

WORKSHOP REPORT

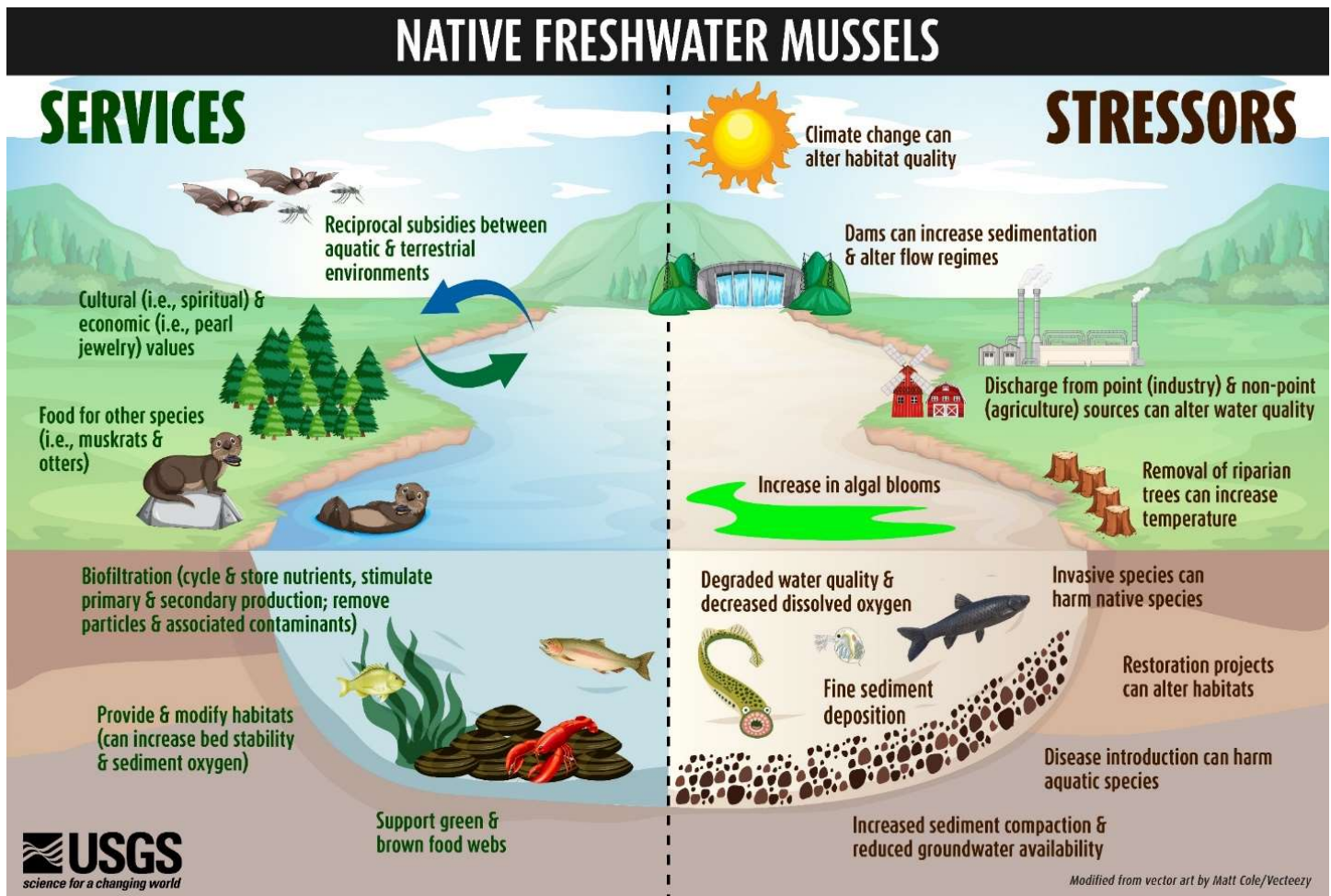
Freshwater Ecosystem Health Workshop:

North American Native Freshwater Mussels and Clean Waters

March 26, 2024, NAWNR Conference, Grand Rapids, MI

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Figure 1: Illustration of the ecosystem services provided by native freshwater mussels and the multiple stressors that threaten their survival and the quality and quantity of their habitats. Infographic created by Sally House, USGS.



This information is intended as a resource for participants of the 89th North American Wildlife and Natural Resources Conference and not intended for broad distribution.

PART I: INTRODUCTION

Ecosystem Health Framework

Freshwater is essential for the survival of many species, including humans. The plants, animals, microbes, rocks, soil, sunlight, and water associated with freshwater resources comprise a freshwater ecosystem. Threats such as water withdrawals for human use, creation of dams and water diversion systems, droughts, floods, and agricultural runoff can disrupt these ecosystems, leading to stress, degradation, and dysfunction in their ability to provide essential ecological services. Natural resource management focused on restoration, resiliency, and mitigating stressors is critical as our climate changes. With limited resources, how can natural resource management agencies prioritize recovery investments across various freshwater habitats? This session introduced a method for assessing the health of freshwater ecosystems (Freshwater Health Index (FHI)). Ecosystem health is a crucial component of the One Health framework, which seeks to sustainably balance the health of humans, animals, and the ecosystem. This workshop was a step towards implementing actions in the report of the AFWA President's Task Force on One Health, which emphasizes the need for training opportunities to help fish and wildlife agencies implement One Health strategies.

At the North American Wildlife and Natural Resource Conference held in March 2025 in Grand Rapids, MI, the USGS convened a workshop titled "Freshwater Ecosystem Health: North American Native Freshwater Mussels and Clean Waters" to focus on North American native freshwater mussels from an ecosystem health perspective. The goal of the workshop was to consider ecosystem health assessments, such as vigor, resilience, and organization, and to highlight the interconnections between mussels and other ecosystem inhabitants, including the end-users (i.e., human health and well-being).

Freshwater mussels are among the most imperiled faunal groups in the world, prompting calls for action to reverse the decline in freshwater biodiversity. One method for measuring ecosystem health is the Freshwater Health Index (FHI), which views freshwater ecosystems as dynamic social-hydrological-ecological networks. The FHI has four components: Ecosystem Vitality, Ecosystem Services, Governance, and Stakeholders. Human water use impacts freshwater ecosystems, and governance plays a critical role in the sustainable delivery of water-based services that depend on maintaining healthy ecosystems. While the FHI has been applied internationally to more than ten basins, this workshop explored its applicability domestically and considered other health indices for freshwater ecosystems.

Workshop Purpose

The purpose of this workshop was to explore and address the interconnected health of ecosystems, focusing on the significant role of native freshwater mussels as ecosystem engineers. Inspired by Aldo Leopold's land ethic, this workshop aimed to foster a comprehensive understanding of ecosystem health and its impact on human well-being. As the first in a series of working sessions on Ecosystem Health, this workshop delved into the concept of "aquatic ecosystem sickness," where ecosystems become stressed, degraded, and dysfunctional in their ability to provide essential services. Restoration and resilience of these ecosystems, particularly in the face of climate change, is a priority for many natural resources management agencies. The workshop aimed to highlight the impact of aquatic ecosystem sickness on imperiled freshwater mussel communities as a way to identify and mitigate stressors hindering overall ecosystem vitality. Insights gathered from this workshop and others will contribute to a peer-reviewed publication, encouraging continued collaboration and research. Participants were invited to join in-person discussions, engage in polls, and contribute to the ongoing dialogue on maintaining healthy, resilient ecosystems that benefit all living organisms.

Workshop Objectives

- *Assessing Ecosystem Health:* Evaluating ecosystem vigor, resilience, and organization to understand the current state of freshwater ecosystems. The health of people and animals is connected to ecosystem health. Emphasizing the link between healthy ecosystems and human well-being, which are best addressed through integrated management approaches.
- *Discuss the Plight of Native Freshwater Mussels in relation to Ecosystem Health:* Exploring their ecological significance and the challenges they face, which often align with stressors to ecosystem health. Examining the interdependencies between mussels, other ecosystem inhabitants, and human health. Discussing the critical ecological services provided by freshwater mussels and their role in supporting biodiversity and water quality.

- *Identify Ecosystem Stressors and Promote Collaborative Solutions:* Characterizing the causes of ecosystem degradation and identifying potential solutions. Integrating diverse perspectives and insights to contribute to a peer-reviewed publication. Engaging participants to provide in-person feedback, poll responses, and written thoughts.

PART II: OVERVIEW OF PRESENTATIONS

1. Freshwater Ecosystem Health: Indicators, Indices, and Implications (*M. Camille Hopkins U.S. Geological Survey*)

This presentation focused on the indicators, indices, and implications of ecosystem health, emphasizing the critical need for targeted conservation efforts for freshwater biodiversity, particularly native freshwater mussels. The critical importance of freshwater ecosystems globally, which support over 100,000 species, including humans was highlighted. Despite covering less than 1% of the Earth's surface, freshwater habitats host approximately one-third of vertebrate species and 10% of all species.

Impact of Rising CO₂ Levels. The presentation underscored that atmospheric CO₂ levels are now higher than any point in the past three million years, leading to significant climatic changes, including increased temperatures, more intense rainfall, and rising sea levels. These changes adversely affect freshwater ecosystems, making them highly vulnerable.

Global Freshwater Biodiversity Crisis. Using the Living Planet Index and the Global Wetland Loss Model, the severe decline in freshwater and terrestrial vertebrate populations from 1700 to present with projections up to 2050 were illustrated. The decline in freshwater vertebrates is faster than in terrestrial vertebrates, coinciding with global wetland loss. Freshwater mussels, in particular, are the most imperiled faunal group worldwide.

Case Study: Grand River, Michigan. Historically, the Grand River contained approximately 32 species of native freshwater mussels. Recent surveys (2013-2017) revealed a reduction to around 20 species, including the federally endangered snuffbox mussel (*Epioblasma triquetra*). The decline emphasizes the impact of habitat degradation and the necessity for rehabilitation projects.

Emergency Recovery Plan for Freshwater Biodiversity. The six priority actions for global implementation to reverse freshwater biodiversity loss were outlined. The plan addresses major causes of freshwater biodiversity loss, including flow alteration, pollution, habitat degradation, overexploitation of species, and invasive species, and loss of freshwater connectivity.

One Health Framework. The One Health framework was discussed, advocating for an integrated approach that encompasses ecosystem, human, and animal health. This holistic perspective is crucial for developing comprehensive conservation strategies. This is not a new concept. Aldo Leopold's land ethic was referenced, which emphasizes the interdependencies of soils, waters, plants, animals, and humans as part of the community.

Global Initiatives and Tools. The 2023 UN Sustainable Development Goals (SDG) Implementation Progress Report and the Global Biodiversity Framework were presented as strategic guides for biodiversity conservation. The Freshwater Health Index (FHI) was highlighted as a tool for evaluating social, hydrological, and ecological dimensions of freshwater health, providing critical data for policymakers and conservationists. The index highlights the crucial role of ecosystem services and the importance of governance and stakeholder engagement

in ecosystem management. Maintaining ecosystem vitality supports provisioning, regulating, and cultural services essential for human well-being and biodiversity.

Camille concluded by acknowledging the workshop planning team and highlighting the imperative for ongoing research, robust conservation efforts, and enhanced collaboration among stakeholders to protect and sustain freshwater ecosystems. The integration of scientific research into practical conservation strategies is paramount in addressing the adverse impacts of climate change and human activities on these critical ecosystems. The presentation served as a clarion call for continued efforts to conserve and restore freshwater biodiversity, emphasizing the interconnectedness of ecosystem health with human and animal health.

2. Introduction to Freshwater Mussels and Context-Dependent Changes in Ecosystem Services from Freshwater Mussels in the Great Lakes Region (*Dave Strayer, Cary Institute, retired*)

This presentation by Dave Strayer provided a detailed examination of the biological, ecological, and socio-economic significance of freshwater mussels. The presentation covered the unique life cycles of mussels, their contributions to ecosystem functioning, the threats they face, and the context-dependent nature of the ecosystem services they provide.

Biological and Ecological Insights

- *Unique Life Cycles:* Freshwater mussels have complex life cycles with species-specific dependencies on host fish for larval development. Some species use a broad range of fish hosts, while others rely on a single species. Mussels have evolved elaborate adaptations to attract fish, ensuring the dispersal of their larvae. Certain mussel species can live for over 50 years, playing a critical role in ecosystem stability and continuity.

Ecological Contributions

- *Suspended Particle Filtration:* Mussels filter suspended particles from water, improving clarity and promoting the growth of submerged vegetation. This process also aids in the removal of pathogens and toxicants.
- *Nutrient Cycling:* Mussels contribute to nutrient cycling through the production of tissue and gametes, which serve as nutrient stores and food sources for other organisms. Their biodeposits support local algal, invertebrate, and fish production, and contribute to denitrification and carbon sequestration.
- *Habitat Structuring:* The physical structure provided by mussel shells, both living and dead, offers attachment sites and shelter for invertebrates and algae, spawning sites for fish, and aids in sediment stabilization.

Biodiversity and Conservation Status

- *Diversity and Imperilment:* North America is a biodiversity hotspot for freshwater mussels, but they are among the most imperiled faunal groups. The Great Lakes basin supports a diverse but threatened native mussel fauna, with 7 to 9 species listed as threatened or endangered by the U.S. Fish and Wildlife Service and 11 species by the Species at Risk Act. The highest diversity is found in and around Lake St. Clair, western Lake Erie, and the Detroit River.

Context-Dependent Ecosystem Services

- *Water Filtration:* Historically, native mussels in western Lake Erie did not filter enough water to control phytoplankton on a large scale. Local, transient depletion around dense mussel beds may have occurred, but the current impact of water filtration by mussels is negligible due to population declines.

- *Shell Production:* Mussel shells often accumulate in certain habitats (e.g., western Lake Erie), providing essential habitat structures for fish spawning and invertebrates. The importance of shell production varies with environmental conditions such as water chemistry and velocity.
- *Existence Value:* The existence value of mussels, or the benefit people receive from knowing that a particular environmental resource exists, is influenced by societal and cultural settings, education, and public awareness. Although difficult to quantify, existence values can be substantial, as evidenced by significant financial contributions to conservation efforts.

Estimating Changes in Ecosystem Services. The value of ecosystem services provided by mussels depends on changes in mussel populations, the abundance-impact curve for specific functions, and the environmental and societal contexts. Assessing these services requires a nuanced understanding of the specific services, the context, and the mussel populations involved.

The ability of mussels to perform ecological functions does not directly equate to their value. Assessing the value of ecosystem services performed by mussels must consider the specific service, the environmental and societal contexts, and the mussel population. This assessment, though complex, is tractable and has not been extensively addressed. Considering the context can identify the most promising settings for the protection and restoration of freshwater mussels.

Effective management actions must feasibly change the mussel population and provide valued services. The presentation emphasized the necessity of integrating ecological, economic, and social dimensions in the conservation of freshwater mussels, advocating for a context-sensitive approach to ecosystem service valuation and biodiversity conservation.

3. National Aquatic Resource Surveys (NARS): Assessing the Health of the Nation's Waters (*Richard Mitchell, US Environmental Protection Agency*)

Richard Mitchell from the US EPA delivered a presentation on the National Aquatic Resource Surveys (NARS). The presentation focused on assessing the health of the nation's waters, including rivers, streams, coastal waters, wetlands, and lakes, using a consistent and comprehensive approach.

Objectives of NARS

- Assess the biological and recreational conditions of the nation's waters and track changes over time.
- Rank stressors based on the relative associations between indicators of condition and indicators of stress.
- Build and enhance state and tribal monitoring and assessment capacities.

NARS Approach

- *National Consistency:* NARS employs a probabilistic design (statistical survey) to provide nationally and regionally relevant data on the condition of each aquatic resource.
- *Sample Size:* Approximately 1,000 sites are sampled annually across the conterminous U.S.
- *Protocols:* Standard field and lab protocols, core indicators, national quality assurance and data management ensure consistency and reliability.
- *Data Interpretation:* The approach allows for the generation of peer-reviewed reports with nationally consistent and regionally relevant data interpretation.

Example of NARS Design. A representative set of 1,853 sites were sampled to assess the national condition of perennial rivers and streams, representing 1,543,290 miles of perennial rivers and streams.

Indicators and Measures of Stress

- *Biological Indicators:* Benthic macroinvertebrates, fish community, plankton, and wetland plants.
- *Recreational/Human Health Indicators:* Fish tissue, pathogens (enterococci), and microcystins.
- *Key Stressors:* Nutrient enrichment, excess sediment, degraded habitat, and sediment contamination.
- *Research Indicators:* eDNA/metagenomic and diatoms.

Findings from the 2015 National Coastal Condition Assessment (NCCA)

- *Excess Nutrients:* Dissolved nitrogen and phosphorus were found in two-thirds of all estuarine areas.
- *Eutrophication:* Persistent throughout the Great Lakes, with almost half of the nearshore areas in fair or poor condition.
- *Sediment Quality:* Over 75% of estuarine areas had good sediment quality as measured by laboratory toxicity testing. However, localized areas in the Great Lakes had highly contaminated sediments.

Fish Contaminants (NRSA 2018/2019 and NCCA 2015 Results)

- *Mercury and Polychlorinated Biphenyls (PCBs):* 26% of river miles exceeded mercury health-based screening levels, and 45% and 74% exceeded total PCB levels for general and high-frequency fish consumers, respectively.
- *Perfluorooctanesulfonic acid (PFOS) Detection:* Found in 91% of all fish tissue samples.
- *Contaminants in Prey Fish:* High levels of contaminants were observed in prey fish in both Great Lakes nearshore habitats and estuarine areas, potentially impacting food webs through stunted growth or reduced reproduction in fish and wildlife.

Summary of Impacts

- The impact of stressors on aquatic life varies across water body types. Nutrients and degraded habitats are the most pervasive stressors nationally.
- Some stressors, although limited in geographic range (e.g., acidification, salinity, heavy metals), have significant impacts on aquatic life when present.
- Human health indicators vary greatly by geography and water body type, but fish contaminants are pervasive throughout rivers and coastal areas.
- Prey fish contaminants are widespread in coastal areas, potentially impacting food webs substantially.

Richard's presentation highlighted the comprehensive and systematic approach of NARS in assessing the health of the nation's waters. The use of consistent methodologies and indicators allows for reliable data collection and interpretation, providing essential insights into the conditions and stressors affecting aquatic ecosystems. The findings underscore the importance of continued monitoring and targeted interventions to address key stressors and protect aquatic life and human health.

4. Environmental Stressors of Freshwater Mussels (Jordan Richard, US Fish and Wildlife Service, University of Wisconsin-Madison)

Jordan Richard from the U.S. Fish and Wildlife Service Southwestern Virginia Field Office and the University of Wisconsin-Madison delivered a presentation on the environmental stressors impacting freshwater mussels. The presentation provided a detailed analysis of the causes of mussel declines, reviewed enigmatic declines and mass mortality events, and outlined the investigative processes needed to understand mussel health and disease.

Declines of Native Freshwater Mussels. North America hosts approximately 300 species of native mussels, with about 10% already extinct and two-thirds classified as threatened, endangered, or vulnerable. Freshwater mussels are at the forefront of the sixth mass extinction.

Causes of Mussel Declines

- *Contaminants and Poor Water Quality*: This includes nutrient enrichment, eutrophication, harmful algal blooms, sedimentation, habitat degradation, and various chemical parameters.
- *Invasive Species*: Non-native species that compete with or predate upon native mussels.
- *Impoundments*: Dams and other barriers that alter natural water flow and habitat conditions.
- *Harvesting*: The collection of mussels for commercial purposes.
- *Mass Mortality Events*: Sudden and acute mortality events impacting significant portions of mussel populations.

Understanding Poor Water Quality. Poor water quality encompasses various factors such as contaminants, nutrient enrichment, harmful algal blooms, sedimentation, and habitat degradation. These stressors interact in complex ways, affecting mussel health.

Epidemiology and Causal Analysis. The presentation used the epidemiologic triad (agent, host, disease) and the concept of causal pies (component causes, necessary cause, sufficient cause) to conceptualize the factors influencing mussel declines. This approach helps understand multi-stressor interactions and the role of various factors in causing declines.

Enigmatic Declines. Enigmatic declines are characterized by rapid population losses and fauna-wide collapses without obvious stressors. These declines often occur in unimpounded and unharvested populations with no clear causes, making them difficult to address.

Mass Mortality Events. Mass mortality events differ from enigmatic declines by their acute nature, leading to the sudden loss of a significant proportion of the population. Historical data from a 1986 workshop highlighted 17 cases of mussel die-offs in eastern North America, with disease, pollution, and invasive species identified as top suspects.

Investigating Mussel Health and Disease

- *Infectious Agents*: Limited knowledge exists on the infectious agents affecting mussels. This presentation identified agents including viruses, bacteria, parasites, and fungi.
- *Pathogen Identification and Characterization*: The investigation process involves identifying pathogens, characterizing them, and developing diagnostic and screening assays.
- *Novel Discoveries*: Research has led to the discovery of over 4,000 novel mussel viruses, bacterial diseases, and new parasite classifications.

Matching Stressors and Impacts. The presentation emphasized the importance of matching the scale of stressors to their impacts. Specific stressors cause specific effects, and understanding these relationships is crucial for effective conservation and management.

Jordan's presentation highlighted the complex and multifaceted nature of the stressors affecting freshwater mussels. It underscored the importance of comprehensive and integrated approaches to understanding and addressing these challenges. The necessity for continued research, robust conservation efforts, and enhanced collaboration among stakeholders was emphasized to protect and sustain freshwater mussel populations and the ecosystems they inhabit.

5. Quick Status Report on Mussel Conservation by Midwest State and Ontario's Fisheries Agencies (*Gary Whelan, Michigan DNR Fisheries Division, retired*)

Gary Whelan of the MI DNR Fisheries Division provided an overview of a survey conducted to assess the current status of mussel conservation efforts across Midwest states and Ontario.

Survey Methodology

- A short email survey was sent to all Midwest state fisheries agencies and Ontario's provincial fisheries agency during the week of March 17, 2024.
- The survey targeted 16 states (NY, PA, OH, IN, IL, MI, WI, MN, IA, MO, KY, ND, SD, NE, KS) and Ontario.
- Three questions were asked:
 - o Is your state/province propagating freshwater mussels? (Yes/No)
 - o Is your state/province actively translocating freshwater mussels to reestablish extirpated populations? (Yes/No)
 - o Does your state/province work to protect existing freshwater mussel populations using permitting and federal licensing opportunities? (Yes/No)

Survey Results

- Propagation of Freshwater Mussels: Yes: 7, No: 7. Four states are working with cooperators but are not directly propagating freshwater mussels.
- Translocation to Reestablish Extirpated Populations: Yes: 6, No: 7. Some states are conducting translocations within the same waters to mitigate human threats.
- Protection of Existing Mussel Populations: Yes: 12, No: 1.

Other Observations

- Many states do not allow the legal take of mussels for commercial or noncommercial purposes.
- Research activities require a collection permit in most states.
- Several states are conducting extensive surveys, with some being very intensive on a statewide level.
- One state is using environmental DNA (eDNA) in addition to standard survey techniques.
- A few states have malacologists on staff who assist with or directly conduct mussel conservation work.

Gary's presentation highlighted the varying levels of involvement and approaches to freshwater mussel conservation across Midwest states and Ontario. The survey revealed that while some states are actively propagating and translocating mussels, others focus more on protecting existing populations through permitting and licensing. The use of innovative techniques like eDNA and the employment of malacologists reflect ongoing efforts to enhance mussel conservation strategies. The findings underscore the importance of continued collaboration and information sharing to effectively manage and restore freshwater mussel populations across the region.

6. Significance of Native Freshwater Mussels to Freshwater Ecosystem Health (*Teresa Newton, U.S. Geological Survey*)

Teresa Newton from the U.S. Geological Survey in La Crosse, WI, delivered a presentation highlighting the critical role of native freshwater mussels in maintaining the health of freshwater ecosystems. The presentation emphasized the linkages between mussel declines and the ecosystem services they provide, outlined the USGS

science vision for mussel research, and explored the application of these insights to broader freshwater ecosystem health.

Ecosystem Services Provided by Mussels

- *Nutrient Cycling & Storage:* Mussels contribute significantly to nutrient cycling and nutrient storage within aquatic ecosystems.
- *Natural Biological Filters:* They act as natural filters, removing particulate matter and contaminants from water, thus improving water quality.
- *Habitat Provision:* Mussels provide and modify existing habitats, supporting a diverse range of aquatic organisms.
- *Support Food Webs:* They play a critical role in food webs, serving as food for various biota, including muskrats, otters, and raccoons.
- *Economic and Cultural Significance:* Mussels have economic value (e.g., tools, jewelry, commercial harvest) and cultural significance, illustrated by initiatives like the large-scale mussel hatchery in Philadelphia to enhance water filtration and improve drinking water quality.

Mussel Declines and Ecosystem Services

- *Historical Declines:* Data from the 1900s to the present show significant declines in mussel populations due to known stressors (e.g., dams, stream channelization, raw sewage, commercial harvest) and enigmatic declines in otherwise healthy streams.
- Case Studies:
 - o *Kiamichi River:* Drought-induced losses of mussels (~60%) led to substantial declines in ecosystem services such as filtration, nitrogen, and phosphorus cycling.
 - o *Upper Hudson River:* Remediation-induced losses of mussels significantly reduced filtration capacity, emphasizing the density-dependent nature of mussel-provided services.
 - o *Upper Mississippi River:* Despite receiving a range of human-mediated stressors, mussel populations remain diverse and abundant, with biofiltration capacity vastly exceeding that of local wastewater treatment plants.

USGS Science Vision for Native Freshwater Mussel Research

- *Research Priorities:* The vision aims to elevate, integrate, and expand mussel research nationwide, engaging 26 partner organizations across 22 states.
- Focus Areas:
 - o *Biodiversity:* Research to enhance the diversity of mussel species and populations to support healthy aquatic ecosystems.
 - o *Environmental Stressors:* Research to improve our understanding of how mussel species, populations, and communities respond to emerging stressors, including environmental contaminants and climate change.
 - o *Conservation:* Research to enhance the recovery of mussel species and populations and identify data gaps limiting the conservation of mussels and their habitats.

Application to Ecosystem Health.

- The presentation linked mussel health to overall ecosystem health, advocating for the use of mussels as bioindicators and emphasizing their role in supporting ecosystem services.
- *One Health Framework:* Highlighted the importance of balancing human, animal, and environmental health. Freshwater mussels contribute to this balance by improving water quality and supporting diverse aquatic ecosystems.

Challenges and Opportunities

- *Complexity of Freshwater Ecosystems*: Freshwater ecosystems are influenced by multiple stressors and require integrated management approaches.
- *Context-Dependent Services*: The ecosystem services provided by mussels are context-dependent, varying with environmental factors such as flow and temperature.
- *Governance and Stakeholder Engagement*: Effective conservation requires coordinated efforts across various stakeholders, emphasizing the need for governance structures that support ecosystem health.

Teresa's presentation underscored the significant contributions of native freshwater mussels to ecosystem health and the necessity for continued research and conservation efforts. The integration of mussel health into broader ecosystem health frameworks, such as One Health, is essential for sustaining the services they provide and ensuring the resilience of freshwater ecosystems. The presentation concluded with a call for collaboration and innovation to address the challenges facing freshwater mussel conservation. The insights provided in this presentation highlight the critical role of mussels in maintaining healthy aquatic ecosystems and the importance of their conservation for the benefit of both natural environments and human communities.

PART III: DISCUSSION

Participants, including federal and state agencies, NGOs, and students at the workshop provided valuable insights into the significance of freshwater mussels, the stressors they face, ongoing conservation efforts, and the application of ecosystem health frameworks.

- *Ecosystem Services Priority*. Freshwater mussels are viewed as an essential component of healthy aquatic ecosystems, particularly for their roles in nutrient cycling, denitrification, habitat structuring, and serving as prey and food resources for semi-aquatic mammals. Their shells also provide and create habitats that support other aquatic species.
- *Priority Stressors*. Several key stressors were identified, including:
 - o *Loss of Wetlands*: Wetlands buffer runoff and flood dynamics, and their loss is a critical concern.
 - o *Invasive Species Spread*: Particularly in urbanized and seasonally flowing areas.
 - o *Stream Alteration*: Changes in stream flow and structure adversely affect mussel habitats.
 - o *Unexplained Mussel Losses*: Enigmatic declines without clear causative factors.
 - o *Urbanization*: Development pressures leading to habitat degradation.
 - o *Seasonal Flow Changes*: Variability in water flow impacting mussel populations.
- *Ongoing Conservation Efforts*. Conservation efforts vary by region and organization, including:
 - o *Rewilding Mussels*: Efforts to repatriate mussels in Southern California.
 - o *Macrofauna Index Development*: Creating indices based on USGS data to assess ecosystem health.
 - o *Mussel Conservation Plans*: State-level plans with dedicated malacologists, though some regions struggle with social leverage for broader implementation.
 - o *General Engagement*: Some organizations are not directly involved in mussel conservation but use ecosystem health frameworks for research.
- *Use of One Health/Ecosystem Health Frameworks*. A mixed response regarding the adoption of One Health or ecosystem health frameworks:
 - o *Yes*: Some organizations use frameworks like the Landscape Health Index and are developing tools like the HUC12 macrofauna index.
 - o *No*: Others are not management organizations and thus do not use these frameworks directly but apply them in research contexts.
- *Information Gaps*. Significant information gaps limit the ability to manage, conserve, and restore mussel populations:

- *Reintroduction Protocols*: Need for standardized protocols to reintroduce mussels effectively.
- *Genetic Frameworks*: Development of genetic frameworks to select source populations for reintroduction.
- *Comprehensive Data*: Extensive lists of data needs, including detailed population assessments and impacts of various stressors.
- *Additional Comments*. Participants appreciated the organization and content of the workshop, acknowledging its importance in advancing ecosystem health and conservation efforts. They emphasized the need for continued collaboration and research to address the complex challenges facing freshwater mussels and the ecosystems they inhabit.
- **Key Takeaways:**
 - *Ecosystem Services*: Freshwater mussels provide crucial ecosystem services, emphasizing the need to prioritize their conservation.
 - *Stressors*: Key stressors include wetland loss, invasive species, stream alteration, unexplained declines, urbanization, and seasonal flow changes.
 - *Conservation Efforts*: Efforts range from rewilding initiatives to developing health indices and state-level conservation plans, though some areas lack active management.
 - *One Health Framework*: Adoption varies, with some organizations using specific indices and frameworks, while others focus on research applications.
 - *Information Gaps*: Critical gaps include the need for reintroduction protocols, genetic frameworks, and comprehensive population data.
 - *Appreciation for Workshop*: Participants valued the workshop's contributions to advancing understanding and collaboration in ecosystem health.

PART IV: CONCLUSION

The series of presentations at this Freshwater Ecosystem Health Workshop provided a profound understanding of the critical role that native freshwater mussels play in maintaining healthy freshwater ecosystems. Through detailed discussions on ecosystem health, environmental stressors, and conservation strategies, the workshop emphasized the need for integrated approaches to manage and protect these vital organisms.

Freshwater Ecosystem Health. Freshwater mussels serve as essential bioindicators and ecosystem engineers, contributing significantly to nutrient cycling, water filtration, habitat provision, and the support of complex food webs. These functions are crucial for the health of aquatic ecosystems and, by extension, human and animal health. The One Health framework, which seeks to balance the health of people, animals, and the environment, provides a comprehensive approach to address the interconnectedness of these elements.

Understanding and Addressing Mussel Declines. Presentations by experts such as Jordan Richard highlighted the alarming decline of freshwater mussels due to various stressors, including climate change, habitat degradation, invasive species, and pollution. Historical data and case studies, such as those from the Grand River and Upper Mississippi River, underscore the severe impact of these stressors on mussel populations and the ecosystem services they provide.

Conservation Efforts and Research Initiatives. The workshop showcased ongoing efforts and innovative strategies to conserve and restore mussel populations. Key initiatives include the development of rewilding programs, the establishment of large-scale mussel hatcheries, and the implementation of ecosystem health indices such as the Freshwater Health Index. The [USGS science vision for mussel research](#) aims to elevate and expand these efforts through extensive partner engagement and advanced research methodologies.

Importance of Ecosystem Services. The ecosystem services provided by mussels, such as natural water filtration, nutrient cycling, and habitat structuring, are indispensable for maintaining water quality and supporting biodiversity. The economic and cultural significance of mussels further emphasizes the need for their conservation. Projects like the mussel hatchery in Philadelphia illustrate the practical benefits of leveraging these services to enhance water quality and support urban infrastructure.

Challenges and Future Directions. Despite the significant progress in understanding and addressing mussel declines, challenges remain. Freshwater ecosystems are complex and dynamic, influenced by multiple stressors and requiring integrated management approaches. Effective conservation strategies must consider the context-dependent nature of ecosystem services and the need for robust governance and stakeholder engagement.

Comprehensive and Collaborative Approach. The insights gathered from this workshop highlight the necessity for a comprehensive and collaborative approach to freshwater mussel conservation. Integrating scientific research into practical conservation strategies, enhancing public awareness, and fostering collaboration among stakeholders are critical steps to ensure the resilience and sustainability of freshwater ecosystems.

The presentations and discussions at the Workshop underscored the imperative for ongoing research, robust conservation efforts, and enhanced collaboration to protect and sustain freshwater mussel populations. By assessing ecosystem health and leveraging the ecosystem services provided by mussels, we can make significant strides in maintaining healthy, resilient freshwater ecosystems that benefit all forms of life. For continued success in these efforts, it is essential to build upon the knowledge and strategies shared during the workshop, promote innovative solutions, and engage diverse stakeholders in the conservation mission. The future of freshwater ecosystems relies on our collective commitment to preserving the invaluable services provided by native freshwater mussels and ensuring a sustainable environment for generations to come.