A study on the impact of zebra mussel (*Dreissena polymorpha*) on the recruitment of benthic macro-invertebrates on artificial substrates in the Hudson River

A Final Report of the Tibor T. Polgar Fellowship Program

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Abstract

Since their introduction, zebra mussel populations (*Dreissena polymorpha*) have rapidly spread throughout the eastern U.S., with significant impacts on all trophic levels. The goal of this study was to determine the abiotic and biotic zebra mussel influences on the abundance and diversity of benthic macro-invertebrates in the Hudson River, and to test the effect of zebra mussel density. Abiotic influence is the presence of physically complex habitats formed by zebra mussels. Biotic influence is the biodeposition of feces and pseudofeces by living zebra mussels. Live zebra mussels and shucked mussel shells were epoxied onto ceramic tiles, which were placed in the Hudson River for 37 days. Although the experimental tiles were recovered with good success, the recovery success of epoxied mussels was poor and in many cases most mussels were lost. Observations of the non-standardized abundance data showed greater numbers of chironomids, amphipods and turbellarians than of juvenile zebra mussels, gastropods and hydras. However, an ANOVA analysis showed no significant differences in the recruitment of benthic macro-invertebrates or in the number of invertebrate classes present due to either the presence of mussels, live versus dead shells, or different mussel densities for non-standardized abundances. On the other hand, the standardized abundances of the six invertebrates (Amphipoda, gastropoda, hydra, chironomid, juvenile zebra mussels, and turbellarians) showed a significant p-value of <0.03, when tested for differences between abiotic and biotic treatments using a Wilcoxon rank test. The abundances of the six invertebrates were consistently and significantly higher in the biotic than the abiotic treatment. The experimental design of paired tiles allowed an analysis of spatial recruitment, which was very patchy for hydra, juvenile zebra mussels, and amphipods. These all have in common a waterborne mode of transportation. Crawling species, by contrast, were not patchy. Based on these results, patchy recruitment may overwhelm substrate variation or variation in mussel density.

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Introduction

Zebra mussel (*Dreissena polymorpha*) populations have rapidly spread throughout the eastern U.S. since their accidental introduction into the Great Lakes in the 1980s. This invasion has had significant impacts on all trophic levels in the affected communities such as decreases in primary producers (phytoplankton) (Caraco et al. 1996), decreases in primary consumers (unionids) (Strayer et al. 1996; Strayer et al. 1998), and changes of diet in secondary consumers (perch) (Graham et al. 1992) with important ecological consequences. Their biotic and abiotic influences have dramatically changed many freshwater habitats in the Great Lakes region, and continue to physically and biologically alter the environment (MacIsaac 1996).

Zebra mussels feed by filtering phytoplankton and particulate organic matter from the water column and they produce pseudofecal and fecal matter. Thus, the amount of organic material transferred from the water column to the benthos may increase as a result of feeding activity of dense populations of zebra mussels. Hudson River phytoplankton biomass has declined by 90% since the introduction of zebra mussels (Caraco et al. 1996). The decrease of phytoplankton and the continued filtering by dense populations of zebra mussels has resulted in a 33-100% increase in water transparency in lakes and slow flowing rivers (Holland 1993; MacIsaac and Rocha 1995) but an increase of only 10-15% in the Hudson River, owing to the persistence of clay particles in the water. Clearer waters have in turn led to increased growth in benthic macroalgae due to the expanded photic zone. Furthermore, settlement of zebra mussel veliger larvae on rocks, plants and other hard substrates (such as the valve surface of native unionids), has resulted in significant changes in species composition in these lakes (Griffiths 1993; Mellina and Rasmussen 1994; Wisenden and Bailey 1995; Ricciardi et al. 1995; Karatayev et al. 1997). In parts of Lake Erie

native unionids face 100% mortality and are now in danger of extinction due to heavy fouling by zebra mussels (Nalepa and Schloesser 1993).

Zebra mussels have had a positive effect on the diversity and abundance of certain benthic invertebrates (Griffiths 1993; Mellina and Rasmussen 1994; Wisenden and Bailey 1995; Ricciardi et al. 1995; Botts et al. 1996; Stewart et al.1998) other than unionids by being "ecosystem engineers" (Jones et al. 1994, Lawton and Jones 1995). Zebra mussels aggregate in clumps or reefs and often form suitable micro habitats for many benthic invertebrates (Dame 1979; Dean 1981; Suchanek 1986; Griffiths 1993). Investigators have studied the abiotic and biotic factors of zebra mussels on invertebrates. Botts et al. (1996) compared abiotic and biotic influences of zebra mussels and found a positive invertebrate response to both live and dead zebra mussel druses (dense attached aggregates of zebra mussels). All benthic invertebrates were significantly higher in abundance, particularly chironimids, for live and non-living druses as compared to control sites with no mussels. Prescott (in press) showed there was a greater abundance of a few macro-invertebrates at high wave exposure with increased zebra mussel density than at low wave exposure. Stewart et al. (1998) showed that the structure provided (abiotic) by the zebra mussel beds may impact the invertebrates more than the increase in organic matter of live mussel beds (biotic).

The unique, well-mixed, lotic Hudson River is physically and biologically different from lakes, which are stratified and of lower energy. Swift tidal currents may diminish local deposition of feces and pseudofeces in the interstices of the shells, possibly decreasing the biotic effects evidenced in lake systems.

The goal of this study is to build on previous studies that focus on the abiotic and biotic zebra mussel influences on the abundance and diversity of benthic macro-

invertebrates. A second goal is to test whether mussel density affects the abundance and diversity of benthic macro-invertebrates in an experimental setting.

Methods

Study Site

The study was conducted on the shores of Cruger Island, between Tivoli Bay and the Hudson River just north of Kingston, NY, which is part of the Hudson River National Estuarine Research Reserve. Cruger Island experiences tidal influences and is exposed to strong currents. The immediate shore surrounding the island consisted of large flat shale rocks, followed by soft sediment and a *Vallisneria americana* bed distal to the island. Unglazed ceramic tiles were used as the experimental substrates and were placed in a cove facing the Hudson River flow off of Cruger Island. The experimental substrates were placed on the flat rock bottom, about 1.5 m below mean tide level.

Design and Procedure

Seven treatments, including a control, were used in the design. The six experimental treatments were designed to test the effects of density and of biotic versus abiotic factors. Three densities were used: low monolayer (2288 mussels m^{-2}, 35 mussels per tile), medium monolayer (4248 mussels m^{-2}, <65 mussels per tile) and high bilayer (6078 mussels m^{-2}, <93 mussels per tile). These were used for both the biotic (live mussels) and abiotic (mussel shells) treatments, for a total of six experimental treatments: Biotic Low (BL), Biotic Medium (BM), Biotic Bilayer (BB), Abiotic Low (AL), Abiotic Medium (AM), and Abiotic Bilayer (AB). There were five replicates for each treatment

and 10 control tiles. The controls consisted of unglazed ceramic tiles with epoxy spots (to control for the use of the epoxy to attach mussel shells) and no live zebra mussels or shells. Both live zebra mussels and shells were attached to tiles using a fast-drying non-toxic epoxy. Live zebra mussels were first dried and then epoxied onto tiles. Live mussels were attached to the tiles two days before deployment and were kept alive, submerged in water in plastic tubs with air pumps. For the abiotic treatments, zebra mussels were shucked and the halves were first epoxied together to simulate habitat structure similar to live mussels.

Tiles were first anchored to bricks using cable ties positioned on either side of the tile. Tile/brick combinations were then paired to help anchor the tiles and thus deter currents from moving them from the study site. Each of the six treatments was paired with one control tile, and the remaining control tiles were paired in two control-to-control pairs. The remaining experimental tiles were paired to each other in all possible treatment combinations. For instance, a biotic low density tile was paired with a biotic medium, a biotic bilayer, an abiotic low, an abiotic medium and an abiotic bilayer. A total of 20 pairs resulted from this procedure.

Retrieval of Experimental Substrates

A total of 15 tiles with live mussels, 15 tiles with mussel shells and 10 control tiles were deployed on June 29, 1998. These were retrieved by hand on August 11, 1998 during a low spring tide, after a colonization period of 37 days. During retrieval, pair orders were recorded as well as the position of the brick/tile substrates. For retrieval, cable ties were carefully cut underwater. The tiles were bagged underwater in gallon-sized plastic bags, with care taken to not tip and expose them to currents. While placing the tiles in the bags underwater, extreme care was taken to minimize water-logging to assure the tile/bags were lite enough for transport. Each tile was double bagged in two plastic zipper bags to minimize leakage of contents. Pair orders were maintained by tying the plastic bags

together through holes punched at the corners. The tiles were then transported in plastic tubs to the shore for processing.

On shore, the remaining shells were removed. Each tile was thoroughly rinsed with distilled water to remove organic matter as well as invertebrates. The water from the rinses and plastic bags was carefully collected and sieved through a 500 μm mesh. The contents from the 500 μm sieve were emptied into labeled 150 mL preserve jar. The total volume of sample plus water was 50 mL. In the lab, 50 mL of buffered 10% formalin tinted with rose Bengal was added to each sample. After 48 hours the formalin was replaced with 70% ethanol. The water that passed through the 500 μm sieve was sieved a second time into a 63 μm mesh to collect silt and pseudofeces. From each 63 μm sieve sample, 50 mL of water containing organic and inorganic contents was placed on ice and organic content was subsequently measured by drying and ashing the samples. The preserving process was then repeated for the contents of the 63 μm mesh sieving.

Macro-invertebrate sampling

The preserved samples were sorted and identified to taxonomic level of class at the Institute of Ecosystem Studies under the guidance of Dr. David Strayer and Heather Malcom. Organisms were enumerated if the heads or shells were still attached to the organism.

Organic Content matter sampling

The 50 mL water sample, which consisted of all contents that passed through the 63 μm sieve, was filtered 6 hours after retrieval.
The water was shaken vigorously and then filtered onto pre-weighed glass fiber using a vacuum filtration device. These filters were dried at 60 ° C for 48 hours in a drying oven, then weighed. In order to estimate the organic content differences between treatments,

the dried filters with the filtrates were combusted in a box furnace at 400 ° C for 4 hours. Following the ash-combustion the filters were re-weighed and the organic content was calculated by taking the difference between the final and the initial weights.

Surface Area of Zebra Mussels in the Experimental Substrates

Due to the low (less than 20 %) recovery of the mussels on all treatments, I did not calculate the surface area for the different treatments.

Statistical Analysis

Data on abundance, diversity and biomass of macroinvertebrates were analyzed using both one - and two-way analysis of variance, non-parametric rank test and correlation coefficients. An alpha value of $p<0.05$ was considered significant.

Results

Probably owing to their proximity there were no significant differences in the number of mussels still attached at retrieval between sites 1 and 2. The diversity, abundance and biomass of benthic macro-invertebrates between the two sites were also not significantly different. The percentage of zebra mussels and shells remaining on the tiles at retrieval ranged from 0 to 73%. The average recovery was 20% (Table 1). Although not statistically significant the data show the recovery of shells in the abiotic treatments were slightly higher than the biotic treatments.

There were no significant differences in abundance between abiotic and biotic treatments. The abundances of five of the six (excluding amphipods) most frequent taxa on control tiles closely reflected the total abundances from both the abiotic and biotic

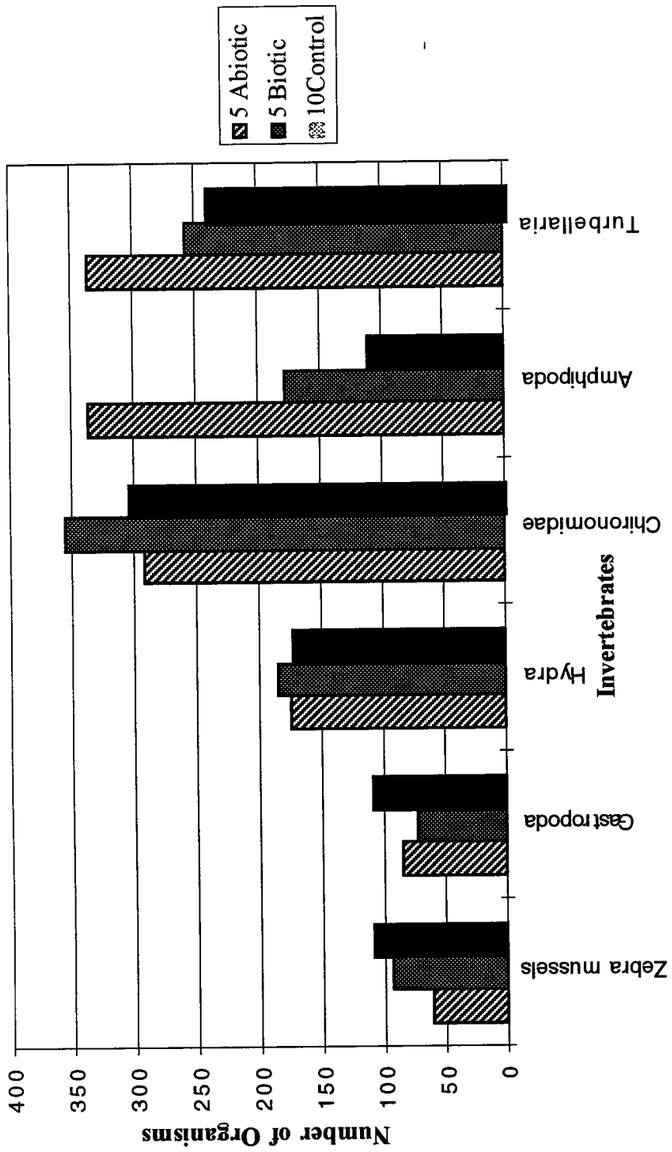

Figure 1: Total Abundance of Invertebrates for Abiotic, Biotic and Control Treatments

Table 1. Average % recovery of mussels & shells per treatment

Treatment (# of Mussels)	%	Treatment (# of Mussels)	%
Abiotic Low (35)	26.9	Biotic Low (35)	18.6
Abiotic Medium (63)	28.9	Biotic Medium (63)	22.5
Abiotic Bilayer (93)	20.6	Biotic Bilayer (93)	7.4

treatments (Figure 1). Observational comparison between the biotic low and control tiles showed gastropods and amphipods on the biotic low treatment to be half the biomass of the control tile biomass. Juvenile zebra mussels showed the lowest biomass in the abiotic low treatments. Chironomid biomass showed a slight increase as the mussel density increased. As for the abiotic tiles, the low density tiles, which had the highest recovery of experimental substrates, had similar chironomid biomass as the biotic treatments (Figure 2).

The abundance data was standardized to calculate differences between abiotic and biotic treatments only (assuming there are no density differences). This was calculated by summing up all the abundances for each of the six invertebrate groups from all fifteen replicates for abiotic and biotic treatments then multiplying by the percent recovery of zebra mussels for that treatment. The standardized invertebrate abundances were then tested for significance between abiotic and biotic treatments using a Wilcoxon signed rank test. There was a significant p-value of < 0.03, indicating an overall positive effect on the abundances of all six taxonomic groups for the biotic treatment.

Juvenile zebra mussels, gastropods, hydras, and chironomids were all significantly greater in standardized abundance by 45-50% for the biotic treatments as compared to abiotic treatments. Amphipods and Turbellarians had only a 10-15 % greater standardized

abundance for the biotic treatments.

An ANOVA, using the non-standardized data (F= 0.25, Table 2) between total number of organism and the two treatments showed no significant differences for the abiotic and biotic treatments or among the density treatments. A comparison of the means from Table 2 showed no significant differences.

Table 2. ANOVA for Total organisms

Treatment	Mean	SE	N
ABIOTIC	83.5333	10.4391	15
BIOTIC	76.9333	10.4391	15
CONTROL	88.4000	12.7852	10

F = 0.25, N.S.

In addition, a pair comparison was done to reflect the experimental set-up (i.e., all the tiles were physically paired together for greater stability against the strong current, but all possible combinations of treatments were paired side by side). Using the Pearson pair-wise correlation test for each taxon, significant correlations were found when the six most abundant classes were compared between tiles of attached pairs. Of the six taxonomic groups, amphipods, hydra and zebra mussels showed significant positive correlations, with p-values of 0.002, 0.005 and 0.0001 respectively (Figures 3, 4 and 5). The remaining three groups (chironomids, turbellarians and gastropods) showed no significant correlation. There were no significant correlations from comparisons between different organisms. Analysis of variance among the different densities with abiotic and biotic treatments were not significant. In terms of diversity of classes, there were only slight, but not statistically significant differences in the number of different classes for each treatment.

Similarly, the pair-wise comparisons showed no significant differences in composition of the classes.

No statistical analysis could be performed for the biomass data due to absence of sample variance. In addition organic matter data showed no significant differences between the abiotic and abiotic treatments. In this experiment higher diversity due to the presence of the zebra mussel or density was not observed, relative to the control treatment. The total number of classes of benthic macro-invertebrates did not vary significantly.

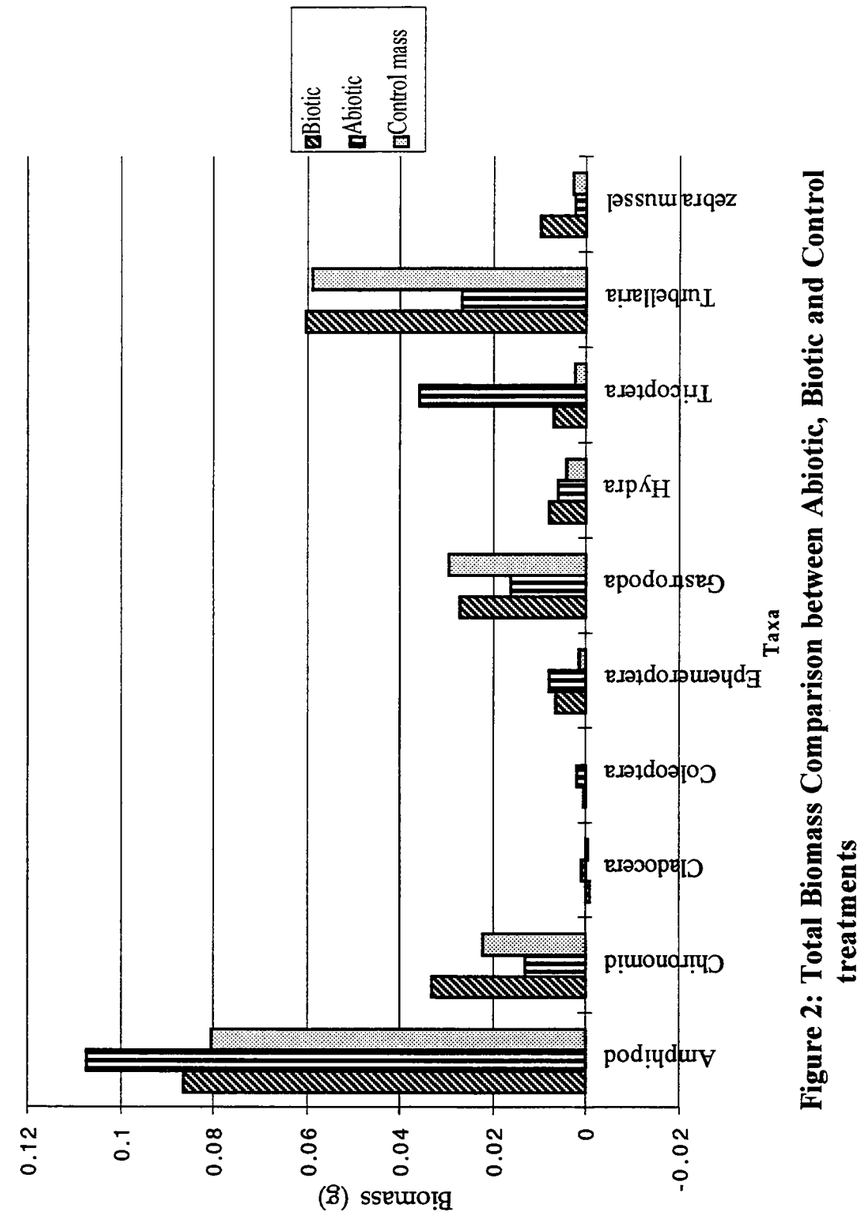

Figure 2: Total Biomass Comparison between Abiotic, Biotic and Control treatments

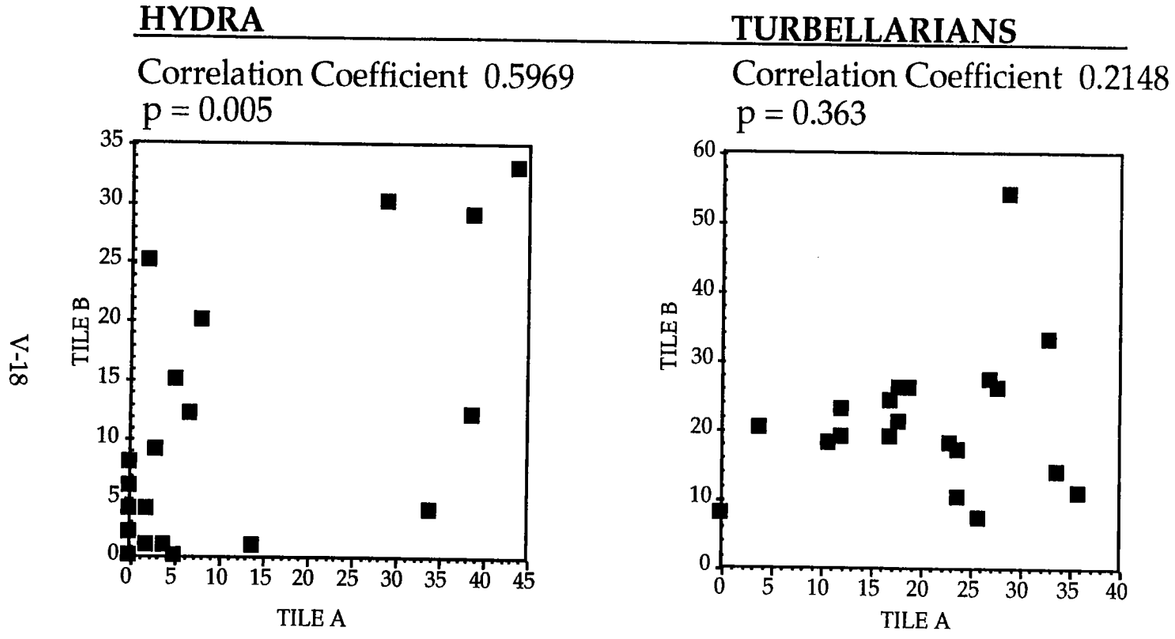

Figure 3: Comparison between Tile Pairs (A and B) for Hydra and Turbellarians

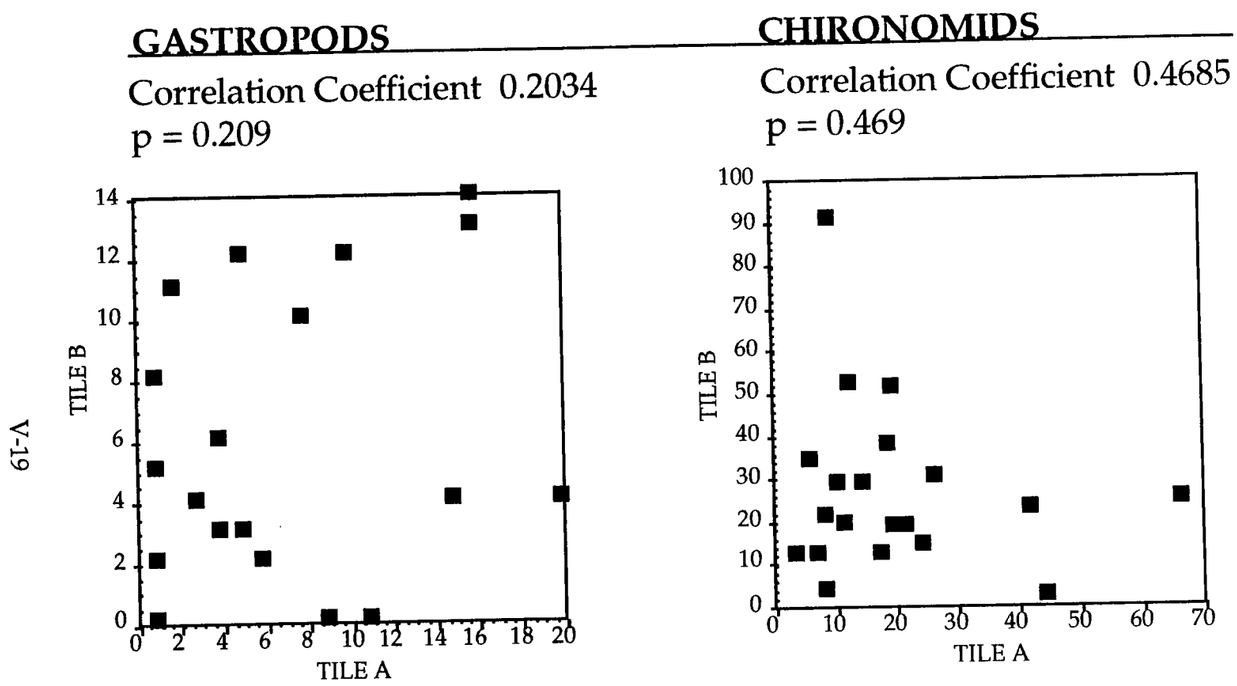

Figure 4: Comparison between each Pair of Tiles (A and B) for Gastropods and Chironomids

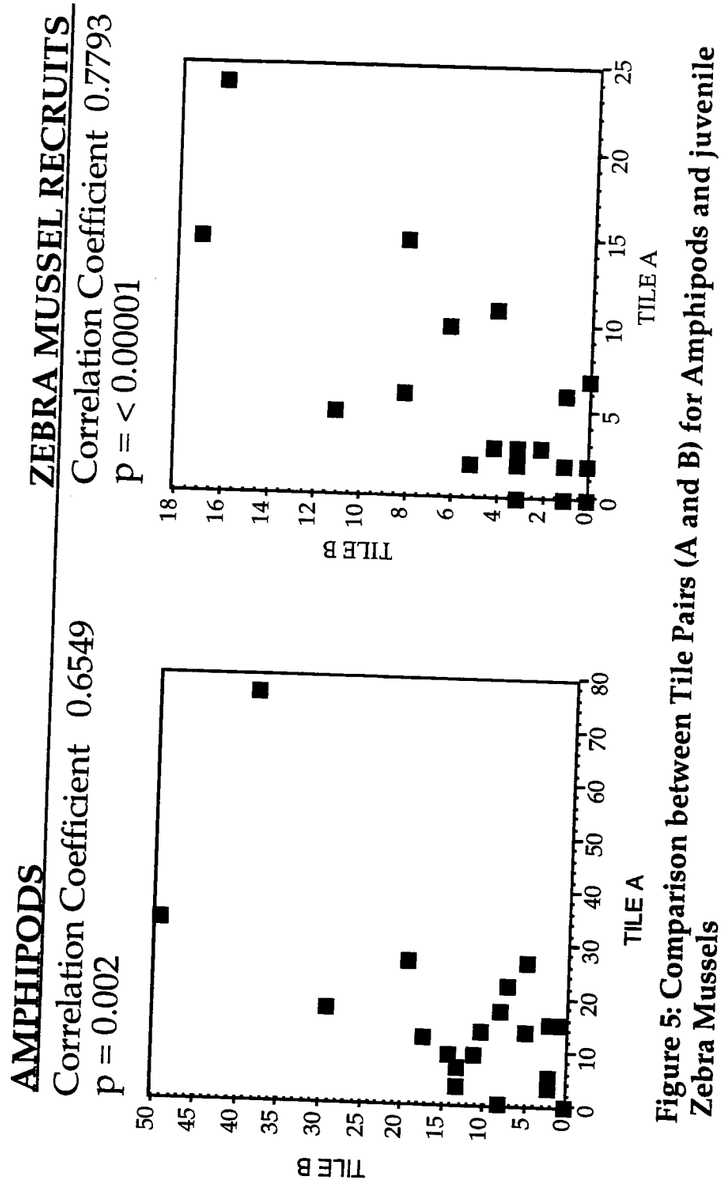

Figure 5: Comparison between Tile Pairs (A and B) for Amphipods and juvenile Zebra Mussels

Discussion

The greater part of United States northeastern freshwater ecosystems has been altered since the introduction of *Dreissena polymorpha*, the zebra mussel. Habitat and organismal changes due to the rapid colonization of zebra mussels have been well documented for lakes such as St. Clair and Lake Erie (Wisenden and Bailey 1995, MacIsaac 1996). The impact of this introduction has been studied at various trophic levels, especially the primary and tertiary levels (Graham et al. 1992, Griffiths 1993). However, the impact on secondary trophic levels represented by benthic organisms, in particular macro-invertebrates has only recently gained attention (Botts et al. 1996, Ricciardi et al. 1997, Stewart 1998). In addition, the negative response on other benthic macro-invertebrates, such as the unionids, has been studied well enough to produce models of the impact of zebra mussels on the mortality of native unionids (Ricciardi et al.1995, Strayer 1998).

Many studies in the last five years showed a positive response by the invertebrates to the presence of the zebra mussel structures and/or live mussels. Wisenden and Bailey (1995), Botts et al. (1996), Ricciardi et al. (1997), and Stewart et al. (1998) showed that the complex structures that zebra mussels create and the production of pseudo-feces and feces has in some cases increased the abundance and diversity of benthic invertebrates except for the unionids.

In this study, the goal was to observe density effects on non-unionid benthic invertebrates. It was hypothesized that specific densities will affect the abundance, biomass and diversity of the benthic macro-invertebrates. Due to the rapid filtration of large volumes of detritus and phytoplankton from the water by dense zebra mussel colonies, transfer of organic matter to the benthos in terms of nutrients is increased. However, in the Hudson River the increased resource is not expected to benefit the benthos due to the fast currents and well mixed conditions (Roditi et al. 1997).

There were some logistical and experimental design problems that may have affected the results. Due to the nature of this study, low retrieval of experimental substrates was expected, but to assure a higher recovery we anchored the experimental substrates by pairing the tiles/brick structures, such that two tile/brick structures were tied together. This provided added resistance against the strong Hudson River currents. The pairing was done in a way such that all possible combinations were achieved. For instance, an abiotic low tile was paired with a control tile, abiotic medium, abiotic bilayer and so on. This pairing of treatments allowed us to address patchiness of recruitment distribution as a function of behavior. Also, to be able to deploy and retrieve the experimental substrates, the study was conducted in shallow water. Although zebra mussels were present in the study area, they are predominately found in deeper waters with only small populations in the shallow area. Strayer et al. (1998) studied the impact of zebra mussel on the benthos. Their findings showed a negative density response from the presence of zebra mussels on macro-benthic invertebrate with increasing depth and a positive response in density of macrozoobenthic in shallow sites. Their study may help explain the significantly higher abundences for chironomids, hydrazoans and juvenile zebra mussels especially, in the presence of live zebra mussels (biotic treatment). In addition a greater number of seasonal blue crab (Strayer, personal communication) may have been signicant source of predation, affecting the number of invertebrates and also the recovery of attached biotic mussels on tiles.

Based on 2-way analysis of variance, there were no significant differences between the abiotic and biotic density treatments in abundance, biomass and diversity of benthic-macro-invertebrates. The retrieval of an average of 20% for the zebra mussels and shells probably homogenized the density differences and all treatments were placed in similar conditions.

However, the significant p-value of <0.03 for the standardized abundances of the six invertebrates (Amphipoda, gastropoda, hydra, chironomid, juvenile zebra mussels, and

turbellarians) assumes no density differences and isolated for only differences between abiotic and biotic treatments using a Wilcoxon rank test. Based on the standardized data, the abundances of the six invertebrates were consistently and significantly higher in the biotic than the abiotic treatment. Observations of the non-standardized abundance data showed greater numbers of chironomids, amphipods and turbellarians than of juvenile zebra mussels, gastropoda and hydras (Figure 1). Other invertebrates such as Ephemeroptera, Tricoptera and Cladocera were also sampled, but these were too few in number, therefore no further analysis was performed. In this study, when abiotic and biotic treatments were tested after normalizing the abundances based on the average recovery, biotic treatment was found to be significantly greater in abundance of invertebrates than abiotic treatments. This finding does not support Stewart et al. (1998), where the complex habitat structure was shown to be significantly more influential than the biotic effects. One explanation for this result may be due to environmental differences between the two studies. Due to the strong mixing from flow, nutrients and organic matter may be a more of a limited resource than habitat in the Hudson River, as opposed to a less turbulent body of water such as Lake Ontario.

In comparing the abundances of each treatment with the control tiles, there are two main observations: (1) that the make-up and the proportion of the invertebrates are similar for all six experimental treatments to the abundances on the control tiles, and (2) the only group with a consistent abundance throughout the treatments were turbellarians. This may be due to the minimal variation of habitat and resource requirements needed by turbellarians among treatments as opposed to the occurrence of different abundances of amphipods through out the six treatments.

No statistical analysis was performed for the total biomass of the 10 most abundant organisms as the weights for each replicate was summed, thus eliminating variance. A

graphical analysis shows amphipods and turbellarians with the highest biomass. There was some similarity of biomass observed for the chironomids, gastropoda and turbellarians; biomass on the biotic treatments is higher than the abiotic treatments (see Figure 2). The presence of increased nutrients due to feces and pseudofeces from live zebra mussels may have affected the higher proportion of gastropods and turbellarians found on the biotic tiles. In comparing the control treatments to the experimental treatments, biotic and control biomass are more similar to each other than abiotic vs. biotic or abiotic vs. control. At this time, a conclusive statement cannot be made due to insufficient data. However, the graphical analysis shows that the presence of the structure provided by zebra mussel colonies may be the more influential that the nutritional resource in this shallow habitat.

The Pearson correlation analysis for all twenty pairs of tiles showed significantly high correlation coefficients for taxa that can disperse by water the hydra, amphipods and juvenile zebra mussels, which recruited probably as planktonic larvae. This analysis shows that the colonization for these three taxonomic groups was very patchy. Such a distribution may be limited to waterborne organisms because, in contrast, turbellarians, gastropods and chironomids did not have a patchy distribution. The latter groups may have arrived by crawling from the surrounding natural substrates. Based on the results patchy recruitment may overwhelm substrate variation or variation in mussel density.

In conclusion, density or substrate may not be as influential as the spatial recruitment of the benthic macro invertebrates on experimental substrate. However, due to the loss of more than 75 % of experimental mussels, I feel that this question has not been sufficiently addressed. Some interesting observations did occur from this study that may deserve further research. The first is that recruitment may be influenced by spatial differences and temporal changes in colonization rates may also matter. Second, a comparison on the rate of colonization of benthic assemblages in the absence and presence

of zebra mussels could provide a better understanding on effect of introduced zebra mussels. The third is that the use of tiles and bricks is an effective way to do experimental studies. However, attaching zebra mussels can be improved.

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