PREDATOR-MEDIATED BIOLOGICAL CONTROL OF THE ZEBRA MUSSEL IN THE HUDSON RIVER ESTUARY

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ABSTRACT

Predation controls community structure in aquatic systems. The success of introduced species like the zebra mussel, Dreissena polymorpha, is due in part to ineffective predators in the newly colonized systems. We quantified distribution, abundance, and mortality rates of a D. polymorpha population in the middle portion of the Hudson River Estuary, New York. Rocks were collected along a depth gradient in the field, and were sampled for density and size structure of the resident mussels. Predator exclusion experiments with rocks harboring a known number of D. polymorpha were used to estimate natural mortality. In addition, we conducted manipulative field experiments to test the effectiveness of the blue crab, Callinectes sapidus, at consuming zebra mussels by presenting similar rocks to crabs in field enclosures. Field sampling in the months of June, July and August indicated a dense (~30,000 m^{-2}) population composed of a single cohort of 1+ year class mussels. Mussel density increased dramatically with depth less than two meters below the spring-low-tide mark. In cage experiments, C. sapidus caused mortality rates an order of magnitude higher than those measured for the local predator guild, which was primarily composed of finfish. Consumption of zebra mussels by pumpkinseed, Lepomis gibbosus, was observed in the field on several occasions. Although blue crabs have the potential to limit zebra mussel abundance, at the present this is unlikely in the Hudson River Estuary due to the low natural abundance of the predator within the system. However, high predation rates of D. polymorpha by C. sapidus in this estuarine habitat indicate that the blue crab is capable of regulating the zebra mussel in habitats where the blue crab is abundant.

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INTRODUCTION

In aquatic systems, predation regulates community structure and the dynamics of benthic species (Peterson 1979, Paine 1980). Predator-prey interactions in these systems are particularly complex and may be relatively stable because they are dominated by guilds of generalist predators capable of switching among diverse prey (Peterson 1979, Hines et al. 1990). Such generalist predators are not coupled to their benthic prey, and therefore are capable of controlling the dynamics of these species without being dependent upon any single species for their own persistence. Such features might characterize the predator-prey interactions between the zebra mussel, Dreissena polymorpha, and natural predators such as the blue crab, Callinectes sapidus, and finfish species, and thereby provide the requisite conditions for predator-mediated control of D. polymorpha population dynamics.

The zebra mussel initially invaded the Great Lakes in 1985, with the first reported sighting in Lake St. Clair in 1988 (Hebert et al. 1989). D. polymorpha rapidly colonized western Lake Erie, and now occurs in all the Great Lakes. The species was first discovered in the Hudson River in 1991, and has since expanded to its salinity limit (3-6 ppt) near Haverstraw, New York (Strayer et al. 1993). The rapid colonization has been facilitated by its high fecundity, a free-swimming larval stage, a fairly broad tolerance of environmental conditions in temperate habitats, and the apparent lack of competitors and predators (Hebert et al. 1991, Lemma 1991, MacIsaac et al. 1991, Strayer 1991). As a consequence, D. polymorpha occurs at densities exceeding 700,000 m^{-2}, and has thereby become a major and costly nuisance (Cooley 1991, Griffiths et al. 1991). Moreover, due to its salinity tolerance, the zebra mussel is expected to colonize and expand into most North American waters, including the low salinity portions of estuaries such as Chesapeake Bay (Bij de Vaate 1991, Strayer 1991, Strayer & Smith 1992). Thus, the potential exists for D. polymorpha to become a serious pest throughout North American waters, unless measures are discovered which effectively eradicate or regulate the zebra mussel in its distribution and abundance.

In this investigation we quantified natural mortality rates of D. polymorpha in the field, and tested the hypothesis that predation by the blue crab, C. sapidus, may serve as an effective biological control of the zebra mussel in the Hudson River estuary and potentially in other North American estuaries. The blue crab, C. sapidus, is a large (males up to 227 mm carapace width (CW)) epibenthic omnivore occurring in various habitats along the Northwest Atlantic Ocean, Gulf of Mexico and Caribbean Sea (Williams 1984). Blue crabs serve as both prey and consumers, and are abundant and actively foraging from late spring through autumn in Chesapeake Bay (Hines et al. 1987, 1990). The diet of Chesapeake Bay blue crabs consists of bivalves, crabs (both blue crabs and xanthids), fish and polychaetes, and to a lesser extent amphipods and isopods (Hines et al. 1990, Mansour & Lipcius 1991). Blue crab ecology in the Hudson River has not been well studied and consequently the abundance and range of the animal within the system is not known. Previous research has shown that C. sapidus is common in the freshwater and low salinity regions of the estuary in some years (Stein & Wilson 1991).

We conducted a series of sampling and field experiments in Hudson River freshwater habitats to determine limitations imposed by finfish and the blue crab upon zebra mussel abundance and distribution. Further trials compared the effectiveness in controlling zebra mussel abundance of the blue crab and the local predator guild (primarily finfish species). The specific objectives of the investigation included (1) a description of D. polymorpha abundance and distribution at the field site, (2) measurement of natural mortality of D. polymorpha and identification of likely finfish predators, and (3) testing the feasibility of biological control of D. polymorpha by C. sapidus and vertebrate species in the Hudson River and other North American estuaries.

STUDY AREA

Field experiments and sampling were conducted on the eastern shore of the Hudson River in the Tivoli Bays Region of the Hudson River National Estuarine Research Reserve,

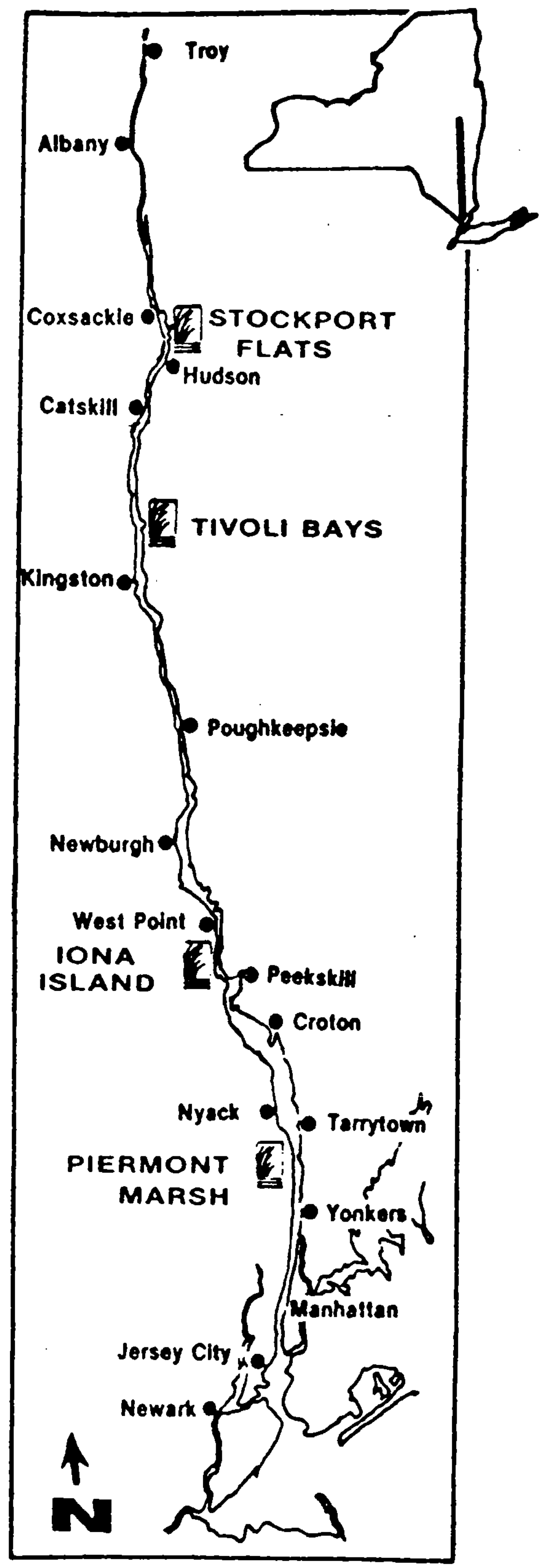
in New York State (Fig. 1). The tidal freshwater habitat was approximately 180 km north of the mouth of the estuary. In this region the benthic environment of the Hudson was characterized by large stones and cobbles covering a steeply sloping bottom that reached over 20 m depths in some areas. Underwater visibility was poor (< 3 meters) due to the heavy sediment load in the river.

METHODS

Rocks were sampled from the Hudson River during June, July and August, 1993 using SCUBA to examine the density and size structure of the zebra mussel. Tweezers were used to remove individuals from randomly-placed 16 cm^2 grids on the rocks. Mussels were counted and their shell lengths measured using Vernier calipers. We also conducted a series of five underwater transects to characterize the depth distribution of D. polymorpha. Four random rock samples were collected using SCUBA along depth profiles to determine density, while a circular grid was used to estimate percent coverage. Samples were collected at increasing depth profiles until consecutive runs generate 100% coverage.

The second component of the study involved manipulative field experiments. We first measured mortality rates of D. polymorpha due to predation. Rocks with attached mussels were collected from the river and maintained in aquaria to insure healthy test animals. These same stones were reintroduced into field enclosures with only 100 mussels remaining on each stone. Cages were constructed of 2.5 cm non-galvanized steel mesh, and covered 1 m^2 of substrate. Control treatments comprised fully-enclosed cages protecting one rock with 100 pre-counted mussels. Whereas, experimental cages were topless and open to predation. There were eight replicates of each treatment, lasting 14

Figure 1. Map of the Hudson River estuary showing the location of the Tivoi Bays National Estuarine Research Reserve.



days after which the rocks were removed from the cages and the surviving mussels enumerated. Differences in proportional mortality of D. polymorpha between the two experimental treatments were analyzed using ANOVA models with angularly transformed proportional mortality as the dependent variable and caged treatment as a fixed factor. Data were examined for normality and tested for homogeneity of variances with an F-max test.

The final experiment utilized the same field enclosures and another set of pre-counted mussels. In this trial all cages were closed and male blue crabs were introduced as predators. Six cages contained small crabs (60-80 mm CW), six cages contained large crabs (110-130 mm CW), and six cages contained only rocks with pre-counted mussels. After 72 h, crabs were removed and surviving mussels enumerated. Differences in proportional mortality of D. polymorpha between the three treatments were analyzed using ANOVA models with angularly transformed proportional mortality as the dependent variable and caged treatment as a fixed factor. Data were examined for normality and tested for homogeneity of variances with an F-max test.

RESULTS

Samples collected along depth transects beginning at the spring low tide mark indicated a significant effect of depth (Table 1), and a correlation of density with increasing depth (Fig. 2). A Scheffe's test of the mean densities indicated that abundance at the shallowest transect (0.26 m) was significantly less than the four deeper transects (Crit. value = 1.329). Densities of D. polymorpha in the Tivoli samples averaged 30,000 m^{-2}. Size frequency distributions (Fig. 3) revealed a single cohort with no individuals exceeding 20 mm shell length. Mean shell length increased 24% over the three month period covered by the study.

Table 1. ANOVA table for mean zebra mussel density along five depth transects in the Tivoli Bays region of the Hudson River.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
depth	4	16.046	4.011	13.879	<.0001
Residual	15	4.335	.289		

Figure 3. Depth distribution of mean zebra mussel density (± 1 std. error) in the Tivoli Bays region of the Hudson River.

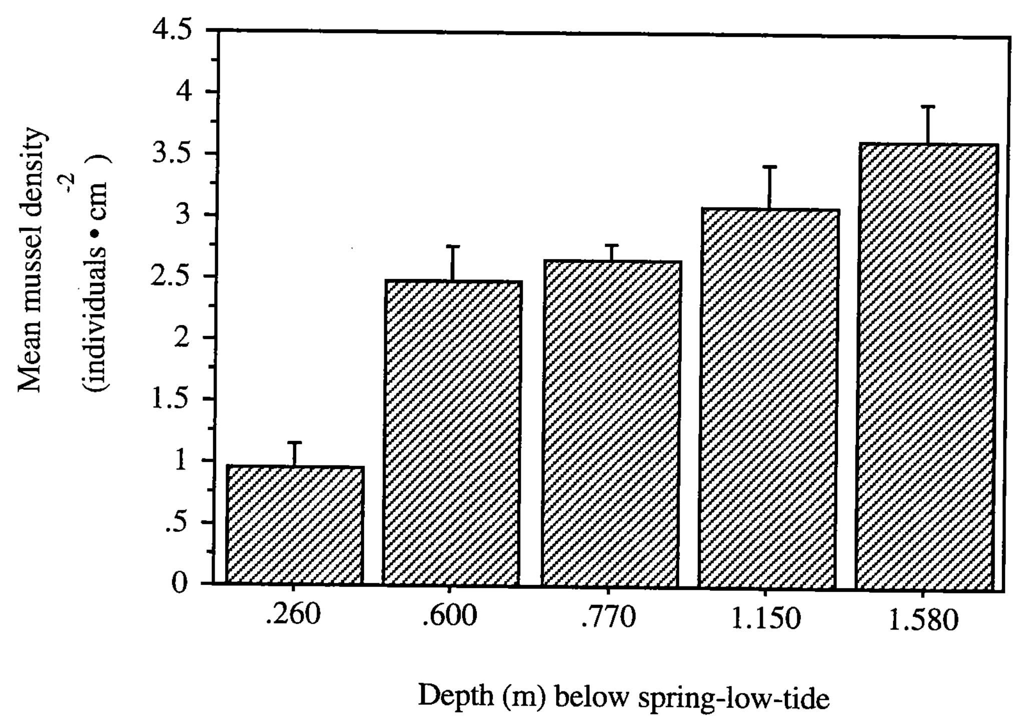
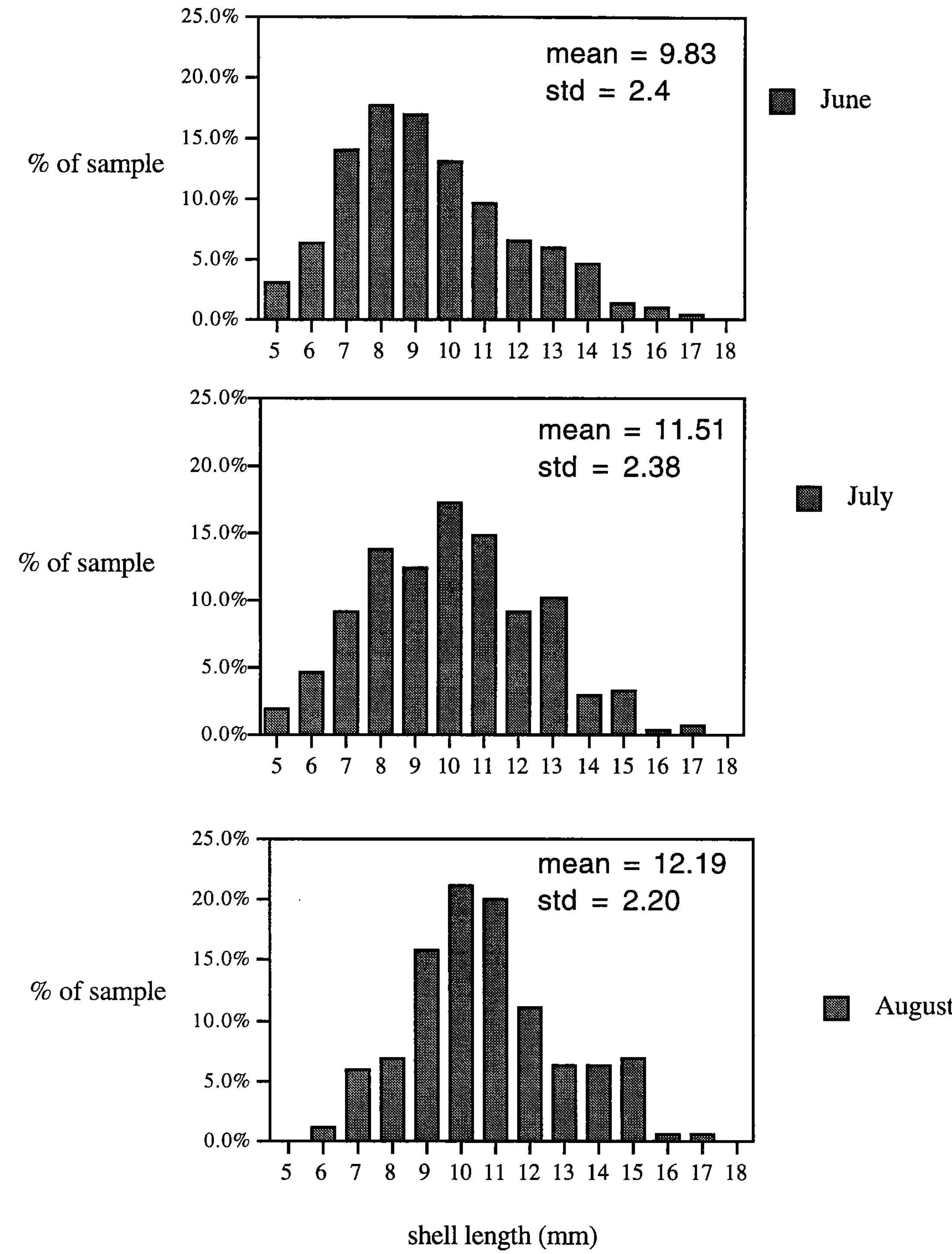


Figure 3. Size frequency distributions of the zebra mussel in the Tivoli Bays region of the Hudson River.



Mean zebra mussel mortality in the first manipulative experiment was significantly greater (Table 2) in the experimental treatments (Fig. 4). Predators consumed a mean of 24% of the attached D. polymorpha in the open cages. Mussels in the cage controls suffered less than 10% mortality over the two-week period.

The introduction of male blue crabs produced higher mortality rates in the second field experiment. Large blue crabs consumed nearly 50% of the prey in the 72 h trials (Fig. 5). Although the effect of crabs was highly significant (Table 3), mussel mortalities did not differ significantly between large and small crab treatments (Scheffe's test, Crit. value = .169).

DISCUSSION

Size-frequency distributions of D. polymorpha in the Hudson River indicated that the population was composed a single cohort spawned the previous year (Jenner and Janssen-Mommen, 1993). Given the planktonic larval stage of the mussel, the likely parental population was several kilometers upriver of the Tivoli Bays site. The depth distribution of increasing density with depth was consistent with the hypothesis that physical factors (e.g., desiccation, ice scour) rather than predation, restrict the upper limit of the vertical abundance of D. polymorpha in the Hudson River estuary.

D. polymorpha in European lakes and large rivers occurs at densities near 3000 mussels m^{-2} (Bij deVaate 1991). Yet in North America, the densities are larger by one or two orders of magnitude. The densities reported here (~30,000 mussels m^{-2}) are well within the ranges observed in North American waters (Dermott & Munawar 1994). Success of the zebra mussel in North America can be attributed at least in part to the lack of effective natural predators. In Europe, mussels are preyed upon by eels (de Nie 1982), fish (Daoulas & Economidis 1984), and ducks (Draulans 1984). These consumers have likely

Table 2. ANOVA table for mean proportional mortality of zebra mussels outplanted at 100 mussels per rock in open and closed cage treatments in the Tivoli Bays region of the Hudson River.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	.087	.087	13.425	.0026
Residual	14	.091	.006		

Figure 4. Mean proportional mortality of zebra mussels (+ 1 std. error) outplanted at 100 mussels per rock in open and closed cage treatments in the Tivoli Bays region of the Hudson River.

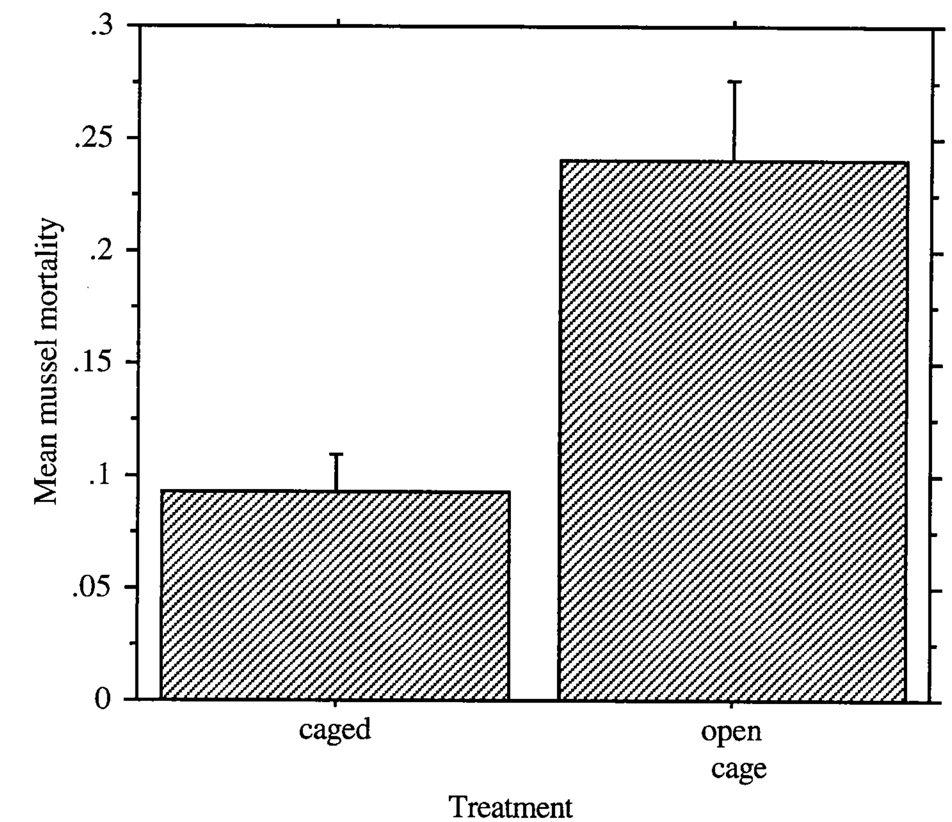
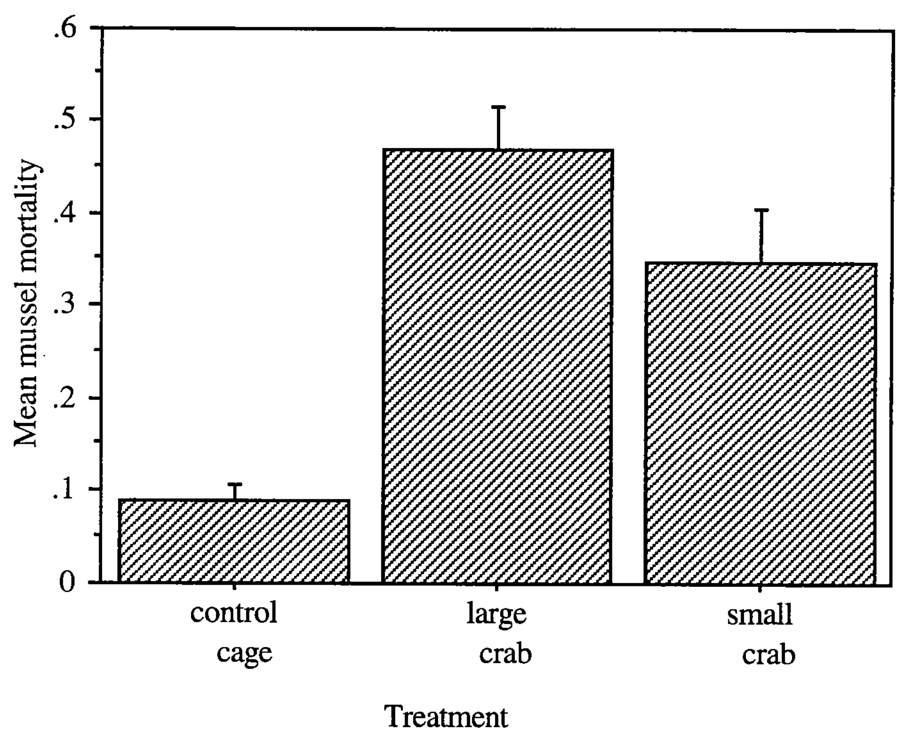


Table 3. ANOVA table for mean proportional mortality of zebra musses outplanted at 100 mussels per rock in large and small crab treatments in the Tivoli Bays region of the Hudson River.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	2	.449	.224	19.205	<.0001
Residual	15	.175	.012		

Figure 5. Mean proportional mortality of zebra mussels (± 1 std. error) outplanted at 100 mussels per rock in control, large, and small crab treatments in the Tivoli Bays region of the Hudson River.



kept zebra mussel populations in check, and thereby prevented them from becoming an ecological nuisance.

A lack of strong predation pressure was evident in our field experiment using predator-exclusion cages. Subtracting control mortalities from those in the experimental treatments resulted in 14% mortality over two weeks. Mortality observed in the controls of both field experiments (approximately 10%) was attributed to handling-related mortality associated with the transport and manipulation of mussels in and out of the field, and was similar over the two experimental time periods (3 and 14-day trials). The only natural predation observed was by several pumpkinseed fish, Lepomis gibbosus, over three separate dives. Pumpkinseed have well-developed molariform teeth capable of cracking mollusk shells (French 1993).

Recently it has been suggested that the blue crab might be the kind of voracious predator that could control the explosive growth of the zebra mussel. The blue crab inhabits estuarine systems through the freshwater reaches (DeFur et al. 1987), and is capable of controlling the dynamics of bivalves (Lipcius & Hines 1986). The results of our crab predation experiment provided support for the hypothesis that blue crabs can be more effective in reducing zebra mussel abundance than local finfish or invertebrate predators. D. polymorpha mortality rates caused by C. sapidus were nearly twice those caused by the local predator guild in only 20% of the time.

Unfortunately, blue crab densities in the Hudson River system are relatively low, varying low to moderate densities capable of supporting a small commercial fishery, but too low to regulate D. polymorpha. In our study no crabs were caught in several baited traps and local fishermen indicated that there were few blue crabs in the middle portion of the Hudson River that summer. Our experimental crab densities (1 m^{-2}) are comparable to those observed in Chesapeake Bay (Orth and van Montfrans 1987).

In contrast, C. sapidus was common in the middle region of the Hudson River in the summer of 1992. During this time a major decline in the abundance of adult zebra mussels was observed near Catskill, New York (D.P. Molloy, pers. comm.). The initial densities of D. polymorpha were lower than those recorded in our study.

In conclusion, D. polymorpha is unlikely to be regulated by the local predator guild in the Hudson River, unless the predator abundance increases significantly. In particular, the blue crab is capable of controlling zebra mussel abundance if the predator abundance increases to levels approximating 0.01 -1.0 m^{-2}, depending on crab size. Such densities are common in other estuaries such as Chesapeake Bay, and indicate the likelihood that the zebra mussel will be regulated in estuaries near the southern limit of the range of the zebra mussel.

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