Invasive Mussel Collaborative

Strategy to Advance Management of Invasive Zebra and Quagga Mussels

November 2018

Preface

The Invasive Mussel Collaborative was established to advance scientifically sound technology for invasive dreissenid mussel control to produce measurable ecological and economic benefits. The Collaborative provides a framework for communication and coordination, identifies the needs and goals of resource managers, prioritizes supporting science, and aligns science and management goals into a common agenda.

The Collaborative has a broad membership base of federal, state, provincial, and tribal agencies, and other entities. Its organizational structure includes a 29-member Steering Committee and a 12-member Science Team (membership list available at www.invasivemusselcollaborative.net). The founding members of the collaborative are the U.S. Geological Survey, Great Lakes Commission, National Oceanic and Atmospheric Administration and the Great Lakes Fishery Commission. The Collaborative members established a “common language agreement” that outlines the mission, goals and objectives of the Collaborative. This agreement states “the goal of the Invasive Mussel Collaborative is to develop and guide the implementation of a long-term adaptive strategy that establishes and prioritizes an agenda for developing effective dreissenid mussel control methods that can be applied at a variety of spatial scales and environments to control or eradicate dreissenid mussels and support the restoration of biodiversity, and ecosystem functions and services.” The enclosed strategy is the product of this collaborative effort.

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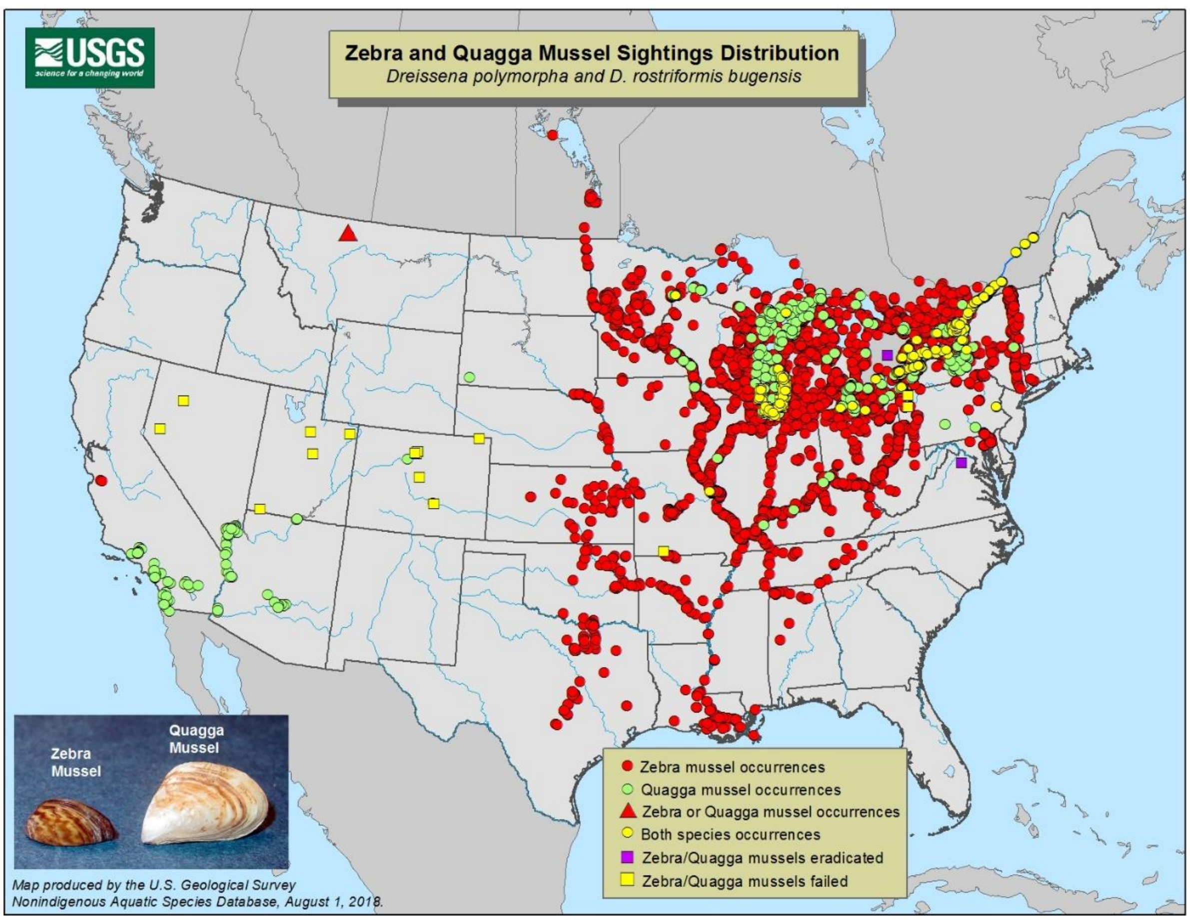
Introduction

Zebra mussels (*Dreissena polymorpha*) are small, fingernail-sized mussels native to the Caspian Sea region of Asia. Considered one of most damaging invasive species in the world, zebra mussels were first discovered in the United States in the 1980s in Lake St. Clair near Detroit, Michigan. Zebra mussels rapidly spread to each of the five Great Lakes, into waterways in many states, and into the provinces of Ontario and Quebec. The quagga mussel (*Dreissena rostriformis bugensis*), a mollusk native to Ukraine, followed the zebra mussel as the second dreissenid species from Eurasia to invade North America. Quagga mussels were first discovered in the Great Lakes in 1989 near Port Colborne in Lake Erie and then in 1991 in the Erie Canal and Lake Ontario. They were found coexisting with dense populations of zebra mussels.

Although these two invasive mollusks are genetically and morphologically distinct, both have similar biological characteristics allowing their widespread establishment. Zebra and quagga mussels are currently found across much of the U.S. and in Canada, and new introductions continue to be identified.



One of the zebra mussel's most defining characteristics is its tendency to colonize hard substrates and surfaces (e.g., rocky bottoms and water intake structures) in high densities, with as many as tens of thousands of individuals living in a square meter. While zebra mussels generally limit colonization to hard substrates, quagga mussels also readily colonize soft substrates. This characteristic has allowed the quagga mussel to spread to areas of sand and sandy silt, such as the bottom of Lake Erie, and substantially increases the area of potentially suitable substrate for colonization.

Another significant concern is the deleterious effects that zebra and quagga mussels have on ecosystems. Through its feeding process, a single zebra mussel can filter approximately a liter of water per day. This immense filtration capacity impacts the entire aquatic food web by reducing the amount of available phytoplankton in the water column that other organisms, such as zooplankton and larval and forage fishes, feed on. Studies indicate that beginning around 2005, quagga mussel filtering dramatically reduced primary production (photosynthetic production of chemical energy) in Lakes Michigan and Huron. The filtration of phytoplankton can also increase water clarity, an impact that can result in changes to the ecological structure of the lake community and promote the growth of nuisance algae.

Dreissenid mussels have been further implicated in the basin-wide crash of populations of *Diporeia*, a bottom-dwelling invertebrate that once served as an important food source for many Great Lakes fishes, and severe impacts to the spring bloom of diatoms (silica-based algae) have been documented. In addition to altering food webs, both species accumulate contaminants within their tissues to levels greater than concentrations in the water column, increasing the exposure of wildlife to contaminants. Zebra and quagga mussel infestations also threaten native mussel populations by attaching, interfering with locomotion, and competing for food resources, leading to the death of the native mussel.

Dense colonies of dreissenid mussels degrade important reef and other habitat that many species rely on, including valuable sport fish, leading to ecological as well as economic consequences. Dreissenid mussels also clog water intake structures, pipes, and screens, thereby interfering with water conveyance of power and water treatment plants and leading to significant remediation costs to industries, companies, and communities. Recreation-based industries and activities also have been impacted by dreissenid mussels as docks, breakwalls, buoys, boats, and beaches all have been heavily colonized by these species, making them more difficult or impossible to use.

Government agencies, non-government organizations, academia, and private industry have spent the last 30 years researching invasive dreissenid mussels and investing in and implementing methods to prevent and control the spread of these species. A majority of this work has been reactive and focused on preventing further spread and mitigating direct impacts to utilities and industrial facilities. While much has been learned from this work, there is still more that is needed. Until recently, little has been done to advance management and control options for open water environments. In addition, there are still aspects of dreissenid mussels' role in an ecosystem that are not well-understood, and these roles become more complicated the longer an established population exists. More effective tools are needed to control and eradicate mussels to mitigate detrimental impacts in a variety of environments. This includes increasing capacity to stop new infestations when they are first discovered and to minimize impacts in areas where they are already present. The continued spread of dreissenid mussels across North America, as well as recent advancements in the development of control methods, has generated significant renewed interest in the potential for management and control of these damaging species.

Purpose and Scope

The purpose of this strategy is to drive investments, policy and research that leads to reducing invasive mussels and their impacts across the Great Lakes region. The strategy is designed to help inform, coordinate and prioritize ongoing research and management efforts with a focus on advancing control and management of zebra and quagga mussels (ZQM) in open-water environments. This strategy identifies five goals for ZQM management and control, and a series of associated objectives that will address information needs, enhance progress, and increase capabilities toward achieving the goals. The goals are aspirational and represent the driving factors for pursuing ZQM management and control. The goals provide a framework to direct and guide future actions which will demonstrate what is feasible for ZQM management and control. The objectives are also intentionally written at a strategic level, to allow managers and researchers flexibility in developing approaches to implementation. Researchers and managers will need to determine the specific actions necessary to address the objectives according to their individual agency mission, priorities, and capacity.

The goals and objectives reflect the fact that ZQM are widespread and established in all five Great Lakes[1], as well as in water bodies across the Great Lakes region. The Invasive Mussel Collaborative (IMC) also recognizes that the goals and objectives, as well as implementation of the strategy, is relevant outside Great Lakes region. Thus, the IMC will strive to connect related management and research efforts across geographic boundaries. Implementation of this strategy does not preclude ZQM prevention and management activities within other systems; it is intended to complement those efforts and expand scientific knowledge and tools for management and control.

Definitions

Control	reduce an established population ***to a target level***[2] in order to minimize deleterious impacts and/or achieve a beneficial outcome
Cost-benefit Analysis	a systematic process for calculating and comparing benefits and costs of a project, decision, or policy
Eradicate	remove or eliminate all living organisms of an established population in a geographically defined area
Establish(ed)	a species with a self-sustaining population outside its native range
Management	any activity or suite of activities undertaken to achieve specified ecologic and/or economic outcomes
Prevent(ion)	preventing organisms from entering a pathway, or preventing organisms that are transported from being released or escaping alive
Response	any activity or suite of activities undertaken to stop establishment, or prevent spread (i.e., containment)
Suppress(ion)	reduce an established population in order to minimize deleterious impacts and/or achieve a beneficial outcome

[1] Quagga mussels are not considered established in Lake Superior.

[2] The IMC recognizes the importance of defining target levels when implementing control efforts, and that target levels may vary depending on desired outcomes, and thus, should be defined on a case-by-case basis using adaptive management principles.

Guiding Principles

- Prevention is the most cost-effective strategy for mitigating against ZQM impacts, and investments in prevention efforts should continue (e.g., ongoing outreach, regulatory harmonization, and compliance efforts)
- Managers may have different reasons for implementing a ZQM response or control action and the decision to act will be made by the appropriate authority for the impacted water body (this strategy does not recommend or define a process for determining if an action should be taken)
- Goals, desired outcomes, and measures of success for a specific response or control action should be clearly defined and communicated at the outset to establish clear expectations
- Complete eradication of mussel populations may not be necessary to achieve the desired management goal or outcome (e.g., restoration of a spawning reef may be achieved through sustained suppression of ZQM populations)
- Success of management and control efforts may be impacted by factors outside manager control (e.g., environmental conditions, administrative delays (e.g., permitting), extreme weather events (e.g. floods), etc.)
- ZQM control is only one component of ecological restoration efforts and additional activities beyond control of ZQM may be necessary to achieve a broader management goal (e.g., restoration of critical spawning habitats may also require removal of shell and sediment to improve interstitial space for egg deposition)
- The Great Lakes are a shared ecological and economic resource with multiple management jurisdictions and stakeholders contributing to societal expectations that are an important part of the context for management actions

Implementation, Tracking Progress and Revision

Implementation of this strategy will occur through the activities of a diverse community of management agencies, research institutions, and other partners. It is intended that funding entities, including government agencies, that invest in ZQM management and control will use the strategy to inform future investments (e.g., through the Great Lakes Restoration Initiative). The IMC will maintain the strategy, developing annual priorities and tracking progress. The IMC may identify priority objectives or focus areas from the strategy for funding, as well as provide guidance for implementing projects to address the objectives (e.g., developing recommended standards/methods for data collection and testing). IMC members and members agencies may seek funding to implement projects to address the objectives. The IMC will provide a forum for sharing results and information gained from related projects and will convene annually to review progress on strategy implementation, hear from researchers and managers on activities underway and lessons learned, and refine or develop new priorities. This strategy may be revised based on new knowledge and/or evolving priorities. Progress on strategy implementation will be documented and made available via the IMC website.

Management Goal I

Respond to new detections of ZQM to slow spread and/or protect assets

1. Compile and evaluate existing data to identify and prioritize uninfested and at-risk water bodies for protection and response
    a. Develop spatial decision-making tools to prioritize site selection and inform management activities (e.g., where to monitor for potential new ZQM infestations, where to target management actions, etc.)
2. Increase knowledge and understanding of ZQM population, dispersal, and recruitment dynamics to optimize response and post-treatment activities
    a. Determine environmental conditions and their influence on ZQM population, dispersal and recruitment dynamics, and their effect on treatment efficacy
    b. Determine ideal treatment areas within a newly infested water body and desired level of mortality for an effective response (e.g., simulation studies that examine the effects of treatment actions on population responses, and field studies that provide information on reproductive success, dispersal and recruitment dynamics to inform modeling)
        - How much of the infested water body needs to be treated?
        - Can the desired suppression level be achieved, and if so, how soon is follow-up treatment needed to sustain suppression?
        - How long does suppression need to be sustained?
    c. Determine when and how frequently monitoring should be conducted following an action to have the best likelihood of detecting survivors and estimating population growth post-treatment
3. Increase knowledge and understanding of ZQM biology to identify and refine suitable control actions
    a. Determine which life stages are most vulnerable and can be targeted with control actions to achieve desired level of mortality (e.g., laboratory toxicity studies and field trial applications to examine how treatments targeted to the most-sensitive life stages could be implemented in a cost-effective manner)
    b. Define minimum viable populations and, conversely, the level of mortality and/or suppression needed to reduce or eliminate reproductive output and prevent establishment (e.g., population modeling and field studies to parameterize models)
    c. Determine environmental factors that influence vital population rates that are needed to understand efficacy and population recovery following control.
4. Investigate non-chemical methods of control (e.g., native molluscivores, genetic biotech, or other biocontrol) and their potential effectiveness when used in conjunction with other control methods
5. Understand non-target impacts of control methods and associated ecosystem responses
6. Develop effective detection methods to identify ZQM at low densities (e.g., survey designs that can be used to estimate the probability of detection so that mussel densities can be estimated when they are low and mussels are sparsely distributed, and molecular detection techniques (eDNA, eRNA, etc.)
7. Evaluate response actions, including post-action monitoring of mussel population responses and other factors, to facilitate adaptive management (e.g., identify lessons learned and understand reasons for success or failure), and develop plans and protocols to facilitate implementation
8. Conduct long-term (i.e., three to five years) monitoring following response actions to understand indirect effects of control methods, ecosystem response, and develop plans and protocols to facilitate effective monitoring

Management Goal II

Protect and restore critical habitats with broad ecological value, focusing on Great Lakes coastal areas

1. Identify, evaluate, and prioritize candidate sites for ZQM control and restoration
    a. Conduct a literature review and/or convene experts to identify and define critical habitats (e.g., spawning and nursery habitat for fish) in which ZQM control could have significant and/or broad-scale ecological benefits
    b. Identify and address survey, map, and other data collection needs to inform site selection
    c. Understand fine scale natural ZQM dispersal patterns, and other potential sources of ZQM introduction, at a candidate site to help assess the potential for re-infestation following a control effort
    d. Determine the status, i.e., condition, level, and impact of ZQM and invasive species infestation, and usage, of infested habitats
2. Assess control needs within critical habitats to achieve restoration goals
    a. Determine what level and scope of ZQM suppression is necessary to restore habitat functionality (e.g., treatment of an entire reef may not be necessary)
    b. Examine recolonization and how long/how often treatment is needed to sustain benefits of suppression
    c. Define end points and performance metrics for measuring "success" of control efforts
3. Develop and evaluate control methods for use in localized areas
    a. Develop delivery methods, e.g., granular, encapsulation, gels, etc., and application methods that can be applied, and target concentrations maintained, in various habitats and depths
    b. Evaluate and compare the feasibility, effectiveness and non-target impacts of toxicants and non-chemical methods, including effectiveness across a range of treatment depths and environmental conditions (e.g., water temperature, weather conditions (waves, currents), co-location of sensitive biota, etc.)
        - Conduct modeling to help assess potential benefits and impacts, ecosystem response, etc., to various methods
        - Conduct small-scale experiments using various methods
    c. Evaluate the potential for integrating multiple control methods to sustain benefits and minimize recovery of ZQM populations
4. Determine additional actions needed to restore habitat function (e.g., mussel shell removal, other activities following mussel suppression) including activities to prevent re-infestation (e.g., engineered solutions such as structures designed to increase water flow/current direction to minimize likelihood of veliger settlement)
5. Conduct long-term (i.e., three to five years) monitoring following treatment actions to understand long-term and indirect effects (e.g., impact on round gobies, impacts on cladophora, changes in habitat use by desirable species, changes in production of local fish stocks)
6. Conduct cost/benefit analysis for control activities to support decision-making (e.g., do activities accrue sufficient benefit to justify ongoing investment in control?)

Management Goal III
Protect/restore native unionid mussel populations and habitat

1. Identify potential locations for control and restoration activities
    a. Assemble and evaluate existing data to determine current distribution/abundance of unionids and identify gaps and needs for updated information
    b. Identify habitats from which unionids have been extirpated by dreissenids and evaluate the potential for reintroduction of the native population
    c. Develop criteria to identify at-risk unionid populations
    d. Assemble and evaluate existing data to identify riverine pools that are ZQM larval sources
2. Determine how fluctuations in ZQM populations and recruitment dynamics impact unionid populations, including reviewing existing literature, to better understand efficacy of control
3. Evaluate control methods for selective toxicity through new toxicant development or alternative delivery mechanisms (e.g., toxicant incorporated particle), and for potential sub-lethal effects on native mussels, fish and other non-target species
    a. Develop and test delivery methods for ZQM toxicants in flowing waters that minimize impacts to unionid mussels
    b. Study ZQM and unionid population response (e.g., abundance, size, growth rates), including long-term effects, to potential toxicants
4. Evaluate non-toxic methods for mitigating impacts of ZQM on unionids (e.g. removal/reintroduction, habitat segregation, manual removal) and compare feasibility and efficacy to other methods
5. Conduct model, laboratory, and field studies to determine impacts on and response of unionids to ZQM suppression and removal (e.g., what level of suppression is needed to generate a response, how long after treatment does response appear, what is the response?)
6. Determine additional actions beyond ZQM management that are needed to ensure survival and successful unionid reproduction, considering external factors that may impact/influence success

Management Goal IV
Restore balanced productivity in impacted lake systems

1. Develop and apply models to evaluate and test current assumptions regarding ZQM ecosystem interactions
    a. Identify the causal mechanism behind boom and bust cycles of ZQM populations
    b. Understand ZQM-nutrient interactions for both live mussel populations and post-mortality
    c. Understand how ZQM influenced changes in phosphorus impact fish populations
    d. Determine ZQM suppression levels necessary to generate an ecosystem response
    e. Quantify potential impacts and benefits to an ecosystem from ZQM suppression
2. Evaluate scalability of control methods and feasibility of whole system treatment and mussel suppression
    a. Conduct small-scale experiments (e.g., laboratory, field, and small lake) to collect empirical data on control methods
    b. Conduct large-scale "proof of concept" activities
    c. Determine the return on investment generated by effective ZQM suppression for the impacted system

Management Goal V
Restore socioeconomic benefits in impacted systems

1. Collate existing data on ZQM management and control methods in water use facilities across North America (e.g., hydropower plants, water treatment facilities, dams, etc.)
    a. Identify effective management actions to reduce the impact of ZQM in these facilities
    b. Assess ecosystem impacts of toxicants used for ZQM control within water use facilities
2. Identify anthropogenic and socioeconomic impacts of control methods (e.g., impacts to drinking water quality, fisheries, recreation, historic preservation, etc.) and evaluate such impacts in decision-making contexts for ZQM management actions
3. Determine additional actions (e.g., shell removal, reintroduction of native species) beyond ZQM management needed to restore anthropogenic uses to impacted systems