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Invasive Mussel Research Roadmap

Science and Technology Program
Research and Development Office
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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Invasive Mussel Research Roadmap

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Peer Review

Bureau of Reclamation
Research and Development Office
Science and Technology Program

Invasive Mussel Research Roadmap

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Contents

	Page
Mission Statements	ii
Disclaimer	ii
Acknowledgements	ii
Peer Review	iii
Executive Summary	1
1. Introduction	3
1.1 Invasive Mussel Research at Reclamation	4
1.2 Resources.....	5
2. Roadmap Development	6
3. Priority Invasive Mussel Research Needs	7
Prevention	7
Early Detection and Monitoring	7
Management and Control.....	8
Impact Assessments.....	8
Increasing Fundamental Knowledge of Mussels	8
4. Complete List of Invasive Mussel Research Needs	8
Prevention	9
Early Detection and Monitoring	9
Management and Control.....	9
Impact Assessments.....	10
Increasing Fundamental Knowledge of Mussels	10
5. Prize Competitions	11
5.1 Resources.....	11
5.2 Completed Mussel Prize Challenge	11
5.3 Future Mussel Prize Challenges	12
6.0 Conclusion	12

Executive Summary

The research roadmap presented in this document has been prepared for the Reclamation Science and Technology (S&T) Program to help direct and prioritize invasive mussel research, which is a topic under the Environmental Issues for Water Delivery and Management research area and Invasive Species category. Research and monitoring of invasive zebra and quagga mussels became a priority for Reclamation in 2007 when quagga mussels were detected at Reclamation hydropower facilities along the lower Colorado River. This roadmap was developed with input from subject matter experts from all Reclamation Regions and the Technical Service Center and also incorporates research priorities that have been established by interagency invasive mussel working groups throughout the United States. Research topics were prioritized based on input from the Reclamation Invasive Mussel Task Force and Integrated Pest Management (IPM) coordinators. This invasive mussel research roadmap is intended to serve as a multi-year outlook of research needs that will help to prioritize future work and address invasive mussel issues that are pertinent to Reclamation. The roadmap provides guidance on current research needs within Reclamation but should not preclude emerging areas of study. This roadmap is considered a living document that can be updated to include new areas of study as they arise. Research topics are organized into five main categories:

1. Prevention
2. Early Detection and Monitoring
3. Management and Control
4. Impact Assessments
5. Increasing Fundamental Knowledge of Mussels

Priority research topics listed below were identified for each of the five categories to help facilitate collaborations and focus research proposals on the most urgent needs.

Prevention

- Optimizing Watercraft Inspection and Decontamination (WID):
 - Prioritizing WID station locations, vector modeling
- Watercraft technologies to prevent mussel transport (e.g. ballast tank filtration)

Early Detection and Monitoring

- Optimizing sample collection and analysis:
 - Sampling strategies – timing, locations, collection methods, etc.
 - Laboratory analysis methods – microscopy, molecular detection, automation
- Develop better understandings of eDNA/eRNA sources
- Develop protocols for assessment of control/eradication efforts – all life stages

Management and Control

- Develop new and examine existing technologies:
 - Shell debris management/removal for piped systems
 - Settlement prevention in piped systems
 - Lake/reservoir-scale eradication or population suppression methods with minimal non-target impacts

- Small-scale population reduction (marinas, forebays, critical habitat)
- Biological control
 - Risk analysis, risk management, safeguards

Impact Assessments

- Ecological impacts
 - Changes in native biota
 - Water quality
- Economic impacts
 - Increased maintenance at facilities

Increasing Fundamental Knowledge of Mussels

- Habitat suitability
 - Biotic/abiotic factors
 - Case studies where mussels were detected but did not survive
 - Gut content and tissue analysis
- Biology/water quality
 - Bioaccumulation of heavy metals and contaminants
 - Water quality issues under mass die-off
- Population dynamics
- Genetics

1. Introduction

The Bureau of Reclamation (Reclamation), established in 1902, is currently the largest wholesale water supplier in the United States. Reclamation operates 348 reservoirs with a total storage capacity of 245 million acre-feet of water in the 17 western states. Water supplied from Reclamation reservoirs is used to irrigate 10 million acres of farmland which produce 60 percent of the Nation's vegetable crops and 25 percent of its fresh fruit and nut crops. Reclamation also delivers 10 trillion gallons of water to more than 31 million people each year. Reclamation is also the second largest producer of hydropower in the United States, with its 58 hydroelectric power plants having annually produced, on average over the last 10 years, 44 billion kilowatt-hours. Reclamation manages 308 recreation sites that have 90 million visits annually. In addition to water delivery, Reclamation's mission includes operating water facilities in both an environmentally and economically sound manner.

The Reclamation Research and Development Office, Science and Technology Program is a Reclamation-wide competitive, merit-based applied research and development program. The program provides funding to researchers addressing the following research areas and categories that support Reclamation's mission:

- Water Infrastructure
 - Dams
 - Canals
 - Pipelines
 - Miscellaneous Water Infrastructure
- Power and Energy
 - Hydro Powerplants
 - Energy Efficiency
 - Pumping Plants
 - Non-Hydropower Renewable
- Environmental Issues for Water Delivery and Management
 - Water Delivery Reliability
 - Invasive Species
 - Water Quality
 - Sediment Management
 - River Habitat Restoration
- Water Operations and Planning
 - Water Supply and Streamflow Forecasting
 - Water Operations Models and Decision Support Systems
 - Open Data
 - Climate Change and Variability
- Developing Water Supplies
 - Advanced Water Treatment
 - Groundwater Supplies
 - Agricultural and Municipal Water Supplies
 - System Water Losses

Research is accomplished within Reclamation by subject matter experts, collaborations with outside partners, and more recently through prize competitions. The Science and Technology Program supports the development of research roadmaps that help direct research and identify research needs and priorities. Development of research roadmaps involves bureau-wide input and roadmaps can be developed for a research area, category, or topic within a category if there is a need for guidance and prioritization. The research roadmap presented in this document is for invasive mussel research, which is a topic under the Environmental Issues for Water Delivery and Management research area and Invasive Species category.

Research and monitoring of invasive zebra and quagga mussels became a priority for Reclamation in 2007 when quagga mussels were detected at Reclamation hydropower facilities along the lower Colorado River. Invasive dreissenid mussels (quagga and zebra mussels) are prolific breeders and are capable of settling on any hard surface they encounter. This behavior is problematic for hydropower facilities because the mussels settle on submerged surfaces like water intakes, trashracks, pipes, and other hydraulic equipment that are utilized for water delivery and hydropower production. When mussel populations are dense, mussels will begin to settle on top of each other which can restrict flow in critical systems leading to increased maintenance and unplanned outages. Along with the impact to hydropower facilities, mussels also negatively impact the ecosystem. As filter feeders, mussels can cause shifts in the natural ecosystem by disrupting the food web, concentrating toxic substances, and degrading critical habitat, which can all lead to the decline of native species and proliferation of pest species such as weeds or toxic algae.

Invasive mussel research continues to be a Department of Interior (DOI) priority, particularly after the implementation of the “Safeguarding the West from Invasive Species: Actions to Strengthen Federal, State, and Tribal Coordination to Address Invasive Mussels” initiative in 2017. The initiative set forth DOI commitments to prevent, contain, and control invasive mussels in the West, and several aspects of Reclamation’s research and monitoring program were included in the commitments. The Reclamation Science and Technology Program continues to receive funding to support invasive mussel research.

This invasive mussel research roadmap is intended to serve as a multi-year outlook of research needs that will help to prioritize future work and address invasive mussel issues that are pertinent to Reclamation and our partners. The roadmap provides current thinking on research needs within Reclamation but should not preclude emerging areas of study. The roadmap is considered a living document that can be updated to include new areas of study as they arise. The invasive species research coordinator can assist researchers or resource managers to facilitate partnerships and provide additional information regarding research ideas.

1.1 Invasive Mussel Research at Reclamation

Funding from the Reclamation Research and Development Office and the American Recovery and Reinvestment Act allowed Reclamation to develop a robust early detection and monitoring program for the Western United States. Since the development of Reclamation’s invasive mussel early detection and monitoring program in 2008, the Ecological Research Laboratory in Denver, CO has processed approximately 21,754 samples from 670 water bodies across 17 states. The lab provides a valuable service to our state partners. Research has focused on development of methods for control

of invasive mussel settlement and shell debris at Reclamation hydropower facilities, control of populations in open water, development of effective monitoring methods, and predictive modeling.

Research into control methods to prevent significant increases in operation and maintenance costs, and potential failure or outages of critical hydropower generation systems, has led to the installation of ultraviolet light treatment for generator cooling systems at three large Reclamation hydropower facilities. Other agencies managing hydropower facilities, including the US Army Corps of Engineers and Tennessee Valley Authority, also rely on and consult Reclamation's researchers when considering mussel mitigation methods. Open water control of invasive mussels requires development of novel methods. Reclamation researchers are currently working to sequence the quagga mussel genome and have partnered with the winning solver of a prize challenge that was funded and administered by Reclamation's Prize Competition Program. Development of novel monitoring and modeling tools for invasive mussels can be applied to a variety of invasive species. Research into a model to predict the spread of invasive mussels in the west and genetic monitoring tools are part of the current effort for timely and efficient detection of invasive species, allowing rapid response to new threats.

1.2 Resources

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Information about [Previously Funded Mussel Research Projects](#) and a [Compendium of Reclamation Mussel Control Research for Hydropower Facilities](#) can be found on the [Reclamation Science and Technology Program Website](#)

R&D Office Knowledge Stream Issues:

- [Knowledge Stream: Invasive Mussels \(Fall 2015\)](#)
- [Knowledge Stream: Invasive Mussels \(Spring 2018\)](#)

Reclamation Invasive Mussels Website: <https://www.usbr.gov/mussels/>

Collaborative Working Groups:

- 1) Department of Interior (DOI) Invasive Mussel Coordinator Team
- 2) DOI Invasive Species Task Force
- 3) Facility Operation and Maintenance Team
- 4) Federal Aquatic Nuisance Species Task Force
- 5) Fish and Wildlife Service Biotechnology Work Group
- 6) Genetic Biocontrol of Invasive Species Working Group
- 7) Government Environmental DNA (eDNA) Work Group
- 8) Invasive Mussel Collaborative
- 9) National Invasive Species Council (Advanced Technology and eDNA Teams)
- 10) Reclamation Invasive Mussel Task Force
- 11) Reclamation Integrated Pest Management & Invasive Species Coordinator Team

- 12) US Army Corps of Engineers and Reclamation Research Collaborative
- 13) US Geological Survey eDNA Standards
- 14) Western Governors Association
- 15) Western Regional Panel

2. Roadmap Development

This invasive mussel research roadmap was collaboratively developed through input from Reclamation subject matter experts from all Reclamation Regions and the Technical Service Center. Invasive mussel control and management is also a priority for many other agencies and entities across the United States and there are numerous multi-jurisdictional working groups, panels, and collaboratives that focus on the issue. Reclamation participates in many of these groups and benefits from input from experts across the United States. Although the research needs and priorities identified by each working group are not always aligned with Reclamation's mission, there are many overlapping priorities. Therefore, the research needs identified in this roadmap build upon many of these larger efforts across the United States and have been tailored to fit Reclamation's specific goals and priorities. The following list describes the steps implemented to develop this research roadmap.

1. Idea generation through collaborative discussions with internal subject matter experts, external partners, and national and international experts
 - a. Participation in meetings and conferences hosted by collaborative working groups across the United States (see list of collaborative working groups in Section 1.2)
 - b. Referenced existing research and action prioritization documents developed by collaborative working groups
 - i. U.S. Department of the Interior: Safeguarding the West from Invasive Species
 - ii. Great Northern Landscape Conservation Cooperative: Dreissenid Mussel Research Priorities Workshop for QZAP
 - iii. Federal Aquatic Nuisance Species (ANS) Task Force: Strategic Plan for 2020-2025
 - iv. Invasive Mussel Collaborative: Strategy to Advance Management of Invasive Zebra and Quagga Mussels
 - v. Western Regional Panel: Quagga and Zebra Mussel Action Plan for Western US Waters (QZAP)
 - vi. Genetic Biocontrol of Invasive Species Working Group
 - c. Reclamation subject matter experts from the Ecological Research Lab convened to discuss research topics
2. The S&T Invasive Species Research Coordinator compiled research topics and developed first draft.
3. The draft list of research topics was presented, discussed, and prioritized at the Joint Integrated Pest Management (IPM) and Invasive Mussel Task Force In-Person Meeting on February 5, 2020
 - a. Members of the task force include representatives from all Reclamation regions, TSC, Office of Policy and Programs, Public Affairs, Dam Safety and Infrastructure- Asset Management Division, Lands and Recreation Team, Operations and Maintenance Team, and Research and Development Office

- b. The draft list of research topics was provided to all in attendance and each participant was asked to review and provide the following feedback
 - i. Identify top 5-10 research priorities
 - ii. Identify the single highest priority
 - iii. Identify research topics that should be removed from the list
 - iv. Provide other topics that should be added to the list
 - v. Review was followed by discussion
 - c. The S&T Invasive Species Research Coordinator updated the draft roadmap and prioritized the research topics based on meeting feedback
4. Technical review of the roadmap was provided by invasive mussel experts in the Ecological Research Lab, Invasive Mussel Regional Coordinators, and the Policy and Programs Office
 5. Finally, the roadmap was posted on the Reclamation peer review agenda website for peer review by external parties

3. Priority Invasive Mussel Research Needs

The priority invasive mussel research topics listed below were selected from a larger list of needs (see Section 4) and are organized into five categories.

1. Prevention
2. Early Detection and Monitoring
3. Management and Control
4. Impact Assessments
5. Increasing Fundamental Knowledge of Mussels

Topics were considered priority if they received two or more priority votes (total votes listed in Section 4) by Reclamation IPM coordinators and members of the Invasive Mussel Task Force. The categories which received the most votes were Increasing Fundamental Knowledge of Mussels and Management and Control. The research topics that received the most votes were biological control, ecological impacts, and habitat suitability.

Prevention

- Optimizing Watercraft Inspection and Decontamination (WID):
 - Prioritizing WID station locations, vector modeling
- Watercraft technologies to prevent mussel transport (e.g. ballast tank filtration)

Early Detection and Monitoring

- Optimizing sample collection and analysis:
 - Sampling strategies – timing, locations, collection methods, etc.
 - Laboratory analysis methods – microscopy, molecular detection, automation

- Develop better understandings of eDNA/eRNA sources
- Develop protocols for assessment of control/eradication efforts – all life stages

Management and Control

- Develop new and examine existing technologies:
 - Shell debris management/removal for piped systems
 - Settlement prevention in piped systems
 - Lake/reservoir-scale eradication or population suppression methods with minimal non-target impacts
 - Small-scale population reduction (marinas, forebays, critical habitat)
- Biological control
 - Risk analysis, risk management, safeguards

Impact Assessments

- Ecological impacts
 - Changes in native biota
 - Water quality
- Economic impacts
 - Increased maintenance at facilities

Increasing Fundamental Knowledge of Mussels

- Habitat suitability
 - Biotic/abiotic factors
 - Case studies where mussels were detected but did not survive
 - Gut content and tissue analysis
- Biology/water quality
 - Bioaccumulation of heavy metals and contaminants
 - Water quality issues under mass die-off
- Population dynamics
- Genetics

4. Complete List of Invasive Mussel Research Needs

The following is the complete list of research needs identified in the idea generation phase. Research topics and sub-topics highlighted in blue received two or more priority votes and are included in the

priority topic list in the previous section (Section 5). The total number of votes for priority topics is included in parentheses next to the topic. Topics and sub-topics highlighted in gray received one vote. Unhighlighted topics did not receive any priority votes but are still viewed as important areas of study.

Prevention

- Optimizing Watercraft Inspection and Decontamination (WID): (4)
 - Prioritizing WID station locations, vector modeling (2)
 - Mussel detection equipment and methods (physical, eDNA)
 - Decontamination equipment and methods
- Watercraft technologies to prevent mussel transport (e.g. ballast tank filtration) (2)
- Methods and equipment for other decontamination (e.g. sampling equipment, diving gear)
- Methods to prevent mussel spread from fish transport
- Infrastructure modifications to decrease susceptibility to mussel fouling and shell debris

Early Detection and Monitoring

- Optimizing sample collection and analysis: (3)
 - Sampling strategies – timing, locations, collection methods, etc. (3)
 - Laboratory analysis methods – microscopy, molecular detection, automation (2)
 - Model development to inform sampling strategies
 - Automated and/or other advanced technologies (UAS)
 - QA/QC improvements
- Develop better understandings of eDNA/eRNA sources (2)
- Develop protocols for assessment of control/eradication efforts – all life stages (4)
- Develop methods for determination of live vs. dead mussels at various life stages
- Develop large-scale population monitoring methods and technologies
- Develop reporting standards and client communication protocols for qPCR, eDNA/eRNA

Management and Control

- Develop new and examine existing technologies: (2)
 - Shell debris management/removal for piped systems (2)
 - Settlement prevention in piped systems (2)
 - Lake/reservoir-scale eradication or population suppression methods with minimal non-target impacts (2)
 - Small-scale population reduction (marinas, forebays, critical habitat) (2)
 - Submerged structure protection (intakes, fish screens, trash racks, etc.)
 - Anti-fouling/foul-release coatings
 - Water management efficacy, flow and drawdown manipulation
- Biological control (5)

- Risk analysis, risk management, safeguards (3)
- Genetic control (gene drive) technical, screening and assessment methods
- Regulatory considerations
- Social research to determine public acceptance
- Develop data collection and analysis standards
 - Settlement analysis
 - Mussel toxicity
 - Live/dead determination at various life stages
- Investigate integrated control efficacy

Impact Assessments

- Ecological impacts (5)
 - Changes in native biota (2)
 - Water quality (2)
 - Impacts to sensitive species
 - Algae, HAB or population shifts
- Economic impacts (3)
 - Increased maintenance at facilities (2)
 - Impacts to lifespan of facility infrastructure and components

Increasing Fundamental Knowledge of Mussels

- Habitat suitability (5)
 - Biotic/abiotic factors (2)
 - Case studies where mussels were detected but did not survive (3)
 - Gut content and tissue analysis (3)
- Biology/water quality (3)
 - Bioaccumulation of heavy metals and contaminants (2)
 - Water quality issues under mass die-off (2)
 - Potential use of mussels as indicators for contaminants or bioremediation
- Population dynamics (2)
 - Causal mechanisms behind boom/bust cycles
 - Requirements for successful establishment
- Genetics (2)
 - Persistence of DNA and RNA in various aquatic conditions
 - Genetic structure
 - Lab techniques for cell culture
- Dispersal mechanisms
 - Survival under different conditions during boat transport
 - Methods to track dispersal and identify source population (genetics, shell composition)

5. Prize Competitions

Prize competitions are a unique tool for accelerating research to address elusive mission and operations challenges through private sector and “citizen solvers”. By tapping into a wealth of knowledge through on-line crowd-sourcing techniques, prize competitions help Federal agencies to advance research and development and drive innovation. Prize competitions are best suited to advance tough problems where solutions have been evasive, to provide new ideas when research becomes stuck, or to move along problems where market forces may not provide sufficient incentives to solve or solve well. Conversely, traditional research can help achieve “reduction-to-practice” of ideas and concepts obtained through prize competitions through follow-up traditional research and in-house demonstration projects, CRADAs, and additional competition stages in which theoretical concepts are proven in the laboratory or in the field.

Reclamation categorizes its prize competitions research needs into three main theme areas:

- Water Availability
- Infrastructure Sustainability
- Environmental Compliance

5.1 Resources

More information on past, present, and future prize competitions can be found at [Reclamation's Water Prize Competition Center](#), as well as posted on the Federal Government's prize competition platform <https://www.challenge.gov/>.

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5.2 Completed Mussel Prize Challenge

On December 2017 Reclamation launched a prize competition titled “Eradication of Invasive Mussels in Open Water”. The competition offered a \$100,000 cash prize and was seeking innovative theoretical solutions to eradicate invasive zebra and quagga mussels from large reservoirs, lakes, and rivers in a cost effective and environmental sound manner. The competition closed in February 2018 with more than 100 submitted solutions. The judging panel consisted of experts from Reclamation, U.S. Army Corps of Engineers, the U.S. Geological Survey, and Molloy and Associates. Three solutions were selected to win a prize. The top prize went to Steven Suhr and Marie-Claude Senut, founders of Biomilab, LLC, for their proposed solution of using genomic modification to induce a lethal malignant hemic neoplasia in mussels that can be transferred from one mussel to another by proximity. Reclamation is currently entered into a cooperative agreement with Biomilab, LLC to research, develop, and pursue the winning solution.

5.3 Future Mussel Prize Challenges

Invasive mussel's pose several unique challenges to researchers and water managers, and there are cases where a prize challenge may be the best approach to address some of these difficult questions. Some ideas that have been considered for future invasive mussel prize challenges include.

- Effective and efficient methods for boat decontamination
- Identification of gene targets and genetic control options using the quagga mussel genome
- Automated DNA and veliger identification for on-site detection
- Development of unique modeling methods to better manage mussel spread

Reclamation's prize competition center is always considering new prize challenge topics. Please contact the Invasive Species Research Coordinator to discuss potential prize challenge ideas.

6.0 Conclusion

Invasive mussels will continue to spread throughout the Western United States and will likely begin to impact additional Reclamation facilities and waters. Reclamation researchers will continue to collaborate with experts at other agencies and in the private sector in order to produce the most beneficial research products. This research roadmap will help prioritize research proposal development to ensure that funding is utilized for research projects that will have the greatest impact across Reclamation and the Western United States.