AQUATIC INVASIVE SPECIES

Metapopulation Dynamics and Control of the Zebra Mussel in Freshwater and Estuarine Systems: The Effects of Hydrodynamics, Larval Supply, and Embayments

Final Report

Abstract

We studied the ability of large-river embayments to act as sources or sinks of zebra mussel larvae and their role in controlling metapopulation dynamics of zebra mussels in rivers and estuaries. We measured abundance, settlement, and water quality parameters in two pairs of side embayments in the Hudson River and conducted a dye tracking experiment in the Hudson River to measure dispersion parameters and retention in one of the two side embayments. The dye study showed the effect of storms and the timing of the dye release on the retention in the embayment. We analyzed previous dye study data from the Hudson River and constructed a quasi-two-dimensional model, calibrated with field data, that examines the effect of an embayment on larval abundance and settlement. We also examined zebra mussel measurements in the Upper Mississippi River and developed a one-dimensional model of larval transport that shows that Lake Pepin (near Lock & Dam 4) can control larval abundances downstream.

Introduction

The goal of the proposed study is to address the role of large-river embayments and/or backwater areas in serving as either sources or sinks of zebra mussel larvae and their role in controlling metapopulation dynamics of zebra mussels in rivers and estuaries. Objectives of the research are to:

- Monitor environmental factors and larval abundances in the Hudson River and contrast conditions in embayments and in the main river channel.
- Conduct dye studies near embayments to determine their ability to retain larvae.
- Use data from the Hudson River and our previous data from the Illinois and Hudson Rivers to determine whether side embayments can act as sources or sinks for larvae.

Narrative report

This project seeks to help in reducing the destructive effects of the zebra mussel. Zebra mussels have affected the ecology of North American water bodies and caused hundreds of millions of dollars of damage at hydropower plants, sewage treatment plants, and water supply facilities. Most schemes to control the zebra mussel focus on individual sites—either to remove them from a particular facility or to prevent future invasions. However, Stoeckel et al. (1997) suggested a scheme to control zebra mussels in an entire ecosystem. They recognized that since local populations of zebra mussels in a large river are maintained not by larvae produced locally but by larvae produced upstream, blocking the upstream larval supply will cause the downstream populations to quickly decline.

The success of such an ecosystem-wide control scheme requires an understanding of both the biological factors and the physical processes affecting the transport. Our previous work had the goal of predicting the transport and settlement patterns of zebra mussel larvae in rivers and estuaries so that a control strategy exploiting the biology of the zebra mussel and the hydrodynamics of the river can be designed and evaluated. We focused on the Illinois River, in which the flow and therefore larval transport is mainly downstream, and a section of the Hudson River in which the tidal effects are significant. We also developed a model that can be used to evaluate the effectiveness of control strategies, like dispersal barriers, under a range of physical and biological conditions. A finding from that work was that side embayments in rivers can affect the zebra mussel populations in the main channel.

The goal of the current project is to understand in more detail the effect of embayments on zebra mussel populations. Side embayments could be either sources or sinks of larvae. If the retention time of an embayment is large, the embayment can house a stable population of adults that could recruit its own larvae. Embayments could have better conditions for settlement and larvae growth, including more suitable temperatures and settlement habitat. In this case, the embayment could act as a source of larvae for the main channel. On the other hand, embayments can act as sinks of larvae if vegetation and reduced mixing produce lower oxygen levels.

A major part of our effort was fieldwork in the Hudson River. We sampled larval abundance, settlement, and environmental conditions intensively during the spawning season, and we conducted a dye study to understand the water movement. In the first year we deployed settlement plates and water quality samplers and data loggers at four sites—two in embayments and two at nearby main channel sites. The embayments were a small bay in Mills-Norrie State Park and the much larger North Tivoli Bay. The biological and water quality sampling was done once per week at each site. We also sampled after heavy rainstorms since our previous work suggested that runoff from storms could flush larvae from the embayment into the main channel. The dye study occurred near the bay in Mills-Norrie State Park. Dye was injected in the main channel, and concentrations were monitored at the injection site, in the embayment (e.g., figure 1), and from a boat in the main channel. In the second year settlement and water quality were measured at four new sites. The smaller embayment was Hyde Park Marina, a non-vegetated bay south of Mills-Norrie State Park and approximately 1/3 the size of the Mills-Norrie embayment. The larger, vegetated embayment was Vanderburgh Cove, located between Mills-Norrie State Park and North Tivoli Bay, with a volume comparable to that of North Tivoli Bay, though much siltier and shallower.

We have analyzed results of dye studies conducted in August 2000 and August 2002 at Norrie Point in Mills-Norrie State Park. We quantified the retention rate of the embayment by computing the fraction of the dye mass that was retained in the bay as a function of time (figure 2). In 2000, 44% of the dye was retained, while in 2002, 13% was retained because we injected the dye at a different phase of the tide. Although the peak retention differed between the two studies, the rate at which the dye mass was discharged from the bay was similar, particularly prior to the storm events, which started at 0.65 and 2.5 tidal periods after injection in 2000 and 2002, respectively. For both studies, there is a drop in the characteristic retention time after the storm passes, though in 2000, during the larger storm, the drop is much larger. The retention times prior to the storm are the same order of magnitude for both studies, which is expected since they took place under similar conditions and at the same site. However, the climatic conditions affecting both the flow in the river and the adjacent Indian Kill resulted in a small net outflow from the bay in 2000 while there was a small net inflow in 2002. Thus, the slightly larger retention time in 2002 suggests an inverse relationship between retention time and discharge from the bay.

We also continued to analyze results from our previous work that included a dye study in North Tivoli Bay. We developed a computer model of the exchange between the bay and the main channel of the Hudson River. The model was calibrated with published data on mixing in the main channel and our measurements of the exchange between the bay and the river. Self-recruitment of zebra mussels spawned in the bay and resulting downstream population structure were examined by comparing spawning events in the bay to spawning events in the river without the bay. The model predicts little mass is retained in the bay after possible settlement times but self-recruitment may be possible due to large numbers of larvae. Less than a day after the spawning event, the bay causes smaller peak concentrations and smaller cloud widths in the river. Over longer times, the bay causes the peak concentration to be farther south for a flood spawning event and farther north for an ebb spawning event, compared to the cases with no bay. If enough larvae are initially spawned, recruitment in the river near the spawning site is possible because the small net southward flow typical of the spawning season provides little downstream transport of the peak of the dye cloud.

We also analyzed samples from the Upper Mississippi River, between Lock & Dam (LD) 2 and LD 12, to study patterns of larval abundance (figure 3) and possible controlling factors. Estimates of retention time in Lake Pepin, which is the pool between LD 3 and LD 4, suggest that larvae spawned in the lake can settle as adults there. Thus, Lake Pepin can support a self-sustaining population of adults. Computer simulations of larval transport suggest that Lake Pepin plays an important role in providing larvae to downstream populations. The abundance of early stage, unshelled larvae was important in determining the role of Lake Pepin. Studies that consider only abundances of older shelled stages (visible by cross polarized lighting) may yield misleading results. Our work suggests that efforts to control zebra mussels should focus on identifying and controlling self-recruiting adult populations within water bodies such as Lake Pepin and reducing or eliminating larvae exiting the lakes.

Potential applications or benefits

- Two seasons of biological and water quality sampling and a dye study were successfully accomplished.
- The dye study showed the importance of storms and the timing of the release of dye (or larvae) on the retention in an embayment.
- A simple numerical model of the exchange between a bay and a tidal river was developed. It can be used to evaluate the effect of a bay on zebra mussel populations in the river.
- The study of zebra mussels in the Mississippi River showed that Lake Pepin can act as a source for larvae in the Upper Mississippi Rive and that a control scheme, such as a dispersal barrier, focused at Lock and Dam 4 could be an effective way to control zebra mussels downstream. The Mississippi study also demonstrated the importance of estimating the abundance of unshelled larvae in predicting downstream populations.

Keywords
zebra mussels, embayments, rivers, invasive species, control schemes, dispersal, metapopulation

Lay summary

This project seeks to reduce the destructive effects of zebra mussels by determining how they are transported in rivers and estuaries. Because a patch of mussels cannot sustain itself without a constant supply of larvae, the number of zebra mussels in an entire river can be drastically reduced if the larval supply can be blocked. For example, the U. S. Army Corps of Engineers is designing a barrier to be placed in the Chicago waterways to reduce the number of larvae that enter the Illinois River from Lake Michigan. The success of this and other control measures depends on the details of the river flow and the biology of the zebra mussel. In particular, if zebra mussels can establish local populations in areas with low flow, such as side embayments, the effectiveness of a dispersal barrier could be reduced. The goal of this project is to understand the effect of embayments on zebra mussel populations.

We conducted fieldwork, analyzed previous data, and constructed computer simulations of larval transport. We sampled larval abundance, settlement, and environmental conditions intensively at several sites in the Hudson River during the spawning season, and we conducted a dye study to understand the water movement. We developed a computer model of the exchange between North Tivoli Bay and the main channel of the Hudson River; the model allows the effect of the bay to be evaluated. We also analyzed samples from the Upper Mississippi River, between Lock & Dam (LD) 2 and LD 12, to study patterns of larval abundance and possible controlling factors. Computer simulations of larval transport suggest that Lake Pepin plays an important role in providing larvae to downstream populations. One implication of our work is that reducing the amount of larvae from a lake such as Lake Pepin can help control downstream mussel populations.

Publications

Journal articles from this project are

Stoeckel, J.A, Padilla, D.K., Schneider, D.W., and Rehmann, C.R. 2004 Laboratory culture of *Dreissena polymorpha* (Pallas, 1771) larvae: spawning success, adult fecundity, and larval mortality patterns, Can. J. Zool., 82, 1436-1443.
Stoeckel, J.A, Rehmann, C.R., Schneider, D.W., and Padilla, D.K. 2004 Retention and supply of zebra mussel larvae in a large river system: importance of upstream lakes, *Freshwater Biology*, 49, 919-930.
Carr, M.L., Rehmann, C.R., Stoeckel, J.A., Padilla, D.K., and Schneider, D.W. Effects of tides and storms on retention in a small side embayment, in preparation for the Journal of Hydraulic Engineering.

Journal articles from our related, previous Sea Grant projects are

Schneider, D.W., Stoeckel, J.A., Rehmann, C.R., Blodgett, K.D., Sparks, R.E., and Padilla, D.K. 2003 A developmental bottleneck in pelagic larvae: implications for spatial population dynamics, Ecology Letters, 6, 352-360.
Carr, M.L., Rehmann, C.R., Stoeckel, J.A., Padilla, D.K., and Schneider, D.W. 2004 Measurements and consequences of retention in a side embayment in a tidal river. *J. Marine Systems*, 49, 41-53.

Conference presentations from this project are

Carr, M.L., Leach, L.M., Jackson, P.R., Rehmann, C.R., Stoeckel, J.A., Padilla, D.K., and Schneider, D.W., “Exchange between embayments and the Hudson River and implications for zebra mussel populations”, American Geophysical Union Ocean Sciences Meeting, Honolulu, HI, 2002.
Rehmann, C.R., Stoeckel, J.A., Padilla, D.K., and Schneider, D.W., “A biophysical model of zebra mussel dispersal in the Illinois River”, American Geophysical Union Ocean Sciences Meeting, Honolulu, HI, 2002.
Rehmann, C.R., Leach, L.M., Carr, M.L., Jackson, P.R., Stoeckel, J.A., Padilla, D.K., and Schneider, D.W., “Transport and trapping of zebra mussel larvae in the Illinois and Hudson Rivers”, 11th International Aquatic Invasive Species Conference, Alexandria, VA, 2002.
Padilla, D.K., Rehmann, C.R., Stoeckel, J.A., Schneider, D.W., and Sparks, R.E. “Metapopulation dynamics, larval mortality, and recruitment in the zebra mussel (*Dreissena polymorpha*): Potential for control in large river systems”, 11th International Aquatic Invasive Species Conference, Alexandria, VA, 2002.
Stoeckel, J.A., Schneider, D.W., Rehmann, C.R., and Padilla, D.K., “Veliger abundance patterns in the Upper Mississippi River, 1998-2000”, Meeting of the Mississippi River Research Consortium, 2002.
Stoeckel, J.A., Rehmann, C.R., Schneider, D.W., and Padilla, D.K., “Supply of zebra mussel larvae in large river systems: role of a run-of-the-river reservoir”, North American Benthological Society Annual Meeting, 2003.

Student support

Meredith Carr, a Ph.D. student at UIUC, received support from the Illinois-Indiana Sea Grant portion of the grant. Several students from the Department of Civil and Environmental Engineering at UIUC participated in the dye study. Meredith Carr led the planning, and Juan Saenz and Ryan Jackson helped. These three graduate students plus graduate students Jin Hwan Hwang and Danielle Wain and undergraduate Chad Gladfelter conducted the dye study. Helen Bustamante, a graduate student in the Program in Ecology and Evolutionary Biology who is supported by the New York portion of the grant, and Grace Lee, a former undergraduate in UIUC Integrative Biology, also assisted in the study.

Related projects

This project continues the work from the Illinois-Indiana Sea Grant project R/ANS-99-07 and the National Sea

Grant project A/NS-SE-04. Rehmann and Schneider were the principal investigators on a project titled "Evaluation of a scheme to control invasive species in the Chicago Sanitary & Ship Canal", in which the possibility of using bubble screens as a dispersal barrier was evaluated; funding was provided by the Illinois Water Resources Center.

Figure 1. View of the embayment during the 2002 dye study. The water is pink because of Rhodamine WT dye that was injected in the main channel and trapped in the embayment.

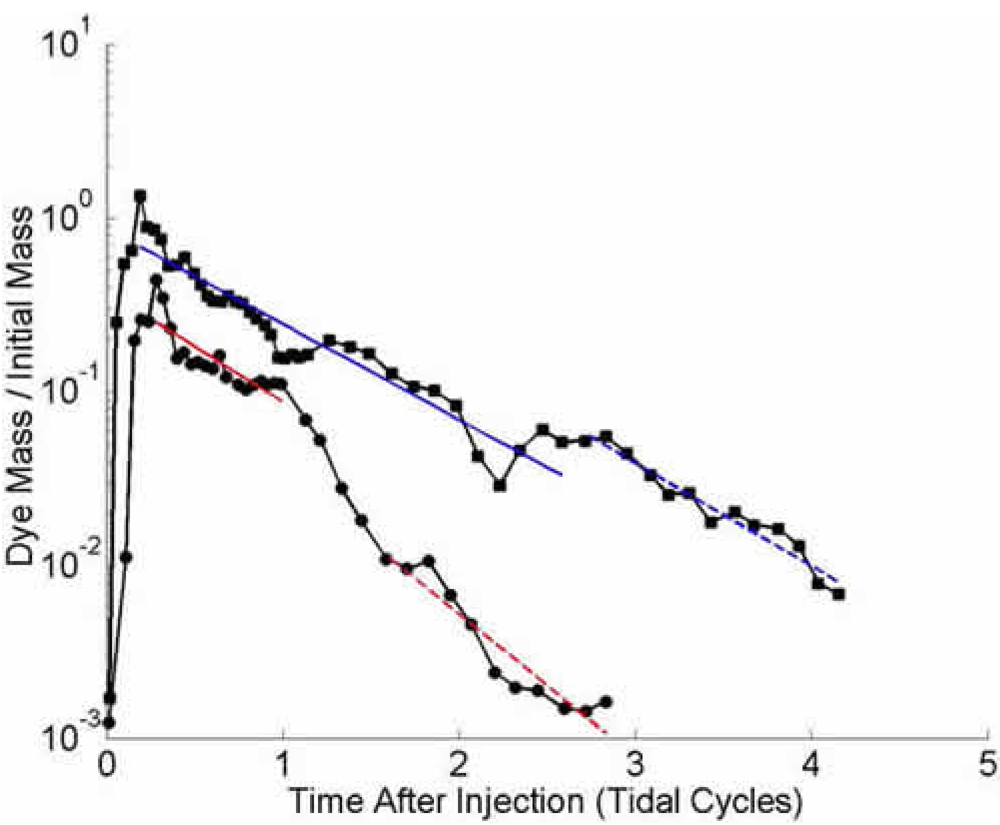

Figure 2. Retention in a side embayment in the Hudson River Circles denote the 2000 study, while square denote the 2002 study (multiplied by 10). Lines are exponential fit to portions of the curve to determine retention times.

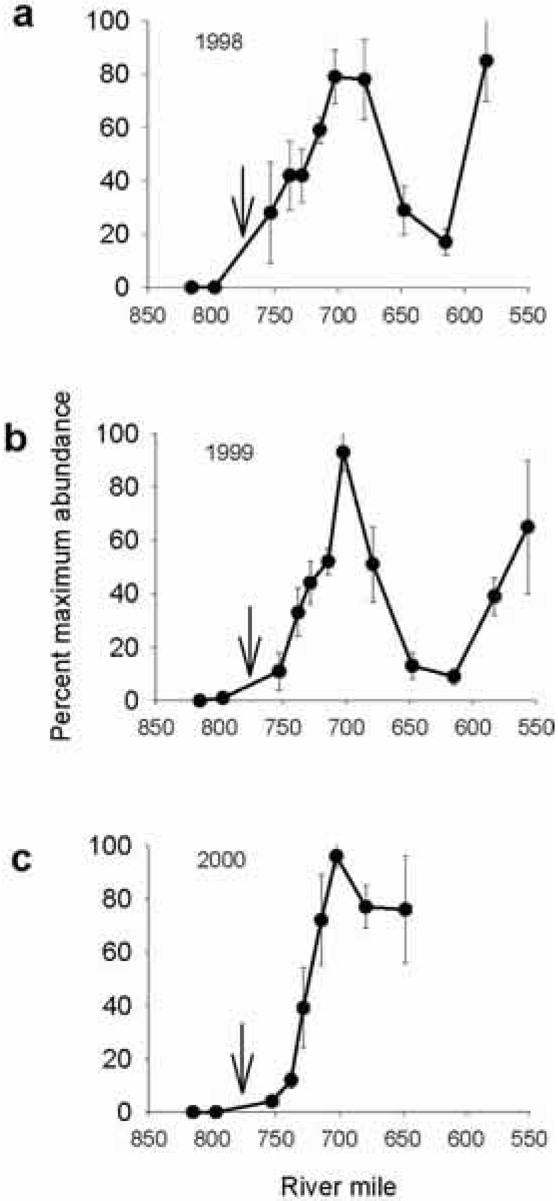

Figure 3. Combined patterns of larval abundance for 1998, 1999, and 2000 in the Upper Mississippi River. Perent of maximum abundance was calculated by dividing abundance at each site by maximum abundance recorded on that date and multiplying by 100. Errors bars represent +/- 1 standard error. Arrows indicate location of Lake Pepin. From Stoeckel et al. 2004, Freshwater Biology.

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Research Information

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