correlated with velocity/depth regime and instream cover. The habitat variables embeddedness and frequency of riffles had no value in predicting sites with freshwater mussels and sites without freshwater mussels and therefore were not included in the analysis. The discriminant analysis correctly classified 95% of the sites based on sites with freshwater mussels and sites without freshwater mussels (Table 5). All sites without freshwater mussels were classified correctly and only one site with freshwater mussels was misclassified as a site without freshwater mussels. A Mann-Whitney U test confirmed that there was a significant difference ($p=0.008$) in the total Habscore between sites with freshwater mussels and sites without freshwater mussels.

Discussion

Correlations

The lack of significant correlations between mussel density and water quality parameters was consistent with the findings of Nicklin and Balas (2007). However, water quality parameters fluctuate over time. A single measurement does not reflect the entire range of conditions that influence freshwater mussel distribution and abundance. It is interesting to note that total orthophosphate approached significance with mussel density. Long term monitoring of phosphorus may provide a better understanding of the relationship (if any) between freshwater mussels and phosphorus concentrations in Honeoye Creek.

Freshwater mussels are unique in that they interact with the both water column and sediment, especially juvenile mussels that live completely buried in the sediment (Strayer and Malcom 2012). The water chemistry of interstitial water may differ from that of the water column, which may further complicate mussel-habitat relationships, i.e., investigators may not be measuring water quality in the right microhabitat.

Correlation of mussel abundance and broad measures of habitat conditions, including instream cover, embeddedness and velocity/depth regime, were consistent with the findings of Nicklin and Balad (2007) and were not surprising. Instream cover, velocity/depth regime, and frequency of riffles were positively correlated with mussel density, and they influence habitat stability and may provide refuge for freshwater mussels during storm events (Barbour *et al.* 1999).

Strayer (1999) noted that the density of freshwater mussels in rivers has not been explained by simple habitat features. Instead he suggested that favorable habitats might be located in flow refuges, parts of the stream bed protected from severe disturbance during floods. It is possible that freshwater mussels in Honeoye Creek utilize flow refuges, leading to the patchiness in mussel density throughout the creek, an idea supported by the positive correlations to instream cover, velocity/depth regimes, and frequency of riffles. According to Barbour *et al.* (1999) optimal ratings of these parameters provide and maintain stable aquatic habitat, allow for the absorption of energy from excessive erosion and flooding, and provide refugia for benthic invertebrates and fish during storm events. The use of tracer particles at sites with high ratings for instream cover, velocity/depth regimes, and frequency of riffles would provide a better understanding of the ability of these sites to provide refuge from floods (Strayer 1999).

Embeddedness had the lowest correlation coefficient (r=0.526) of all the significant habitat variables. It stands out because it is the only variable (of the four correlated to mussel density) that doesn't influence habitat stability. There are two reasons why it might be correlated to mussel density: 1) embeddedness is measure of how sunken gravel, cobble, and boulders are in the sediment, which could impact a mussel's ability to burrow, and 2) it is a result of large-scale sediment movement and deposition, which is has been found to be detrimental to freshwater mussels (Strayer and Jirka 1997).

Discriminant Analysis

Stepwise discriminant analysis was able to provide a more predictive relationship between freshwater mussels and habitat parameters, producing a single discriminant function positively correlated with instream cover and velocity/depth regime, which also had the strongest correlations to mussel density. This analysis incorrectly predicted site 2, a site with freshwater mussels, as a site without freshwater mussels. The incorrect predication may be attributed to the low mussel density (third lowest among sites with mussels present), the lower Habscore ratings of instream cover and velocity/depth regime at the site, or the presence of a refugium.

The ability of the model to correctly classify 95.0% of sites in this study provides support for the use of easily obtained habitat parameters to accurately locate freshwater mussel populations in Honeoye Creek.

The significant difference in total Habscores between sites with freshwater mussels and sites without freshwater mussels suggests the EPA's rapid bioassessment protocol may be able to distinguish such sites. Sites with freshwater mussels had a significantly higher total Habscore than sites without freshwater mussels. However, this does not provide a definitive predictive relationship between mussel density and habitat variables, suggesting there may be other variables influencing freshwater mussels and supports other inconsistent findings (Layzer and Madison 1995, Vaughn and Pyron 1995, Strayer and Ralley 1993) on mussel-habitat relationships. The significant differences in total Habscore at sites with freshwater mussels and without freshwater mussels offered some insight in developing mussel-habitat relationships that may prove beneficial for the management and conservation of freshwater mussels in Honeoye Creek.

Conclusion

Due to the complexity of freshwater mussel-habitat relationships and the lack of definitive, predictive relationships among habitat and mussel density in streams, rapid bioassessment may only be useful as a guideline for identifying presence or absence of freshwater mussels. Furthermore, important variables may be specific for individual bodies of water (e.g., Honeoye Creek). Additional research is needed in order to determine if this method is suitable for use in other bodies of water. Resource managers looking to develop baseline data for freshwater mussels in not-previously-surveyed locations could benefit from this method. Implementing a rapid bioassessment protocol would provide a cost effective method for identifying areas that warrant quantitative surveys to assess and monitor mussel population health.

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Tables

Table 1. Field data ranks used to assess the physical habitat of Honeoye Creek, NY (Barbour *et al.* 1999).

Habitat Parameter	**Condition Category**			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e. logs/snags that are not new fall and not transient).	30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.

Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
Score	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1 0**
Velocity/Depth Regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast shallow).	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/depth regime (usually slow-deep).
Score	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1 0**

Sediment Deposition	Little or no enlargement of islands or point bars and less than 20% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 20-50% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 80% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
Score	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1 0**
Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
Score	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1 0**

Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
Score	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1 0**

Frequency of Riffles or Bends	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
Score	**20 19 18 17 16**	**15 14 13 12 11**	**10 9 8 7 6**	**5 4 3 2 1 0**

Bank Stability	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars
Left Bank Score	**10 9**	**8 7 6**	**5 4 3**	**2 1 0**
Right Bank Score	**10 9**	**8 7 6**	**5 4 3**	**2 1 0**
Vegetative Protection	More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes;	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to

	vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	to any great extent; more than one-half of the potential plant stubble height remaining.	potential plant stubble height remaining.	5 centimeters or less in average stubble height.
Left Bank Score	**10 9**	**8 7 6**	**5 4 3**	**2 1 0**
Right Bank Score	**10 9**	**8 7 6**	**5 4 3**	**2 1 0**
Riparian Vegetative Zone Width	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
Left Bank Score	**10 9**	**8 7 6**	**5 4 3**	**2 1 0**
Right Bank Score	**10 9**	**8 7 6**	**5 4 3**	**2 1 0**

Table 2. Water quality data collected at each of the 20 sampling locations on Honeoye Creek, NY.

Site Number	**Temperature (Celsius)**	**Specific Conductance (us/cm)**	**Dissolved Oxygen (mg/L)**	**pH**	**Nitrate (ppm)**	**Orthophosphate (ppm)**	**Mussel Density (per m^2)**
1	19.1	553	7.34	8.10	15.4	0.4	2.56
2	18.0	539	6.52	7.93	13.2	0.3	0.35
3	22.1	550	7.24	7.84	13.2	0.4	0.93
4	22.0	430	8.32	8.08	8.8	0.4	3.15
5	13.1	664	8.83	8.10	17.6	0.4	1.01
6	18.3	589	6.43	8.40	17.6	0.5	2.96
7	21.7	535	8.53	7.65	13.2	0.4	0.75
8	21.4	533	7.20	8.10	15.4	0.5	0.40
9	22.1	972	8.71	8.33	17.6	0.5	1.89
10	17.5	458	6.50	8.15	15.4	0.6	0.00
11	16.8	512	6.90	8.28	13.2	0.5	0.24

12	21.1	541	8.58	8.09	13.2	0.5	0.00
13	13.6	571	12.10	8.55	22.0	0.8	0.00
14	20.7	540	8.73	7.78	13.2	0.4	0.00
15	20.2	550	7.25	7.85	13.2	0.5	0.83
16	20.3	725	6.21	8.82	22.0	0.8	0.00
17	20.3	740	5.89	8.09	22.0	0.8	0.00
18	21.7	532	8.47	6.98	13.2	0.4	0.00
19	21.4	520	6.98	8.10	15.4	0.5	0.78
20	19.7	489	6.89	7.90	13.2	0.5	0.33

Table 3. Spearman correlation coefficients between mussel density and measured habitat parameters.

Variable	Spearman Coefficient	Significance Value
Water Quality		
Temperature	0.045	0.852
Specific Conductance	0.079	0.740
Dissolved Oxygen (mg/L)	0.104	0.661
pH	0.039	0.872
Nitrate	-0.114	0.663
Phosphate	-0.434	0.056
Physical Habitat		
Instream Cover	0.783	0.000**
Embeddedness	0.526	0.017*
Velocity/Depth Regime	0.889	0.000**
Sediment Deposition	0.18	0.448
Channel Flow	-0.067	0.778
Channel Alteration	0.277	0.237
Frequency of Riffles	0.529	0.017*
Bank Stability	0.263	0.263
Vegetative Protection	-0.051	0.831
Riparian Zone Width	-0.129	0.588
Total Habscore	0.574	0.008**

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

Table 4. Physical habitat assessment estimates at each of the 20 sampling locations on Honeoye Creek, NY.

Site Number	Instream Cover	Embeddedness	Velocity/Depth Regime	Sediment Deposition	Channel Flow	Channel Alteration	Frequency of Riffles
1	16	16	15	16	15	19	17
2	6	7	11	11	10	18	8
3	16	16	15	12	12	19	15
4	16	12	13	14	14	15	11
5	15	11	14	5	15	20	13
6	17	7	12	8	6	16	6
7	16	12	12	14	13	18	11
8	18	14	12	13	12	18	13
9	11	11	15	4	11	19	14
10	7	7	8	11	13	18	8
11	11	13	11	13	14	18	10

12	2	7	7	4	14	16	13
13	7	6	4	0	13	19	5
14	8	11	5	13	12	18	8
15	13	9	12	9	14	18	12
16	5	8	7	5	14	16	2
17	7	7	5	10	14	16	2
18	5	8	6	14	13	15	11
19	13	10	8	11	12	18	12
20	14	9	9	8	14	18	12

Table 4. Physical habitat parameters continued.

Site Number	Bank Stability	Vegetative Protection	Riparian Zone Width	Total Habscore	Mussel Density (per m^2)
1	15	14	18	161	2.56
2	8	5	16	100	0.35
3	15	13	12	145	0.93
4	13	12	16	136	3.15
5	16	17	10	136	1.01
6	13	9	10	104	2.96
7	12	14	16	138	0.75
8	15	14	12	141	0.40
9	12	13	7	117	1.89
10	15	18	17	122	0.00
11	15	9	6	120	0.24
12	12	16	16	107	0.00

13	16	18	18	106	0.00
14	8	5	16	104	0.00
15	15	15	14	131	0.83
16	6	4	2	69	0.00
17	5	5	2	73	0.00
18	13	15	17	117	0.00
19	15	16	15	130	0.78
20	15	15	14	128	0.33

Table 5. Discriminant analysis of mussel presence/absence versus measured habitat variables. Variables embeddedness and frequency of riffles were statistically significant in describing mussel sites with freshwater mussels and sites without freshwater mussels, and were included in the stepwise discriminant model; the percentage of sites whose mussel presence/absence were correctly classified is presented.

	Presence	Predicted Group Membership		Total
		Present	Absent	
Count	Present	12	1	13
	Absent	0	7	7
Percent	Present	92.3%	7.7%	100.0%
	Absent	0.0%	100.0%	100.0%

*95.0% of cases were correctly classified

Figures

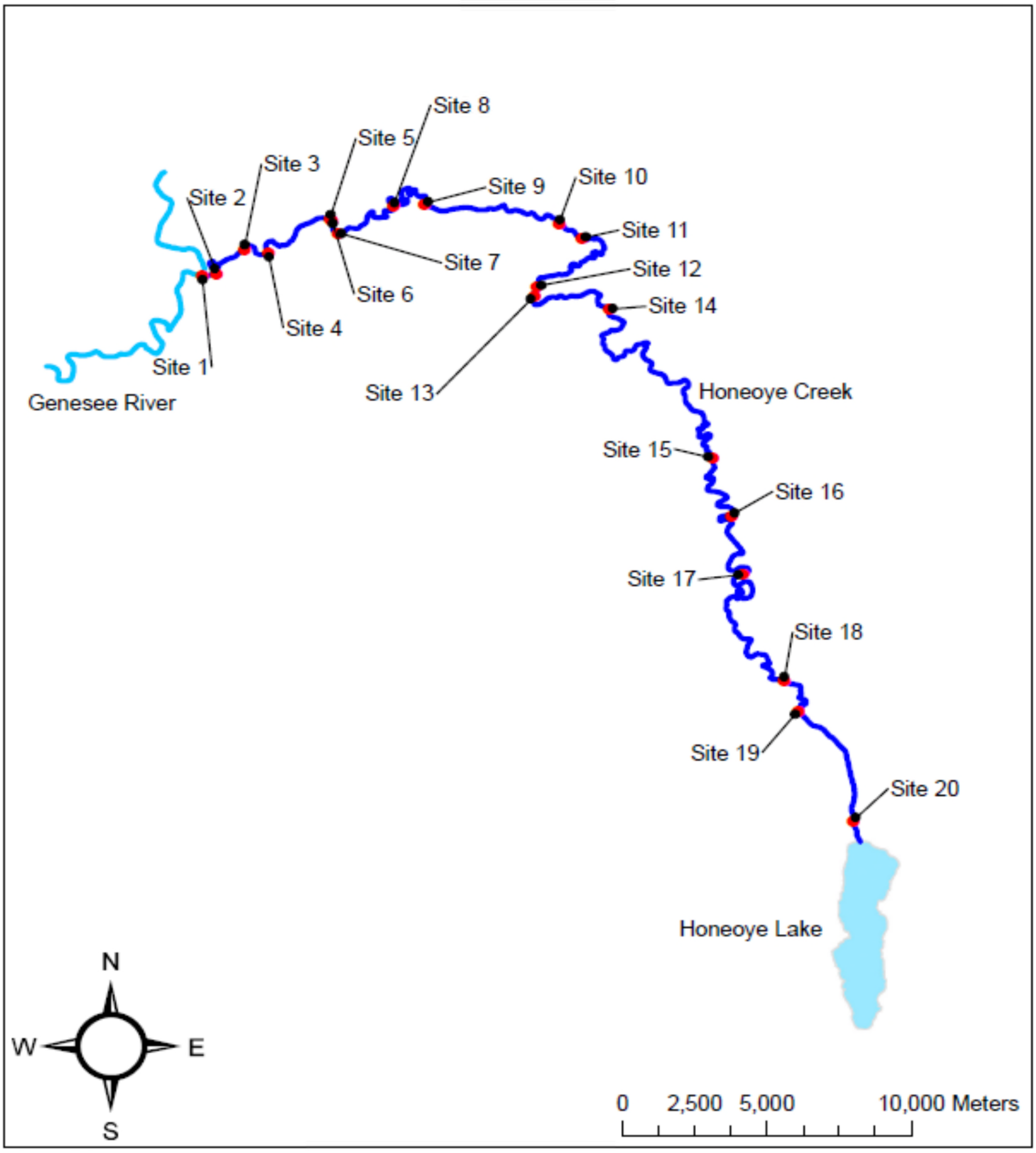

Figure 1. Habitat parameter sampling locations in Honeoye Creek, New York.

Chapter 3: Fish Distributions in Honeoye Creek, with Emphasis on Host Species for Freshwater Mussels

Introduction

Results presented in Chapter 1 show that Honeoye Creek provides habitat for a diverse assemblage of freshwater mussels in a southern Lake Ontario watershed in the Finger Lakes region of New York State. Quantitative surveys conducted in 2012 confirmed 15 species freshwater mussels in Honeoye Creek. Successful reproduction is critical to recovering mussel populations, and their reproduction is dependent on the presence of host fish that carry a mussel's glochidia larvae during a critical development period (Haynes and Wells 2006). Knowledge of fish hosts is essential to understanding patterns of distribution and abundance of mussels (Haag and Warren 1997).

The purpose of this part of my study was to survey the fish population in Honeoye Creek and to determine the presence and distributions of host fishes for the freshwater mussels inhabiting the creek. Additionally, this portion of my study provides an updated species distribution list for the fishes of Honeoye Creek.

Materials and Methods

Fish surveys were performed during summer 2013. Sampling sites coincided with the sampling sites for freshwater mussels; however, only 18 of the 20 sites were surveyed for fish (Figure 1). Sites 5 and 6 were combined into one fish survey because these sites were so close together. Sites 16 and 17 were not surveyed for fish due to lack of land owner permissions. Sampling sites were accessed by bridge crossing or the Lehigh Valley Trail, which crosses Honeoye Creek in several locations.

The sampling protocol was modified from Haynes and Wells (2006). A three-person crew used a backpack electro-fishing unit and a beach seine to sample fish semi-quantitatively. The 30 min with power on electro-fishing effort was standardized to allow similar collection effort at each site. Five seine hauls were made at each site. Following Haynes and Wells (2006), in order to be counted a seine haul had to produce a minimum of six fish. Seines were pulled through a variety of habitat types and currents in order to provide good spatial coverage. Captured fish were identified in the field or preserved and brought back to the College at Brockport to be identified.

The proportional index of community similarity (Brower and Zar 1984) was calculated as a way of comparing the fish communities between the upper, middle, and lower zones. For each of the three zones, the percent of each species was calculated by taking the number of individuals of that species and dividing it by the total number of fish sampled in that zone. Percent similarity was calculated by taking the sum of the lowest percent value for each species between the communities being compared.

Results and Discussion

Fish Community

Twenty seven fish species (1,035 individuals) representing eight families were observed during the surveys at 18 sites (Table 1). Dominant taxa were bluegill (*Lepomis macrochirus*), bluntnose minnow (*Pimephales notatus*), emerald shiner (*Notropis atherinoides*), rock bass (*Ambloplities rupestris*), and northern hogsucker (*Hypentelium nigricans*). Among the fish species caught, 19 were known mussel hosts; 21 known hosts were not caught (Table 2).

Results were consistent with Foust (2008) who collected 35 species in a similar study. Eight fish species collected in this study were not collected by Foust and he found 13 species not collected in this study. This study targeted sites with known mussel presence, which probably accounts for not finding as many species as Foust (2008) who sampled a wider range of habitats.

The proportional index of community similarity (Brower and Zar 1984) for fish species observed during this study was calculated between pairs of the three zones of Honeoye Creek described in Chapter 1. Community similarity between the zones was relatively even. The upper and middle zone had the highest similarity at 67.8%. The middle and lower zones had the lowest community similarity at 60.2%. The fish community of the upper and lower zones were 62.3% similar (Table 3). Differences in the fish communities between zones may be attributable to the impassible barriers that restrict the movement of fish species within Honeoye Creek (Watters 1996).

Although the fish surveys were intensive it is possible that some host species were not collected. Limitations to this study's ability to capture fish species include seasonality and the mobile nature of fish. Additional fish surveys, especially during known breeding seasons of freshwater mussels, might capture additional host fish species. Expanding site sizes for fish surveys would also provide better spatial, and perhaps microhabitat, coverage which also might capture additional host species. These considerations should be taken into account for future studies.

Mussel and Fish Associations

Relative abundance and potential associations of host fishes captured in this study were compared with the freshwater mussels sampled (Chapter 1). Fifteen species of freshwater mussels were observed; three species were found at eight or more sites, five at 5-6 sites, and seven at 1-2 sites (Table 4).

Fish hosts for *Fusconaia flava* were present at all sites where this mussel was observed. The high percent abundance of *F. flava* and presence of host fish suggests that healthy populations of this mussel are supported in Honeoye Creek. Host fish for *Lampsilis siliquoidea* also were widespread and abundant enough to suggest healthy populations of this mussel as well (Table 4).

One mussel with no known host (*Ligumia nasuta*) was observed in the upper zone of Honeoye Creek. Four mussels were recorded at a single site during the surveys reported in Chapter 1. Three species (*Leptodea fragilis*, *Potamilus alatus*, and *Truncilla truncata*) with a single known host (freshwater drum, *A. grunniens*) not found in Honeoye Creek, were recorded during the mussel surveys. *L. fragilis* and *T. truncata* were recorded at a single site, while *P. alatus* was recorded at five sites. The lack of individuals representing recent recruitment and no presence of a host species suggests a correlation between the abundance of these freshwater mussel species and the absence of their fish hosts.

L. fragilis, *P. alatus*, and *T. truncata* were all found within the lower zone in Honeoye Creek, and mostly near the confluence with the Genesee River. Neither this study nor Foust (2008) found *Aplodinotus grunniens* (freshwater drum), the only reported fish host for *L. fragilis*, *P. alatus*, and *T. truncata*. However, *A. grunniens* inhabits the Genesee River near the confluence with Honeoye Creek (NYSDEC 2014). Three hypotheses are proposed based on these findings: 1) *A. grunniens* may occasionally enter Honeoye Creek from the Genesee River giving any glochidia of these three mussel species a chance to inhabit the creek, 2) unreported species are serving as mussels hosts, and 3) *L. fragilis*, *P. alatus*, and *T. truncata* are unable to complete their life cycles in Honeoye Creek. Due to low numbers encountered and lack of juveniles, it is most likely that the last hypothesis is correct but additional research should be done to investigate these hypotheses.

Testing the first hypothesis above would require locating *A. grunniens* near the confluence of Honeoye Creek with the Genesee River, followed by a telemetry study to investigate the movement of *A. grunniens* into Honeoye Creek, especially during the mussel reproductive season. Additional mussel surveys would be required on the Genesee River to determine the presence/absence of the *L. fragilis*, *P. alatus*, and *T. truncata*. Landry and Mahar (2014) found an otter midden littered with *T. truncata* shells on the Genesee River downstream of the confluence with Honeoye Creek, suggesting this species is present in the Genesee River. Additional research on this topic would help investigate the source-sink hypothesis presented in Chapter 1.

Testing the second hypothesis above would require a field study during the mussel reproductive season to look for non-host fishes carrying glochidia, followed by culturing those fish in the laboratory until the glochidia or resulting juvenile mussels can be identified. In a subsequent year, these putative host fishes and their mussel species would be put in laboratory aquaria before the mussel spawning season to see if field observations could be repeated.

Conclusion

Further research to investigate mussel-host species relationships should be conducted to determine which fishes in Honeoye Creek are actually serving as hosts for each mussel species. This is especially important for mussel species with low abundance, no evidence of juveniles, and those with no known host recorded. Maintaining or enhancing conditions for fish hosts will be important for maintaining and restoring these mussel species (Haynes and Wells 2006).

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Tables

Table 1. Fish catches in Honeoye Creek, June-August 2013.

		Site																	
Common Name	**Scientific Name**	**1**	**2**	**3**	**4**	**5 and 6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**18**	**19**	**20**	**Total**
NEOTROPICAL SILVERSIDES	**ATHERINOPSIDAE**																		
Brook silverside	*Labidesthes sicculus*	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	**9**
SUCKERS	**CATOSTOMIDAE**																		
Northern hog sucker	*Hypentelium nigricans*	10	21	-	4	8	-	6	5	6	5	3	3	6	9	-	5	-	**91**
Golden redhorse	*Moxostoma erythrurum*	-	-	-	6	-	-	-	-	4	-	-	-	-	-	-	-	-	**10**
SUNFISHES	**CENTRARCHIDAE**																		**0**
Rock bass	*Ambloplites rupestris*	3	10	12	8	8	-	-	11	9	7	6	5	-	-	6	4	6	**95**
Green sunfish	*Lepomis cyanellus*	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**5**
Pumpkinseed	*Lepomis gibbosus*	-	-	12	-	9	9	7	7	-	-	-	4	-	8	-	-	-	**56**
Bluegill	*Lepomis macrochirus*	7	8	8	5	8	6	8	32	-	6	6	7	8	5	8	-	9	**131**
Smallmouth bass	*Micropterus dolomieu*	2	6	-	4	-	-	-	-	-	5	-	3	-	3	-	-	-	**23**

Largemouth bass	*Micropterus salmoides*	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	**5**
Black crappie	*Pomoxis nigromaculatus*	5	4	-	8	2	-	-	-	-	-	-	-	-	-	-	-	-	**19**
MINNOWS AND CARPS	**CYPRINIDAE**																		
Central stoneroller	*Campostoma anomalum*	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	**3**
Common carp	*Cyprinus carpio*	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	**2**
Spotfin shiner	*Cyprinella spiloptera*	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	
Cutlips minnow	*Exoglossum maxilingua*	-	-	-	-	-	-	-	-	4	6	-	-	-	-	-	-	-	**10**
Common shiner	*Luxilus cornutus*	-	-	-	-	-	-	-	9	5	4	-	-	-	-	-	-	-	**18**
Emerald shiner	*Notropis atherinoides*	-	-	8	9	12	-	9	16	12	8	5	6	-	-	14	-	12	**111**
Spottail shiner	*Notropis hudsonius*	6	6	-	3	-	-	-	48	8	-	-	-	-	-	-	-	-	**71**
Bluntnose minnow	*Pimephales notatus*	32	6	10	-	20	2	5	25	-	-	5	9	-	5	-	-	-	**119**
Creek chub	*Semotilus atromaculatus*	-	-	-	-	4	-	-	8	8	-	-	-	-	-	-	-	-	**20**
GOBIES	**GOBIIDAE**																		
Round goby	*Neogobius melanostomus*	3	14	3	14	-	12	9	9	-	-	-	-	-	-	12	7	8	**91**
N. AMERICAN CATFISHES	**ICTALURIDAE**																		
Stonecat	*Noturus flavus*	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	**2**

PERCHES	**PERCIDAE**																		
Greenside darter	*Etheostoma blennioides*	-	-	-	3	3	-	-	8	-	-	-	-	-	-	-	-	-	**14**
Rainbow darter	*Etheostoma caeruleum*	-	-	-	-	5	-	-	9	-	-	-	-	-	-	-	-	-	**14**
Fantail dater	*Etheostoma flabellare*	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	**6**
Johnny darter	*Etheostoma nigrum*	-	-	12	6	5	7	4	18	9	-	8	3	4	3	5	3	-	**87**
Logperch	*Percina caprodes*	-	-	-	-	6	-	-	7	-	-	-	-	-	-	-	-	-	**13**
Blackside darter	*Percina maculate*	-	-	-	5	-	-	-		-	-	-	-	-	-	-	-	-	**5**
TROUT-PERCHES	**PERCOPSIDAE**																		
Trout-perch	*Percopsis omiscomaycus*	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	**5**

Table 2. Live freshwater mussels found in Honeoye Creek during quantitative surveys reported in Chapter 1 and their reported host fish. Information about potential host fish hosts was obtained from the Mussel/ Host Database at the Molluscs Division of the Museum of Biological Diversity at the Ohio State University, http://140.254.118.11/MusselHost/. Fish collected in this study are in bold.

Common name (Scientific name)	**Host Fish for Transport of Glochidia of Unionid Mussels**
Elktoe (*Alasmidonta marginata*)	White sucker, **northern hogsucker**, shorthead redhorse, **rock bass**, warmouth
Cylindrical papershell (*Anodontoides ferussacianus*)	White sucker, mottled sculpin, brook stickleback, **spotfin shiner**, **bluegill**, **common shiner**, **bluntnose minnow**, fathead minnow, **black crappie**
Eastern elliptio (*Elliptio complanata*)	Banded killifish, **green sunfish**, **pumpkinseed**, **bluegill**, **largemouth bass**, yellow perch, white crappie
Wabash pigtoe (*Fusconaia flava*)	**Black crappie**, white crappie, **bluegill**, **creek chub**
Plain pocketbook (*Lampsilis cardium*)	**Bluegill**, **largemouth bass**, **smallmouth bass**, white crappie, yellow perch, sauger, walleye)
Fat mucket (*Lampsilis siliquoidea*)	**Black crappie,** white crappie, **bluegill**, **pumpkinseed**, **green sunfish**, **rock bass**, **largemouth bass**, **smallmouth bass**, yellow perch, sauger, walleye, **common shiner**, white sucker, **bluntnose minnow**
Creek heelsplitter (*Lasmigona compressa*)	Black bullhead, yellow bullhead, brook stickleback, **spotfin shiner**, **green sunfish**, **bluegill**, **smallmouth bass**, yellow perch, **black crappie**, **creek chub**

Flutedshell (*Lasmigona costata*)	**Carp**, bowfin, northern pike, **bluegill**, **largemouth bass**, yellow perch, walleye, **northern hogsucker**, **pumpkinseed**, **rock bass**, brown bullhead, **rainbow darter**, **green sunfish**
Fragile papershell (*Leptodea fragilis*)	Freshwater drum
Eastern pondmussel (*Ligumia nasuta*)	No known host (Possibly similar to Black sandshell: **largemouth bass**, **bluegill**, sauger, walleye, white crappie)
Pink heelsplitter (*Potamilus alatus*)	Freshwater drum
Giant floater (*Pyganodon grandis*)	**Rock bass**, yellow bullhead, freshwater drum, **central stoneroller**, goldfish, white sucker, brook stickleback, **rainbow darter**, **johnny darter**, **brook silverside**, **green sunfish**, **pumpkinseed**, **common shiner**, **largemouth bass**, **round goby**, **bluntnose minnow**, **black crappie**, **creek chub**, yellow, perch,
Creeper (*Strophitus undulatus*)	**Rock bass**, yellow bullhead, black bullhead, **spotfin shiner**, **rainbow darter**, **fantail darter**, banded darter, **bluegill**, **bluntnose minnow**, fathead minnow, white crappie, longnose dace, walleye
Deertoe (*Truncilla truncata*)	Freshwater drum
Rainbow (*Villosa iris*)	**Greenside darter**, **rainbow darter**, **green sunfish,** **smallmouth bass**, **largemouth bass**, yellow perch, **rock bass**

Table 3. Fish community similarity between zones in Honeoye Creek.

Zones Being Compared	**Percent Similarity**
Upper and Middle	67.96
Upper and Lower	62.34
Middle and Lower	60.18

Table 4. Freshwater mussel and host fish associations at sampling sites in Honeoye Creek. s = number of sites where mussels and their reported host fishes were observed, f = number of reported host fishes collected at sites associated with mussels, % = average percent abundance of fishes at sites where both mussel and host were found. Information about potential host fish hosts was obtained from the Mussel/Host Database at the Molluscs Division of the Museum of Biological Diversity at the Ohio State University, http://140.254.118.11/MusselHost/.

Common/Scientific Name Locations & Percent Abundance	**Reported Host Fishes at Sites**	**Comments and Hypotheses for Mussel Hosts**
Elktoe *Alasmidonta marginata* 1 sites; 0.19%	Northern hogsucker (1s, 5f, 12.2%) Rock bass (1s, 7f, 17.1%)	H: Northern hogsuck and rock bass may not be significant hosts, as this mussel had low percent abundance
Cylindrical Papershell *Anodontoides ferrusacianus* 1 site; 0.19%	Bluegill (1s, 6f, 14.6%) Common shiner (1s, 4f, 9.7%)	H: Bluegill and common shiner may not be significant hosts, as this mussel had low percent abundance
Eastern elliptio *Elliptio complanata* 6 sites; 6.8%	Pumpkinseed (3s, 22f, 13.9%) Bluegill (5s, 59f, 13.8%) Largemouth bass (1s, 5f, 2.1%)	H: Centrachids likely to be the important host fishes

Wabash pigtoe *Fusconaia flava* 9 sites; 46.8%	Bluegill (9s, 82f, 11.6%) Black crappie (4s, 19f, 5.8%) Creek chub (2s, 12f, 3.6%)	H: Centrachids likely to be the important host fishes
Plain pocketbook *Lampsilis cardium* 8 sites; 10.1%	Bluegill (8s, 74f, 11.6%) Smallmouth bass (3s, 12f, 5.3%) Largemouth bass (1s, 5f, 2.2%)	H: Centrachids likely to be the important host fishes
Fatmucket *Lampsilis siliquoidea* 10 sites;16.7%	Rock bass (8s, 19f, 8.9%) Green sunfish (1s, 5f, 6.8%) Pumpkinseed (6s, 44f, 9.2%) Bluegill (10s, 88f, 11.8%) Smallmouth bass (4s, 17f, 6.3%) Largemouth bass (1s, 5f, 2.1%) Black crappie (5s, 19f, 5.9%)	H: Centrachids likely to be the important host fishes

	Common shiner (2s, 13f, 4.8%)	
Creek Heelsplitter *Lasmigona compressa* 2 sites; 1.2%	Bluegill (2s, 18f, 13.6%) Black crappie (1s, 2f, 2.1%) Creek chub (1s, 4f, 4.2%)	Low abudnace of this mussels suggests other hosts may be more important for successful reproduction
Flutedshell *Lasmigona costata* 6 sites; 3.5%	Northern hogsucker (5s, 38f, 13.1%) Rock bass (6s, 48f, 11.2%) Green sunfish (1s, 5f, 6.8%) Pumpkinseed (2s, 21f, 13.0%) Bluegill (6s, 42f, 9.8%) Rainbow darter (1s, 5f, 5.2%)	Mussel utilizes a variety of hosts, as host present at sites where mussel was found were balanced in terms of percent abundance
Fragile papershell *Leptodea fragilis* 1 site; 0.19%	*No hosts reported*	Freshwater drum is only known host H: host may not be present due to low percent abundance
Eastern pondmussel *Ligumia nasuta*	*No known hosts*	H: Hosts may be similar to Black sandshell (*Ligumia recta*); however, bluegill, largemouth

1 site, 0.78%		bass, nor white crappie were present
Pink heelsplitter *Potamilus alatus* 5 sites, 4.7%	*No hosts reported*	Freshwater drum is only known host H: host may not be present due to low percent abundance
Giant floater *Pyganodon grandis* 2 sites; 0.97%	Rock bass (2s, 16f, 9.1%) Pumpkinseed (1s, 9f, 9.4%) Black crappie (2s, 10f, 5.7%) Bluntnose minnow (1s, 20f, 20.8%) Creek chub (1s, 4f, 4.2%) Round goby (1s, 14f, 17.5%) Rainbow darter (1s, 5f, 5.2%) Johnny darter (2s, 11f, 6.2%)	Appears to be a generalist in terms of host species preference. It is surprising with this observation, that it was not encountered more often.

Creeper *Strophitus undulatus* 6 sites; 1.7%	Rock bass (5s, 49f, 8.9%) Bluegill (6s, 69f, 11.6%) Spotfin shiner (1s, 3f, 1.3%) Bluntnose minnow (5s, 66f, 12.8%) Rainbow darter (2s, 14f, 4.3%) Fantail darter (1s, 6f, 6.2%)	H: bluegill and bluntnose minnow may be the important hosts for this mussel
Deertoe *Truncilla truncata* 1 site; 0.58%	*No hosts reported*	Freshwater drum is only known host H: host may not be present due to low percent abundance
Rainbow *Villosa iris* 6 sites;5.5%	Rock bass (5s, 33f, 11.7%) Smallmouth bass (2s, 7f, 5.8%) Greenside darter (2s, 6f, 3.4%) Rainbow darter (1s, 5f, 5.2%)	H: Centrachids and darters are likely important hosts

Figures

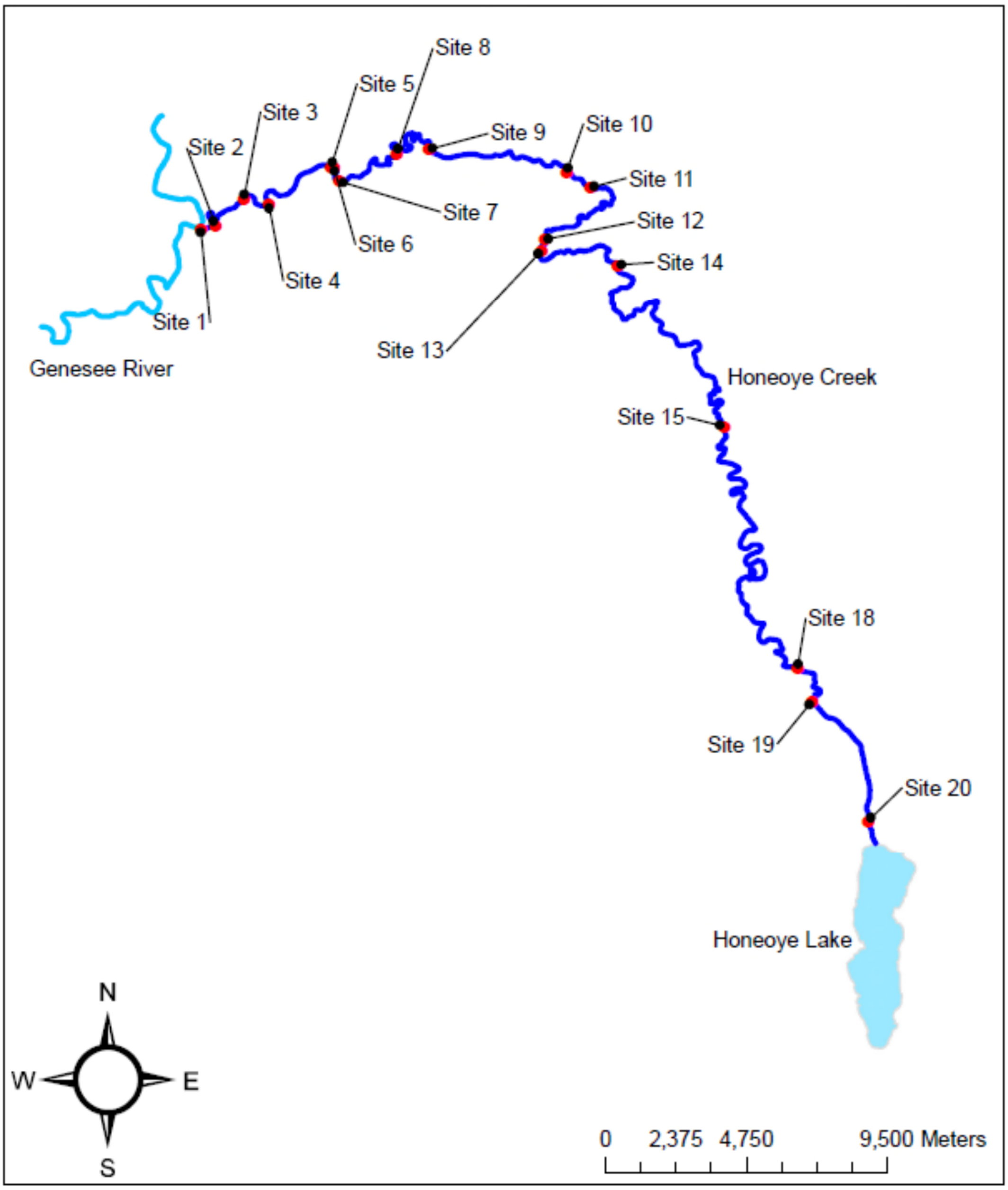

Figure 1. Honeoye Creek sites sampled for host fishes in 2013.