Scientific framework for research on unionid mussels in the Upper Mississippi River System

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Freshwater mussels are highly imperiled animals that provide important ecosystem services, and historically supported large commercial fisheries. Over the past 50 years, about 20 species have been lost or greatly diminished from the Upper Mississippi River System (UMRS) basin and overall abundance of mussels has substantially declined in many portions of the river. Where mussels remain abundant, they are vital components of the riverine ecosystem. Mussels can compose a large percentage of the total benthic biomass (tissue biomass of 5-100 g dry mass/m^2). These dense assemblages are likely to influence the abundance of seston, nutrient cycling, and sediment mixing and stability, although these roles have not often been quantified. Moreover, mussels provide critical links in the riverine food web, both indirectly as physical habitat for invertebrates and fish, and directly as a food sources for many organisms (e.g., fish, muskrat). Because the magnitude of ecological services performed by mussels often scales with biomass, decreases in biomass may lead to alterations in ecosystem function.

Mussels have declined in the UMRS for a variety of reasons. Overharvest, habitat destruction, point-source pollution, non-point source pollution due to land-use changes, navigation impacts, and exotic species introductions have caused many mussel populations to decline or disappear. Mussel assemblages are also affected in more subtle, but equally important ways, by changes in flow patterns caused by dams, dikes, and levees. Because of their at-risk status and importance to the riverine ecosystem, conservation and restoration of mussel populations is of great concern to the States, the Fish and Wildlife Service, and the Corps of Engineers. Presently, considerable effort is being expended to assess the effects of proposed management actions such as habitat restoration projects on mussels.

In the past decade there has been substantial research on native mussels in the Upper Mississippi River. For example, we now believe that (1) changes in the geomorphology and hydrodynamics of the river due to dams and channelization structures have altered dispersal of excysted juvenile mussels, (2) habitats with low current velocity are more prevalent now than they were historically causing a shift in community structure and distribution of mussels, (3) commercial harvest was a source of significant mortality that is now much reduced, and (4) zebra mussels have increased overall mortality of native mussels in the UMRS downstream of Lake Pepin. In addition, recent pool-wide mussel surveys show that large mussel populations exist in selected reaches, most mussels occur in deeper (>0.5 m) water, and juveniles (<5 yrs old) make up a substantial proportion of the population. However, there are still significant unknowns that limit conservation and management efforts. For example, we do not know: (1) which habitats support the most dense and diverse mussel assemblages, (2) what role mussels play in modifying habitats and ecological processes that affect other biota, (3) how changes in hydrodynamics affect mussel distribution and life histories, (4) what mussels eat and where this food is produced, and (5) what defines a sustainable mussel population (e.g., rates of reproduction, growth, and mortality)? These questions form the basis for the research framework below.

Because of the slow response times for some parts of ecosystems (e.g., sediment routing, effects of exotic species) and the long life-spans of many mussel species (30-100 years), the full effects of some ecological disturbances on mussels may not be expressed for decades. The slow responses also suggest that considerable time might be necessary for the consequences of management actions to become apparent. If responses of rivers and mussel populations to changes in river management are very slow, adaptive management might not be practical, unless sensitive indicators of river responses and mussel populations can be developed. Thus, traditional measures such as species richness and abundance of adults may not be sensitive enough to detect subtle environmental changes. Rather, indicators such as population vital rates (e.g., survivorship, recruitment, growth) and age structure may be more appropriate.

The goal of this research framework is to outline a focused approach for obtaining the information needed to *preserve and restore a sustainable mussel assemblage and its associated ecological services in the UMRS.* The framework does not propose specific methodologies for addressing each research question, nor does it synthesize available scientific information on these topics. This level of detail will fall within the scope of future research proposals developed to address specific topics outlined in this framework. The focus of the framework is on the main corridor of the UMRS, however, some questions may have a strong linkage to tributary streams (e.g., questions related to host fish movement). Although the framework does not preclude this research, these efforts may need to be funded by other sources. Because of the longevity of mussels, it will take many years to gather some of this information (Figure 1). However, the framework will also provide information on early indictors of healthy populations and communities, such as rates of growth, recruitment, and mortality; biochemical indicators; and diversity. These leading indicators may show progress through management actions in shorter time periods. The framework consists of the following broad research questions and their component sub-questions. Under each question, we provide example approaches to help answer each question.

Question 1. What are the spatial and temporal patterns in mussel distribution, abundance, and assemblage structure within the UMRS?

Question 1a. What are the spatial (including longitudinal patterns among pools) and temporal (including within and among years) patterns in mussel assemblages in the UMRS?

Approach: Conduct multivariate and geostatistical analyses of existing data (e.g., pool-wide surveys, USACE mussel database) and new field surveys of mussels to identify spatial patterns in mussel diversity and assemblage structure. Develop statistical and geospatial models of habitat for key mussel assemblages. Conduct surveys at specific locations or reaches to validate models and track changes in assemblage structure over time.

Question 1b. What are the patterns of mussel distribution and abundance and their key habitat drivers across a hierarchy of scales in the UMRS riverscape?

Approach: Use existing data (e.g., pool-wide surveys, USACE mussel database) or new field surveys of mussels to evaluate variability in mussel distribution and abundance at a range of spatial scales (e.g., mussel bed, habitat type, navigation pool, geomorphic reach). Develop statistical and geospatial habitat models to identify key factors, and validate the predictive capability of models with independent survey data.

Question 1c. What are the effects of hydrologic regime on the distribution and abundance of UMRS mussel populations?

Approach: Compare current data on age-structure and distribution of mussels with earlier data sources (e.g., prehistoric shell middens and surveys from the 1930s and 1950s) to determine how hydrologic and hydraulic conditions have affected reproduction, growth, mortality, and recruitment. Assess the distribution and abundance of mussels over a range of hydrologic conditions, ideally including flood and drought years. Use the models developed in 1b to predict the locations of newly settled juveniles under specific flow regimes, and evaluate the predictions through field sampling when those flow regimes occur. Conduct laboratory studies to evaluate the effects of specific components of the hydrologic regime on mussel assemblages. Compare mussel assemblages in channels at the lower end of pools that are drawn down annually to pools that are not being managed that way.

Question 2. What ecosystem services do freshwater mussels provide to the UMRS?

Question 2a. What role do mussels play in processing nutrients, stabilizing sediments, and providing habitat for biota (including themselves)?

Approach: Identify and characterize reference sites in the UMRS to establish baseline ecosystem service parameters (i.e., nutrient cycling, particle filtration, biodeposition rate, measures of substrate stability). Conduct laboratory or *in situ* experiments to determine which physicochemical and biological variables moderate the ecological roles of freshwater mussels in the UMRS ecosystem.

Question 2b. Is there a threshold abundance, biomass, or assemblage composition below which ecosystem services are lost?

Approach: Conduct field or mesocosm studies across a gradient of mussel abundance, biomass, and species composition and measure a suite of potential ecological services (e.g., filtration rates, nutrient excretion rates) that mussels provide across this gradient.

Question 3. What are the biological characteristics of self-sustaining mussel populations in the UMRS and what limits populations?

Question 3a. What is the difference and annual variation in population-level characteristics (e.g., mortality, recruitment, growth) across species with varying life histories?

Approach: Measure annual rates of mortality, recruitment, and growth in key species from the UMRS. Key species will be chosen to encompass diversity in life history strategies (e.g., short-lived vs. long-lived, host fish use), phylogeny (i.e., Anodontini, Amblemini, Lampsilini, Pleurobemini, Quadrulini), habitat use (e.g., main channels, side channels, impounded areas), and conservation status (e.g., declining vs. currently stable). Target species can be used as surrogates to provide information on rare species that are difficult to study directly in this context. Use data to construct population models that can predict future trends in mussel abundance relative to life history traits and other intrinsic differences among species. Validate model predictions based on past and future observed population trends.

Question 3b. What factors (e.g., toxicological, invasive species, hydrologic regime, host fish, food sources, etc.) have been most important in affecting or limiting UMRS mussel populations in the past?

Approach: Examine historical associations between timing of impacts and changes in mussel assemblages and use multifactor predictive models and correlations to examine relationships between potential limiting factors and mussel occurrence. Use biochemical analyses (e.g., stable isotopes, fatty acids) to evaluate food uptake by mussels and the sources and availability of those foods under different sets of observed conditions. Examine assemblage and population characteristics in areas with different existing conditions (e.g., areas directly modified for navigation vs. less impacted areas) which may be applicable to assessing effects of habitat restoration projects.

Question 3c. How do the biological characteristics of mussel populations influence metapopulation structure and assemblage dynamics?

Approach: Identify and evaluate the sustainability of mussel assemblages at bed and larger scales based on biological characteristics such as carrying capacity, colonization and extinction rates. Use the leading indicators developed in question 3a to assist in this evaluation.

Question 4. How can we most effectively monitor the health and recovery of the UMRS mussel resource?

Question 4a. Are there sampling designs and methods that can provide a quick and low cost assessment of mussel distribution and abundance?

Approach: Compare semi-quantitative (e.g., sleds, remote sensing) and quantitative (e.g., diver-assisted quadrat sampling) survey methods for their cost and precision with respect to estimating mussel distribution and abundance, species composition, reducing size selectivity, and probability of detecting uncommon species.

Question 4b. How can we assess the health of the mussel assemblage?

Approach: Develop bioassessment metrics that can evaluate the overall integrity of mussel assemblages. Metrics should incorporate variables such as species diversity and composition, abundance, recruitment strength, and biochemical markers.

Question 4c. What scale of analysis (e.g., pool, reach, or mussel bed) is best suited for describing mussel assemblages in the UMRS?

Approach: Examine the metapopulation structure of mussel assemblages in the UMRS using geostatistical methods and landscape ecology (e.g., spatial autocorrelation via semivariograms and Morans I).

Question 5. How can we expect mussel populations and assemblages to respond to future conditions and management scenarios on the UMRS?

Question 5a. What are the short term (< 5 yrs) and long term (> 10 yrs) consequences of habitat restoration projects (e.g., pool-wide drawdowns, island construction) on mussel populations and assemblages?

Approach: Integrate relationships between mussel populations and hydrology and hydrophysical conditions (question 1) into population models (e.g., developed in question 3a). Use periodic surveys of restoration projects to validate model predictions.

Question 5b. What are the effects of alternative habitat restoration activities on mussels in an adaptive management framework (in essence, using mussels as experiments)?

Approach: Compare the predicted hydrophysical conditions of alternative restoration project designs with criteria based on habitat and population models (questions 1 and 3). Validate hydrophysical conditions and biological responses of mussels using surveys after habitat restoration project completion.

Question 5c. How can we expect the magnitude of ecosystem services to change in the future in response to management scenarios and other factors (e.g., invasive species, climate change)?

Approach: Develop and validate predictive models of changes in ecosystem services (e.g., nutrient cycling, filtration) provided by mussels, by linking population and assemblage responses of mussels to models of future condition (e.g., climate models, alteration of riverscape).

Tier 1

1a. What are the spatial and temporal patterns in mussel assemblages in the UMRS?

1b. What are the patterns of mussel distribution and abundance and their key drives across a hierarchy of scales in the UMRS riverscape?

3a. What is the difference and annual variation in population-level characteristics across species with varying life histories?

3b. Which factors have been most important in affecting or limiting UMR mussel populations in the past?

4a. Are there sampling designs and methods that can provide a quick and low cost assessment of mussel abundance?

4b. How can we assess the health of the mussel assemblage?

Tier 2

1c. What are the effects of hydrologic regime on the distribution and abundance of UMRS mussel populations?

2a. What role do mussels play in processing nutrients, stabilizing sediments, and providing habitat for biota?

2b. Is there a threshold abundance, biomass, or assemblage composition below which ecosystem services are lost?

3c. How do the biological characteristics of mussel populations influence metapopulation structure and assemblage dynamics?

4c. What scale of analysis is best suited for describing mussel assemblages in the UMRS?

5a. What are the short and long term consequences of habitat restoration projects on mussel populations and assemblages?

5b. What are the effects of alternative habitat restoration activities on mussels in an adaptive management framework?

5c. How can we expect the magnitude of ecosystem services to change in the future in response to management scenarios and other factors ?

Figure 1. Sequence of research sub-questions outlined in the scientific framework for research on unionid mussels in the Upper Mississippi River System. These are not to be viewed as a prioritization of research, rather as a sequence of studies that maximizes science and learning. This is an iterative process in which information gathered in tier 1 can be used to better answer questions in tier 2 and then results in tier 2 can be used to gather more information in tier 1.