Ecological Complexity 7 (2010) 243–255

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

A risk-based decision model and risk assessment of invasive mussels

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ARTICLE INFO

Article history:
Received 14 December 2009
Received in revised form 4 February 2010
Accepted 10 February 2010
Available online 16 March 2010

Keywords:
Zebra mussels
Invasive species
Risk-based decision model
Ecological risk assessment
CASM

ABSTRACT

Ecological risks and economical impacts of zebra mussels (*Dreissena polymorpha*) include alterations in the transfer of energy and cycling of materials in aquatic systems, increased accumulation of contaminants in aquatic food chains, clogging of water intakes, and damage to related infrastructure. A risk-based decision model was developed to assess the likelihood of zebra mussel invasion and establishment throughout the St. Croix Basin. The risk-based decision model $CASM_{ZM}$ is a version of the comprehensive aquatic systems model (CASM) and that was modified to simulate the growth, reproduction, and spatial distribution of zebra mussels. As a risk management tool, the model simulates the population dynamical complexity of zebra mussel populations, as well as their impacts on phytoplankton, zooplankton, benthic invertebrates, fish and natural mussel populations. The $CASM_{ZM}$ is based in part on a set of zebra mussel's physical–chemical habitat requirements such as calcium concentration (17 mg/L), total hardness (57.5 mg/L), conductivity (62 μS/cm), dissolved oxygen concentration (6 mg/L), salinity (7 PSU), pH (6.8 and 9.4), Secchi disk depths (75 and 205 cm), and water temperatures for growth (14 °C) and reproduction (30 °C). The $CASM_{ZM}$ also includes a bioenergetics framework that describes the growth of zebra mussels and their trophic impacts on aquatic food webs. The $CASM_{ZM}$ can be used to forecast the risk of successful dreissenid invasions and assess the associated impacts of invasive mussels on food web dynamics of previously uninfested aquatic systems throughout the St. Croix Basin.

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1. Introduction

The zebra mussel (*Dreissena polymorpha*) is freshwater mollusks native to the Black and Caspian Sea region of Asia. It is believed that these mussels were introduced to the Great Lakes via ballast water from foreign ships in the early to mid 1980s. Since then, these mussels have spread aggressively throughout the Great Lakes and the Illinois and Mississippi Rivers (USGS, 1997; McMahon et al., 1993; Mackie et al., 1989). The invasion and establishment of zebra mussels have dramatically changed aquatic ecosystems (MacIsaac et al., 1991). The ecological and economical impacts of the dreissenid include alteration of food webs, changes in water quality, increased levels of contaminants in food chains, and damage to water intake pipes and similar infrastructure (Kovalak et al., 1993).

Perhaps the most obvious system-wide effects of zebra mussels have been in large lakes or relatively lake-like sections of river impoundments. Following the settlement of first zebra mussels in the 1980s, the numbers of the amphipod *Diporeia* in the Great Lakes have declined substantially. Declines in *Diporeia* appear correlated with reduced numbers and condition of its fish predators, including young lake trout (Karatayev et al., 1997). In contrast, the abundance and diversity of benthic invertebrates has been observed to increase in the presence of high numbers of zebra mussels (Cohen and Weinstein, 1998a,b). Additionally, the removal of seston by zebra mussel filter-feeding can increase water clarity and stimulate the growth of benthic algae and macrophytes (Karatayev et al., 1997; Leach, 1993). Concerns regarding the potential impacts of zebra mussels on the continued viability of native unionid mussels further underscore the need for a risk-based decision support model (Bartell et al., 1992). These concerns are especially important for threatened or endangered mussel species such as the Higgins eye pearlymussel (*Lampsilis higginsii*) a freshwater mussel found only in the Upper Mississippi River, the St. Croix River in Wisconsin, the Wisconsin River and the Rock River in Illinois (Pothoven and Madenjian, 2008; Miller and Payne, 2007; Nalepa et al., 1993; Thiel, 1981).

Biofouling is the greatest abiotic effect of dreissenid mussels in newly invaded lakes, reservoirs, streams, and rivers. In the Great Lakes, fouling by dreissenids is generally limited to structures submerged below 1.2 m depth (Claudi and Mackie, 1994; Martel, 1993; EPRI, 1992). The economic costs of biofouling by zebra

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doi:10.1016/j.ecocom.2010.02.010

mussels have been substantial (Claudi and Mackie, 1994). Zebra mussel prevention, control, and monitoring were estimated to have cost facilities in the Great Lakes region as much as $2–5 billion dollars throughout the late 1990s (Payne and Miller, 2004; Bemy et al., 2003; OTA, 1993).

In addition to biofouling, zebra mussels can concentrate and transfer toxic contaminants through aquatic food webs by accumulating chemicals in mussel tissues as much as 100,000 times the concentration in the surrounding water (de Kock and Bowner, 1993). Waterfowl that consume contaminated zebra mussels noticeably show elevated concentrations of metals, organic pesticides and polychlorinated biphenyl compounds. Species that feed on zebra mussels such as round gobies, freshwater drum and ducks might be impacted by eating contaminated zebra mussels. Bioaccumulation may further increase the concentration of chemical contaminants in predator species (Bemy et al., 2003). A habitat modification by dreissenids of potential importance is the "pelagic-to-benthic" shift in organic carbon resulting from suspended organic materials being ingested by mussels, bundled in mucus, and deposited as pseudofeces (Schloesser et al., 1998). Ironically, this modification can create an environment that is not suitable for zebra mussels.

This research was conducted in the St. Croix Basin, which is located in northwest Wisconsin, USA and includes all or parts of Douglas, Bayfield, Burnett, Washburn, Sawyer, Polk, Barron, Pierce and St. Croix counties. The purposes of the research were to (1) assess the vulnerability and risk of surface waters within the St. Croix Basin to invasion and establishment of zebra mussels, (2) develop a risk-based decision model to assist in the control and management of invasive mussels, and (3) evaluate the effectiveness of alternative technologies in controlling or reducing the rate of mussel spread throughout the basin. In this research, the potential effects of zebra mussel establishment on the population viability of the endangered Higgins eye pearlymussel (*L. higginsii*) were also addressed.

To establish a persistent population, zebra mussels introduced to a previously uninfested system must be able to survive, grow, and reproduce. Assessing the risk of dreissenid mussel infestation in the St. Croix Basin should be based on an understanding of their life cycles, habitats, food resources, and vectors for transport (Vanderploeg, 2002; Lange and Wittmeyer, 1996). First, the general life cycle characteristics of these species are of interest in this study because environmental factors that define habitat quality and influence the successful completion of the cycle can be used to forecast the vulnerability of non-infested surface waters to invasion and establishment of zebra mussel populations (De Blasio and De Blasio, 2009).

Second, it is important to understand that the veligers are transported and distributed not only by natural flows among connected surface waters, but also by commercial navigation and recreational boating (Johnson et al., 2001; Johnson, 1997; Johnson and Carlton, 1996; New York Sea Grant Extension Fact Sheet, 1994; Carlton, 1993; Penaloza, 1991). Data that describe and quantify these pathways for zebra mussel infestation of surface waters were used to develop an inoculation component of the risk-based decision support model for invasive mussels in the St. Croix Basin (Morozov et al., 2008).

Third, a newly invaded physical–chemical environment must be inhabitable and favorable for successful reproduction. A set of important habitat factors that determine habitat quality for zebra mussels has been defined (Cohen and Weinstein, 2001). This set includes total hardness, conductivity, pH, salinity, Secchi disc depth, water depth, water temperature, current velocity, and concentrations of calcium, potassium, and ammonia. Chlorophyll *a* concentration is also included as a surrogate for food availability. Water temperature includes both temperature requirements for growth and survival, as well as temperatures conducive to successful spawning. Habitat factors determined to be important in the successful invasion and establishment of these mussels have been used as one component of an integrated risk-based decision support model. Food must be available in sufficient quantity and quality. Zebra mussels use food resources similar to those required by native zooplankton and benthic invertebrates (Medvinsky et al., 2007; Alderman and Hinsley, 2007; Nalepa et al., 2006; Leach, 1993).

The model construct requires derivation of a functional relationship between numbers of an invasive species and the likelihood of establishing a self-reproducing population. The overall approach is a consistent in concept with the multi-criteria decision analysis encouraged by Payne and Miller (2004). The model attempts to be comprehensive by including the many recognized events, processes, and pathways that convey invasive species to non-infested surface waters. Each of these mechanisms of inoculation can be associated with management actions and decision criteria aimed at reducing the likelihood of introducing invasive mussels.

The potential methods for model development range from a simple ranking scheme using the combined (i.e., summed) results of the individual model component scores to more complex analyses based on decision trees (e.g., Payne and Miller, 2004), genetic algorithms (e.g., Drake and Bossenbroek, 2004), or neural networks. Instead of a using fixed, static decision-tree calculus, the risk-based decision model was formulated as a dynamic, event-driven simulation (Bartell et al., 2000).

The formulation of the risk-based decision model and estimation of necessary parameters implies uncertainties in model implementation and in the evaluation of management alternatives. Where possible, the input parameters were defined as statistical distributions to characterize uncertainty. Monte Carlo methods were used to propagate these uncertain parameter values through the model to describe uncertainties of the model results. This approach importantly provides the capability for numerical sensitivity and uncertainty analyses as part of the overall decision model. The results of sensitivity and uncertainty analyses can be used to (1) assess the risk of establishment in more probabilistic terms consistent with the definition of ecological risk (Bartell et al., 1992), and (2) determine the value of new data in reducing risk and improving model results used to evaluate management actions. Additional data can be collected that will reduce uncertainties and increase the usefulness of model results for management and decision-making (Rai et al., 2007).

An ecological risk assessment is a commonly used framework for assessing environmental impacts and evaluating management actions in relation to ecosystem management and restoration (Bartell et al., 1999; CENR, 1999). In this research, the integration of the risk assessment and the risk-based decision model was used to characterize risks of invasive mussel establishment for surface waters within the St. Croix Basin. Risk of establishment was assessed as a function of habitat quality characterized for individual water bodies. In addition, spatio-temporal patterns of reported and estimated infestation were used to infer rates and directions of dreissenid spread throughout the Basin. The overall model construct was designed to incorporate uncertainty associated with the habitat, location, and inoculation components of the model (Borrett et al., 2007).

2. Methods

Data and information that described the life history, biology, and ecology of the dreissenid mussels were collated from the technical literature. This information was used to identify key state variables and derive parameter values for the risk assessment and risk-based decision model $CASM_{ZM}$.

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