U.S. Geological Survey Science Vision for Native Freshwater Mussel Research in the United States

Mussels use a large muscular foot to move around river substrates; image is from the Upper Mississippi River. Photograph by Teresa J. Newton, U.S. Geological Survey.

Front cover.   An *Alasmidonta varicosa* mussel filter feeding in the Wesserunsett Stream in Maine. Photograph by Ayla Skorupa, U.S. Geological Survey.

Back cover.   An assemblage of freshwater mussels, including the federally endangered *Epioblasma triquetra*. Photograph by Douglas K. Hardesty, U.S. Geological Survey.

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By Teresa J. Newton, Nathan A. Johnson, and David H. Hu

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Scientists use scuba divers to obtain *Lampsilis cardium* mussels for use in laboratory toxicity tests. Photograph by Teresa J. Newton, U.S. Geological Survey.

Acknowledgments

Margaritifera falcata mussels in Montana. Photograph by Christopher S. Guy, U.S. Geological Survey.
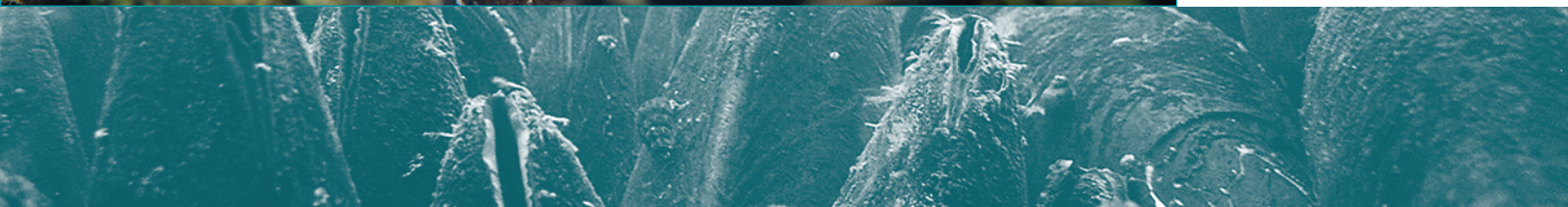
A scuba diver holds an *Amblema plicata* mussel while radio tracking the movements of native mussels during a survey in the Upper Mississippi River. Photograph by Kathy Bibby, U.S. Geological Survey.

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Abbreviations

BLM	Bureau of Land Management
DOT	U.S. Department of Transportation
eDNA	environmental DNA
EPA	U.S. Environmental Protection Agency
GBIF	Global Biodiversity Information Facility
IWAA	Integrated Water Availability Assessment
lidar	light detection and ranging
NGOs	non-governmental organizations
NPS	National Park Service
OBIS	Ocean Biodiversity Information System
USACE	U.S. Army Corps of Engineers
USFS	U.S. Department of Agriculture Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

A Margaritifera falcata mussel in Montana. Photograph by Christopher S. Guy, U.S. Geological Survey.

U.S. Geological Survey Science Vision for Native Freshwater Mussel Research in the United States

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Executive Summary

North America is a global center for native freshwater mussel (order Unionida, hereinafter "mussels") diversity, with more than 350 species (Haag, 2012; Graf and Cummings, 2021). Mussels are among the most imperiled fauna on the planet (Williams and others, 1993; Strayer and others, 2004). Reasons for both local and widespread declines in mussels are mostly unknown, although the threats may include habitat loss and fragmentation, diseases, environmental contaminants, altered flow regimes, migration barriers to larval hosts, non-native species, and climate change.

Over the past three decades, research on mussels has been substantial. Nevertheless, current conservation and management efforts are limited by significant information gaps. For example, the effects of emerging stressors on mussels are largely unknown and identifying when habitats are rehabilitated and suitable for reestablishment of mussels remains challenging. Additionally, historical and current information on the distribution, taxonomy, and life histories are often unreliable or lacking altogether, and more reliable information is needed for many species.

We identified focal research themes, goals, and objectives where research on mussels is needed based on information gaps identified through conversations with resource partners across local, regional, and national organizations. Research on **biodiversity** seeks to enhance the diversity of mussel species and populations to support healthy aquatic ecosystems. Research on **emerging stressors** seeks to improve the understanding of how mussel species, populations, and communities respond to emerging stressors, including environmental contaminants and climate change. Research on **conservation** seeks to enhance the recovery of species and populations and to identify data gaps limiting the conservation of mussels and their habitats. Mussels are in urgent need of proactive conservation because they are an integral part of our natural heritage, enhance biodiversity, and provide vital ecological services that support freshwater ecosystems (Quaempts and others, 2018; Vaughn and Hoellein, 2018).

The U.S. Geological Survey (USGS) has been, and continues to be, a leader in mussel research. Although the USGS is well suited to address the broad-scale multidisciplinary research needed to conserve mussels, the USGS has had substantial loss of scientists with mussel expertise over the past 20 years. However, the breadth of the USGS expertise on mussels can be leveraged internally across other USGS mission and program areas and externally across research partners. Given the breadth and scope of the issues facing mussels across the United States, the research themes outlined in this science vision can only be accomplished through extensive collaborations between the USGS and the full spectrum of natural resource partners, including other Federal and State agencies, Tribal organizations, universities, industries, and nongovernmental organizations.

One-month-old juvenile mussels. Photograph by Douglas K. Hardesty, U.S. Geological Survey.

U.S. Geological Survey Science Vision for Native Freshwater Mussel Research

The U.S. Geological Survey (USGS) science vision for native freshwater mussel research (hereinafter "science vision" or "vision") in the United States is to conduct unbiased research and science to support the conservation of sustainable native mussel communities and to communicate research findings to partners and stakeholders in a relevant and timely manner to inform management decisions. This report provides an overview of the science gaps that exist in mussel conservation that are relevant to the USGS mission and identifies opportunities where the USGS can address these gaps based on its capabilities and expertise. The intent of this science vision is to identify focal mussel research themes that are urgently needed to inform conservation and management decisions while making efficient use of available resources. This vision is specific to native freshwater mussels (order Unionida) in the continental United States.

The integrated science activities described in this report are designed to address critical research needs at local, regional, and national scales. The scope of the science is strategically focused on information and data needs that are common to many agencies. Consequently, this vision has a broad scientific scope and is not intended to address the specific needs of any one agency or interest group. The research goals and objectives are designed to be specific and targeted; they are not intended to assess the full spectrum of research needs pertinent to mussels. The vision is meant to be flexible and adjusted as personnel, resources, and stakeholder priorities change.

The USGS science vision for freshwater mussels is intended to be a resource for scientists who are prioritizing and planning research on mussels as well as for facilitating partnerships with USGS scientists and other researchers, agencies, and stakeholders. This vision is also intended to serve as a tool and road map for program managers throughout all USGS mission areas to help identify crosscutting science efforts and priorities. Finally, this vision is intended to highlight the tangible benefits the research may provide to the American people.

A *Lampsilis cardium* mussel in the Upper Mississippi River. Photograph by Teresa J. Newton, U.S. Geological Survey.

Reasons for Native Freshwater Mussel Conservation

Biodiversity

Nowhere is the biodiversity crisis more acute than in freshwater ecosystems. Rivers, lakes, and wetlands are home to an extraordinary diversity of life. With more than 300 freshwater mussel species in the United States alone, mussels add critical biodiversity and ecological services to the aquatic landscape (Haag and Williams, 2014; Freshwater Mollusk Conservation Society, 2016). Many species are endemic and isolated to small geographic areas, such as a single creek or watershed (Hornbach and others, 1996; Johnson and others, 2016). The consequences of their catastrophic declines extend well beyond the loss of species (see "Ecological Services" below).

Cultural Significance

Mussels play an important role in the culture and history of native peoples of North America. Historically, mussels were used as food and their shells were used as currency for trade, tool implements, and clothing adornments (Quaempts and others, 2018). Today, mussels are an integral part of the First Foods philosophy for natural resource management in which the five First Foods (water, fish, big game, roots, berries) are served formally and before any other foods at ceremonial feasts. Because the First Foods relate to Tribal creation belief, wherein First Foods promised to take care of the Indian people, the Indian people have a reciprocal responsibility to take care of First Foods (Quaempts and others, 2018). Thus, many tribes are working to conserve and restore mussels.

Economic Value

Mussels have been and continue to be a major economic resource, first in the pearl button industry and more recently in the cultured pearl industry (Anthony and Downing, 2001; Haag, 2012). Estimates of the total value of the mussel fishery in the United States alone are substantial (about $10 billion in 2017 dollars; Strayer, 2017).

Ecological Services

Mussels provide critical roles in aquatic ecosystems. As filter feeders, they are important consumers of seston (particles suspended in water) and play a significant role in particle dynamics and nutrient cycling (Newton and others, 2011; Vaughn and Hoellein, 2018). They provide food for animals, habitat for other benthic invertebrates (for example, caddisflies and aquatic worms), alter hydraulic and sediment dynamics at the sediment-water interface, and stabilize river substrates (Newton and others, 2008; Sansom and others, 2020).

Need for Proactive Mussel Research

Globally, mussels inhabit every continent except Antarctica, but North America is an epicenter of diversity with more than 350 species currently recognized (Haag, 2012; Graf and Cummings, 2021). While mussel species are associated with nearly every type of aquatic habitat, the greatest diversity is found in flowing freshwater ecosystems. Mussels have among the highest extinction and imperilment rates of any group of organisms on the planet, including the continental United States where dramatic and widespread declines have occurred (Lopes-Lima and others, 2018). Many declines in the first half of the 20th century have been attributed to habitat modification from construction of dams, channelization, and altered flow regimes (Haag, 2019). In contrast, no clear causes have been identified for more recent declines. Mussels face many challenges, including habitat loss and fragmentation, diseases, environmental contaminants, altered flow regimes, migration barriers for larval hosts, water withdrawals, non-native species, and climate change.

Episodic mass mortality events that are seemingly specific to mussels continue to occur in relatively undisturbed systems and our ability to conserve remaining mussel populations will be limited until we understand why they are declining (Haag, 2019; Richard and others, 2020; Leis and others, 2023). For freshwater mussels whose life history often includes a parasitic stage on a host (often a fish), the challenges facing mussels may also affect their hosts, making mussels even more vulnerable. Because many species are long lived (up to 100 years), the recent declines may result from environmental degradation that has been ongoing for decades or longer. Proactive mussel conservation is urgently needed because (1) their dramatic and widespread declines reduce biodiversity, (2) they are an integral part of our cultural and natural heritage, (3) they have commercial importance, and (4) they provide vital ecological services that support freshwater ecosystems and benefit society (see sidebar "Reasons for Native Freshwater Mussel Conservation").
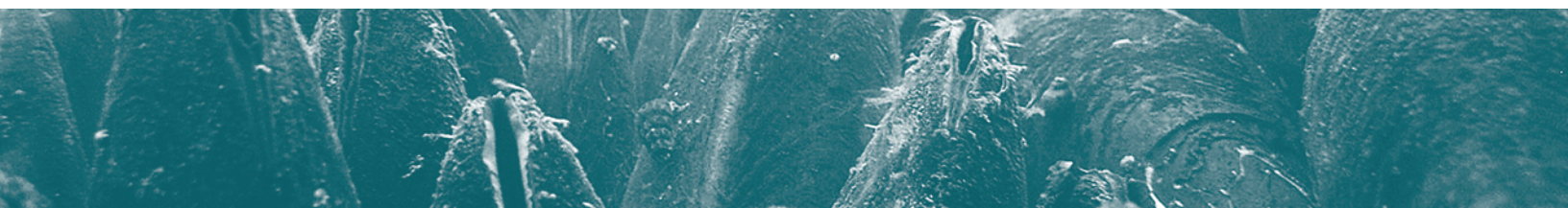
Science Vision Development

Development of this science vision is intended to help the USGS make the best use of our scientific expertise and capabilities to achieve our goals and objectives. Moreover, this vision offers a roadmap toward innovation and success by advancing technologies and enhancing collaborations to improve conservation of imperiled mussels. Over the past three decades, research on mussels has been substantial in the United States. For example, we know much more about distribution patterns, taxonomy, and systematics; sensitivities to environmental contaminants; and how to captively propagate certain species. However, conservation efforts are limited by substantial information gaps. The following data and information gaps provide the foundation of research needs for our science vision for mussels.

- Identify the factors contributing to recent declines in mussel populations across many ecosystems.

- Obtain information on the distribution, taxonomy, and life histories for many species, including information on larval hosts.

- Obtain and synthesize information on the status and trends of mussel populations and communities.

- Assess the effects of emerging stressors, such as environmental contaminants and climate change on mussels and their hosts and habitats.

- Understand how current management practices for water quality and water quantity affect mussels and their habitats.

- Understand how habitat rehabilitation projects can be designed to simultaneously benefit mussels and other species, such as fish and aquatic arthropods (for example, crayfishes).

- Identify the demographic, physiological, and genetic characteristics that affect long-term population viability.

- Understand when habitats are rehabilitated and suitable for reestablishment of mussels.

- Evaluate the effects of water withdrawals on mussel populations, such as those from agriculture, urban development, and energy development.

Focal Research Themes

Based on conversations with resource partners across local, regional, and national organizations and on identification of data and information gaps, the USGS has strategically focused research efforts into three themes based on science application. These themes represent research that is urgently needed to inform mussel conservation and management decisions while making efficient use of available resources.

- **Biodiversity**—Research to enhance the diversity of mussel species and populations to support healthy aquatic ecosystems.

- **Environmental stressors**—Research to improve our understanding of how mussel species, populations, and communities respond to emerging stressors, including environmental contaminants and climate change.

- **Conservation**—Research to enhance the recovery of mussel species and populations and identify data gaps limiting the conservation of mussels and their habitats.

Research Goals and Objectives

For each research theme, we identified specific research goals and objectives based on projected research capacity and identified external research needs. Table 1 provides a description of potential outcomes for partners and stakeholders related to the focal research themes, goals, and objectives.

Obtaining hemolymph from *Amblema plicata* in the Upper Mississippi River to assess relative health. Photograph by Teresa J. Newton, U.S. Geological Survey.

Table 1.   Focal science themes, goals, and objectives identified in the U.S. Geological Survey science vision for native freshwater mussels, and potential outcomes for partners and stakeholders.

| Theme	Goal	Objectives	Potential outcomes
1. Biodiversity	Enhance the diversity of mussel species and populations to support healthy aquatic ecosystems.	1a. Refine knowledge of systematics, taxonomy, and genetic structure of species and populations. 1b. Identify, develop, and synthesize geospatial data on mussel distributions across the United States. 1c. Use emerging molecular tools to improve detection of rare species. 1d. Characterize how loss of intraspecific genetic diversity affects population resiliency and adaptability of populations. 1e. Refine existing methods to understand reproductive biology and larval host requirements. 1f. Develop benchmarks and metrics to assess the relative health of mussels at individual, population, and community levels. 1g. Develop methods to quantify the social, cultural, ecological, and economic value of mussels.	New information and tools to guide decisions and models related to conservation of freshwater biodiversity. Novel tools to inventory and monitor mussels to identify trends in species ranges and inform listing decisions, including critical habitat designations. Data to inform regulatory decision-making processes. Criteria to identify self-sustaining populations as defined in recovery plans. Provide data needed to inform species status assessments.
2. Environmental stressors	Improve understanding of how mussel species, populations, and communities respond to environmental stressors.	2a. Investigate how mussels respond to variable flow, sediment, and thermal regimes resulting from climate-related hydrological changes. 2b. Assess how management of water quantity and water quality affects mussels. 2c. Quantify the threats that non-native species pose to native mussels. 2d. Estimate the lethal and non-lethal responses of mussels to the full spectrum of environmental contaminants. 2e. Assess the relative contribution of a suite of environmental contaminants to develop a risk profile. 2f. Understand and characterize the role of pathogens and diseases in mussel declines.	Ability to predict resource-specific outcomes and set management targets for mussels under a changing climate. Toxicity data for mussels are integrated into regulatory decisions for existing and new water quality standards. Provide data to inform species status assessment. Risk assessment that identifies which environmental and legacy stressors are most likely to affect mussels.
3. Conservation	Enhance the recovery of mussel species and populations and identify data gaps limiting the conservation of mussels and their habitats.	3a. Develop and enhance tools to measure the physical, chemical, and biological characteristics of suitable habitats. 3b. Identify habitats that are resilient to disturbance and have high conservation potential. 3c. Identify the demographic, physiological, and genetic characteristics that affect long-term population viability. 3d. Develop criteria to help determine when habitats are rehabilitated and suitable for reestablishment of mussels. 3e. Refine best management practices for captive propagation, augmentation, and reintroduction. 3f. Understand and describe how dispersal limitations of larval hosts affect connectivity of mussel communities.	Develop tools to identify habitat features to monitor pre- and post-rehabilitation that promote resilient mussel communities. Decision tools to predict the reintroduction success of mussels following rehabilitation of degraded habitat. Integration of the results of habitat rehabilitation and species reintroduction efforts into long-term monitoring programs. Best practices to monitor populations and habitats to inform natural resource damage assessments. Provide data to inform species recovery and status assessments.
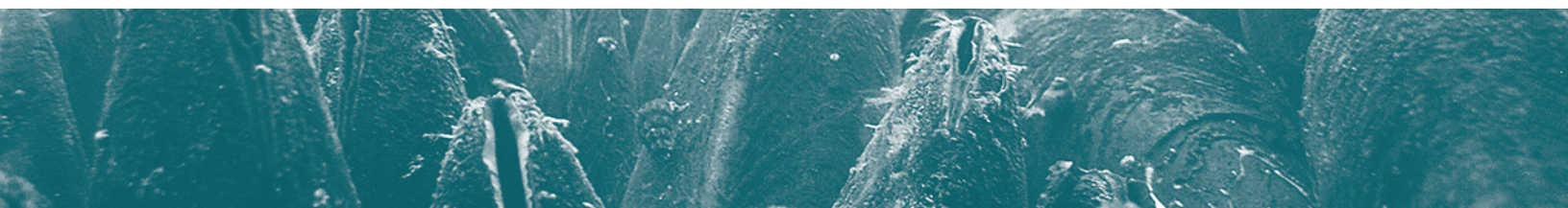
## Role of the U.S. Geological Survey in Mussel Conservation

With our long history of conducting mussel research and our workforce of nearly 9,000 scientists and support staff distributed across about 400 locations, the USGS is well suited to address today's science needs for native mussels. The USGS also provides hands-on training opportunities in cutting-edge research across 16 ecological science centers, 1 national climate adaptation science center and 9 regional climate adaptation science centers, 41 cooperative research units, and 50 biological field stations nationwide. In addition to our broad multidisciplinary research focus and large hydrological and biological datasets, the breadth of existing USGS mussel expertise can be leveraged with other USGS colleagues who have related skills and expertise in fields such as hydrology, wildlife, and environmental contaminants to expand our existing program with modest effort. U.S. Geological Survey scientists have been in the forefront of studying mussel life history traits, assessing potential causes for their decline, developing genetic tools to assess conservation status and taxonomy, and monitoring the effects of a changing environment on individuals, populations, and communities. However, given the breadth and scope of the issues facing mussels, the focal research themes outlined in this report can only be accomplished in close collaboration with colleagues from other Federal and non-federal agencies and organizations.

Contribution to U.S. Department of Interior and U.S. Geological Survey Needs and Strategies

The research described in this science vision meets many of the goals identified in the U.S. Department of the Interior Strategic Plan for Fiscal Years 2022–26 (U.S. Department of the Interior, 2022) for species, habitats, and ecosystems; for support to Indigenous communities; and for workforce diversity. It addresses elements of other USGS initiatives on drought, water quality, foundational species, long-term datasets, early warnings for endangered species, revolutions in science and technology, and recruiting young scientists to overlap with existing expertise. The research identified will contribute to the goals and objectives of the USGS Species Management Research Program, especially those relating to increasing cross-center and cross-mission area collaborations and to developing an agency-wide shared vision and long-term (10 years) plan for fish and aquatic species research in the USGS.

Scientists count microscopic glochidia (larval stage of mussels) before beginning a laboratory toxicity test. Photograph by Teresa J. Newton, U.S. Geological Survey.
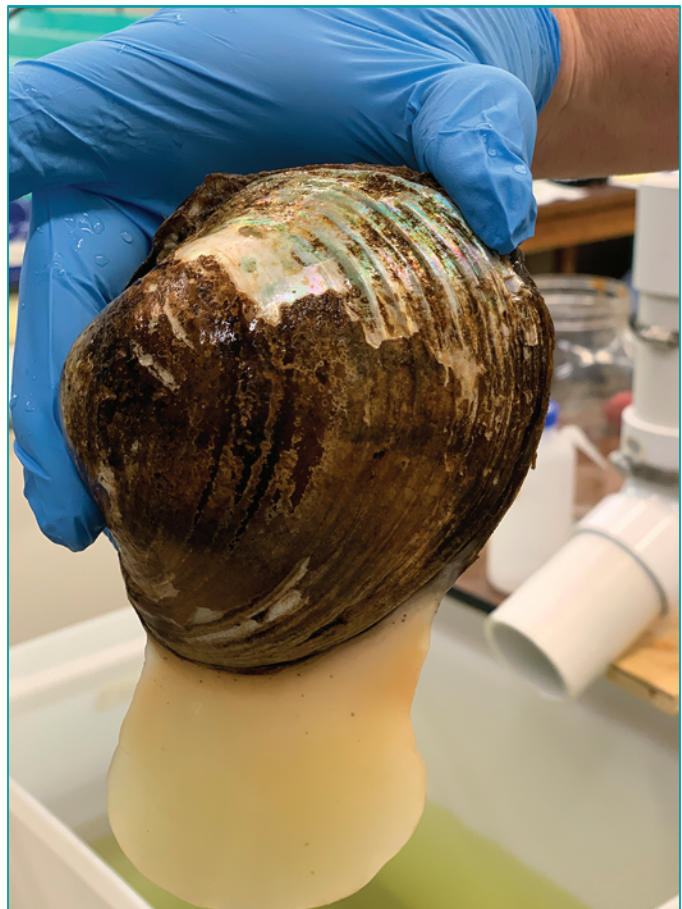
Exposure of *Lampsilis cardium* mussels to lampricides often causes narcosis—a state of stupor evidenced by valve gape, foot extension, and mucus production. Lampricides are chemicals applied to aquatic systems to control larval sea lamprey. Photograph by Teresa J. Newton, U.S. Geological Survey.

The proposed research complements other USGS agency programs and identifies areas with opportunities for leveraging expertise within and across USGS mission areas and programs (table 2). Some of the strongest opportunities are with the Ecosystems and Water Resources Mission Areas. For example, this strategy complements the Ecological Flows program and National Water Census effort within the Water Availability and Use Science Program by developing additional tools to assess and predict the effects of hydrological alteration on native mussels. This strategy also complements programs at the climate adaptation science centers by using their climate change models to develop predictions of adverse effects on mussels. Research described in this science vision supports the Environmental Health Program by identifying the potential health risks caused by environmental contaminants to biota (including mussels) and to humans who recreate in the water, eat the fish, and drink the water. The research also supports efforts of the Biological Threats and Invasive Species Research Program by furthering science that addresses the effects of non-native species and their control strategies on sensitive native species.

Experimental setup to determine suitable hosts for the federally threatened *Medionidus walkeri* mussel. Photograph by Nathan A. Johnson, U.S. Geological Survey.

Table 2. Examples of opportunities for leveraging expertise between the U.S. Geological Survey science vision for native freshwater mussels and other mission areas and programs.

[Note that the table is not exhaustive and other opportunities undoubtedly exist. More information on the Core Science Systems, Ecosystems, and Water Mission Areas can be found at https://www.usgs.gov/mission-areas/core-science-systems, https://www.usgs.gov/mission-areas/ecosystems, and https://www.usgs.gov/mission-areas/water-resources, respectively. lidar, light detection and ranging; USGS, U.S. Geological Survey; eDNA, environmental DNA]

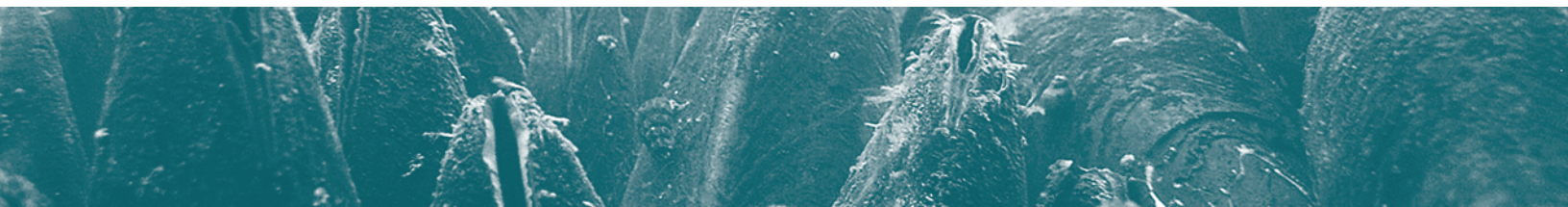| Mission area	Program	Opportunities for leveraging with the science vision on mussels
Core Science Systems	Science Analytics and Synthesis	Provide data to the Global Biodiversity Information Facility (GBIF) and the Ocean Biodiversity Information System (OBIS) from field and museum research; collaborate with scientists associated with the GBIF, OBIS, and Protected Areas database on use of biodiversity resources to model changes in species occurrence over space and time; collaborate with staff at the Gap Analysis Project to develop and use tools that support distribution modeling and visualizations; use advanced computing resources to analyze large datasets to quantify long-term patterns in mussel communities; use the national database of Species of Greatest Conservation Need to inform conservation priorities of key stakeholders; collaborate with staff on updates of mussel taxonomy within the Integrated Taxonomic Information System; leverage Science Analytics and Synthesis Program expertise and tools to develop and manage mussel datasets.
	National Geospatial Program	Assess the extent to which datasets and tools from lidar, the 3D Hydrography Program, the National Hydrography Program, and other environmental datasets can be used to predict how mussels will respond to variable flow regimes.
	National Land Imaging	Use large-scale patterns in water quality (for example, from Landsat 8) and mussel distribution data to make predictions about changes in populations and ecological services performed by mussels.
	National Geological and Geophysical Data Preservation Program	Use scientific collection resources and the expertise of the USGS Collections Steering Committee to guide management of scientific collections for mussels.

Table 2. Examples of opportunities for leveraging expertise between the U.S. Geological Survey science vision for native freshwater mussels and other mission areas and programs.—Continued

[Note that the table is not exhaustive and other opportunities undoubtedly exist. More information on the Core Science Systems, Ecosystems, and Water Mission Areas can be found at https://www.usgs.gov/mission-areas/core-science-systems, https://www.usgs.gov/mission-areas/ecosystems, and https://www.usgs.gov/mission-areas/water-resources, respectively. lidar, light detection and ranging; USGS, U.S. Geological Survey; eDNA, environmental DNA]

Mission area	Program	Opportunities for leveraging with the science vision on mussels
Ecosystems	Biological Threats and Invasive Species Research	Assess how mussel species and communities may change in response to invasive non-native species and pathogens including the development of an early detection and rapid response system for new aquatic invaders (for example, eDNA).
	Climate Adaptation Science Centers	Use climate change models to develop predictions of the effects of altered thermal regimes on mussel communities; identify habitats that may be resilient to changing climates; explore how variability in temperature and water levels (for example, flood and droughts) affect risk of extirpation.
	Cooperative Research Units	Identify and train future scientists with mussel expertise for careers at the USGS; facilitate partnerships with researchers from academia; address research and information needs of cooperating agencies.
	Environmental Health	Improve awareness, planning, and forecasting of the origins of environmental contaminants; identify how mussels are exposed to environmental contaminants; assess how contaminants move through the environment and how these pathways are mediated by hydrology; quantify how contaminants are transferred up the food web (including to humans); develop thresholds for how mussels respond to environmental contaminants; understand the effects of environmental contaminants to mussel hosts; integrate mussels into the One Health biosurveillance approach that uses mussels as indicators of human and wildlife exposure to contaminants.
	Land Management Research	Understand how habitat restoration projects on public lands affect mussels and their habitats; determine the potential for habitat manipulation to restore declining populations of mussels; evaluate if efforts to mitigate shoreline erosion as a nature-based solution could benefit mussels; assess how upstream land-management activities affect mussels (for example, through sediment and contaminant inputs) and how mussels could contribute to sediment stability.
	Species Management Research	Estimate the role of hosts in sustaining mussel communities; quantify the economic values that sustainable mussel communities provide; increase societal awareness and perceived value of mussels; support threatened and endangered species listing and recovery efforts; understand how mussels and their habitats respond to altered flow regimes; understand the role of disease in mussel declines and the potential for mussel diseases to threaten wildlife and human health; assess the potential for mussels to serve as an early warning for diseases that might indicate risks to wildlife and humans; assess the effects of climate change on the productivity and vulnerability of freshwater mussels.
Water Resources	Groundwater and Stream Flow Information	Use streamflow data to identify rivers with stable flow regimes that could be suitable refugia for mussels in translocation projects; quantify the importance of groundwater inputs and groundwater chemistry on mussels and their habitats; incorporate water quality and water quantity data from the Next Generation Water Observing System to assess how these influence mussel communities; understand how severity and duration of floods and droughts affect mussels.
	Integrated Water Availability Assessment	Use data from the Integrated Water Availability Assessment (IWAA) program to identify rivers with suitable long-term water quality that could be suitable refugia for mussels; use IWAA data to assess if dense communities of mussels can reduce harmful algal blooms; add mussel benchmarks to IWAA assessments that integrate long-term streamflow and water-quality trends in the context of environmental thresholds (for example, exceedances of regulatory standards and aquatic life thresholds); determine if restoration of mussel communities can ameliorate infrastructure costs of maintaining suitable water quality.
	Water Availability and Use Science	Develop tools and strategies to assess the effects of hydrological alteration on mussel habitat; assess how departure from expected streamflow conditions could affect mussels and their habitats; identify how long-term trends in water availability affect persistence of mussels.
	Water Resources Research Act	Identify opportunities to better align native mussel research within the Water Resources Research Act; increase awareness of water availability issues at local and regional scales; provide information to stakeholder groups; recruit and train young scientists; facilitate conflict resolution in regional water management problems.
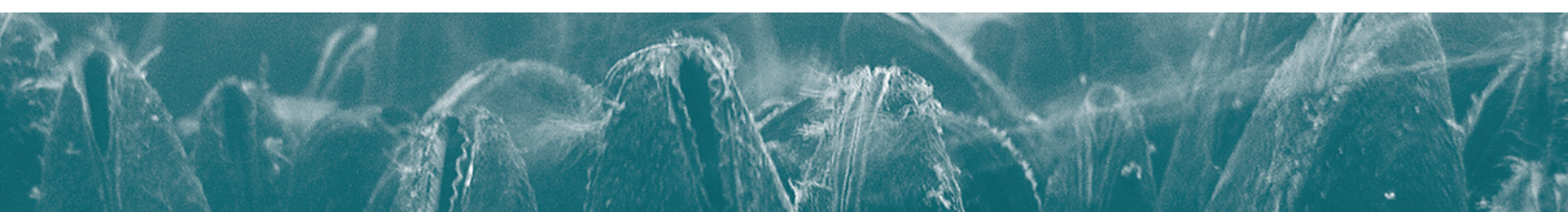
An assemblage of native freshwater mussels from the lower Altamaha River, Georgia. Photograph by Nathan A. Johnson, U.S. Geological Survey.

Contribution to External Partner Needs and Strategies

This science vision encourages extensive collaborations between the USGS and the full spectrum of natural resource partners, including other Federal and State agencies, Tribal organizations, universities, industries, and nongovernmental organizations across the globe. In addition to collaboration, implementation of this vision is intended to require investments by the USGS and its partner agencies. It also is intended to develop mechanisms to engage watershed councils, local municipalities, local and regional conservation groups, and the public in helping to conserve mussels. A matrix of the three research themes that were identified as a function of partner needs (largely through direct feedback from agency-specific science plans) shows that the proposed research is urgently needed by our partner agencies (table 3). For each research theme, we identified potential outcomes that may help resource managers make informed decisions about conserving mussels (table 3). These outcomes are intentionally broad, as different partners have different needs in different geographic locations.

A draft of this science vision report was shared with more than 500 individuals from 151 organizations across 49 States, 1 Canadian province, and 2 Tribes in March 2021 and reviews were received from 37 individuals in 26 partner organizations across 22 States. The reviews and associated discussions received were positive and many individuals expressed their appreciation of past and present leadership being shown by the USGS to conserve mussels. The organizations that provided comments on an earlier draft of this report are recognized in the acknowledgments.

This science vision complements similar strategies developed by other partner agencies. For example, it supports the U.S. Fish and Wildlife Service mission to protect threatened and endangered species by providing science support for Endangered Species Act of 1973 (16 U.S.C. 1531 et seq.) regulatory decisions, such as listing decisions, biological opinions, species status assessments, and recovery planning for delisting and downlisting species. It also closely aligns and contributes to management and monitoring actions of State fish and wildlife agencies. State fish and wildlife agencies play an important role in managing and monitoring our Nation's mussel populations and may be able to leverage State and Federal resources to meet many of the research needs identified in this science vision. Research needs identified in this science vision are intended to support the Sustainable Rivers Program, a partnership between The Nature Conservancy and the U.S. Army Corps of Engineers, to improve ecosystem health by looking at the effects of altered flow regimes on mussels (https://www.nature.org/en-us/what-we-do/our-priorities/protect-water-and-land/land-and-water-stories/sustainable-rivers-project/, https://www.hec.usace.army.mil/sustainablerivers). Our strategy supports regional plans for mussels such as the Xerces Society's plan to develop best management practices for protecting native western freshwater mussels during aquatic and riparian restoration activities (https://xerces.org/endangered-species/freshwater-mussels). Additionally, our research objectives directly support Tribal efforts to study and promote conservation of mussels in the western United States (Quaempts and others, 2018).

Setup of a long-term contaminant study with native freshwater mussels. Photograph by Douglas K. Hardesty, U.S. Geological Survey.
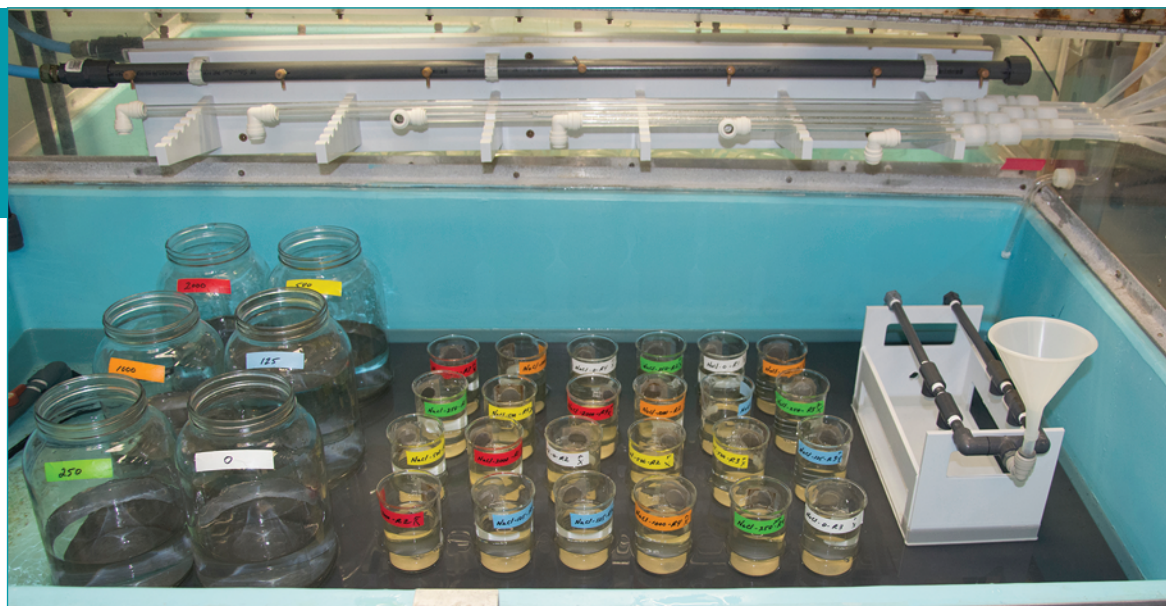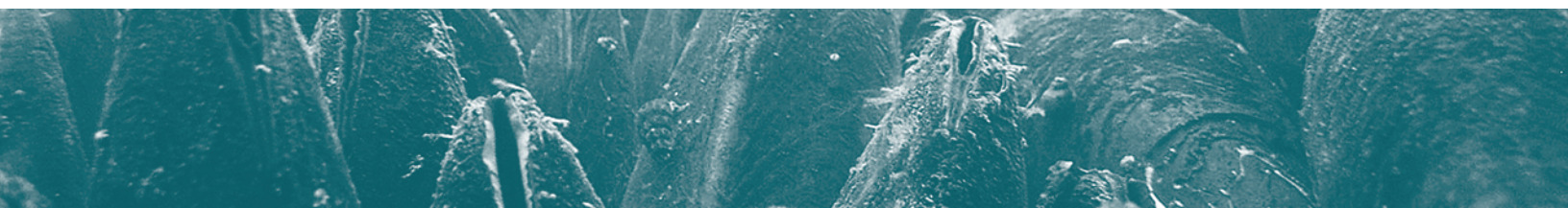
Table 3. Examples of opportunities for leveraging between the U.S. Geological Survey science vision for native freshwater mussels and research identified by partner agencies within each focal research theme.

[Note that the table is not exhaustive and other opportunities undoubtedly exist. NPS, National Park Service; EPA, U.S. Environmental Protection Agency; USFWS, U.S. Fish and Wildlife Service; DNA, deoxyribonucleic acid; USACE, U.S. Army Corps of Engineers; DOT, U.S. Department of Transportation; USFS, U.S. Department of Agriculture Forest Service; NGOs, nongovernmental organizations; BLM, Bureau of Land Management]

Research theme	Partner agency research needs
Biodiversity	NPS: Protect species distribution, diversity, and ecosystem services within park lands and watersheds.
	EPA, multiple State agencies, USFWS: Evaluate whether current management and water-quality standards protect threatened and endangered mussels.
	USFWS: Use emerging DNA technologies to identify critical watersheds where threatened and endangered mussels may exist; develop molecular markers to identify populations responding to an environmental stressor.
	Multiple State agencies, USFWS: Identify local adaptations to environmental conditions to inform translocation efforts; provide information to protect genetic diversity during recovery efforts; use molecular assessments to identify species boundaries to support conservation and management efforts.
	Multiple State agencies, USACE, USFWS: Obtain distribution data to identify trends in species ranges, inform listing decisions, and assess the effects of proposed construction activities on mussels.
	DOT, EPA, multiple State agencies, NPS, USACE, USFWS: Develop efficient ways to document the presence or absence of imperiled mussels for regulatory tasks; develop standardized tools for ensuring accurate identification to the species level.
	DOT, EPA, multiple State agencies, NPS, USACE, USFWS: Obtain accurate taxonomic classification to facilitate restoration efforts, understand mussel distributions, and design effective management strategies.
	Multiple State agencies, NGOs, USFS, USFWS: Obtain information on the life history of mussels, including information on hosts and habitat preferences.
	Tribes: Develop information on propagation and monitoring programs to restore populations to levels where sustainable harvest and ceremonial usage is possible.
Environmental stressors	BLM, EPA, NGOs, NPS, USFWS: Evaluate the degree to which emerging stressors (for example, climate change, energy development, hormone disruptors, disease, aquifer drawdown or depletion via pumping) affect mussels.
	Multiple State agencies, NPS, USACE, USFWS: Develop sensitive metrics of mussel condition to assess how a given stressor may affect mussels.
	NPS: Understand how anthropogenic disturbances, such as global warming, will change flow regimes and affect mussels in parks.
	NGOs: Understand the effects of pesticides, including molluscicides, on mussels; develop novel containment delivery methods that limit exposure of native species.
Conservation	USFWS: Complete species status reviews for threatened and endangered species, which often require critical habitat definitions that are currently limited by a lack of data on what constitutes mussel habitat.
	DOT, multiple State agencies, USACE, USFWS: Understand how restoration projects (for example, barrier removals, island creation, host reintroduction) affect mussels.
	NGOs: Understand how to determine if a relocation effort has been successful.
	USFWS: Understand the potential for Federal Energy Regulatory Commission relicensing and dam removal planning efforts to benefit or adversely affect mussels; research methods to propagate and translocate mussels associated with restoration activities.
	Multiple State agencies, USACE, USFWS: Obtain distribution data to examine trends in species ranges, make listing decisions, and determine the impact of proposed construction activities.
	DOT, EPA, multiple State agencies, NPS, USACE, USFWS: Obtain taxonomic identification to plan restoration efforts, understand mussel distributions, and design management strategies.
	USFWS: Develop criteria to understand when assemblages of threatened and endangered mussels may be self-sustaining as defined in recovery plans.

The federally endangered *Hamiota subangulata* mussel from the Flint River, Georgia. Photograph by Andrea K. Fritts, U.S. Geological Survey.

U.S. Geological Survey Workforce in Mussel Conservation

Although the USGS is well suited to address the broad-scale multidisciplinary research needed to conserve mussels, the USGS has had substantial loss of scientists with mussel expertise over the past 20 years. The imperiled status of mussels, now and into the foreseeable future, demonstrates the need for a robust workforce with mussel expertise in the USGS. Our partners rely on the USGS to lead focused research to conserve and restore sustainable mussel communities. Biologists from numerous Federal and State fish and wildlife agencies, during ongoing conversations, have shared their concern about the loss of capacity and mussel expertise in the USGS, a trend that if not reversed, may limit the ability of the USGS to meet partners' future mussel research needs. This highlights the importance of needed changes in the USGS workforce and support of existing programs as they pertain to mussels. The USGS needs to expand our pool of scientists with expertise in mussels, recruit early career scientists into the USGS, and provide training for existing scientists to elevate the USGS presence in the field of mussel conservation. Mussel conservation science requires a process to identify, connect, and fund scientists in other programs and mission areas to build strong multidisciplinary collaborations within the agency. For example, collaborations with ecohydrologists could assess interdependencies between hydrology and native and non-native mussels; scientists working at the interface of ecology and economics could help delineate ecological services; bioinformaticists could help increase our capacity to answer large-scale molecular questions; landscape ecologists could work to amalgamate data across spatial scales; collaborations with scientific collection teams could help resolve long standing taxonomic issues and understand how species' distributions have changed across time and space; and microbiologists could work toward identifying microbial symbionts essential to mussel health. The USGS is uniquely poised to lead and conduct innovative multidisciplinary work needed to conserve mussels.

Workforce planning should also seek to enhance diversity, equity, inclusion, and accessibility across all positions as outlined by the USGS Office of Diversity and Equal Opportunity, Equal Opportunity Program. The bureau ensures a discrimination-free workplace where all employees and applicants are provided a full and fair opportunity to contribute to the fullest extent of their abilities in pursuing a career at USGS. Thus, USGS is devoted to building an inclusive and diverse workforce throughout its research programs, including within its work on mussel conservation, by creating an environment where all employees are respected, valued, and able to develop and perform to their maximum potential (https://www.usgs.gov/office-of-diversity-and-equal-opportunity).

Outreach and Communication

One of the tangible outcomes of this science vision will be the development and implementation of a community of practice for mussels. A community of practice is an organized group of professionals who share a common concern or an interest in a topic and who interact on a regular basis to fulfill both individual and group goals. Our vision for a nationwide native freshwater mussel community of practice is to provide an open forum where all partners and stakeholders can learn, share expertise, and work collaboratively to conserve global mussel populations. Potential activities of the community of practice could include assessing what types of outreach and communication tools are most effective in promoting the value of mussels and providing a forum to link research results with decision tools to identify and evaluate management actions.

Summary

This report describes the USGS science vision for native freshwater mussel research in the United States. The report was written by a team of USGS scientists with expertise on mussels from several USGS science centers across the United States and with varied scientific backgrounds. The reviews and associated discussions received from earlier drafts of this report were instrumental in developing the research themes, goals, and objectives for conducting integrated research on mussels. Implementation of this science vision is intended to require extensive collaborations between the USGS and the full spectrum of resource partners. This science vision can guide the implementation of integrated science that provides usable, robust, scientific information to resource managers at relevant spatial and temporal scales; foster new collaborations; and serve as an information resource for others engaged in mussel science.
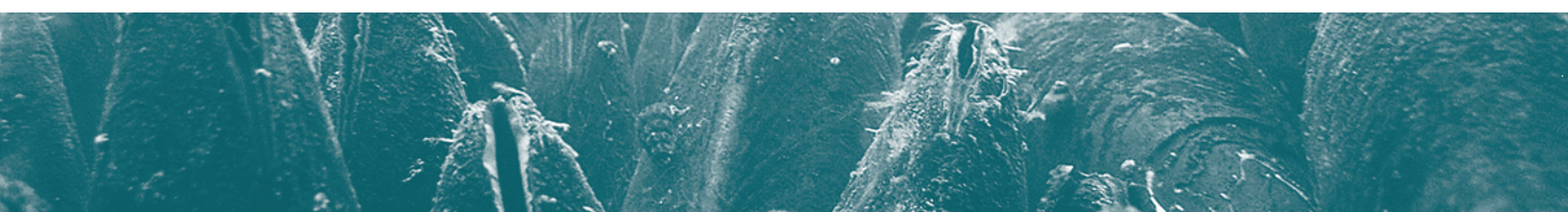
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Lampsilis reeveiana lure. Some mussel species use a lure that resembles a small fish or an aquatic insect to aid reproduction. Photograph by Douglas K. Hardesty, U.S. Geological Survey.

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Researchers use backpack electrofishing to obtain fish for a host suitability study in the Suwannee River, Florida. Photograph by Nathan A. Johnson, U.S. Geological Survey.

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