# AQUATIC INVASIVE SPECIES

## Predicting Zebra Mussel Transport in rivers and Estuaries

## Final Report

Lake Michigan is a source of zebra mussel larvae which establish nuisance populations of adult zebra mussels downstream in the Illinois and Mississippi rivers. Similar situations, where source populations "seed" downstream reaches will become increasingly common as the zebra mussel continues to spread. An important question is whether downstream populations of zebra mussels might be controlled by cutting off the flow of larvae from upstream. Since each downstream population in turn serves as a source, cutting off the flow of larvae at the head of the system might cause a downstream cascade of extinctions of zebra mussel populations. Control of nuisance populations of zebra mussels over substantial distances in rivers might be achieved by larval control at one critical upstream location. Barriers or other control measures for planktonic larvae will be expensive, so it is important to predict whether they will work or not. The biological component of this project is supported by a NSI to Dr. Daniel Schneider (University of Illinois at Urbana-Champaign) and several co-investigators. The hydraulic transport of the zebra mussel larvae will be addressed in both the Illinois River and the Hudson River by Dr. Chris Rehmann (University of Illinois at Urbana-Champaign) and co-PIs Schneider and Dr. Dianna Padilla (State University of New York at Stony Brook). A single model that combines physical transport mechanisms with the biology and population dynamics of the zebra mussel will be developed and verified in these two rivers. The approach and the model should be applicable to other systems. The investigators will meet periodically with the Chicago District of the U.S. Army Corps of Engineers, which is constructing a dispersal barrier in the Chicago canal system in the spring of 2000. Although this first phase barrier targets benthic fishes (round goby), later phases would also target drifting larvae.

### Goals and Objectives

The goal of the project is to predict the transport of zebra mussel larvae in rivers and estuaries so that control strategies can be designed and evaluated. The physical processes of the transport are being coupled with models of the biological processes to determine the most important factors affecting settlement. This work will help in applying the results of this study to other rivers and estuaries. To achieve the goals, we will

1. Identify the main mechanisms affecting physical transport in the Illinois and Hudson Rivers.
2. Model the less well-understood mechanisms in detail and parameterize them in terms of easily-measured parameters.
3. Construct a single model that combines the physical transport mechanisms with the biology and population dynamics.
4. Identify the processes controlling the transport and settlement patterns.

### Summary of Progress

Separated effects of dispersion, mortality, and settlement on the evolution of zebra mussel larvae in the Illinois River and predicted settlement patterns for simple hydrodynamic conditions.

Constructed and started testing a model that predicts the transport of larvae and evolution of adult zebra mussels in a river with more realistic hydrodynamics.

Identified several key areas in the Illinois River that affect larval transport, including Peoria Lake and several locks and dams.

Conducted two dye tracking experiments in the Hudson River to measure dispersion parameters and assess the importance of side embayments on the trapping of zebra mussel larvae.

### Accomplishments/Benefits

Data from previous float trips following cohorts of zebra mussels in the Illinois River allowed us to obtain quantitative estimates of dispersion, mortality, and settlement in the field rather than in a laboratory. This information was used in a simplified model to predict settlement patterns in the Illinois River and estimate transport and settlement in other large rivers. The model shows that differences in flow and larval cohort characteristics can lead to significant variations in settlement location, area, and abundance.

A mathematical model of transport of larvae and evolution of adult populations will allow us to account for the biological and physical processes in more detail and predict settlement pattern in the Illinois River and other rivers. This model includes effects of ‘dead zones’ (such as backwater lakes and areas behind locks and dams) and nonuniform larval age in a cohort. Agencies like the Army Corps of Engineers can use such a model to predict effects of control schemes on the downstream zebra mussel populations.

A dye study in the Hudson River in August 2000 suggested that side embayments can be important in trapping zebra mussel larvae and that accounting for the hydrology of the region can be important. In particular, embayments may act as refuges for zebra mussels and runoff from large storms may flush larvae (or dye) into the main channel of the river. Measurements of abundance and settlement from the companion National Sea Grant project that show a correlation between settlement and rainfall support the inferences from the dye study.

A dye study in the Hudson River in August 2001 measured the exchange between a large bay and the main channel. The dye, which acts as a surrogate for nutrients or zebra mussel larvae, was released at two inlets to North Tivoli Bay as water started entering the bay (i.e., just after low tide). Preliminary results from one of the inlets suggest that much of the dye leaves the bay in a single tidal cycle but little returns. The final results of the study will allow us to quantify the exchange between the bay and the main channel and construct an approximate exchange model for the monthly tidal cycle.

### Narrative Report

This project, along with a companion project funded by the National Sea Grant College Program, 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. The goal of this project is to predict 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 have 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 have progressed toward developing a model that can be used to evaluate the effectiveness of control strategies, like dispersal barriers, under a range of physical and biological conditions. The model can also be used to identify the main factors affecting the establishment of zebra mussel populations to facilitate the design of control measures in other rivers.

For the Illinois River we have estimated effects of dispersion, mortality, and settlement on the evolution of zebra mussel larvae and identified and started modeling key areas that affect larval transport. Data collected during float trips on the Illinois River have allowed us to estimate physical and biological parameters. As part of a previous Sea Grant project, co-PI Schneider and other investigators on the companion National Sea Grant project followed cohorts of zebra mussel larvae as they drifted downstream. Thus, we are able to observe the evolution of a cohort from early in the life cycle to settlement. A time series of larval abundance measurements typically shows three stages. At first, the abundance decreases simply because the cohort is spreading due to physical dispersion along the channel. In the second stage, a sharp decrease typically occurs because of increased mortality as the larvae move from the D-stage to the umbonal stage. In the final stage, the abundance decreases sharply once more when the larvae are large enough to settle.

We have used these data in developing a model that combines the hydrodynamics with the biology. We estimated dispersion, which affects the cohort throughout its evolution, from regressions based on the tracer experiments of Zuehls (1987) in the Illinois River. Once dispersion is accounted for, mortality and settlement as a function of time or larval age can be estimated from solutions to a transport equation that includes advection, dispersion, mortality, and settlement. The scientific impact of this part of the project is that it provides one of the few estimates of mortality and settlement in the field rather than the laboratory. It also shows a large increase in mortality occurs near the transition between the D-stage and umbonal stage. Compared to the decrease in peak abundance due to mortality, the decrease due to dispersion is small. The practical benefits include improved ability to predict settlement patterns and information that can be exploited in targeting zebra mussels during critical stages of their development.

The analysis of the field data used a relatively simple description of the physical transport. However, the details of the transport can be crucial for the success of a control scheme; for example, if zebra mussels can form and sustain a local population behind a navigation dam, they may be able to supply downstream populations with larvae and reduce the effectiveness of a dispersal barrier in the Chicago waterways. To include the effects of these details, we have developed a mathematical model based on the aggregrated dead zone model (Rutherford 1994). Because the mortality and settlement depend strongly on age or stage of the larvae, we have also accounted for variations in ages of the larvae in a cohort. We are now implementing a numerical simulation of the mathematical model. This model can then be used by agencies like the Army Corps of Engineers to assess the effect of control schemes.

To choose the parameters for the model, we have used two dye studies in the Hudson River to help us understand and quantify exchange between a side embayment and the main channel of a river. In August 2000 we injected a slug of fluorescent dye, Rhodamine WT, at Mills-Norrie State Park and measured concentrations at the injection site and nearby sites over several tidal cycles, or two to three days. Because the reach of the Hudson River we studied has significant tidal influence, an issue with the injection was the timing relative to the tidal cycle. To minimize dispersion during the injection and avoid high concentrations near Poughkeepsie, we released the dye just as the current turned north. We injected dye twice; the first release of 3 gallons of dye showed that much of the dye entered a marina just north of the injection site. For the second experiment, we released 9 gallons of dye and focused on the exchange between the side embayment (i.e., the marina) and the main channel. We sampled concentrations at the injection site, at five locations in the marina, and one location just north of the marina. Sampling continued until concentrations reached the background level measured before the injection.

During the second release much of the dye entered the marina and remained visible for about a tidal cycle, or half a day. A severe thunderstorm arrived about eight hours after the injection and lasted for several hours. Over 500 water samples were collected in the marina. From these samples, we determined the fraction of the dye that is in the marina or embayment as a function of time and obtained a quantitative estimate of the exchange between the marina and the main channel. The embayment initially trapped nearly 50% of the dye, but runoff from the storm entered the marina and apparently flushed the dye, bringing concentrations back to background levels after about 1.5 tidal cycles. In contrast, dye concentrations measured in the main channel showed that the dye cloud returned to the injection site three times (that is, over three tidal cycles) before it dispersed enough to be undetectable.

The dye study results suggest that side embayments can trap significant amounts of zebra mussel larvae spawned near the shore. However, they also show that while the small tributaries may have a minor effect on the flow in the main channel, they may affect zebra mussel populations dramatically by flushing larvae from refuges on the side of rivers. Measurements of abundance and settlement over several months, which were part of the companion National Sea Grant project, support this conclusion: At Mills-Norrie State Park, which was downstream of the marina, settlement and rainfall were highly correlated. However, at Marist College in Poughkeepsie, which is far from any side embayment, no such correlation was observed. This combined study of hydrodynamics and biology illustrates the importance of sporadic hydrologic events such as storms and local geometric features such as side embayments.

In August 2001 we conducted another dye study to measure exchange between a side bay and the main channel. This study, partially supported by the National Estuarine Research Reserve System, occurred in North Tivoli Bay near Annandale, NY. This bay has four main inlets and outlets: two channels under railroad bridges that connect the bay directly to the main channel, a small area on a peninsula between North and South Tivoli Bays in which the bays exchange water at high tide, and Stony Creek, which empties into the eastern part of the bay. We measured the flow in Stony Creek, neglected the exchange between the North and South Bays, and focused on the two channels under the bridges. We injected 6 gallons of Rhodamine WT at each bridge as the water started entering the bay (i.e., just after low tide), and we measured profiles of dye concentration and water velocity across the cross-section. The detailed measurements occurred over about one tidal cycle, and continuously-recording fluorometers measured the dye concentration over about 1.5 tidal cycles.

From these measurements, the inflow and outflow of dye will be estimated, and a dye mass balance will be evaluated. In particular, the fraction of dye leaving the bay and the fraction of dye remaining in the bay can be estimated. Results from one of the fluorometers allow for some preliminary conclusions. If the dye cloud did not spread as it moved through the channels in the bay, it would theoretically reappear at the outlet after one tidal cycle. The fluorometer data show that dye returns to the outlet after about half a tidal cycle, or almost immediately after the tide turns. This observation suggests that some of the dye is trapped in dead zones near the outlet. Concentrations remained relatively high as the water left the bay. After the tide turned again, significant dye concentrations were recorded over only about one hour. Thus, once the dye (or larval cohort) enters the main channel, not much appears to return to the bay. After fully analyzing the results of this dye study, we hope to construct a mathematical model of the mixing and exchange in this bay.

## Brief 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 the Illinois River, zebra mussels may be able to establish local populations in areas with low flow, like backwater lakes and areas behind locks and dams. In the Hudson River, which has significant tidal effects over much of its length, larvae may simply oscillate around the spot where they were spawned. The goal of this project is to understand the interaction between the physics of the river flow and the biology of the zebra mussel so that control schemes can be designed and evaluated.

We have used our previous field measurements of larval abundance and size from the Illinois River to determine the spread of a cloud or cohort of larvae as it moves downstream, the larval death rate, and the rate at which they settle out of the flow. This information is critical for predicting the spread and establishment of zebra mussel populations; by knowing how quickly they die and when they settle, we can predict the location and size of mussel patches. To determine where larvae might travel in the Hudson River, we performed two experiments in which we tracked the spread of a non-toxic, fluorescent dye. These studies allowed us to evaluate the ability of side bays to act as refuges for zebra mussel larvae. If adult mussels can live in side bays and serve as sources of larvae for the rest of the river, then a single dispersal barrier upstream would be relatively ineffective at controlling zebra mussels.

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