Upper Mississippi River Restoration Program

Science in Support of Restoration and Management
FY18 SOW

Enhancing Restoration and Advancing Knowledge of the Upper Mississippi River

Addressing the FY2015–2025 UMRR Strategic Plan

Developing and Applying Indicators of Ecosystem Resilience to the UMRS (FY15-FY18)

Ecological resilience can be defined as the ability of an ecosystem to absorb disturbance and still maintain its fundamental ecological processes, relationships, and structure. The concept of ecological resilience is based on the understanding that most ecosystems can exist in multiple alternative states rather than exhibiting a single equilibrium state to which it is always capable of returning. For example, shallow lakes have been shown to exist in either a clear-water heavily vegetated condition, or a turbid condition with little or no vegetation. The magnitude of disturbance (e.g., change in nutrients or turbidity) a lake in either state could sustain and remain in that state is the ecological resilience of that system.

Most management agencies are interested in quantifying the resilience of ecosystems because it can help them identify locations, scales, and degrees of management intervention needed to maintain healthy, productive ecosystems, or to shift ecosystems to more desirable states. In some cases, managers might be interested in reducing the resilience of an undesirable state (e.g., the turbid, unvegetated state above), whereas in other cases, managers might be interested in maintaining or increasing the resilience of a desirable state (e.g., the clear-water, vegetation state above).

Although there exists a substantial theoretical and conceptual literature on ecological resilience and how it could inform ecosystem management, applied examples are less common. Very little work has been done to develop indicators of ecosystem resilience for large rivers. Nevertheless, many of these concepts are clearly relevant to the Upper Mississippi River System (UMRS) and the U.S. Army Corps of Engineers' Upper Mississippi River Restoration (UMRR) Program. For example, the UMRS has experienced changes that have been associated with reduced resilience and shifts to undesirable states in other ecosystems. Examples of such changes include accumulation of nutrients and sediments, redirection of water flows, altered flow regimes and water elevations, changes in flood frequency and floodplain connectivity, and proliferation of non-native species. How have these changes influenced the health and resilience of the UMRS?

The UMRS also exhibits characteristics that likely contribute to its resilience and which may be augmented by various management actions. The longitudinal orientation of the river provides a diversity of climatic and environmental conditions, which might maintain the resilience of, for example, fish communities in the face of interannual variability and long term changes in climate and other ecological drivers. Some portions of the UMRS maintain extensive lateral connections and hydrogeomorphic diversity across the floodplain, which allow fish species to persist through substantial seasonal and interannual fluctuations by seeking suitable habitat in various locations. How do these hydrogeomorphic characteristics and the diversity of fish, vegetation, invertebrates, and other biota they contribute to the health and resilience of the UMRS?

It is likely that management actions could alter some of the features typically attributed to resilience. For example, if connections among contrasting aquatic areas substantially contribute to the resilience of the UMRS, then how and where could managers modify hydrological connectivity (e.g., dredging, altering channel-backwater connections, island construction) to improve the resilience of desired states or reduce the resilience of undesired states?

OBJECTIVES (*Note: Objective 3 (bold text below) will be the emphasis during FY2018*)

This project will be the primary responsibility of a post-doctoral scientist collaborating with scientists at the U.S. Geological Survey, Upper Midwest Environmental Sciences Center (UMESC) and scientists and managers throughout the UMRR partnership. The objectives are:

1) Establish a resilience working group to capitalize on the diversity of expertise and perspectives that comprise the UMRR partnership. This working group will be substantially involved in the formulation and conduct of this project. *Completed in FY15*.
2) Develop a clear conceptual understanding and definition of ecological resilience as applied to the UMRS.
   a) Small working group will develop a draft ("strawman") conceptual model of ecological resilience in the UMRS.
   b) Convene workshop to discuss and refine this model. Participants will be determined by resilience working group.
   c) Small working group will refine conceptual model based on input from workshop

   Working Draft Conceptual models of UMRS in support of the resilience assessment were completed in FY16. Given the iterative nature of a resilience assessment. These models will continue to be refined throughout the project
3) **Use the conceptual model to guide:**
   a) **Development of indices of resilience for the UMRS using data from the UMRR-LTRM.**
   b) **Description of the current resilience of multiple reaches of the UMRS.**
   c) **Evaluation of the factors contributing to the resilience of the UMRS**
      i) **Where the UMRS is in a desirable state, what contributes to the resilience of that state and what management actions might maintain or increase that resilience?**
      ii) **Where the UMRS is in a less desirable state (e.g., lack of vegetation in the lower impounded reach), what contributes to the resilience of that state and how might management actions overcome that resilience?**

   Indicators of general resilience were developed in FY17 and a manuscript has been drafted for review by the Resilience Working Group. Evaluating aspects of specified resilience derived from the conceptual models will be the focus of FY18.

WORKPLAN AND DELIVERABLES

In FY18, the next phase of the project will use UMRR LTRM data to quantify select relationships from those conceptual models and explore the implications for the resilience of the UMRS. Following that, we will begin to examine theoretical and empirical descriptions of the effects management actions have on the resilience of the UMRS.

Results of these efforts will be communicated to the partnership via a seminar or workshop and presentations at various UMRS meetings. We will communicate results to a national and international audience via presentations at scientific conferences and in peer-reviewed publications.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018R1	Updates provided at each quarterly UMRR CC meeting and A team meeting	Bouska, Houser	Various
2018R2	Submit General resilience manuscript for peer-reviewed publication. Bouska, K. L., J. N. Houser, N. R. De Jager, J. Rogala, and M. Van Appledorn. Applying concepts of general resilience to large river ecosystems: case studies from the Upper Mississippi and Illinois rivers.	Bouska, Houser	30 January 2018
2018R3	Draft report summarizing trends in controlling variables and research framework for specified resilience	Bouska, Houser	15 September 2018

Intended for Distribution
Manuscript: Bouska, K.B., J.N. Houser, and N. De Jager. Developing a shared understanding of the Upper Mississippi River: the foundation of a resilience assessment. (Accepted with revisions by Ecology and Society)

Modelling and mapping current and projected future habitats of the Upper Mississippi River System (HNA-II; FY17-FY18)

UMRR's Habitat Needs Assessment-II consists of a series of maps, models, and quantitative measures that provide a system-wide assessment of the hydrogeomorphic and ecological condition of the UMRS. In FY2017, UMESC conducted work related to mapping and modelling aquatic and floodplain habitats (see FY2017 SOW for milestones) as well as developing a draft document summarizing the methods, analyses, and data produced in support of HNA-II (not in FY2017 SOW). For 2018, UMESC will complete all work related to data development for HNA-II (see 2017AH9, FH5,GEO1). In addition, UMESC will complete the draft document started in FY2017 (see 2018HNA1), which includes written summaries of the methods and results of modelling efforts related to aquatic habitats (2017AH8), floodplain habitats (2017FH4), sedimentation (2017FAH3), and forest succession (2017FFH3). UMESC had originally identified the above summaries as formal draft documents. However, to expedite completion of HNA-II, these efforts will be summarized in the form of appendices to the main HNA-II chapter (2018HNA1). Formal draft documents for these efforts will be pursued in 2018 under separate components of the UMRR SOW (see sedimentation research, eco-hydrologic research, and landscape pattern research). This will allow UMESC to complete additional modelling efforts and more formal publications that go beyond what was required for HNA-II. Below is a list of remaining milestones from FY2017 to be completed in FY2018. Note that product descriptions may have changed slightly to match the evolution of HNA-II. A new milestone for the HNA-II summary document has been added. Any milestone from FY2017 not listed below has been completed in FY2017.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018HNA1	Draft HNA-II chapter documenting informational content for HNA-II	De Jager, Rogala, Bouska, Houser, Van Appledorn, Rohweder, Fox, Ruhser	December 30, 2017
2017AH8	Draft Appendix A in 2018HNA1-Summarize methods used to develop Aquatic Areas	Jim Rogala, Janis Ruhser, Jason Rohweder, Jeff Houser	December 30, 2017
2017AH9	Complete Aquatic Areas Geodatabase	Jason Rohweder and Jim Rogala	December 30, 2017
2017FAH3	Complete Appendix C in 2018HNA1-Summarize methods used to develop sedimentation model	Jim Rogala	December 30, 2017
2017FH4	Complete Appendix B in 2018HNA1-Summarize methods used to develop flood inundation model	Molly Van Appledorn	December 30, 2017
2017FH5	Complete Floodplain Areas Geodatabase	Jason Rohweder, Tim Fox, and Molly Van Appledorn	December 30, 2017
2017FFH3	Complete Forest Succession Modelling work and Appendix D in 2018HNA1-Summarize methods used to develop forest simulation model	Nathan De Jager	December 30, 2017
2017GEO1	Compile any remaining data used in HNA-II into geodatabase	Tim Fox and Jason Rohweder	December 30, 2017

Assessing recent rates of sedimentation in the backwaters of Pools 4, 8, and 13 to support river restoration and the Habitat Needs Assessment-II (FY17-18)

In a previous LTRM study between 1997 and 2001, annual bed elevations were measured along a set of backwater transects in Pools 4, 8 and 13 of the Upper Impounded Reach of the UMRS (Rogala et al. 2003). These survey data provided basic information on rates of backwater sedimentation across a gradient of depth and among backwaters that varied in their hydraulic connectivity with channels.

This study will use the same sampling design and survey methodology used in the 1997-2002 study (Rogala et al. 2003).

Milestones and products:

Tracking number	Products	Staff	Milestones
2018ST1	Reestablishment of horizontal and vertical temporary benchmarks, and a data base for horizontal and vertical benchmarks (Continuation of 2017ST1)	Rogala, Moore, Kalas, Bierman	30 March 2018
2018ST2	Open-water nearshore surveys completed and a database (Continuation of 2017ST2)	Rogala, Moore, Kalas, Bierman	31 December 2018
2018ST3	Over-ice surveys completed and a database (Continuation of 2017ST3)	Rogala, Moore, Kalas, Bierman	30 March 2018
2018ST4	Data analysis and completion report on sedimentation rates along transects (Continuation of 2017ST4)	Rogala, Moore, Kalas, Bierman	30 September 2018

Literature Cited:

Rogala, J. T., P. J. Boma, and B. R. Gray. 2003. Rates and patterns of net sedimentation in backwaters of Pools 4, 8, and 13 of the Upper Mississippi River. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. An LTRMP Web-based report available online at:
http://www.umesc.usgs.gov/data_library/sedimentation/documents/rates_patterns/rates_patterns.pdf

Landscape Pattern Research and Application

The goal of landscape pattern research on the Upper Mississippi River System is to develop concepts, maps and indicators that provide both regional-level decision makers and local-level resource managers with information needed to effectively manage the UMRS.

As described in the UMRR Landscape Pattern Research Framework (De Jager 2011), landscape pattern research on the UMRS focuses on linking decisions made at regional scales with restoration actions carried out at local scales. While regional program managers and decision makers are concerned with improving the overall ecological condition of the entire UMRS, local resource managers work to address site specific habitat and resource limitations. Landscape ecology, which focuses on the linkages between patterns visible at broad scales and ecological patterns and processes that occur at local scales, can help to integrate these two scale-dependent management activities. (Strategic Plan Outcome 2, Output 2.2, Outcome 4)

Objectives

1) To develop broad-scale indicators of habitat amount, connectivity and diversity for the purposes of a) identifying areas for ecosystem restoration across the entire system and b) to track status and trends in habitat area, diversity and connectivity.

2) To connect broad-scale landscape pattern indicators with local-scale ecological patterns and processes critical to restoration project development.

Product Descriptions

2018L1: Draft Manuscript: In support of HNA-II, we have developed a spatially explicit model of forest succession that links a newly developed flood inundation model with a model of plant establishment and growth. The methods for this work will be summarize in HNA-II. However, additional scenarios, model validation, sensitivity analyses, and discussion will be provided in this separate document.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018L1	Draft Manuscript: Modelling Forest succession in the UMRS.	De Jager	30 September 2018
On-Going			
2016L3	Draft Manuscript: Review of Landscape Ecology on the UMR	De Jager	30 September 2018
Intended for distribution			
Manuscript: Swanson, W., De Jager, N.R., Strauss, E.A., Thomsen, M. In Review. Effects of flood inundation and invasion by *Phalaris arundinacea* on nitrogen cycling in an Upper Mississippi River floodplain forest. (2016L2)			
Manuscript: De Jager, N.R., Swanson, W., Hernandez, D.L., Reich, J., Erickson, R., Strauss, E.A. Effects of flood inundation, invasion by *Phalaris arundinacea*, and nitrogen deposition on extracellular enzyme activity in an Upper Mississippi River floodplain forest. (2015L5)			
Manuscript: Van Appledorn, M., De Jager, N.R., Johnson, K. Considerations for improving floodplain research and management by integrating inundation modeling, ecosystem studies, and ecosystem services (2016L5)			
Map Set: Reed Canarygrass abundance and distribution in the UMR (Pools 3-13) (2017L2)			
Manuscript: De Jager, Rohweder, Hoy. 2017. Mapping areas invaded by *Phalaris arundinacea* in Navigation Pools 2-13 of the UMRS. LTRM Completion Report (2016L4).			

Reference

De Jager, N.D. 2011. Scientific Framework for Landscape Pattern Research on the Upper Mississippi and Illinois River Floodplains. Available online: http://www.umesc.usgs.gov/ltrmp/ateam/landscape_patterns_research_framework_final_june2011.pdf

Eco-hydrologic Research

Flooding is believed to be a key driver of form and function of the Upper Mississippi River System (UMRS). Understanding the role of inundation in driving dynamics in both aquatic and terrestrial ecosystems is essential for improving the health and resilience of the UMRS through informed management practices. Only recently, however, have inundation dynamics been characterized and mapped systematically in ecologically meaningful ways. The characterizations of flooding, together with existing geospatial datasets of physical and ecological attributes developed through the UMRRP, offer abundant new opportunities to understand biophysical relationships in the UMRS, especially regarding the role of inundation in shaping forest patterns (composition, structure) and processes (dispersal, regeneration, succession) across multiple spatial and temporal scales.

The goal of this research is to leverage the inundation model along with other existing UMRRP datasets to learn about patterns of floodplain-river connectivity throughout the UMRS, to understand how these patterns may influence ecosystem dynamics, and to contribute to the improved health and resilience of the UMRS by developing concepts, maps, and models relevant to management activities.

Specific Activities for FY2018:

Component 1 – UMRS inundation model completion and support: LTRM will maintain some level of expertise to provide basic model archiving and assistance using the UMRS inundation model. In FY2018, we will:

- 1a. Facilitate the inundation modelling framework's long-term curation by creating an accessible platform for its distribution
- 1b. Continue evaluations of model outputs using empirical data
- 1c. Provide technical assistance on the proper use of model outputs
- 1d. Assist partner agencies on the development of additional uses for the model in HREP project planning

Component 2 – Model application to understand eco-hydrologic patterns and processes: It is a goal of the UMRS management community to restore and sustainably manage floodplain forests to serve as a vital resource for future generations. Ongoing forest management is informed by inventory and monitoring programs that summarize current species distributions and forest conditions. Data from the programs also have the potential to provide novel insights into how and at what spatial and temporal scales forest structure and composition are influenced by environmental conditions (e.g., flooding dynamics, soils, climate), land use history, biotic factors (e.g., dispersal, competition), and their interactions. Research is needed to gain an integrative understanding of how abiotic and biotic factors structure UMRS floodplain forests and to identify environmental conditions suitable for supporting healthy, resilient forests. This research will:

- 2a. Integrate flood inundation model outputs with vegetation data to better understand how multiple aspects of flood regime shape vegetation communities and their dynamics
- 2b. Identify opportunities to apply a better understanding of flood-vegetation interactions at the HREP scale
- 2c. Examine inundation model outputs for spatial and temporal trends in different aspects of flooding regimes that may have impacts on important biophysical patterns and processes

Product Descriptions

2018EH01: Manuscript – A draft manuscript describing inundation process zones occurring throughout the UMRS. Results from inundation model evaluation study (products 2017FH11 and 2017FH12) will be included in the manuscript.

2018EH02: Analysis – Data analysis describing relationships among vegetation distributions and inundation dynamics of the UMRS, including spatial and temporal patterns.

2018EH03: Tool – Draft a plan to facilitate the long-term curation of the UMRS inundation model that considers end-user access and needs, data storage, and updates to computational processing scripts.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018EH01	Draft manuscript describing inundation process zones across the UMRS	Van Appledorn, De Jager, Rohweder	30 September 2018
2018EH02	Inundation and Vegetation Data Analysis	Van Appledorn, De Jager	30 September 2018
2018EH03	Draft inundation model curation plan	Van Appledorn, Fox, Rohweder, De Jager	30 September 2018

Evaluation of a System-Wide Floodplain Inundation Model for Ecological Applications (FY17-FY18)

Inundation dynamics are considered to be a key driver of floodplain ecosystem structure and function. In the Upper Mississippi River System (UMRS), floodplain inundation is believed to affect such diverse ecological processes such as sedimentation dynamics (Knox 2001, Benedetti 2003), biogeochemical cycling (De Jager et al. 2015), population dynamics of native and nonnative fishes (Chick et al. 2005), and forest succession (De Jager et al. 2013). Because of the numerous linkages between flooding dynamics and ecological processes, characterizing inundation is an essential step towards informing management decisions and understanding the structure and function of the UMRS floodplain ecosystem.

The overall goal of this study is to evaluate the performance of the UMRS inundation model using empirical evidence of floodplain inundation. Such information is useful in understanding spatial distributions of model error and its potential sources, which ultimately can inform at what spatio-temporal scales the model is most appropriate. Model evaluation also aids end-users in understanding the approach's strengths and weaknesses to avoid misuse or misinterpretation of model results.

Products and Milestones

Tracking number	Products	Staff	Milestones
2017FH11	Post-processing and analysis of logger data and water-edge mapping	Van Appledorn	29 December 2017
2017FH12	A written summary of validation results will be submitted as a supplement to the Habitat Needs Assessment II that identifies potential sources of UMRS inundation model error, discusses the validity of the model's assumptions, and provides guidance on appropriate model use.	Van Appledorn	30 September 2018

Citations:

Benedetti, M. M. 2003. Controls on overbank deposition in the upper Mississippi River. Geomorphology 56: 271 – 290.

Chick, J. H., B. S. Ickes, M. A. Pegg, V. A. Barko, R. A. Hrabik, and D. P. Herzog. 2005. Spatial structure and temporal variation of fish communities in the Upper Mississippi River System. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, May 2005. LTRMP Technical Report 2005-T004. 15 pp.

De Jager, N.R., Cogger, B.J., and Thomsen, M.T. 2013. Interactive effects of flooding and deer browsing on floodplain forest recruitment. Forest Ecology and Management 303:11-19.

De Jager, N.R., Swanson, W., Strauss, E. A., Thomsen, M., and Yin, Y. 2015. Flood pulse effects on nitrification in a floodplain forest impacted by herbivory, invasion, and restoration. Wetlands Ecology and Management 23: 1067 – 1081.

Knox, J.C. 2001. Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. Catena 42: 193-224.

Aquatic Vegetation, Fisheries, and Water Quality Research

New Projects

2018D12: Development of a White Paper on UMRR LTRM's interactions with programs for other large rivers, nationally and internationally

This white paper will describe UMRR LTRM's historic and current involvement with other large river programs and develop a vision for the future to further our international collaboration. The paper will first review the scope and status of LTRM's work to date to assist the development of other large river monitoring efforts. For example, this work has included work in the Amazon and Parana-Paraguay Rivers in Brazil and the Yangtze River in China; large rivers in PA; and the Rio Grande. The paper will then describe potential ways of developing collaboration between UMRR LTRM and other large river programs (e.g., The Global Rivers Observatory, American Rivers), managers, and researchers that could lead to more data syntheses across river systems, better understanding of how to conceptualize the structure and function of large rivers, and improved predictions of responses to management actions on the UMRS and other large rivers. Rivers across the world are being dammed, redirected and developed at an ever-increasing pace, and knowledge gained by UMRR about how to monitor change and maintain ecological function through restoration at the scale of a large river basin could be of great value internationally.

This paper will address the following questions:

- Why is thinking strategically about international collaboration important for the UMRR program and river science more generally?
- What are our main goals for facilitating international collaboration? What do we hope to achieve?

  Strategic Plan: Objective 3.3: Exchange knowledge with other organizations and individuals nationally and internationally. Strategy 1 – Serve as a resource for similar programs nationally and internationally, Strategy 2 – Seek knowledge from other organizations and individuals nationally and internationally to enhances UMRR's efforts in advancing its vision

  "Focus and enhance knowledge exchange with other organizations and individuals nationally and internationally in a communications plan and implementation framework". (see "actions" column in table of strategic plan for further description)

- What have we done over our 30-yr history to share knowledge with other programs?
- What is the state of international collaboration on developing monitoring programs and restoration techniques across big river ecosystems?
- Where/how could UMRR-LTRM support understanding and restoration internationally? What are some learning opportunities that can enhance our program?
- List specific and general steps of how we can achieve our aims, for example:
  - USGS Powell Center proposal on "big river science, monitoring, restoration, and data needs"
  - Proposed sessions at meetings on big river monitoring tools (ASLO)

- Exchanges with other water agencies or restoration groups – China, Brazil, New Zealand, Elwha River, others?
- Restoration – e.g., workshops with other restoration programs (NOAA NWFSC on watershed restoration planning and implementation on the Columbia and Elwha Rivers, Chesapeake Bay

2018D13: Using physical landscape metrics of hydrological connectivity to understand limnnological conditions in backwaters of the Upper Mississippi River

Rivers are dynamic ecosystems in space and time, and contain a mosaic of diverse and interconnected aquatic areas. The modern Upper Mississippi River (UMR) is composed of a main navigation channel and a diversity of side channels, backwaters, and floodplain lakes. Connectivity among these areas has been shown to affect biogeochemical processes and habitat suitability for riverine organisms, but our quantitative understanding of the relationship between connectivity and various limnological characteristics of these areas is rudimentary. A better understanding of how connectivity affects physicochemical conditions in backwaters such as velocity, temperature and dissolved oxygen is needed to inform restoration and conservation of off-channel aquatic areas.

We aim to better quantify backwater connectivity across the large spatial extent of the UMR though the use of spatial analysis and long term data analysis. To do so, we will use simple metrics of connectivity for backwater habitats using GIS layers of land and aquatic area cover. We will then use the 30-year LTRM dataset of water quality on the UMR to test the ability of these metrics to describe variability in multiple limnological variables including velocity, temperature and oxygen concentrations in backwaters. We will assess how well these relationships can be used to quantify the availability and condition of backwater habitat and inform restoration strategies across a range of hydrological conditions in the UMR.

2018B12-B14: A framework for research and applied management technical support in the Fish Component of the UMRR LTRM

The Long Term Resource Monitoring (LTRM) on the Upper Mississippi River System (UMRS), an element of the Upper Mississippi River Restoration Program (UMRR), stands as the nation's largest river monitoring program and has amassed geospatial, hydrological, biological, and chemical databases unrivaled by other North American river systems. Presently, the LTRM is transitioning from a period of data banking and critical program evaluations into a period of directed research and modeling to better understand ecosystem properties and dynamics in this heavily human-impacted river basin. Notably, the UMRS is managed as a multiple-use resource, resulting in rich research opportunities for conducting socially-relevant science.

This framework will identify several research topics and questions that can be addressed with existing data resources within the UMRS. A variety of topics will be forwarded in an attempt to match research topics with individual interests, and to foster distributed, collaborative approaches to research across the basin (and beyond). In all, a "systemic" perspective will be pursued. In addition, ideas for technically-supporting applied management actions in the basin, using existing program assets and capabilities, will be outlined.

2018B15: Technical support for USACE Fish Community Model

B. Ickes will serve as a readily-available technical support resource as the team considers applying AHAG 2.0 models to their new habitat assessment techniques.

Products and Milestones

Tracking number	Products	Staff	Milestones
Aquatic Vegetation			
2015A7	Data compilation and analysis: Aquatic macrophyte communities and their potential lag time in response to changes in physical and chemical variables	Lund	30 December 2017
2015A8	Draft completion report or manuscript: Aquatic macrophyte communities and their potential lag time response to changes in physical and chemical variables in the LTRM vegetation pools	Lund	30 June 2018
2016A7	Draft completion report: How many years did the effects of the 2001-2002 Pool 8 drawdown on arrowheads (*Sagittaria latifolia* and *S. rigida*) last?	Yin	30 September 2018
Fisheries			
2018B12	Draft fish framework for research and applied management technical support in the Fish Component of the UMRR LTRM	Ickes	30 May 2018
2018B13	Coordination of draft fish framework with A-Team	Ickes	August 2018
2018B14	Final draft fish research framework	Ickes	30 September 2018
2018B15	Technical support for USACE Fish Community Model	Ickes	30 September 2018
2015B17	Draft Manuscript: Fish Trajectory Analysis	Ickes, Minchin	28 October 2017
2016B17	Draft Manuscript: Developing and applying trajectory analysis methods for UMRR Status and Trends indicators – Year 2	Ickes, Minchin	28 October 2017
2016B14	Draft completion report: Exploring Years with Low Total Catch of Fishes in Pool 26	Gittinger, Ratcliff, Lubinski, Chick	30 Sept 2018
Water Quality			
2015D16	Draft manuscript: Trends in water quality and biota in segments of Pool 4, above and below Lake Pepin	Burdis	29 December 2017
2018D12	Draft White Paper on UMRR LTRM's interactions with programs for other large rivers, nationally and internationally	Jankowski	30 September 2018
2018D13	Using physical landscape metrics of hydrological connectivity to understand limnnological conditions in backwaters of the Upper Mississippi River	Jankowski, Rogala, Houser	30 September 2018
Intended for Distribution			
Manuscript: An Assessment of Long Term Changes in Fish Communities within Large Rivers of the United States (Environmental Monitoring journal) Counihan, Ickes, Casper, Sauer 2016B13 (Resubmitted to PLOS One)			
Manuscript: Aquatic Plant Response to Large-Scale Island Construction in the Upper Mississippi River. Drake and Gray; 2016A6a. (Submitted to journal)			

Statistical Evaluation

Statistical support for the UMRR LTRM provides guidance for statistical analyses conducted within and among components, for contributions to management decisions, for identifying analyses needed by the Program, for developing Program-wide statistical projects, and for reviewing LTRM documents that contain statistical content. The statistician is also responsible for ensuring that newly developed statistical methods are evaluated for use by LTRM. Guidance for management includes assistance with modifications to program design and with standardizing general operating procedures.

The statistical component will help identify useful analyses of data within and across components, ensure analytical methods are appropriate and consistent, and, when possible, coordinate multiple analyses to achieve larger program objectives regardless of which group (UMESC, field stations, USACE, etc.) conducts analyses. The statistician is also responsible for reviewing LTRM documents that contain substantial statistical components for accuracy, and for ensuring that quality of analyses is consistent among products. A primary goal of statistical analyses is to draw appropriate conclusions to inform effective management actions. Appropriate statistical analysis and interpretation is critical to making proper inferences from LTRM data. This, in turn, is critical for distinguishing between natural variation and human effects and in evaluating the long-term effects of management actions, such as HREPs, water level manipulations, or increases in navigation.

Product Description

Tracking number	Products	Staff	Milestones
On-Going			
2016E2	Draft manuscript: How well do trends in LTRM percent frequency of occurrence SAV statistics track trends in true occurrence?	Gray	30 September 2017
Intended for distribution			
Draft manuscript: Inferring decreases in among- backwater heterogeneity in large rivers using among-backwater variation in limnological variables (2010E1)			

Investigation of metabolism, nutrient processing, and fish community in floodplain water bodies of the Middle Mississippi River (FY17-FY18)

Floodplains are a vital component of large river ecosystems. Floodplains provide refuge areas for sensitive and juvenile aquatic organisms during flood events and increase ecosystem diversity by providing variable habitats (Ward et al 1999). As the floodplain undergoes cycles of connectivity nutrient processing and sediment capture occurs, removing potential pollutants from the system (Noe and Hupp 2009, Kroes et al 2015). Distribution of water bodies across the floodplain results in a suite of backwaters, channels, and lakes with different connectivity regimes. River control structures have disconnected the Middle Mississippi River (MMR) from over 80% of its historic floodplain. In many areas this has resulted in a narrow floodplain with limited connectivity to floodplain water bodies. Personal observation does suggest that a connectivity regime exists even within the restricted floodplain. However, very little is known about how these water bodies function independently and as part of the greater Mississippi River system. This information is needed by managers in order to effectively restore limited functional processes (i.e. HREP) or manage floodplain habitats.

Milestones and products:

Tracking number	Products	Staff	Milestones
2017MMF2	Draft report completed - will detail differences between the floodplain habitats and the main channel and associations between fish community and water quality attributes with connectivity of the water body to floodwaters or the main channel	Sobotka	30 December 2017
2017MMF3	Final Report	Sobotka	30 June 2018

References

Kroes, D. E., Schenk, E. R., Noe, G. B., & Benthem, A. J. 2015. Sediment and nutrient trapping as a result of a temporary Mississippi River floodplain restoration: The Morganza Spillway during the 2011 Mississippi River Flood. Ecological Engineering. 82, 91–102. https://doi.org/10.1016/j.ecoleng.2015.04.056

Noe, G. B., & Hupp, C. R. 2009. Retention of Riverine Sediment and Nutrient Loads by Coastal Plain Floodplains. Ecosystems. 12(5), 728–746. https://doi.org/10.1007/s10021-009-9253-5

Ward, J. V., Tockner, K., Schiemer, F. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regul. Rivers: Res. Mgmt. 15, 125–139. doi:10.1002/(SICI)1099-1646(199901/06)15:1/3<125::AID-RRR523>3.0.CO;2-E

Advancing our understanding of habitat requirements of fish assemblages using multi-species models (FY17-FY18)

The identification and selection of habitat restoration projects within the UMRR are meant to address ecological needs representing a diversity of native species. The partnership has thus far advanced our understanding of the ecological needs for groups of species such as diving ducks, dabbling ducks, and Centrarchids. This understanding of habitat requirements for particular life history activities (i.e., migratory foraging habitat, overwintering habitat) is critical to maintain sufficient ecological conditions that, if limiting, may negatively influence populations. From a fish assemblage perspective, our understanding of habitat requirements for specific life-history activities is limited, though our understanding of life history guilds allows us to infer broad habitat needs. Yet, specific criteria are required to design rehabilitation projects for the objectives of habitat provision. The issue at hand is then how to identify habitat criteria to develop habitat restoration projects that benefit the broader fish community without undergoing species-specific analyses of all 140+ species?

Species archetype models cluster species based on their response to environmental gradients (Dunstan et al. 2011). We propose the use of archetype models with existing LTRM fisheries data to gain insight into habitat requirements across the fish community, with emphasis on environmental covariates that are commonly manipulated through Habitat Rehabilitation and Enhancement Projects (e.g., depth, velocity, temperature).

Milestones and products:

Tracking number	Products	Staff	Milestones
2017FA1	Draft LTRM Completion report on period-specific inferences on environmental gradients and species-environment associations by period	Bouska, Gray	15 Feb 2018
2017FA2	Final LTRM Completion Report	Bouska, Gray	15 Sept 2018

Mapping the thermal landscape of the Upper Mississippi River: A Pilot Study (FY17-FY18)

Temperature is a master variable that controls physical, chemical and biological processes in aquatic ecosystems. For instance, temperature influences fundamental physical characteristics of water such as its density and movement; controls the rates of biogeochemical processes important to river functioning such as nitrogen and carbon cycling (Allen et al. 2005, Yvon-Durocher et al. 2012, Jankowski et al. 2014); and affects all aspects of organism physiology including growth, feeding, and reproduction (Arrhenius 1889, Brown et al. 2004). Thus, shifts in the thermal environment can have effects across all scales of ecological organization.

Understanding the both the natural and anthropogenic drivers of thermal patterns in rivers is fundamentally important to understanding how they will respond to future changes in land use and climate.

Milestones and products:

Tracking number	Products	Staff	Milestones
2017TL1	Draft report on feasibility and utility of surface water temperature map	Jankowski, Robinson, Ruhser	30 December 2017
2017TL2	Final report and data distribution	Jankowski, Robinson, Ruhser	30 March 2018

References:

Allen, A.P., J.F. Gilooly, and J.H. Brown. 2005. Linking the global carbon cycle to individual metabolism. Functional Ecology 19:202-213.

Arrhenius, S. 1889. Uber die Reaktionsgeschwindigkeit bei der Inversion von Rohrzucker durej Sauren. Zeitschrift fur Physik Chemique 4: 226-248.

Brown, J.H., J.F. Gilooly, A.P. Allen, V.M. Savage, and G.B. West. 2004. Toward a metabolic theory of ecology. Ecology 85: 1771-1789.

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology 51: 1389-1406.

Jankowski, K.J., D.E. Schindler and P.J. Lisi. 2014. Temperature sensitivity of community respiration rates in streams is associated with watershed geomorphic features. Ecology 95: 2707-2714.

Yvon-Durocher, G., J.I. Jones, M. Trimmer, G. Woodward and J.M. Montoya. 2010. Warming alters the metabolic balance of ecosystems. Philosophical Transactions of the Royal Society B-Biological Sciences 365: 2117-2126.

Estimating backwater sedimentation resulting from alluvial fan formation (FY17-FY18)

Introduction/Background:

The need for information on sedimentation in the Upper Mississippi River System (UMRS) was established early in the planning for a monitoring/research component in what is now the Upper Mississippi River Restoration (UMRR) Program. Sediment deposition in backwaters derives from two primary mechanisms: 1) deposition of fine sediment as it precipitates out from the water column and 2) deposition of near-bed coarse sediments delivered from adjacent channels.

Coarse sediment deposition in backwaters is often in the form of delta-like deposits (i.e., alluvial fans) where channels enter backwaters. Other depositional areas can be found as side channels enter into impounded areas in the lower portions of pools in the upper reaches. Sand deposits provide valuable habitat diversity, but at the expense of deeper water habitats. The accumulation of sand is a longer-term deposition, whereas fine sediment deposits can be removed during future high flow events. Given the potential for altering backwaters in a long-term manner, a better understanding of alluvial fan formation is needed when considering future conditions of the UMRS.

Products and Milestones

Tracking number	Products	Staff	Milestones
2017SED2	Draft LTRM Completion Report summarizing findings and providing recommendations for expanding the project system-wide	Rogala, Hansen, Nelson	31 Dec 2017
2017SED3	Final LTRM Completion Report	Rogala, Hansen, Nelson	30 June 2018

Pool 12 Overwintering HREP Adaptive Management Fisheries Response Monitoring

2018P13: Fisheries Population Monitoring (FY2006-Present)
This is a continuous project that builds on several years of pre-project fisheries monitoring for the Pool 12 Overwintering HREP. We have been performing pool-wide electrofishing in Pool 12 since 2006. We have also been performing fyke netting in backwater lakes that will be rehabilitated, as well as other backwaters in Pool 12 that will not be rehabilitated (as a control). We also perform otolith extraction from bluegills from the lakes we net in to obtain aging, sexing, and mortality information.

Questions still exist as to the most effective longitudinal spacing of fisheries overwintering HREP projects. The Pool 12 Overwintering HREP is unique because four backwater lakes (Sunfish, Stone, Tippy, and Kehough - in order of construction) are being rehabilitated in the same navigation pool (all within roughly eight river miles of each other), in the same window of time, and as part of the same HREP.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018P13a	Collect annual increment of pool-wide electrofishing data	Bierman and Bowler	1 November 2017
2018P13b	Collect annual increment of fyke netting data from backwater lakes	Bierman and Bowler	15 November 2017
2018P13c	Perform otolith extraction from bluegills for aging	Bierman and Bowler	1 December 2017
2018P13d	Age determination of bluegills collected in Fall 2014	Bierman and Bowler	1 February 2018
2018P13e	In-house project databases updated	Bierman and Bowler	31 March 2018
2018P13f	Summary letter compiled and made available to program partners	Bierman and Bowler	30 September 2018

2017AM: Pre-project Biological Response Monitoring; Crappie Telemetry –Kehough Lake (FY16-Present)
This project was initially attempted during FY16. However there was an unusual and extended high-water period from late December through most of January that resulted in the loss of all tagged crappie.

In this study, transmittters were implanted in 50 white and/or black crappie in one overwintering backwater in Pool 12: Kehough Lake. Kehough Lake will be rehabilitated in Phase III of the Pool 12 Overwintering HREP.

Milestones and products:

Tracking number	Products	Staff	Milestones
2017AM5	Summary letter Analysis of tracking data and quantification of 80% UDs for Kehough lake	Hansen, Bierman, Bowler, Theiling	30 September 2018

Pool 4 - Peterson Lake HREP Water Quality Monitoring – Pre and Post-Adaptive Management Evaluation (FY17-present)

The Peterson Lake HREP (Habitat Rehabilitation and Enhancement Project) was constructed in 1995 to maintain the lake as a productive backwater resource by reducing the loss of barrier islands to erosion and sand sedimentation in the lake (USACE 1994). One of the specific objectives of the initial project was to create a winter fish refuge in the upper portion of the lake, despite concerns of possible negative effects on summer water quality due to the reduction of flow into the area. While a small area of upper Peterson Lake does currently support a winter fish refuge the project objectives for current velocity (< 1 cm/sec) and water temperature (> 1^{o} C) were considered unsuccessful (USACE 2011). In an effort to increase the area suitable for winter fish use a proposal to shut off a major inlet into the upper lake and partial closures of two other inlets is being proposed. Pre and post water quality monitoring of upper Peterson Lake would determine if this adaptive management strategy is successful.

Products and Milestones

Tracking number	Products	Staff	Milestones
2017PL3	Collection of post-construction winter water quality data	Burdis, Moore, DeLain, Lund	February 2018 – 2019(?) Dependent on construction date
2017PL4	Collection of post-construction summer water quality data	Burdis, Moore, DeLain, Lund	August 2018 – 2019(?) Dependent on construction date
2017PL5	Summary letter: Tabular and graphical summary of water quality data	Burdis, Moore	December 2018 - 2019 (?) Dependent on construction date

References

United States Army Corps of Engineers (USACE). 1994. Upper Mississippi River System Environmental Management Program, Definite Project Report/Environmental Assessment (SP-16), Peterson Lake (HREP). US Army Corps of Engineers, St. Paul District.

United States Army Corps of Engineers (USACE). 2011. Peterson Lake Pool 4 Mississippi River (HREP) Project Evaluation Report. Environmental Management Program for the Upper Mississippi River System. US Army Corps of Engineers, St. Paul District.

UMRR Science Coordination Meeting

The objective of the meeting is to develop a set of research projects in support of the restoration and management of the UMRS for the UMRR Program. Past planning documents will be revisited while developing a framework to assist in the development of research projects to improve the effectiveness of our research and monitoring – integrating state agency science needs into regional science and monitoring objectives. The results of these integrated research efforts will provide critical insights and understanding regarding a range of key environmental management concerns, including how the basic condition of the ecosystem is changing; interactions and associations of hydrogeomorphology with biota and water quality, and ecosystem structure and function.

Products and Milestones

Tracking number	Product	Staff	Milestone
2018N1	Science Planning Meeting	Houser, Sauer, Hubbell, and Hagerty, all LTRM staff, UMRR Partners	Winter 2018

The meeting location is La Crosse, Wisconsin.

Update UMRR LTRM Fact Sheet

To communicate with UMRR LTRM Partners and others on program accomplishments, we will develop a fact sheet highlighting information to knowledge. This will be the 3rd fact sheet in a series highlighting LTRM accomplishments. This effort addresses information relevant to Outcome 4 (Output 1.1) of the Strategic and Operational Plan.

A-Team and UMRR-CC Participation

USGS-UMESC and Field Station staff are often called upon to participate at quarterly A-Team (http://www.umesc.usgs.gov/ltrmp/ateam.html) and UMRR-CC (www.mvr.usace.army.mil/Missions/EnvironmentalProtectionandRestoration/UpperMississippiRiverRestoration/Partnership/CoordinatingCommittee.aspx) meetings. The field station team leaders, component specialists, and UMESC LTRM management staff are expected to participate in the A-Team meetings, if possible. Additional staff may participate as appropriate. Participation at UMRR CC meetings will be by request only. This participation could include sharing of scientific knowledge and/or presentations on current projects. Any participation by LTRM staff at A-Team and/or UMRR CC meetings will be listed in the quarterly activity products.

Conceptual Model and Hierarchical Classification of Hydrogeomorphic Settings in the UMRS

Previous LTRM project:

No

Name of Principal Investigator:

Faith Fitzpatrick, USGS Upper Midwest Water Science Center, 608-821-4818, fafitzpa@usgs.gov

Collaborators (Who else is involved in completing the project):

Jim Rogala USGS
Jon Hendrickson, USACOE
Susannah Erwin, USGS
Lucie Sawyer, USACOE
Jayme Stone, USGS

Introduction/Background:

There is a substantial body of scientific research and monitoring for the Upper Mississippi River System (UMRS) (fig. 1) concerning long and short-term changes in geomorphic patterns, processes, and rates of change. However, a high-level study is needed to synthesize results from existing studies and recent data collection efforts to better design and prioritize future research and monitoring to inform restoration efforts. Information gaps exist for a basin-wide synthesis of recent research and effects from multiple human alterations at various scales (land-use change, dam construction, navigation, flow regulation, shore hardening, and channelization of lower tributary valleys) on sediment and flow connectivity among aquatic areas of the river system. There also is a need to describe potential future trajectories of geomorphic evolution of the river given past and present human-imposed constraints. Lastly, with knowledge of a broader context of hydrogeomorphic settings, local changes in sediment transport, channel morphometry, hydraulic connectivity, floodplain and aquatic vegetation, and ultimately aquatic and riparian habitats can be better described in terms of both basin-wide and locally derived factors. This system wide framework will provide a context for targeting research and monitoring efforts as well as for evaluating performance of past HREPs and improving the design of future HREPs.

Locks and dams, the raised water level elevations they maintain, and the resulting geomorphic responses have caused both erosion and deposition in navigation pools. In general, a river with dams has a predictable series of morphological characteristics with associated bed sediment characteristics, channel morphology, and floodplain aggradation (Skalak et al., 2013). Overall, long-term deposition is ongoing, but local rates and spatial patterns in deposition and bank erosion are influenced by levee construction, restoration activities, artificial structures, or changes in side channel connectivity to the main stem. Rates of geomorphic change along dammed and open river reaches also are affected by factors outside of the main river valleys including agricultural land use practices, tributary channelization, and bank stabilization, and large-scale climatic shifts in rainfall patterns.

Figure 1. *Location of the Upper Mississippi River System (excerpted from Wilcox, 1993).*

The aquatic habitat classification system developed for the UMRS by the Long Term Resource Monitoring Program (LTRMP) (Wilcox, 1993) has a detailed hierarchical structure that facilitated habitat mapping and inventories. This classification system was based land cover and land-use and included geomorphic settings as well as anthropogenic features. The core naming system of aquatic areas (corresponding to geomorphic and constructed features) was linked to a similar classification developed for the lower Mississippi River. The aquatic areas reflected hydrologic and sediment connectivity to the main river along with an indication of how dynamic or predisposed the area might be to geomorphic change. Criteria used to describe these areas included water depth, current velocity and turbulence, water temperature, dissolved oxygen, turbidity, light, substrate type, and vegetative cover. This classification also encompassed a vertical dimension with recognition of habitats that might exist on the water surface, in the water column, and on or in the river bottom.

The Cumulative Effects Study (CES), Volume 1 (WEST Consultants, Inc., 2000) described the cumulative effects of a 9-foot navigation channel on channel morphology and ecology along the entire UMRS. As part of the CES a classification system also was developed that emphasized hydraulic features. This classification system was more simplistic than the Wilcox (1993) system (WEST Consultants, Inc., 2000, fig. 5-29). The CES study described in detail current and future UMRS conditions with a detailed: (1) overview of hydrologic characteristics and effects on flow and stage; (2) discussion of hydraulics of the system and available hydraulic models; (3) discussion of the geology and glacial history for the watershed and historical changes in channel planform, morphology, and sediment; (4) compilation of a sediment budget identifying major sources and sinks; and (5) estimates of future geomorphic conditions for the year 2050. Recommendations from the CES concerning geomorphology included more research on: (1) the effects of climate change and global warming on hydrology and sediment transport; (2) backwater areas and possible loss of diversity; (3) loss of contiguous and isolated backwaters; and (4) the role of secondary channels. Specific to sediment transport, recommendations included evaluating (1) suspended loads and bedload contributions for both gaged and ungauged tributaries; (2) contributions from bank erosion; and (3) changes in trapping efficiency of reservoirs. A second volume of the CES included an assessment of ecological effects from changes in physical habitat. Additionally, since it has been almost 20 years since the CES was completed, there is an opportunity to review where the river is at in terms of the projections for future geomorphic conditions for the year 2050.

The GIS query tool developed for the first Habitat Needs Assessment (HNA; Theiling and others, 2000; DeHaan and others, 2000) (https://www.umesc.usgs.gov/habitat_needs_assessment/summ_report/approach.html) identified existing, predicted and desired future habitat conditions. This tool also includes a vegetation successional model. The tool can be used to forecast future geomorphic changes over the next 50 years, based on results from the CES and updated with the knowledge and experience of local natural resources managers. Major classes used for the HNA include channel, backwater, and floodplain classes and whether they are connected or isolated. As part of the query tool the greater than 2.6 million acres within the floodplain area also are classified into 16 land cover classes. The features can serve as a base for an updated process-based classification that encompasses valley-wide morphology and potential for geomorphic change.

First, there is a need to revisit the findings of the Cumulative Effects Study and aquatic habitat classification. It would be beneficial to review the available Natural Resource Agency comments on the CES to help guide future updates and needs. Secondly, because of advances in spatial data and analyses technology, there is an opportunity to expand the existing geospatial, georeferenced approach to mapping and classification of the hydrogeomorphology of the UMRS. The hydrogeomorphology forms the backbone to almost every activity on the river including restoration and research. It forms the ultimate physical control on biological and chemical traits and processes. The hydrogeomorphology includes floodplains as well as channels. The expanded hydrogeomorphic framework can be linked with UMMR LTRM research frameworks (Ickes, 2005; Newton et al., 2010; De Jager et al., 2011; Kreiling et al., 2016(?)), an ecosystem restoration model for the Mississippi River valley (Klimas et al., 2009), reports and recommendations from previous workshops (Gaugush and Wilcox 1994; Gaugush and Wilcox 2002), synthesis from previous studies, such as the special 2010 issue of Hydrobiologia, the 2009 research objectives publication (USACE, 2011), and the 2015-25 UMMR Strategic plan (UMMR, 2015), and available conceptual models (USACE, 2011; Nestler et al. 2016), Bouska et al. (in review). The HNA 2 and the UMRS Resilience Assessment require information related to future hydrogeomorphic conditions of the river. Frequent questions that emerge from partner meetings and workshops are 1) What physical processes determine changes in hydrogeomorphology? and 2) What changes will occur in the river's flow characteristics and basin land use?

The new geomorphic framework could be used to address future change in habitats and assist in selecting, planning and designing HREP projects. The intent of HREPs is to modify geomorphic aspects of the river. However, a systematic geomorphic framework is still needed to provide a context for current and future conditions. Within a process-based classification is the opportunity to qualitatively describe the potential sensitivity of a geomorphic area to changes in local flows and sediment transport regimes (Montgomery and Buffington, 1993; Buffington and Montgomery, 2013; Brierley and Fryirs, 2005). An example of areas with a high potential for geomorphic change are channels and islands associated with an active delta building out into an impoundment, aided by a heavy sediment load from a nearby tributary. The framework can also be used to identify baseline conditions, the trajectory of a project area and the urgency for HREP construction. The framework will also help in determining the timing and spatial distribution of resurveys of reference cross sections, or identify new areas for monitoring. Another aspect that is problematic for HREP projects is channel planform and size changes that might affect channel to backwater water connections and aquatic to terrestrial habitat transitions. Areas will be identified in terms of dominant geomorphic processes, patterns, and rates of geomorphic change. Potential changes in patterns and rates based on future changes in flows and sediment transport will be identified. Existing structures will be mapped because of their local effects on geomorphic setting and potential geomorphic change. The framework can also be used to prioritize protection or preservation of certain existing habitats that support ongoing distinctive and potentially rare ecological functions.

Relevance of research to UMRR:

The overall objective of this study is to **develop a hydrogeomorphology-based conceptual model and hierarchical classification system** for the UMRS. This model and classification system will build off the existing classification systems for the UMRS and include an aspect of potential for geomorphic change. This follows the concept model introduced by Schumm (1977) to describe the river continuum of geomorphic processes and channel forms in relation to predictable zones of erosion, transport, and deposition in a stream network. Over the last couple of decades there have been several classifications developed for large rivers that describe geomorphic response potential; relative stability of channel types related to type and amount of sediment load, sediment size, flow velocity, and slope; and floodplain-river interactions (Nanson and Croke, 1992; Thorne, 2002; Church, 2006; Fryirs, 2003; Fryirs and Brierley, 2000; Buffington and Montgomery, 2013). This objective can be accomplished through the geomorphic and local knowledge of a small team, similar in makeup to the Board of Consultants assembled for production of the CES. The scope of the work is to incorporate research results and restoration activities that have been conducted since the CES was completed, such as the results from a feasibility investigation of hydrogeomorphic modeling and analyses for the UMRS (Heitmeyer, 2007). An ultimate goal is to map the hydrogeomorphic units along the entire valley of the UMRS system so that it can be used to help managers regarding the type, location, and amount of restoration techniques as well as evaluate the success of those restoration techniques.

The relevance of this work is to give context to why, how, and where geomorphic change is happening. What are the reaches and hydrogeomorphic units that are most prone to hydrologic, hydraulic, or sediment-related change? Which reaches are changing at slower rates and why? These questions have direct application to all other habitat restoration and research conducted as part of the UMRR Program. The results will directly inform two other subprojects under Focal Area 1 (Geomorphic Change), and will also provide a foundation for showing the relation between hydrogeomorphic conditions and issues raised by every other focal area (Table 1).

Table 1. *Examples of relevance of conceptual model and hierarchical classification of hydrogeomorphic settings of the UMRS for focal areas for UMRR FY 2018 Science Support*

Focal area number	FY 18 Focal area	Example relevance to geomorphic change
1	Understanding changes in geomorphology	Understanding sedimentation/erosion patterns, processes, rates; effects on physical/chemical properties of substrates; changes in hydraulic connectivity
2	Effects of recent and projected changes in land use and climate on hydrogeomorphology	Existing hydrologic studies included in FA2 studies could be linked with specific hydrogeomorphic region
3	Interactions of hydrogeomorphology with biota and water quality	Need for hydrogeomorphic context and spatial framework to help understand results from existing research on spatial distribution and changes in aquatic vegetation, fish communities, mussels, and large wood
4	Relations among floodplain hydrogeomorphic patterns, vegetation and soil processes, and effects on wildlife habitat and nutrient export	Need for a mapping context to synthesize results for the river system
5	Vital rates of biotic communities	The life cycle of fishes and changes in populations are dependent on where species-specific habitats are potentially changing.
6	Critical biogeochemical rates	Nutrient cycling and retention as well as oxygen levels, are affected by sedimentation and connectivity of flows
7	The effects of sustained high nutrient inputs (eutrophication) on the biota	Phosphorus-related eutrophication issues are affected by retention and release of phosphorus associated with sedimentation, legacy sediment accumulation, and temporally variable flow dynamics.

Methods:

Clearly describe methods and how they will achieve the stated objectives. Provide sufficient detail so that the likelihood of achieving each of the objectives can be fully evaluated. Include a description of study area(s). If you are uncertain of the validity of your statistical approach, review by Brian Gray is recommended prior to submission.

The development of a hydrogeomorphic conceptual model and hierarchical classification system will expand upon the settings described in the CES (WEST Consultants, Inc., 2000) which included eight reaches along the Mississippi River upstream of Pool 26, two reaches on the Middle Mississippi between Cairo and St. Louis, and two reaches on the Illinois Waterway. These reaches were identified by having distinct characteristics related to valley and floodplain morphology, locations of geologic controls, breaks in slope along the river's longitudinal profile, and sediment transport characteristics. They help to describe hydrogeomorphic conditions in the river, the major controls on geomorphic change, and potential future trajectories of change. These settings will then be linked to the HNA 2 mapping units. Additional information on sediment dynamics will be gathered from the UMESC loading data base (https://www.umesc.usgs.gov/data_library/sediment_nutrients/subarea.html) and the regional suspended sediment and nutrient yield models and mappers such as SPARROW (https://wim.usgs.gov/sparrowmrb3/sparrowmrb3mapper.html#). The CES reaches were linear-based descriptions of their hydrogeomorphic setting. With the additional mapping capabilities available currently and expanded georeferenced data sets of physical characteristics, we could expand these linear descriptions into distinctive two-dimensional hydrogeomorphic mapping units. There is also the potential to add a third dimension to describe the two-dimensional hydrogeomorphic units based on a range of seasonally changing stage, flow, temperature, and oxygen conditions. The development of these units will be closely linked with the existing aquatic habitat classification, the HNA 2, and the detailed spatial data layers that are readily available such as topobathy layers (https://www.umesc.usgs.gov/data_library/topobathy.html).

The following tasks are included in the initial development:

1) The FA1 workgroup identifies potential members for a core team to investigate the development of a hydrogeomorphic conceptual model and hierarchical classification system for the UMRS. The workgroup considers the team make up for the CES. The team includes Faith Fitzpatrick (USGS), Susannah Erwin (USGS), Lucie Sawyer (USACE), and Jayme Stone (USGS) Jim Rogala (USGS), and Jon Hendrickson (USACE), plus 2-3 others with geomorphic and/or GIS expertise.
2) The team reviews the CES and new literature since 2000 for understanding the major hydrogeomorphic settings in the UMRS. The team considers the review comments that the natural resource agencies provided for a draft version of the CES. Included are examples of similar endeavors for other large rivers across the world and what has been found to have the best application for restoration and biological/chemical interaction studies.
3) The team identifies a panel similar in expertise to those that wrote the CES. A workshop is convened with the panel and team to develop the conceptual model and outline the hierarchical classification system. The panel will include 3-5 geomorphologists familiar with the UMRS or regions within.
4) Based on the workshop results, a high-level conceptual model for identifying major hydrogeomorphic settings in the UMRS which includes potential for geomorphic change relative to tributary inputs, lock and dams, impoundments, and artificial structures.
5) Based on the workshop results, a hierarchical classification system is proposed to describe sedimentation and flow patterns, processes, and rates in the UMRS.
6) A prototype GIS data base and mapping is completed for an example reach of the UMRS which compliments existing GIS tools (Jayme and GIS assistance from UMESC).
7) The team develops a plan for future classification and mapping, and visualization.
8) The team identifies information gaps.
9) The team keeps the FA1 workgroup informed of the process and any pitfalls.
10) The team will present results to the FA1 workgroup, and then to all the FA workgroups.
11) The team publishes a USGS report or journal article on the conceptual model and proposed classification system.

Products and Milestones

Tracking number	Products	Staff	Milestones
2019CM1	Workshop	Fitzpatrick, Henderson, Rogala, Erwin, Sawyer	30 November 2018
2019CM2	Summary of workshop findings and minutes; internal document	Fitzpatrick, Henderson, Rogala, Erwin, Sawyer	31 December 2018
2019CM3	Presentation to Focal Area 1 workgroup, LTRM researchers, HREP designers, and state resource agency partners	Fitzpatrick, Henderson, Rogala, Erwin, Sawyer, Stone	31 August 2019
2019CM4	GIS data base and query tool	Fitzpatrick, Henderson, Rogala, Erwin, Sawyer, Stone	31 December 2019
2019CM5	Submit draft LTRM Completion report on hydrogeomorphic conceptual model and hierarchical classification system	Fitzpatrick, Henderson, Rogala, Erwin, Sawyer, Stone	31 December 2019
2019CM6	Submit Final LTRM Completion report on hydrogeomorphic conceptual model and hierarchical classification system	Fitzpatrick, Henderson, Rogala, Erwin, Sawyer, Stone	30 June 2020

References:

Brierley, G.J., Fryirs, K.A. 2005. Geomorphology and River Management: Applications of the River Styles Framework. Blackwell, Oxford, UK, 398 pp.

Bouska, K.L., J.N. Houser, N. R. De Jager, J. Hendrickson. *Submitted.* Developing a shared understanding of the Upper Mississippi River: the foundation of an ecological resilience assessment. Submitted manuscript

Buffington, J.M., Montgomery, D.R. 2013. Geomorphic classification of rivers. In: Shroder, J. (Editor in Chief), Wohl, E. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 9, Fluvial Geomorphology, pp. 730–767.

Church, M. 2006. Bed material transport and the morphology of alluvial rivers. Annual Review of Earth and Planetary Sciences 34, 325–354.

DeHaan, H.C., Fox, T.J., Korschgen, C.E., Theiling, C.H., Rohweder, J.J. 2000. Habitat Needs Assessment GIS Query Tool, User’s Manual, U.S. Geological Survey, La Crosse, WI.

De Jager, Nathan R. and J. Rohweder. 2011. Spatial scaling of core and dominant forest cover in the Upper Mississippi and Illinois River floodplains, USA. Landscape Ecol (2011) 26:697–708 (Abstract)

Fryirs, K. 2003. Guiding principles for assessing geomorphic river condition: application of a framework in the Bega catchment, South Coast, New South Wales, Australia. Catena 53, 17–52.

Fryirs, K., Brierley, G.J. 2000. A geomorphic approach to the identification of river recovery potential. Physical Geography 21, 244–277.

Gaugush, R. F., and D. B. Wilcox. 1994. Planning document: Investigate sediment transport/deposition and predict future configuration of UMRS channels and floodplain. National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94-P004. 9 pp. + Appendixes A-E. (NTIS PB95-166351)
Gaugush, R. F., and D. B. Wilcox. 2002. Recommended investigations of sediment transport and deposition for predicting future configurations of Upper Mississippi River System channels and floodplain. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, September 2002. LTRMP 2002-P001. 5 pp. + Appendix. (NTIS PB2003-101509)
Heitmeyer, M.E. 2007. Feasibility investigation, Hydrogeomorphic modeling and analyses, Upper Mississippi River System floodplain: Greenbrier Wetland Services, Advance, MO, 32 p.
Ickes, B. S., M. C. Bowler, A. D. Bartels, D. J. Kirby, S. DeLain, J. H. Chick, V. A. Barko, K. S. Irons, and M. A. Pegg. 2005. Multiyear synthesis of the fish component from 1993 to 2002 for the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP 2005-T005. 60 pp. + CD-ROM (Appendixes A–E). (NTIS PB2005-107572)
Klimas, C., Murray, E., Foti, T., Pagan, J., Williamson, M., and Langston, H. 2009. An ecosystem restoration model for the Mississippi Alluvial Valley based on geomorphology, soils, and hydrology: Wetlands 29(2):430-450.
Kreiling, R., Y. Yin, H. Langrehr, T. Cook, K Dalrymple, M. Moore, S. Romano. 2016? Plan for research on aquatic vegetation in the Upper Mississippi River System. UMRR LTRM Document.
Montgomery, D.R., and Buffington, J.M. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Washington State Department of Natural Resources. Timber, Fish, and Wildlife Agreement Report TFW-SH10-93-002, Olympia, WA, 84 pp.
Nanson, G.C., Croke, J.C., 1992. A genetic classification of floodplains. Geomorphology 4, 459–486.
Nestler, J.M., D. L. Galat, R. A. Hrabik. 2016. Side Channels of the Impounded and Middle Mississippi River: Opportunities and Challenges to Maximize Restoration Potential. US Army Corp of Engineer Research and Development Center Report. DRDC/EL CR-16-4.
Newton, T. J., S. J. Zigler, J. T. Rogala, B. R. Gray, and M. Davis. 2011. Population assessment and potential functional roles of native mussels in the Upper Mississippi River. Aquatic Conservation-Marine and Freshwater Ecosystems 21 (2): 122-131.
Schumm, S.A. 1977. The Fluvial System. Blackburn Press, Caldwell, NJ, 338 pp.
Skalak, K.J., Benthem, A.J., Schenk, E.R., Hupp, C.R., Galloway, J.M., Nustad, R.A., Wiche, G.J. 2013. Large dames and alluvial rivers in the Anthropocene: the impacts of the Garrison and Oahe Dams on the Upper Missouri River: Anthropocene v. 2, p. 51-64.
Theiling, C.H., C. Korschgen, H. De Haan, T. Fox, J. Rohweder, and L. Robinson. 2000. Habitat Needs Assessment for the Upper Mississippi River System: Technical Report. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Contract report prepared for U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 248 pp. + Appendices A to AA.
Thorne, C.R. 2002. Geomorphic analysis of large alluvial rivers: Geomorphology 44:203-219.
UMRR. 2015. Enhancing Restoration and Advancing Knowledge of the Upper Mississippi River: A strategic plan for the Upper Mississippi River Restoration Program 2015 – 2025. UMRR Document.
USACE. 2011. Upper Mississippi River System Ecosystem Restoration Objectives, 2009. U.S. Army Corps of Engineers Report.
WEST Consultants, Inc. 2000. Upper Mississippi River and Illinois Waterway cumulative effects study, Volume 1: Geomorphic Assessment: ENV Report 40-1, Contract No. DACW25-97-R-0012, WEST Consultants, Inc., Bellvue, WA.
Wilcox, D. B. 1993. An aquatic habitat classification system for the Upper Mississippi River System. U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, May 1993. EMTC 93-T003. 9 pp. + Appendix A. (NTIS PB93-208981).

Develop a better understanding of geomorphic changes through repeated measurement of bed elevation and overlay of land cover data.

Previous LTRM project:

This work builds on recent studies of backwater sedimentation and delta formation. The network of backwater sedimentation transects established in 1997 were resurveyed starting in 2017 to provide information for HNA-II under the FY2017 Science in Support of Restoration and Management (SSRM) SOW (2017ST1-4; 2017FAH3). Delta formation (previously referred to as alluvial fan formation) mapping using land cover/use (LCU) data was a project in the FY2017 SSRM SOW (2017SED1-3). This proposed FY18 work expands the delta formation project to other planform changes (e.g., island dissection and side-channel widening) and proposes expansion and permanent establishment of sedimentation transects in backwaters.

Name of Principal Investigator:

Jim Rogala, USGS UMESC, 608-781-6373, jrogala@usgs.gov
Role: Oversee all components of the study; lead on planform change analysis

Collaborators:
Jayme Stone - USGS UMESC;
Role: Lead on side channel bathymetric mapping

John Kalas – WI-DNR
Role: Lead on backwater sedimentation study

Faith Fitzpatrick – WSC-WI
Role: Advisor of planform change study

Jon Hendrickson – USACE-SP
Role: Advisor of planform change study

Larry Robinson - USGS UMESC
Role: Support with land cover GIS data

JC Nelson - USGS UMESC
Role: Support with data aspects of all components

Introduction/Background:

What's the issue or question?

Geomorphic change in the Upper Mississippi River System (UMRS) has long been identified by resource agencies as a concern (GREAT 1980; Jackson et al. 1981; USFWS 1992). The changes in geomorphic processes are a result of system alteration (e.g., dam construction) and land use changes in the basin

(e.g., increased sediment loads). These process changes often have direct effects on bed elevation, and thereby water depth. The direct changes in bed elevation, as well as changes in planform features (e.g., island dissection), influence water exchange rates in the river. Some changes in water exchange rates will be investigated in a separate proposal (PI: Jon Hendrickson). Water depth and water exchange rates are the most prominent features describing habitat quality in the UMRS, and in some cases, the projected changes threaten habitats in the river (Theiling 2000; De Jager, in review).
What do we already know about it?

The Cumulative Effects Study (WEST 2000; CES) is the most recent summary of our knowledge on geomorphic change in the UMRS. That extensive study used primarily existing data, with limited additional data collection. For planform changes, the analysis was limited to a few years for comparison, and only two land cover/use (LCU) years for post-dam datasets (1975 and 1989). A specific overlay of land cover data using multiple dates was used to track island loss in impounded areas, but most other studies of planform changes have not included more recent systemic LCU data generated from the UMRR Program. Analysis of sedimentation data from a variety of sources, including new studies, was used to predict habitat loss for the CES report. Again, nearly all of the data used did not reflect current rates of change, as often times the rates were determined over long time periods in the past.

There have been few recent sedimentation studies since the Cumulative Effects Study. Some of those studies used sediment dating methods to further look at accumulation rates over longer periods in the past (Theis and Knox 2003; Belby 2005). Direct measurement of recent backwater sedimentation rates over a short period of 5 years (Rogala et al. 2003) was completed after the Cumulative Effects Study. Direct measurement of rates was repeated at the same locations for a recent 20-yr period. A complete synthesis of findings from past studies is being proposed in a separate project proposal (Conceptual Model and Hierarchical Classification of Hydrogeomorphic Settings in the UMRS; PI: Faith Fitzpatrick) that would convene a workshop using Science in Support of Restoration and Management FY18 funding. In addition to that synthesis, the workshop would develop a conceptual model and database framework for tracking geomorphic changes in the UMRS. The empirical measurements proposed here would be the initial contributions to that database.

Why is it important?

Understanding the magnitude of current geomorphic changes is critical to planning restoration actions that retain desired habitat conditions into the future (Theiling 2000; De Jager, in review). In addition to direct effects on water depth and connectivity, sedimentation can alter substrate composition, and thereby effect water quality, nutrient availability, and suitability for SAV. The consequences of the varied effects geomorphic changes for nearly all physical, chemical, and biological components of the River are substantial. Given the importance of geomorphic change on the ecology of the UMRS, a more complete understanding of the changes is needed to effectively manage the system to maintain and improve the health and resilience of the UMRS.

Relevance of research to UMRR:

Objective(s) or hypothesis:

1. Add to our knowledge of patterns and rates of sedimentation using selected measurements.
2. Establish a network of locations for measuring sedimentation into the future.
3. Better understand recent planform changes in the UMRS.

Relevance (demonstrate scientific and/or management value):

Several past and ongoing geomorphic changes have been identified in recent Program initiatives such as two habitat needs assessments (Theiling 2000; De Jager, in review). Backwater sedimentation, whether through wide-spread deposition (generally fine sediment) or localized deposition resulting in delta formations (generally coarse sediment), remains a major management and restoration concern. Changes in side channel depth and channel width have also been identified as concerns. Island erosion and dissection have similarly been identified as changes that may have negative effects on habitats.

Progress on the above objectives will further our understanding of the effects of geomorphic change on habitat conditions in the UMRS. The more recent backwater sedimentation studies have been limited to the upper part of the system, so expansion downstream in the UMR and into the Illinois River fill a substantial gap in information. To assure the capacity to measure backwater sedimentation in the future, a set of locations adequately marked in order to permit future measurements in the same location.is needed. Very few studies have looked at spatial patterns in planform changes in side channels despite such changes being frequently identified as a concern. A comprehensive summary of planform change analysis using the Program's LCU data likewise has not been done. The magnitude and location of planform changes such as delta formation in backwaters, island dissection, and channel widening are not well known.

How this work relates to needs of UMRR and river managers (I.e., How will the results inform river restoration and management?):

The results of this study will provide a better understanding of recent rates of geomorphic changes for the UMRS and improve our forecasts of future conditions. This understanding will allow for management to more accurately consider the underlying changes in the river's physical template when selecting and designing restoration projects In addition to understanding recent and present rates of geomorphic change, predictions of future river configurations are needed to inform the selection and design of restoration projects. The proposed work will specifically address: 1) backwater sedimentation, 2) side channel sedimentation, and 3) planform changes in islands, side channels, and backwaters. Most results will be spatially mapped, thus providing for identification of locations where current and expected planform changes may be of particular concern.

Describe how the research addresses one or more of the 2018 Focal Areas:

The emphasis of the 2018 UMRR Science Focal areas is the role in geomorphology in the structure and function of the UMRS. This research directly addresses that basic concept and specifically the Geomorphic Change Focal Area (FA1).

This research will also indirectly be of value to these other focal areas:

1. Native freshwater mussels in the UMRS (FA3.3) – It has been found in recent studies that native mussel mortality is related to geomorphic changes of the river bed. Information on geomorphic change could assist in describing the spatial distribution of mussels, and aid in understanding past changes in mussel population, and considered in forecasting future mussel populations.
2. Woody Debris (FA3.4) – Geomorphic changes related to bank erosion processes of the river could provide information on sources and location of woody debris.
3. Generally, across other focal areas – Any change through time investigations in other focal areas can use the information on geomorphic change when considering explanatory variables for past and future changes in other system components (e.g., aquatic vegetation response to sedimentation).

Methods:

The project has three components:
1) Determine geomorphic changes in selected side channels of selected reaches using hydroacoustics,
2) Establish a network of transects in backwaters to measure sedimentation, and
3) Determine recent planform changes using UMRR LCU datasets.

Determine geomorphic changes in selected side channels of selected reaches using hydroacoustics

Principal Investigator: Jayme Stone

Geomorphic changes in bed elevation and aquatic habitats can be detected with repeated hydroacoustic surveys. The proposed work will look at changes in selected side channels during recent periods in the last 30 years. The selected side channels will be in LTRM study reaches (Pools 4, 8, 13 and 26, the Open River Reach, and La Grange Pool), plus Pool 18. To provide accurate habitat change information, only hydroacoustic surveys with transects spaced 200 feet apart or less will be used. The final products from the hydroacoustic surveys will include digital elevation models (DEMs) for two or more dates, from which rates and spatial patterns of deposition and erosion can be detected.

Suitable bathymetric data can come from a variety of sources: UMRR topobathy dataset, past survey data from USACE districts, and new surveys conducted as part of this project. Comparisons will be made of two or more surveys from any of these sources. Side channels that have not been surveyed after 2013 will be surveyed as part of this project, and change detected from any past surveys. By default, the UMRR topobathy would be used as the previous survey used to detect change by comparing to the new survey data. The new side channel surveys in study reaches would be completed by UMESC or USACE district hydro-surveyors. All survey data assembled will be used for detecting change in the past, and provide the opportunity to resurvey in the future to detect future changes. Periods over which change is detected will vary depending on available data.

In summary, this component of the project would:
1. Determine whether past USACE survey data suitable for change detection in side channels exists in the selected study reaches. Compile suitable data into a central GIS database to be housed at UMESC.
2. Selected side channels for which recent (post-2013) data do not exist will be surveyed using hydroacoustic methods. Details on vertical control would be developed. All data would be put into the central GIS database.
3. Develop and apply methods for detecting geomorphic changes in side channels over time. Interpolation will be used to produce a raster map, from which a simple overlay of maps from two or more dates will be used to detect change.
4. Write report summarizing the findings of geomorphic change in the selected side channels.

Establish a network of transects in backwaters to measure sedimentation

Principal Investigator: John Kalas

Bed elevation changes in backwaters are typically at a rate of about 1 cm/yr. Even at a decadal interval between surveys, change is expected to be smaller than can be detected with hydroacoustic surveys. Many previous studies have used tapes, sounding poles and differential leveling to detect changes along backwater transects over periods of <20 years (Aspelmeier 1994; Rogala and Boma 1996; Rogala et al. 2003; John Sullivan, Wi-DNR unpublished; US Army Corps of Engineers, unpublished). The work proposed here will follow similar methods, and in particular, those used by Rogala et al. (2003) in previous LTRM studies.

Two changes to the methods used in previous LTRM studies will be made. First, each transect will use permanent monuments for vertical and horizontal control, these replacing the use of temporary controls such as fence posts and spikes in trees. Initially, these monuments will not be accurately tied to true elevation, but rather be used just to detect change. The monuments could be surveyed more accurately with RTK GPS or traditional survey methods in the future. Second, due to the expansion of transects into southern pools, open water (i.e., no ice) surveys will be used. Open water surveys along shorter transects can use tape measures, while longer transects will use electronic distance measurement (EDM) devices.

The network of approximately 100 transects will be distributed as follows:

Pools 4, 8, and 13 (~25 previously established transects per pool)
La Grange Pool (~12 transects. A selected set of previously established transects will be used; new transects will be established in other backwaters of interest)
Pools 18 and 26 (~6 new transects per pool)
Open River reach in one recently connected backwater (2 new transects)

In summary, this component of the project would:
1. Monument a set of backwater transects in selected pools to establish permanent vertical and horizontal control. The set of transects would include those from previous LTRM studies when they can be recovered, plus new transects where they are needed.
2. Those transects without a recent (within 5 years) survey, whether they are old transects or newly established ones, will be surveyed.

3. All data will be assembled in a central database at UMESC. This includes bed elevation data and data on the transects themselves, including maps, monument descriptions, and interval distance between measurements.

Determine recent planform changes using UMRR LCU datasets

Principal Investigator: Jim Rogala

A pilot study in FY17 (2017SED1-3) developed methods to detect delta formations in selected pools using UMRR LCU data for 1989, 2000, and 2010/11. The methods considered such things as: specific transitions from one vegetation class to another, proximity of other such changes, and the size and shape of the change polygon. The methods addressed issues related to registration/rectification errors and photointerpretation errors and differing methods. The methods developed during the delta pilot project will be applied systemically to detect delta formations. While developing the methods to detect delta formations, the application of those methods to detect other planform changes (e.g., island loss/gain, channel widening) showed promise. As part of the proposed work, we would continue to develop methods for detecting channel and island changes.

In summary, this component of the project would:
1. Complete a systemic analysis of delta formations methods developed in the previous pilot study.
2. Modify the delta formation detection methods to detect the following planform changes: island migration (loss/gain) and changes in channel width (meandering, widening, narrowing).
3. Report on planform changes (in one or more reports).

Products and Milestones

Tracking number	Products	Staff	Milestones
2019GC1	Begin Side Channel Surveys	Stone, Wallace, Klingman	1 July 2018
2019GC2	Complete geodatabase of previous surveys and begin updating as needed. Begin developing and apply change detection methods.	Stone, Rogala	1 December 2018
NEW	Complete Side Channel Surveys	Stone, Wallace, Klingman	30 September 2019
2019GC3	Submit draft LTRM Completion report	Rogala, Stone	1 March 2020
2019GC4	Begin setting monuments at existing transects. Establish, survey and monument new transects as needed	Kalas, Rogala	1 October 2018
2019GC5	Establish methods. Determine database structure and begin entering data into database (including transect maps, description of monuments, etc.)	Rogala, Kalas	1 December 2018

2019GC6	Complete setting monuments and surveying remaining transects		Kalas	30 September 2020
2019GC7	Complete database for all transects.		Kalas	30 September 2020
2019GC8	Submit draft LTRM Completion Report on recent planform changes using UMRR LCU datasets		Rogala	1 July 2019

References:

Aspelmeier, B. 1994. Pool 14 Sedimentation Study: 1984 – 1994. Iowa Department of Natural Resources.

Belby, C.S. 2005. Historical floodplain sedimentation along the upper Mississippi river, Pool 11. Master's thesis submitted to University of Wisconsin-Madison.

De Jager N.R., J. Rogala, J. Rohweder, M. Van Appledorn, K. Bouska, J. Houser, K. Jankowski. In review. Indicators of Ecosystem Structure and Function for the Upper Mississippi River System.

GREAT I. 1980. A study of the Mississippi River, volume 4: technical appendix g, Great River Environmental Action Team I, US Army Corps of Engineers, St. Paul, Minnesota.

Jackson … 1982. Comprehensive Master Plan for the Management of the Upper Mississippi River System, Technical Report F, Volume I. prepared for the Upper Mississippi River Basin Commission, St. Paul, MN.

Rogala, J. T. and P. J. Boma. 1996. Rates of sedimentation along selected backwater transects in Pools 4, 8, and 13 of the Upper Mississippi River. U.S. Geological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, October 1996. LTRMP 96-T005. 24 pp. (NTIS-#PB97-122105).

Rogala, J.T., P.J. Boma, and B.R. Gray. 2003. Rates and patterns of net sedimentation in backwaters of Pools 4, 8, and 13 of the Upper Mississippi River. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. An LTRMP Web-based report available online at
http://www.umesc.usgs.gov/data_library/sedimentation/documents/rates_patterns/. (Accessed December 2017.)

Theiling, C.H., C. Korschgen, H. De Haan, T. Fox, J. Rohweder, and L. Robinson. 2000. Habitat Needs Assessment for the Upper Mississippi River System: Technical Report. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Contract report prepared for U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 248 pp. + Appendices A to AA

Theis, L.J and J.C Knox. 2003. Spatial and temporal variability in floodplain backwater sedimentation, Pool Ten, Upper Mississippi River. *Physical Geography* 24: 337-353.

USFWS. 1992. Operating plan for the Long Term Resource Monitoring Program for the Upper Mississippi River System.

WEST Consultants, Inc. 2000. Final report: Upper Mississippi River and Illinois Waterway cumulative effects study, volume 1: geomorphic assessment. ENV Report 40–1.

Water Exchange Rates and Change in UMRS Channels and Backwaters, 1980 to Present

Previous LTRM project:

N/A

Name of Principal Investigator:

Jon Hendrickson, U.S. Army Corps of Engineers – St. Paul District, 651-290-5634, jon.s.hendrickson@usace.army.mil
Role – Lead the synthesis of existing water exchange data

Collaborators (Who else is involved in completing the project):

Keith LeClaire, USACE – St. Paul District, 651-290-5491, keith.r.LeClaire@usace.army.mil
Role – GIS coordination to develop maps of discharge measurement locations

Jim Rogala, USGS UMESC, 608-781-6373, jrogala@usgs.gov
Role – Review and Support with Sedimentation Implications

Shawn Giblin, WDNR, 608-785-9995, Shawn.Giblin@Wisconsin.gov
Role – Review and Support with water quality implications

Introduction/Background:

What's the issue or question?

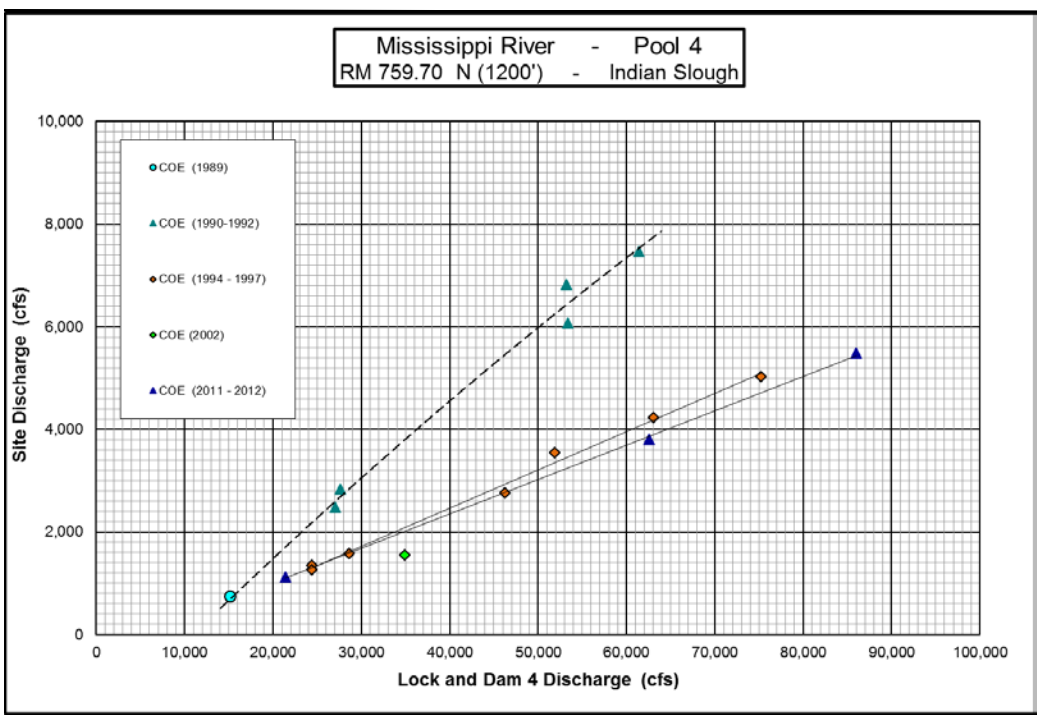
Physical, chemical, and biological conditions in channels, off-channel areas, and floodplains of the Mississippi River are affected by water exchange rates between these water bodies. Transport of sediment, nutrients, and chemicals may have short-term seasonal effects on biota that vary among years due to the annual hydrograph or long-term effects due to geomorphic processes such as sediment deposition or secondary channel erosion. Water exchange rates vary over space due to the way that navigation pool water level regimes are superimposed on the existing geomorphic template of the river. The upper reaches of navigation pools are more riverine and less connected because the water level regime is similar to pre-lock and dam conditions, while the lower reaches of navigation pools are more submerged and more connected. Anthropogenic factors such as locks and dams, levees, training structures, and other infrastructure affect water exchange rates. Many UMRR Habitat Rehabilitation and enhancement Projects (HREPs) implemented over the last three decades have achieved project objectives by intentionally changing these exchange rates. Discharge measurements obtained for pre- and post-project monitoring have been used to determine the effects of individual projects on water exchange rates, however these discharge measurements have never been analyzed and synthesized at the navigation pool or geomorphic reach scale. For example, the physical, chemical, and biologic conditions in a given project area, may be influenced by water exchange rates with multiple upstream water bodies, but a team working on a single project generally doesn't have the information or time to consider this.

What do we already know about it?

Discharge measurements have been obtained since the early 1980s to document water exchange rates at projects. These measurements are collected in the main channel, secondary channels, backwaters, and floodplains to determine the water exchange rate between these water bodies for pre-project and post-project conditions. The following protocols were used when collecting this data:

- Collect three to five discharge measurements at a site (e.g. a secondary channel) to determine the water exchange rate at that site for different total river flow conditions ranging from low flows to floods. The number of measurements varies depending on funding and the project timeline. Often this takes two or three years to accomplish.
- Determine the quality of the measurements by testing for hydraulic continuity. This is done by comparing the measured total river flow to the estimated flow at the nearest Lock and Dam or USGS gaging station.
- Fit a rating curve of site discharge versus total river discharge to the data, adjusting for continuity if needed.

These measurements are used to determine how HREPs affected water exchange rates and whether the project effects have been stable over time. The data and rating curves shown below were obtained at Indian Slough in Lower Pool 4, River Mile 759.7. An HREP was completed here in 1994 and included a rock partial closure structure across Indian Slough, to reduce water exchange rates. A comparison of the pre-project data, which was collected from 1989 to 1992, to the post-project data, which was collected from 1994 to 1997, indicates a significant decrease in discharge at the site. For example, at a total river discharge at Lock and Dam 4 of 50,000 cfs (horizontal axis), the discharge at Indian Slough was reduced by a factor of two from 6,000 cfs to about 3,000 cfs (vertical axis). Additional data collected in 2011 and 2012, show that the water exchange rate has been relatively stable at this site.



Why is it important?

As the UMRR HREP program continues into its 4th decade, the selection of projects, the establishment of project objectives, project design, and operation and maintenance cost estimates would all be improved by a better understanding of the effects of water exchange, long-term changes in water exchange, and the resulting effects on habitat and project function. While a significant amount of data is available, it has been collected at the project scale and has not been interpreted and synthesized more systemically. In the St. Paul District, which includes the navigation pools between St. Paul, Minnesota and Guttenberg, Iowa, water exchange rates between channels and off-channel areas were generally increasing from 1980 to 2010. Recent measurements indicate that water exchange rates may have stabilized and even been reduced at some channels. While the data exists to document the change in water exchange rates at sites or backwaters due to project features, or due to ongoing geomorphic change, this has not been done for larger reaches (i.e. multiple projects and navigation pools). Estimating the trajectory of future water exchange rates and communicating this with the entire river management community will improve decision making.

If work involves an HREP, name it.
All the HREPs in the St. Paul District constructed since the beginning of the UMRR program that involved altering water exchange rates (about 25 projects) will be included in this analysis. This includes projects that have features such as islands, secondary channel closures, dredge cuts, and water control structures. Data from other research and monitoring efforts and other programs will be included. This includes water exchange data collected in the early 1980s as part of the Great River Environmental Action Team Study, State DNR data collected at HREPs and other sites, and data collected as part of the USACE navigation mission.

Relevance of research to UMRR:

Objective(s) or hypothesis

Water exchange rates are affected by geomorphic processes such as secondary channel erosion, island erosion, and sediment deposition. Pre-project measurements obtained for HREPs during the first two decades that the UMRR Program was in existence indicated that backwaters within the St. Paul District were conveying increasing amounts of water over time suggesting that secondary channel erosion was occurring. Because of this, many HREPs included structures such as secondary channel closures or islands to stabilize or reduce water exchange rates. Recent measurements, obtained over the last decade or so, indicates that some secondary channels that were not modified as part of an HREP are conveying less water. The objectives of this project are to synthesize available data on water exchange rates, the change in water exchange rates due to HREPs, the change in water exchange rates due to geomorphic processes, and the trajectory of water exchange rates. This will provide the foundation for future scientific investigations on geomorphic change, nutrient processing, water quality, and habitat resilience. Management decisions such as project selection, developing project objectives, and choosing project features will be improved with this information. This project will provide information valuable to several of the focal areas.

Relevance (demonstrate scientific and/or management value)

Progress on these objectives will further our understanding of past, existing, and possible future water exchange rates. This will form the foundation for other scientific investigations of sediment or nutrient fluxes, or processes that are affected by hydraulic residence time. The effects of project features on water exchange rates will be determined and synthesized at individual sites and entire backwaters. Estimating the future trajectory of water exchange rates will provide river teams such as the Fish and Wildlife Workgroup information to help select projects. It will provide river managers and HREP teams information to make better decisions on project objectives, the selection of project features, and operation and maintenance requirements.

How this work relates to needs of UMRR and river managers (I.e., How will the results inform river restoration and management?)

There is some confusion regarding water exchange rates, how they have changed in the past, the effects of projects on these rates, the future trajectory of these rates, and how they affect sediment deposition, nutrient processing, and habitat. The fact that a number of connectivity terms and methods to quantify them have been used in the past probably adds to the confusion. This project will provide quantitative information on water exchange rates past, present, and future. The interpretation of this data will be made available to scientist, river managers, and HREP team members.

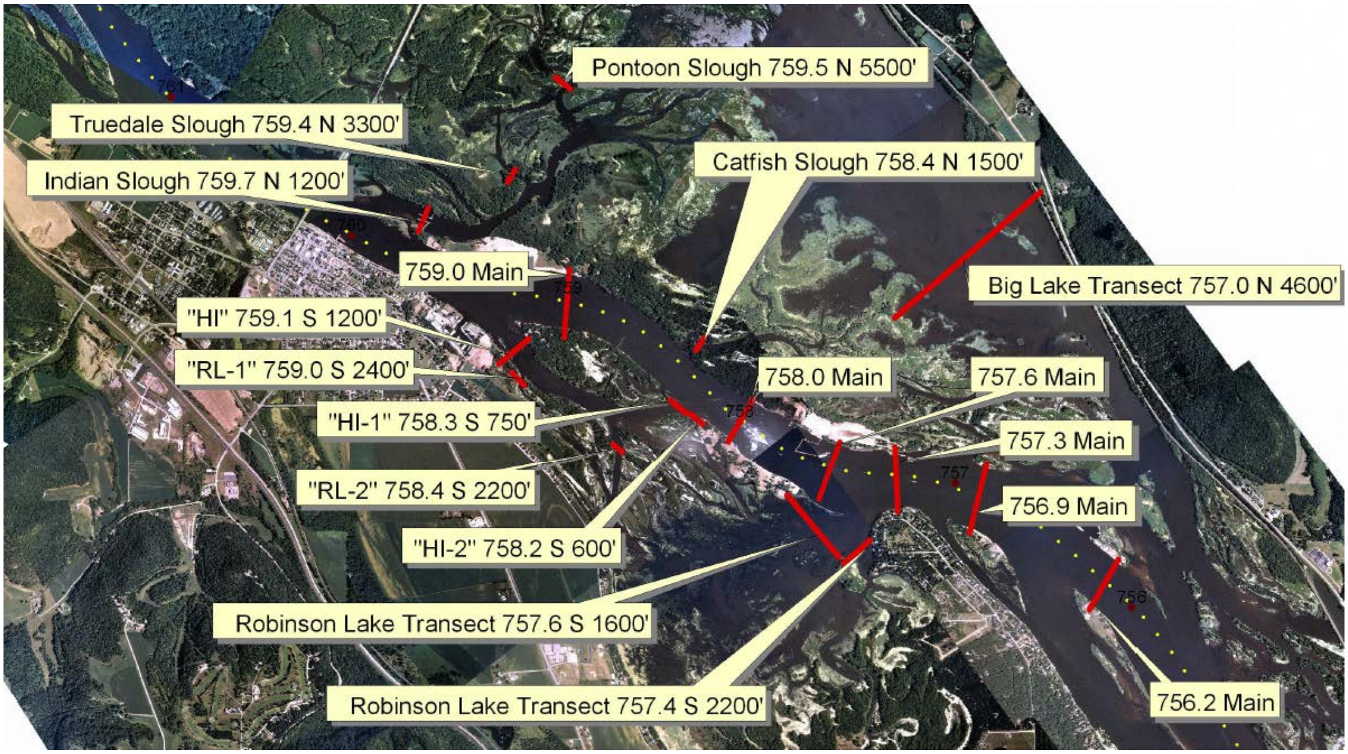
Describe how the research addresses one or more of the 2018 Focal Areas.

This proposal directly influences Focal Area 1, geomorphic change, since it will quantify water exchange so that it can be used to determine the potential for sediment fluxes between water bodies. Backwater sediment deposition occurs due to both coarse (sand) and fine (silts and clays) sediment deposition. The sediment load entering an aquatic area, the residence time in that area, and the sediment trap efficiency are all a function of the water exchange rate. This information will be of value to other focal areas that need information on the flux of constituents (e.g. nutrients), hydraulic residence times, or the effects of water exchange on other water quality parameters like temperature or dissolved oxygen.

Methods:

Water discharge data collected from the late 1970s to the present exists in data bases maintained by the USACE.

The image below shows sites (red lines) where the water exchange rate has been measured in a 5 mile reach of lower pool 4. USACE began collecting this data starting in the late 1980s, for the planning and design of the Indian Slough HREP. Additional measurements have been obtained in the main channel to assess navigation channel conditions.



Because of project schedules and funding constraints, a limited amount of water discharge data points are available at each site for any given time period, however the use of hydraulic continuity tests allows assessment of the quality of the data. When possible, continuity tests are done to determine if the measured total discharge, or the total discharge from rating curves, matches the reported flow at the nearest lock and dam. These checks can be done if the total measured river flow can be determined by summing the flow from selected individual secondary channels and main channel sites. Both the measured and reported discharges can have errors associated with them, however they represent two independent methods of determining total river discharge. A difference of 5-percent is desirable, however a 10-percent difference is acceptable. This test will not be used to adjust data, but may be used to adjust rating curves.

Rating curves will be fit to the data to represent the relationship between site discharge and total river discharge at the nearest lock and dam or USGS gaging station. Fitting a rating curve to measured data is desirable so that not too much weight is given to individual points which might be influenced by hysteresis effects or measurement errors. Rating curve shape is a function of 1) fit to data, 2) maintaining hydraulic continuity, 3) the expected shape of rating curves based on the rating curves for nearby sites or for other time periods. Separate rating curves will be drawn if the data indicates a shift in discharge from one time period to the next. Once a rating curve is drawn, it can be used to obtain the water exchange rate for a given total river discharge within the range covered by the data.

Once rating curve(s) are determined, they can be used to determine existing and past water exchange rates at secondary channels. The discharge at all of the secondary channels entering a backwater can be summed to determine the total flow entering the backwater. In some navigation pools, or at least at some sites, there may be enough data available to estimate the trajectory of future inflows. This type of information could be used to determine the hydraulic residence time of backwaters, and sediment fluxes in the future. A report and updated data base will be produced describing these results system-wide.

Products and Milestones

Tracking number	Products	Staff	Milestones
2019WE1	Data Analysis	Hendrickson	31 March 2019
2019WE2	Base Maps of Discharge Measurement Location	Le Claire	31 May 2019
2019WE3	Submit draft LTRM Completion Report	Hendrickson	30 September 2019
2019WE4	Submit Final LTRM Completion Report	Hendrickson	30 March 2019

Intrinsic and extrinsic regulation of water clarity over a 950-km longitudinal gradient of the UMRS

(Part B. Does nutrient supply limit algal growth and suspended particle quality, and ultimately drive water clarity in the UMRS? Not Funded)

Previous LTRM project:

Extrinsic vs Intrinsic Control of Water Clarity in the UMRS. Tracking number 2018 EX1.

This was a retrospective study of factors controlling water clarity in UMR Pool 8. The resulting manuscript, entitled "Intrinsic processes regulate water clarity in a large, floodplain-river ecosystem" by D. C. Drake, A. Carhart, J.R. Fischer, J. Houser, K. Jankowski, and J. Kalas, is currently undergoing revision.

Principal Investigator:

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Collaborators:

Work on this project is scheduled to begin in January 2019. We have not yet identified all collaborators, but authors of the previous manuscript will be invited to contribute, along with field team members in pools 4, 13 and 26.

Alicia Carhart - data acquisition, processing and analyses. WDNR aweeks@usgs.gov,
John Kalas –data acquisition and processing, literature review. WDNR jkalas@usgs.gov
KathiJo Jankowski - quantitative analysis - USGS kjankowski@usgs.gov
Eric Lund – Pool 4 data and analyses – MN DNR eric.lund@state.mn.us

Professor Eric Strauss, Assistant Director, UWL River Studies Center
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Introduction/Background:

What are the issues or questions?

At the broadest level, the work proposed here revolves around understanding the regulation of water clarity in the UMRS. The proposed study includes a desktop analysis of existing LTRM data (Part A) and an experimental field component (Part B) to determine whether small changes in nutrient supply can have large effects on algal abundance and water clarity.

In Part A of this study, we propose to expand the Pool 8 analyses described above (a previous LTRM project) to pools 4, 13 and 26. The purpose is to better understand when and where intrinsic (e.g., local vegetation abundance) and extrinsic drivers (e.g., upstream suspended sediment input) regulate water clarity by investigating these dynamics in pools spanning gradients of water clarity and vegetation abundance. The previous study quantified the effects of aquatic vegetation, common carp and main channel and tributary TSS inputs in regulating off-channel TSS and water clarity of Pool 8. Here we propose to repeat those analyses in pools 4, 13, and 26, and also examine a number of additional factors that may affect water clarity but are not directly measured by LTRM. These include invasions by filter feeders, HREP projects (island construction and water level drawdowns), and top-down regulation of aquatic vegetation by waterfowl (Proposal 2). Additionally, the ability to estimate *biomass* of submersed aquatic vegetation, in addition to basic measures of prevalence, (an ongoing study by Drake and Lund; tracking number 2018BIO1-3) would add considerable power to our understanding of the feedback between aquatic vegetation and water clarity. The degree and timing of water level fluctuation (Proposal 1) may also play a role as an extrinsic driver of water clarity, and relevant metrics produced by that study will potentially be included in our analyses.

The ultimate controlling factor of water clarity in shallow lakes and coastal seagrass ecosystems is nutrient availability (Scheffer et al 1993, McGlathery et al. 2013). In these systems, small changes in nutrient supply are ultimately responsible for dramatic changes in water clarity, and the process is mediated by competition between aquatic macrophytes and algae. We see some similarities in the UMRS; as water clarity has increased in Pool 8, N and P concentrations have decreased subtly and aquatic vegetation has increased in abundance. Part B of the study comprises manipulative field studies to determine whether nutrient availability could be playing a similar role as a controlling factor in the UMRS. This work will be conducted in collaboration with Professor Eric Strauss and graduate students at the University of Wisconsin, La Crosse. We propose to conduct a series of field trials to formally test N and P limitation of algal growth over a relevant range of nutrient availability and water residence time, to examine the spatial and temporal dynamics of seston quality in SRS water quality samples, and describe the relationships between seston quality and water clarity. Results of this work may allow us to rule out small changes in nutrient availability as the controlling factor of water clarity in the UMRS, or to determine whether limitation by N, P or both nutrients (co-limitation) is driving the relationship.

What do we already know?

In Pool 8 of the UMRS, water clarity has increased considerably over the last two decades. This improvement has been associated with increased abundance of native aquatic vegetation, a major decrease in exotic common carp biomass, and subtle decrease in nutrient concentrations (Drake et al. in revision, Tables 1 and 2). There have also been relatively small decreases in tributary phosphorus and total suspended solids (TSS) concentrations (Kreiling and Houser 2017). Similar changes have been documented in other key pools (e.g. Popp et al. 2014), but the timing and magnitude of these changes have not been consistent among pools (e.g. Figure 1, Table 1). Extrinsic drivers related to flow regime, physical disturbance and the kinetic energy of moving water are generally thought to dominate river ecosystems (e.g. Poff and Zimmermann 2010). But TSS in Pool 8 is also clearly influenced by its extensive, shallow, vegetated, backwaters, likely through biological mechanisms such as vegetation abundance. Common carp biomass (mass per unit effort (MPUE)) and extrinsic drivers (TSS in main channel and tributary inputs) appear to have had less impact on changes in Pool 8 TSS over time, but their effects in other parts of the UMRS are unknown. Since 1998, the prevalence of aquatic vegetation has increased substantially in three northern LTRM key pools (pools 4, 8, and 13; Figure 1), but not in Pool 26 where aquatic vegetation has remained essentially absent. Because aquatic vegetation appears to play a central role in water clarity regulation, comparisons of how patterns in abundance and interact with TSS across the range of conditions between and within Key Pools will provide a critical basis for the expanded analysis.

Table 1. 2016 TSS data illustrate both longitudinal gradients and consistent differences between main channel and backwater strata. Trend data illustrate fundamental differences between changes over time (trends) in backwater habitats and main channel habitats which represent the endpoints of the gradients of water residence time and water velocity. Pool 4 aquatic vegetation prevalence was

estimated separately for the Upper (above Lake Pepin) and Lower Pool (below Lake Pepin). Data were downloaded from the LTRM graphical browsers (www.umesc.usgs.gov/data_library/water_quality/graphical/wq_browser.html, and www.umesc.usgs.gov/data_library/vegetation/graphical/veg_front.html)

	2016 median Summer TSS (mg/l)			2016 SAV prevalence		Trends in Summer TSS 1993 - 2016	
Pool	**Pool average**	**Connected backwaters**	**Main channel**	**Connected backwaters**	**Main channel**	**Connected backwaters annual % change (90% CI)**	**Main channel annual % change (90% CI)**
4	7.97	3.74	7.9	Upper 57.8 Lower 93.6	Upper 15.0% Lower 26.7%	-6.1 (-7.4, -4.7)	-2.4 (-4.3, -0.3)
8	4.3	3.61	9.8	81.80%	28.60%	-7.9 (-9.4, -6.4)	-3.9 (-5.5, -2.3)
13	28	10.61	41.13	68.10%	16.70%	-3.9 (-4.0, -0.8)	-1.3 (-3.4, 0.7)
26	107	58.84	106.5	not sampled	not sampled	-2.4 (-4.0, -0.8)	2.6 (-1.1, 6.5)

Table 2. Seasonal nutrient concentrations and change over time in Pool 8, 1994-2015. Statistically significant change over time is denoted by *, although note that all trends in spring and summer are negative.

	TN	**NO_X-N**	**TP**	**SRP**
SPRING				
Average seasonal median (mg/l) (SD)	2.54 (1.12)	1.70 (1.18)	0.100 (0.02)	0.017 (0.02)
Annual % change (90% CL)	-0.7 (-3.1, 1.8)	-0.5 (-6.2, 5.5)	-0.7 (-2.1, 0.7)	-2.7 (-10.1, 5.3)
SUMMER				
Average seasonal median (mg/l) (SD)	1.99 (0.59)	1.11 (0.62)	0.152 (0.02)	0.061 (0.03)
Annual % change (90% CL)	-1.1 (-2.6, 0.5)	-1.7 (-6.8, 3.6)	-0.7 (-1.6, 0.1)	-0.2 (-3.4, 3.1)
FALL				
Average seasonal median (mg/l) (SD)	1.73 (0.61)	1.03 (0.70)	0.135 (0.03)	0.054 (0.03)
Annual % change (90% CL)	0.4 (-1.6, 2.4)	0.9 (-3.3, 5.2)	**-1.3 (-2.2, -0.4) ***	0.7 (-3.6, 5.3)

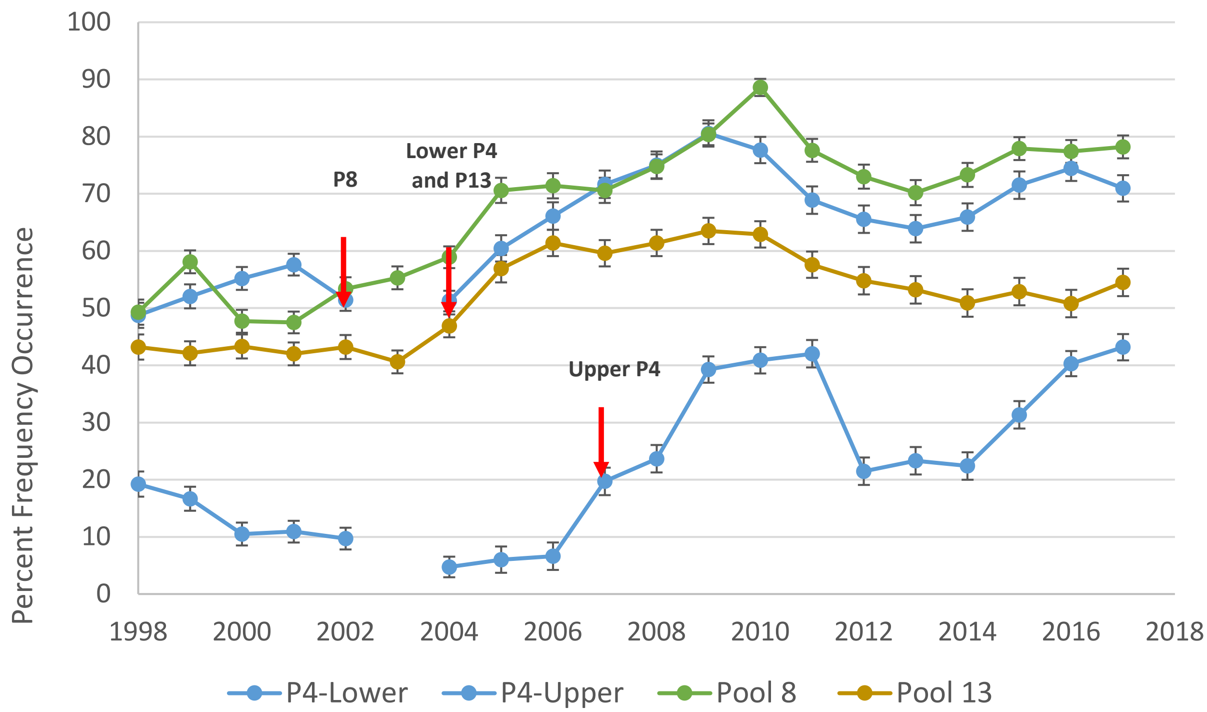

Figure 1. Prevalence of SAV (pool-wide mean percent frequency occurrence) has increased over time in all three vegetated Key Pools, but sustained, positive trends began (indicated by red arrows) during different years in each pool. Pool 4 SAV prevalence is separated into Upper and Lower Pool means, and data were not collected in Pool 4 in 2003. Data were downloaded from the LTRM graphical browser (www.umesc.usgs.gov/data_library/vegetation/graphical/veg_front.html)

Why is it important?

Water clarity and the light environment impose primary limits on productivity and growth of plants, algae, fishes and other higher trophic levels. Water clarity is also strongly linked to public perception of resource quality, the efficacy of management, and the economic value of recreational uses (Corrigan et al 2009). Understanding water clarity regulation in the UMRS would inform restoration of aquatic vegetation and help identify other restoration approaches (e.g. altering levels of herbivory or nutrient loading via hydrologic manipulation). Identification of an overall “controlling factor” for water clarity in the UMRS would allow for focused management efforts on changing that factor, with a relatively large potential payoff in being able to influence water clarity. The controlling factor in shallow lakes is usually phosphorus availability (Scheffer et al. 1993), while in coastal seagrass beds, nitrogen has been implicated (McGlathery et al. 2013). Water column concentrations of both phosphorus and nitrogen in Pool 8 have decreased subtly, but with seasonal differences, over the last two decades (Table 2), and this decline is potentially responsible for observed changes in water clarity. However, many other changes have occurred over the same period, and water clarity in the UMRS may not be strongly nutrient-driven. Thus a clear demonstration of algal response (or lack of response) under field conditions to increased N and P supply is a critical step toward understanding the mechanisms that regulate water clarity in the UMRS.

Objectives

A) Determine the extent to which water clarity in LTRM Key Pools is driven by external inputs from the watershed vs. selected internal biological drivers. Describe changes in water clarity drivers and regulation across ecological gradients within or among navigation pools.

B) Evaluate the mechanistic role of a specific biological driver of water clarity in the UMRS by assessing the role of nutrient limitation in determining the abundance of sediment-interface periphyton and water-column phytoplankton.

Relevance

The UMRR seeks to maintain a "healthier and more resilient Upper Mississippi River Ecosystem that sustains the river's multiple uses". Increased water clarity, as described above, integrates many goals of UMRR projects. It is a primary objective of many HREPs (reduced wind fetch and sediment re-suspension resulting from island construction, sediment consolidation as a result of water level drawdowns), is strongly linked to the abundance and growth of aquatic vegetation, and clearer water has higher societal and recreational value.

If we continue to see strong evidence for biological control of water clarity, management could target key elements or mechanisms in regulation, for example: prioritize management of aquatic vegetation or higher trophic levels identified as the most important drivers, or if nutrient supply emerges as a controlling factor, plan engineering projects to alter water residence time change nutrient supply rates in backwaters. When or where physical controls are important, management focus would shift to processes such as flow management and or catchment processes.

How this work relates to needs of UMRR and river managers

Part A will expand our understanding of the relationships between biotic and abiotic regulators and water clarity initially described by Drake et al. (in review) and Part B (Not funded) will help determine whether nutrient supply is the controlling factor of water clarity in the UMRS (or parts of it), as demonstrated in other ecosystems. Regulation of water clarity is likely an important component of resilience in the UMRS. Improving our understanding of these mechanisms and processes should aid efforts to avoid a return to turbid, unvegetated conditions that occurred previously in the UMRS. This may also inform efforts to restore aquatic vegetation in reaches downstream of ~ Pool 17. Possible outcomes of this work include recognition of potential early warning signs of transitions to a more turbid state, information that directs mitigation of major disturbances which may trigger transitions to a more turbid state, and a better understanding of which controlling factor(s) need to be managed to support persistence of aquatic vegetation.

Describe how the research addresses one or more of the 2018 Focal Areas.

Focal Subarea 3.1.i What are the main drivers of the longitudinal gradient in vegetation abundance/distribution? (Kreiling et al.)

A positive feedback between water clarity and aquatic vegetation in off-channel areas, and seasonal differences in the relative influence of drivers have already been described in the Pool 8 study (Drake et al. in review). Project A expands those analyses to span the longitudinal gradient in water clarity, nutrients, and aquatic vegetation of LTRM Key Pools 4, 8, 13 and 26. The primary drivers of water clarity in this complex ecosystem may change considerably over time and space. Comparisons across existing temporal and spatial gradients should yield insights into the interactions among components and improve our understanding of the causes and consequences of fluctuations in water clarity in the UMRS.

Focal Subarea 3.1.ii Thresholds for vegetative persistence or colonization? Are there areas close to thresholds where management and restoration might be most effective? (Kreiling et al.)

Describing a threshold value for a controlling factor (such as nutrient availability) would be of particular value for management, as changing a controlling variable by a small amount can provide high "bang for the buck". Drake et al. (in review) included a segmented regression analysis of Pool 8 data from 1994-2015, but a distinct ecosystem threshold (abrupt, co-occurring changes in water clarity and its predictor(s)) was not detected. Instead, water clarity increased gradually over time and there were only relatively small shifts in rates of change of predictors. Nutrient concentrations also decreased subtly over this period (Table 2), suggesting a potential role in regulation. We will expand the threshold analysis to the other key pools with different dynamics and will include additional potential drivers.

Focal Subarea 3.1.iii Physical, chemical or biological feedback loops that reinforce or undermine the persistence of aquatic vegetation? (Bouska et al. in prep; Drake et al. in review).

Feedbacks between aquatic vegetation and water clarity that were described in Pool 8 (Drake et al. in review). This work will extend the analyses to include a much larger gradient of pool-scale vegetation abundance and range of other conditions.

Focal area 6.1 **Critical biogeochemical rates/ nutrient cycling**

The experimental nutrient limitation study (Part B) is a direct investigation of nutrient limitation of primary production, with links to other primary producers and trophic interactions that may be ultimately controlled by nutrient dynamics and supply.

Methods:

The estimated starting date of the retrospective analysis is January, 2019. Initial steps will include data acquisition and meetings with potential contributors from Pools 4, 13 and 26. Pool 26 may serve as an unvegetated control to determine whether changes in the Upper Impounded reach are detectable downstream. Results from ongoing studies (Projects 1 and 2) will also potentially contribute to the analysis.

Data acquisition: USACE gauge records and LTRM fish, vegetation and water quality records will provide basic data. Weighted TSS in main channel inputs (including monitored spillways), monitored tributaries, and outputs (including monitored spillways) will be calculated for each Pool. Other data sources (e.g. zebra mussel or invasive carp abundance records) will be identified and assembled.

Although the analyses will likely evolve substantially from our current ideas, our initial plan is to conduct analyses in two phases. The first phase compares input TSS concentrations to off-channel TSS concentrations over time in each key pool to determine the relative strength of extrinsic and intrinsic regulation of off-channel TSS. The second phase of analysis uses off-channel TSS over time as a response variable, against which a suite of predictors will tested (e.g. Table 3).

Table 3. Potential predictors or regulators of TSS in UMRS off-channel habitats.

Response	Potential Intrinsic effect predictors	Potential extrinsic effect predictors
Off-channel TSS	aquatic vegetation prevalence	tributary TSS
	aquatic vegetation biomass	main channel TSS
	vegetation cover	water level fluctuation rate and extent
	common carp metrics	flood intensity, water velocity
	other benthic fishes	HREPs
	waterfowl grazing pressure	
	significant presence of zebra mussels	
	nutrient concentrations	

Products and Milestones

Tracking number	Products	Staff	Milestones
2019IE1	Database complete	Carhart, Drake, others	30 April 2019
2020IE2	Draft analysis and annual progress summary	Drake, Carhart and others	31 December 2019
2020IE2	Submit Draft manuscript	Drake, Carhart and others	30 March 2020
2021IE2	Submit Final manuscript	Drake, Carhart and others	30 December 2020

Literature Cited

Biggs, B. J.F. and Kilroy, C. 2000. Stream periphyton monitoring manual. National Institute of Water and Atmospheric Research, Ministry of the Environment. Christchurch, New Zealand. 227 Pages.

Bouska, K. L., Houser, J., and De Jager N. In Press. Developing a shared understanding of the Upper Mississippi River: the foundation of a resilience assessment. Ecology and Society.

Corrigan, J.R., K.J. Egan, and J.A. Downing. 2009. Aesthetic Values of Lakes and Rivers. Likens, G.E. ed. Encyclopedia of Inland Water Vol 1. 14-24. Elsevier.

Drake, D.C., A. Carhart, J. Fischer, J. Houser, K. Jankowski, and J. Kalas. In review. Intrinsic processes regulate water clarity in a large, floodplain-river ecosystem. Submitted to: Limnology and Oceanography, special issue on long-term monitoring.

Drake, D.C. and E. Lund. Estimation of submersed aquatic vegetation biomass in the Upper Mississippi River for application within the LTRM element (Proposal title) Ongoing study.

McGlathery, K.J., M.A. Reidenbach, P. D'Odorico, S. Fagherazzi, M.L. Pace, and J.H. Porter. 2013. Nonlinear dynamics and alternative stable states in shallow coastal systems. Oceanography. 26:220–231. doi: 10.5670/oceanog.2013.66.

Poff, N.L. and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: A literature review to inform the sciences and management of environmental flows. Freshwater Biology. 55: 194-205. doi: 10.1111/j.1365-2427.2009.02272.x

Popp, W. A., R. M. Burdis, S. A. DeLain, and M. J. Moore. 2014. Upper Mississippi River Restoration Long Term Resource Monitoring Program Completion Report. Temporal trends in water quality and biota in segments of Pool 4 above and below Lake Pepin, Upper Mississippi River: indications of a recent ecological shift. (2010D6). U.S. Army Corps of Engineers, Rock Island, IL.

Scheffer, M., S.H. Hosper, M.L. Meijer, B. Moss, and E. Jeppesen. 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution. 8:275-279. doi: 10.1016/0169-5347(93)90254-M

Effectiveness of Long Term Resource Monitoring vegetation data to quantify waterfowl habitat quality

Previous LTRM project: N/A

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At a global and continental scale, the Upper Mississippi River provides critical habitat for wildlife such as migratory birds, particularly waterfowl (Ramsar 2010, Serie et al. 1983, USFWS 2006, Wilkins et al. 2010). For waterfowl species such as canvasbacks (*Aythya valisineria*) and tundra swans (*Cygnus columbianus*), a large proportion of their diet during spring and fall migration primarily consists of tubers and other carbohydrate storage organs of aquatic plants, especially "winter buds" of wild celery (*Vallisneria americana*; Korschgen et al. 1988). The great importance of food resources to waterfowl populations is exemplified by the fact that regional conservation planning efforts [e.g., Upper Mississippi River and Great Lakes Region Joint Venture; Soulliere et al. 2007] use a bioenergetics approach to link available food energy from waterfowl habitats to continental and regional waterfowl population goals (Soulliere et al. 2007, Straub et al. 2012). These linkages between food energy and waterfowl populations are the foundation for prioritizing conservation efforts in locations where habitat enhancement and restoration would be most effective.

Wild celery often is a dominant submerged aquatic plant species and forms large homogenous beds in areas on the Upper Mississippi River, particularly in Pools 4 through 13 (De Jager and Rohweder 2017, Moore et al. 2010). Production of wild celery biomass is positively correlated with water clarity (Doyle and Smart 2001, Kimber and others 1995); and, depending on whether a plant grows from a winter bud or seed, 3 to 15 winter buds may be produced for every gram of dried biomass (Titus and Hoover 1991, Korschgen et al. 1997). Since 1994, nutrient concentrations in Pool 8 have been negatively associated with water clarity and SAV abundance and positively associated with phytoplankton biomass (Drake et al. in review). Furthermore, while waterfowl consume wild celery winter buds, researchers have shown that production of wild celery biomass is resilient to waterfowl foraging below a threshold level (Sponberg and Lodge 2005); however, this threshold is unknown for the Upper Mississippi River.

Since 1998, the UMRR-LTRM element has collected stratified-random data on aquatic vegetation in Pools 4, 8, and 13 (LTRM key pools) of the Upper Mississippi River. Additional recent efforts have sought to determine the strength of the relationship between traditional LTRM 'rake' scores of species-specific abundance and both wet and dried biomass (Drake et al. 2016, Deppa 2007). While the UMRR LTRM element has generated a wealth of data describing the distribution and abundance of aquatic vegetation such as wild celery, so far that data are only useful for describing the quantity of waterfowl habitat, but not the quality. The data have never been used to quantify or model waterfowl habitat quality where quality is defined as the energetic value of waterfowl food resources that are available.

Our project seeks to determine if LTRM aquatic vegetation data collected during summer (i.e. traditional rake scores and newly incorporated fresh weight measures) can be used to predict the biomass and size of wild celery winter buds at the start of waterfowl migration in fall (Figure 1). We predict that a relationship between LTRM data and wild celery winter bud biomass exists; therefore, LTRM data can be used to quantify the bioenergetic value of waterfowl habitats. Information about the bioenergetic value of waterfowl habitats can be used for conservation planning at scales ranging from local (UMRR HREP projects) to continental (e.g., waterfowl population goals specified in the North American Waterfowl Management Plan; NAWMP Plan Committee 2012). Additionally, our proposed project will assess herbivory of waterfowl food resources from fall migration (mid-October) to just prior to spring migration (mid-March). The quantity of waterfowl food resources remaining after fall migration will be important in determining waterfowl habitat quality during spring migration.

When considering waterfowl habitat, Habitat Rehabilitation and Enhancement Project (HREP) planning and post-project monitoring typically have been concerned with measures of waterfowl habitat quantity (e.g., acres of habitat, percent cover of vegetation, average rake score, etc.) such as for the Capoli Slough HREP (USACE 2011), but with limited consideration of waterfowl habitat quality (e.g., energetic value of waterfowl foods). If our project establishes a relationship between LTRM data and the bioenergetic values of waterfowl foods at the beginning of fall migration, then LTRM data generated in key pools could serve as a "control" when compared to waterfowl habitat quality envisioned in HREP planning scenarios (future without construction, future with project features, etc.). Additionally, establishment of a relationship between the data types would validate the use of LTRM rake methods in assessing levels of pre- and post-project waterfowl habitat quality.

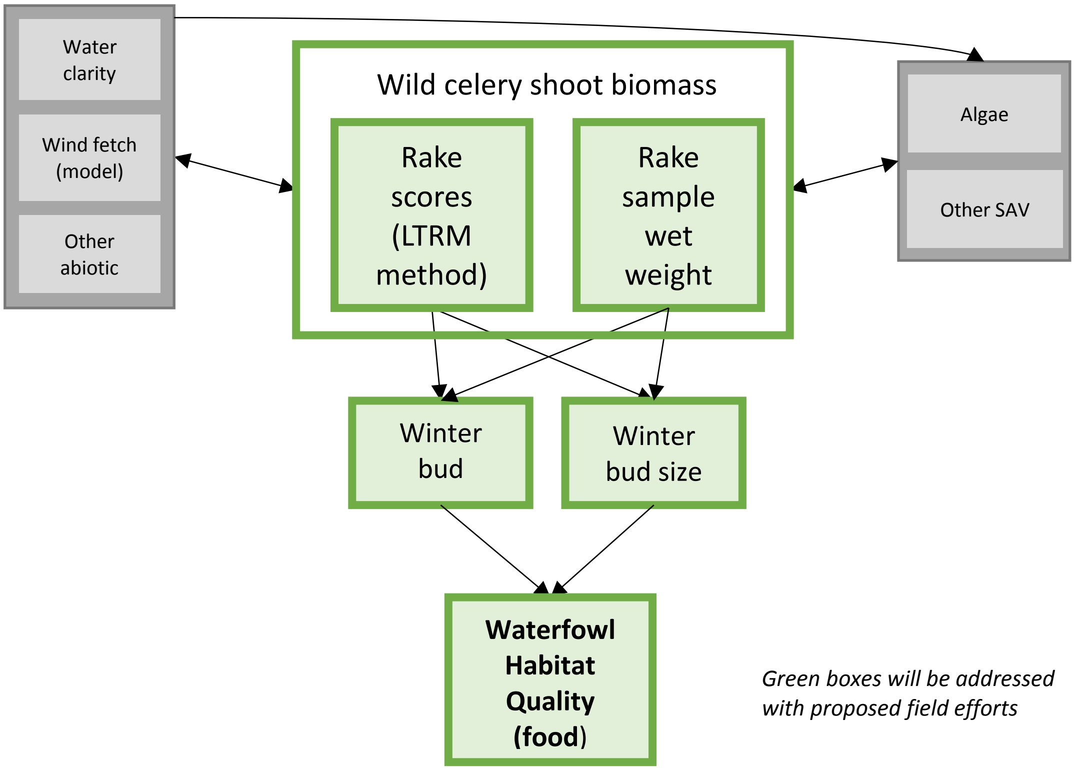

Figure 1. Conceptual model of interactions among abiotic variables, submerged aquatic vegetation (SAV), and waterfowl in the UMRS. Visual estimates for SAV using rake scores is the current LTRM method used to estimate SAV cover; current LTRM efforts are investigating whether the addition of fresh weights (on a subset of rakes) to rake scores is a better estimate for SAV biomass (ongoing study by D. Drake, E. Lund and others). Gray boxes indicate data available through LTRM that could be used as covariates in additional modelling.

Relevance of the Research to UMRR

Objective(s) or hypothesis: 1) determine the relationship between LTRM aquatic vegetation data and winter bud biomass and size in select areas of LTRM key pools (4, 8, and 13) and 2) model the quality of waterfowl habitat using LTRM aquatic vegetation data. Our specific research questions ask how well do LTRM aquatic vegetation rake scores and biomass estimates predict:

1. Summer bio-energetic foraging value for waterfowl
2. Fall bio-energetic foraging value for waterfowl

Relevance: This project expands our understanding of the relationships among water quality, aquatic vegetation, and biota (in this case waterfowl) in support of the UMRR's goals to "enhance habitat and advance knowledge for restoring and maintaining a healthier and more resilient Upper Mississippi River Ecosystem" (Goals 1 and 2, UMRR Strategic Plan 2015-2025). In addition, the ability to quantify the quality of waterfowl habitat (i.e. calculate the bioenergetic value) would represent a new wildlife habitat performance criteria in support of the UMRR mission to "construct high-performing habitat restoration, rehabilitation, and enhancement projects."

How this work relates to needs of UMRR and river managers: An expected outcome of this project is to define the extent to which LTRM data can be used as a predictor of waterfowl habitat quality (food availability and abundance). If LTRM data are highly correlated with the energetic value of waterfowl food resources (i.e. winter bud production), river managers will realize an increased capacity to assess project habitat performance objectives using existing data and methods.

How the research addresses one or more of the 2018 Focal Areas: Specifically, the proposed work addresses Focal area 3*: Interactions and associations of hydrogeomorphology with biota and water* of the UMRR FY 2018 Science in Support of Management document (Houser 2017). This project would evaluate whether LTRM aquatic vegetation rake and biomass data could be used to estimate food abundance, quality, and distribution in key pools for waterfowl.

Methods
We propose conducting standard LTRM vegetation surveys in select areas of Pools 4, 8, and 13 in August of 2018 and 2019. In addition we will record the fresh (wet) weight of wild celery captured on individual rakes. These efforts will be concentrated in areas of high waterfowl use as documented by fall aerial surveys and long-term observations by river managers (USFWS unpublished data). We will employ a stratified sampling design whereby sampling effort is allocated to areas that are closed to hunting and areas that are open to hunting (Figure 2). Waterfowl abundances during the fall in areas closed to hunting is much higher than in areas open to hunting, and use of food resources by waterfowl in these two types of areas likely differs greatly. Prior to the initiation of field work, historic LTRM data will be used to determine the level of sampling effort needed to achieve desired levels of confidence in estimated parameters. Sampling efforts that exceed the capacity of LTRM field station resources will be supplemented by partner resources (Upper Mississippi River National Wildlife & Fish Refuge, state agencies).

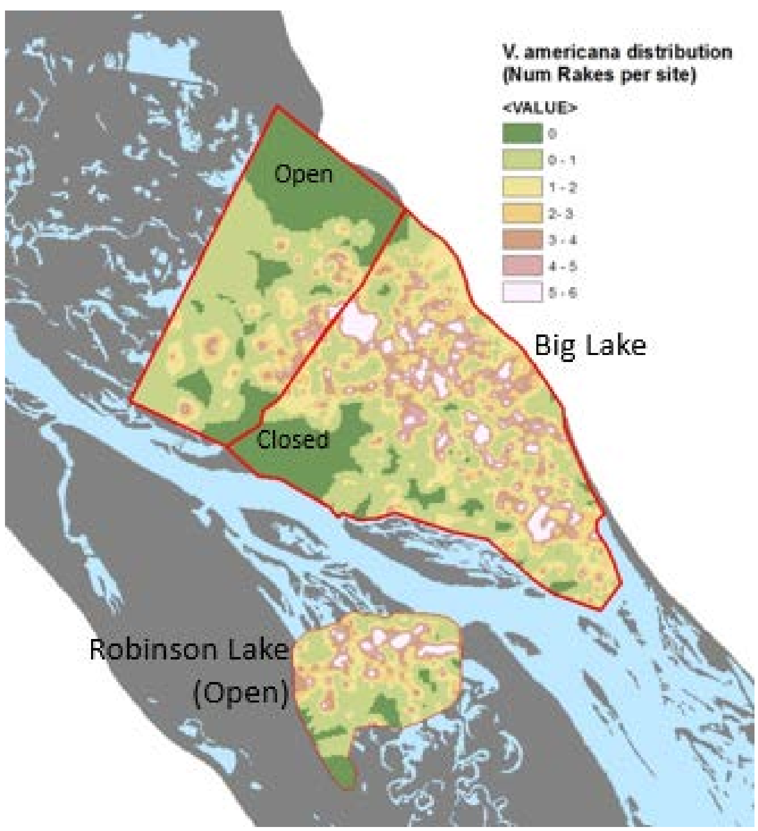

Figure 2. Distribution of wild celery (1998-2017) in lower Pool 4 of the Mississippi River in backwater areas open and closed to waterfowl hunting. Distribution is represented as a GIS interpolation based on the number of rakes (out of the six taken per site) on which *V. americana* was found during LTRM surveys (map created by E. Lund).

We also propose to collect benthic core samples in these same areas at the onset of waterfowl fall migration (early October) using methodology described in Korschgen et al. (1988) to estimate wild celery winter bud biomass and size. We will be use winter bud biomass estimates to estimate kilocalories available to waterfowl using previously established relationships between biomass and caloric content (Korschgen et al. 1988). If funding and staff/equipment resources are sufficient, we will also obtain benthic core samples in March/April of 2019 to assess herbivory of waterfowl food resources during fall migration (mid-October) to just prior to spring migration (March/April, depending on when ice-out occurs). One component of herbivory will be due to waterfowl consumption during the fall, and sampling in areas that differ in waterfowl abundance during the fall (areas open to hunting vs. areas closed to hunting) will help elucidate the magnitude of this component.

Special needs/considerations, if any: This project *likely* will have some financial support from USFWS and UW-Stevens Point during summer 2018. Thus, we would like to start work on this project in July 2018, if USGS fund allotment is available.

Products and Milestones

Tracking number	Products	Staff	Milestones
2018WF1	Collect data in Pools 4, 8, 13 using LTRM rake and biomass methodology	Winter, Lund, Drake, Bales	30 August 2018
2019WF2	Collect data in Pools 4, 8, 13 using benthic core sampling	Winter	30 October 2018
2019WF3	Collect data in Pool 8 using benthic core sampling	Winter	30 April 2019
2019WF4	Submit preliminary report with results from data collected in the summer and fall of 2018, and data collected in the spring of 2019	Schmidt, Straub, Schultz	30 July 2019
2019WF5	Collect data in Pools 4, 8, 13 using LTRM methodology	Winter, Lund, Drake, Bales	30 August 2019
2020WF6	Collect data in Pools 4, 8, 13 using benthic core sampling	Winter	30 October 2019
2020WF7	Conduct final analyses, submit draft LTRM Completion report	Schmidt, Straub, Schultz	30 May 2020
2020WF8	Submit Final LTRM Completion Report	Schmidt, Straub, Schultz	30 September 2020

References Cited

De Jager, N.R. and Rohweder, J.J. 2017. Changes in aquatic vegetation and floodplain land cover in the Upper Mississippi and Illinois rivers (1989-2000-2010). Environmental Monitoring and Assessment 189(2).

Deppa, B. 2007. Assessment of the rake method for the estimation of submersed aquatic vegetation levels. U.S. Army Corps of Engineers' Upper Mississippi River Restoration Program Long Term Resource Monitoring Element Completion Report LTRMP-2007A9. Department of Mathematics and Statistics, Winona State University, Winona, MN.

Doyle, R.D., and R.M. Smart. 2001. Impacts of Water Column Turbidity on the Survival and Growth of *Vallisneria americana* Winterbuds and Seedlings. Journal of Lake and Resevoir Management 78(1), 17-28,

Drake, D., J. Kalas, and S. Giblin. 2016. Potamogeton crispus: Detection in LTRM summer surveys, seasonal biomass and nutrient standing stocks, and links to water quality in Pools 7 and 8 of the Upper Mississippi River System. U.S. Army Corps of Engineers' Upper Mississippi River Restoration Program Long Term Resource Monitoring Element Completion Report LTRMP-2016PC2.

Drake, D.C., A. Carhart, J. Fischer, J. Houser, K. Jankowski, and J. Kalas. In review. Intrinsic processes regulate water clarity in a large, floodplain-river ecosystem. Submitted to: Limnology and Oceanography, special issue on long-term monitoring.

Kimber, A., Owens, J.L., and W.G. Crumpton 1995. The Distribution of *Vallisneria americana* Seeds and Seedling Light Requirements in the Upper Mississippi River. Canadian Journal of Botany 73: 1966-1973.

Korschgen, C. E., L. S. George, and W. L. Green. 1988. Feeding ecology of Canvasbacks staging on Pool 7 of the Upper Mississippi River. Pages 237–249 in M. Weller, editor. Waterfowl in winter. University of Minnesota Press, Minneapolis, USA.

Korschgen, C.E., Green, W.L. and Kenow, K.P. 1997. Effects of irradiance on growth and winter bud production by *Vallisneria americana* and consequences to its abundance and distribution. Aquatic Botany 58(1), 1-9.

Moore, M., Romano, S. and Cook, T. 2010. Synthesis of Upper Mississippi River System submersed and emergent aquatic vegetation: past, present, and future. Hydrobiologia 640(1), 103-114.

NAWMP Plan Committee. 2012. North American Waterfowl Management Plan 2012: People Conserving Waterfowl and Wetlands. Canadian Wildlife Service, U.S. Fish and Wildlife Service, Secretaria de Medio Ambiente y Recursos Naturales. 70 pp.

Ramsar. 2010. Upper Mississippi River Floodplain Wetlands. Site description available at Ramsar Sites Information Service; https://rsis.ramsar.org/ris/1901

Serie, J. R., D. L. Trauger, and D. E. Sharp. 1983. Migration and winter distributions of canvasbacks staging on the Upper Mississippi River. Journal of Wildlife Management 47:741–753.

Soulliere, G.J., B.A. Potter, J.M. Coluccy, R.C. Gatti, C.L. Roy, D.R. Luukkonen, P.W. Brown, and M.W. Eichholz. 2007. Upper Mississippi River and Great Lakes Region Joint Venture Waterfowl Habitat Conservation Strategy. U.S. Fish and Wildlife Service, Fort Snelling, MN. 117pp.

Sponberg, A.F. and Lodge, D.M. 2005. Seasonal belowground herbivory and a density refuge from waterfowl herbivory for *Vallisneria americana*. Ecology 86(8), 2127-2134.

Straub, J. N., R. J. Gates, R. D. Schultheis, T. Yerkes, J. M. Coluccy, J. D. Stafford. 2012. Wetland food resources for spring-migrating ducks in the Upper Mississippi River and Great Lakes region. Journal of Wildlife Management 76:768–777.

Titus, J.E. and Hoover, D.T. 1991. Toward predicting reproductive success in submersed freshwater angiosperms. Aquatic Botany 41(1-3), 111-136.

U.S. Army Corps of Engineers (USACE) 2015. Enhancing restoration and advancing knowledge of the Upper Mississippi River, a strategic plan for the Upper Mississippi River Restoration Program 2015 – 2025. Available at: http://www.mvr.usace.army.mil/Portals/48/docs/Environmental/EMP/Key%20Docs/umrr-strategic-plan-fy15-25-jan2015.pdf

USACE. 2011. Capoli Slough Habitat Rehabilitation and Enhancement Project Final Definite Project Report and Integrated Environmental Assessment, Volume 1 Main Report. Upper Mississippi River System Environmental Management Program. 143 pages. Available at: http://www.mvr.usace.army.mil/Portals/48/docs/Environmental/EMP/HREP/MVP/CapoliSlough/Capoli_DPR_Signed.pdf

USFWS. 2006. Upper Mississippi River National Wildlife and Fish Refuge Comprehensive Conservation Plan. U.S. Fish and Wildlife Service. Fort Snelling, Minnesota. 168 pp + Appendices A–G.

Wilkins, K. A., R. A. Malecki, P. J. Sullivan, J. C. Fuller, J. P. Dunn, L. J. Hindman, G. R. Costanzo, and D. Luszcz. 2010. Migration routes and Bird Conservation Regions used by Eastern Population Tundra Swans *Cygnus columbianis columbianus* in North America. Wildfowl 60:20–37.

Understanding constraints on submersed vegetation distribution in the UMRS: the role of water level fluctuations and clarity

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Introduction/Background:
Submersed aquatic vegetation (SAV) improves water clarity by stabilizing substrates and reducing re-suspension from wind and watercraft-generated waves (Madsen et al. 2001; De Jager and Yin 2010), and is critical for fish and wildlife in the UMRS (DeLain and Popp 2014; Moore et al. 2010). In many UMRS pools (1-3, 16-26 and Illinois River), SAV remains scarce (De Jager and Rohweder 2017). Better understanding of the factors limiting SAV colonization and persistence will help identify locations most and least likely to benefit from management and restoration efforts, and improve our understanding of how changing river conditions may affect SAV distribution.

SAV requires certain conditions to establish and grow (Koch 2001; Moore et al. 2010). Two important factors that can limit the distribution and growth of SAV are light availability and water level fluctuation (Moore et al. 2010; Sass et.al 2010). SAV requires areas shallow enough for light to reach the plants, but deep enough to remain submersed (i.e. not dewatered by fluctuating water levels) nearly all of the growing season. The spatial extent of the area meeting these criteria is determined by water level fluctuations (stage), water clarity, and bathymetry. Each of these varies within and among pools, and water level fluctuation and clarity varies among years. Figure 1 illustrates how water level fluctuations and photic zone depth can determine where conditions are suitable for SAV.

There is substantial spatial and temporal variation in river stage both within and among UMRS pools. Within pools, stage tends to be more stable in the lower third and more variable in the upper pool (Bouska et al. *in press*). For example, in Pool 8, water level typically varies ~ 7 feet in the tailwaters and only ~ 2 feet in the lower, impounded part of the pool (Table 1). Moreover, water level fluctuations are greater in the lower UMRS pools compared to the upper pools. For example, in Pool 26, stage can vary by more than 15 feet during the growing season (Table 1).

There is also substantial spatial and temporal variation in water clarity within and among UMRS pools. Water clarity decreases from the upper to lower river (Houser et al. 2010), and exhibits temporal and spatial variability within pools (Houser 2016). Water clarity determines depth of the photic zone, which is the depth to which at least 1% of the surface light penetrates (Wetzel 2001). As a result, the area of the river bed included in the photic zone varies with both water level and water clarity. We propose to investigate the constraints on SAV distribution imposed by the combined effects of these two factors. Of particular interest for management will be the identification of areas where light and depth conditions appear suitable, but vegetation remains scarce.

Relevance of research to UMRR:
The overall objective of the proposed work is to assess the suitability of each navigation pool for SAV based on the combined effects of water level fluctuations and water clarity. We will accomplish this by estimating the areas within each pool that meet the water level fluctuation and water clarity criteria that allow SAV beds to establish and persist. The following specific tasks will address this objective:

1) Quantify water level (stage) fluctuations annually from 1972 to 2014 for all main stem gages in UMRS pools 3-26 including the Open River Reach and Illinois River.
2) Estimate daily photic zone depth for pools 3-26 including the Open River Reach and Illinois River (1993–2014) using water clarity data from the LTRM water quality database and possibly other extant data. These data will be interpolated spatially and temporally to fill in missing data as needed.

3) At each UMRS river gage, use known physiological requirements (tolerance for dewatering; light requirements) for select species of SAV, daily stage and estimated photic zone depth (See #2) to identify the bed elevation ranges over which SAV may be supported.
4) Use the bed elevation ranges from #3 and existing topobathy data to generate maps of areas in each navigation pool that meet the light and water level fluctuation criteria. Maps will be created by interpolating longitudinally between gages and extrapolating laterally across the aquatic areas in each pool.
5) Calculate the area within each pool suitable for SAV bed establishment and persistence based on water level fluctuation and clarity conditions.
6) Identify areas that are predicted to have acceptable light and WLF conditions but have scarce/no vegetation.

Information generated by this project will advance our understanding of how water level fluctuations and water clarity constrain SAV distribution within the UMRS and aid in HREP selection by indicating areas that are likely suitable for SAV but where SAV is scarce. Establishment of SAV is often an objective of HREP's because of its importance to fish and wildlife in the UMRS (USACE 2011).

This effort fits in Theme 2: <u>Focal area 3: Interactions and associations of hydrogeomorphology with biota and water quality</u>. <u>Subarea 3.1 Interactions between aquatic vegetation and hydrogeomorphology.</u>

i. What are the main drivers of the longitudinal gradient in vegetation abundance/distribution? Specifically, what are the main drivers limiting vegetation colonization and recolonization on the Illinois River and in Pools 1-3 and 16–26? (Kreiling et al.)
ii. What are the thresholds for vegetative persistence or colonization? If such thresholds can be identified, are there areas close to these thresholds where management and restoration actions might be particularly effective? (Kreiling et al.)

Methods

Requisite initial data sets
Daily stage data (1972-2014) for UMRS pools 3-26 plus the Open River Reach and Illinois River at stream gage locations (typically 3-4 stream gages per pool). This is available in an existing UMESC-compiled database.

Main channel water clarity data (1993-2014) for LTRM study pools (4, 8, 13, 26, La Grange, Open River Reach). Fixed-site water clarity data is collected on a monthly to bi-monthly basis.

Analytical approach

Water level fluctuation
We will quantify water level fluctuations using daily stage data from 1972 to 2014. Water level fluctuations will be characterized using select descriptive statistics (i.e. mean, range, standard deviation, etc.). The results will be compared within and between pools, at annual time periods.

Photic zone depth
We will generate daily estimates of photic zone depth for LTRM study pools using water clarity data

from the LTRM WQ component; extant light penetration data from the UMRS and literature sources (e.g. Giblin 2017; Giblin *et al*. 2010) will be used to convert the water clarity measurements to photic zone depth. The sampling regime of the LTRM water clarity data will require us to interpolate daily readings between sample dates. Water clarity for the non-LTRM pools will be estimated by interpolating longitudinally between LTRM pools.

Estimating suitable SAV bed elevation

We will develop a model combining water level and water clarity data to determine the bed elevation ranges over which SAV may be supported (hereafter referred to as SAV band). The parameters for our analysis will be based on a literature review of SAV physiology and will correspond to the minimum light requirements (e.g. number of days light reaches the sediment-water interface), as well as maximum air exposure limit (e.g. number of days SAV can withstand being dewatered); similar parameters were used in the LTRM SAV model (Yin et al. 2016). Our model will estimate the upper and lower elevations where, based on photic zone and dewatering, SAV could potentially grow.

The upper SAV band boundary is the highest bed elevation suitable to SAV at a given pool location. It can be thought of as the transition between land and water at low river flows (Figure 1); the model computes the highest bed elevation that is within the air exposure limit (e.g. the maximum number of days SAV can withstand being dewatered).

The lower SAV band boundary is the lowest bed elevation that meets SAV light requirements at a given pool location. It can be thought of as the boundary between the vegetated and the unvegetated or aphotic zone (Figure 1). Our model will compute the minimum (deepest) bed elevation where light conditions are suitable for SAV by subtracting the daily photic zone depth estimate from the daily stage elevation. The model then tallies the number of days each bed elevation fell within the photic zone. The lowest bed elevation with suitable light represents this boundary.

These annual, gage-specific SAV bands generated above will be linearly interpolated (by river mile) between gages to generate spatial coverages for each pool. Bed elevation data from topobathy will be overlaid to delineate the areas within each pool that correspond to the SAV band estimates.

The estimates of SAV bands involves a number of approximations. Specifically, the longitudinal interpolation and lateral extrapolation of river stage and water clarity values will be approximate. We will assess the sensitivity of the results to error in those approximations by comparing results generated across a reasonable range of water clarity and water level variation for each gage. The sensitivity to changing river stage and water clarity may be highly dependent on the geomorphology of the pool (i.e. gradually sloped pool with shallow areas vs. steep channelized pool).

The spatial coverages of the SAV band areas generated above will be compared to LTRM land cover/land use (LCU) maps that show the distribution of SAV. We will also use existing LTRM vegetation data in areas that can complement our analysis. Select maps will be generated showing areas that lie within the acceptable bounds for SAV, based on water level and water clarity, but are lacking SAV. These unvegetated areas will be considered potential SAV restoration areas.

Next steps:

By addressing these two fundamental constraints (water level fluctuation and water clarity), this work is laying the foundation for a range of future research and restoration. There is a lot that could be done to inquire further as to why these areas within the predicted SAV bands are unvegetated:

1. Are there hydrogeomophological reasons these areas are unsuitable (e.g. channels that likely have high flow or impounded areas with high wind fetch)?
2. Is the water less clear than predicted because of local bioturbation (e.g. abundant common carp)?
3. Is there reason to expect high herbivory (e.g. waterfowl, turtles, grass carp, etc.)? These areas might be good candidates for future "exclosure" experiments.
4. Is the seed bank depauperate in these areas; is the substrate suitable for SAV?

Milestones and products:

Tracking number	Products	Staff	Milestones
2019SVD1	Retrieve existing systemic datasets for elevation gages, topobathy and water clarity.	Kalas, Carhart, Rogala,	30 December 2018
2019SVD2	Estimate/interpolate photic zone and generate predicted SAV bands systemically.	Kalas, Carhart, Rogala,	30 June 2019
2019SVD3	Submit annual progress summary	Kalas, Carhart,	30 September 2019
2019SVD4	Spatial coverages and databases complete, begin draft report.	Kalas, Carhart, Rohweder	30 October 2019
2019SVD5	Submit draft manuscript	Kalas, Carhart, Drake, Rogala, Rohweder	30 September 2020
2019SVD6	Webpage to house database information	Kalas, Carhart, Rogala, Rohweder	30 September 2020

References

Bouska, K., Houser, J., De Jager, N., Van Appledorn, M., and Rogala, J. In press. Applying principles of general resilience to large river ecosystems: case studies from the Upper Mississippi and Illinois rivers.

De Jager, N. and Rohweder, J. 2017. Changes in aquatic vegetation and floodplain land cover in the Upper Mississippi and Illinois rivers (1989–2000–2010). Environmental Monitoring and Assessment 189:77.

De Jager, N. and Yin, Y. 2010. Temporal changes in spatial patterns of submersed macrophytes in two impounded reachf the Upper Mississippi River, USA, 1998–2009. River Systems 19:129–141.

DeLain, S.A., and Popp, W.A. 2014. Relationship of weed shiner and young-of-year bluegill and largemouth bass abundance to submersed aquatic vegetation in Navigation Pools 4, 8, and 13 of the Upper Mississippi River, 1998– 2012: Submitted to the U.S. Army Corps of Engineers' Upper Mississippi River Restoration-Environmental Management Program from the U.S. Geological Survey, Technical Report 2014–T001, 29 p.

Giblin, S.G. 2017. Thirty years of light data on the Upper Mississippi River: What is it telling us? Wisconsin Department of Natural Resources.

Giblin, S., Hoff, K., Fischer, J., and Dukerschein, T. 2010. Evaluation of light penetration on Navigation Pools 8 and 13 of the Upper Mississippi River: U.S. Geological Survey Long Term Resource Monitoring Program Technical Report 2010–T001, 16 p.

Houser, J. N., 2016. Contrasts between channels and backwaters in a large, floodplain river: testing our understanding of nutrient cycling, phytoplankton abundance, and suspended solids dynamics. Freshwater Science 35(2):457-473. doi:10.1086/686171.

Houser, J.N., Bierman, D.W., Burdis, R.M. and Soeken-Gittinger, L.A. 2010. Longitudinal trends and discontinuities in nutrients, chlorophyll and suspended solids in the Upper Mississippi River: implications for transport, processing, and export by large rivers. Hydrobiologia 651:127–144.

Koch, E. 2001. Beyond light: Physical, Geological, and Geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries 24: 1-17.

Kreiling, R., Yin, Y. and Gerber, T. 2007. Abiotic influences on the biomass of Vallisneria Americana Michx. In the Upper Mississippi River. River Research and Applications 23: 343-349.

LTRM Fisheries 2007 Report https://umesc.usgs.gov/reports_publications/ltrmp/fish/2007/pool_26/summary_p26.html

Madsen, J., Chambers, P., James, W., Koch, E., and Westlake, D. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. Hydrobiologia 444:71–84.

Moore, M., Romano, S., and Cook, T. 2010. Synthesis of Upper Mississippi River System submersed and emergent aquatic vegetation: past, present and future. Hydrobiologia 640: 103-114.

Sass, G.G., T.R. Cook, K.S. Irons, M.A. McClelland, N.N Michaels, and T.M. O'Hara. 2010. Experimental and comparative approaches to determine factors supporting or limiting submersed and aquatic vegetation in the Illinois River and its backwaters. LTRMP Report, U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, WI

USACE (2011) Upper Mississippi River system ecosystem restoration objectives – 2009. United States Army Corps of Engineers, Rock Island, Illinois. http://www.mvr.usace.army.mil/Portals/48/docs/Environmental/EMP/UMRR_Ecosystem_Restoration_Objectives_2009.pdf

USACE. 2011. Upper Mississippi River system ecosystem restoration objectives- 2009. United States Army Corps of Engineers, Rock Island, Illinois.

Wetzel, R.G., 2001, Limnology (3d ed.): San Diego, Academic Press, 1,006 p.

Yin, Y., Rogala, J., Sullivan, J. and Rohweder, J. Last updated on January 29, 2016. Submersed aquatic vegetation modeling output online. https://umesc.usgs.gov/management/dss/sub_veg_model.html.

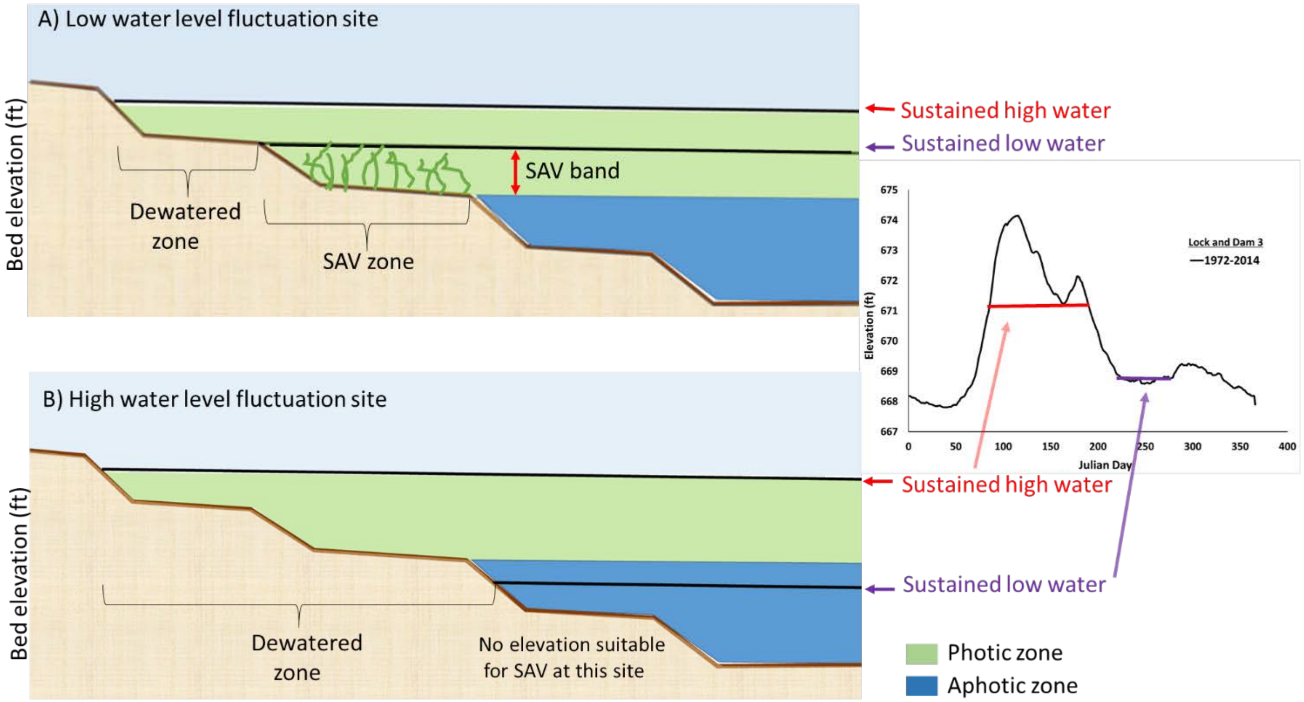

Figure 1. Conceptual illustration of the effects of the magnitude and duration of water level fluctuation on conditions for SAV. Shown are examples of a navigation pool with relatively small (A) and large (B) water level fluctuations (WLF). Water clarity, and therefore photic zone depth (PZ), is the same in both panels. Sustained high water elevation (red line on hydrograph) determines the lowest bed elevation receiving sufficient light to support SAV, i.e. the lower SAV band boundary. Sustained low water elevation (purple line on hydrograph) determines the highest bed elevation suitable for SAV because bed elevations above this are excessively dewatered, making them unsuitable for SAV. In panel A, PZ is greater than the range of WLF and there is a range of bed elevation suitable for SAV. In panel B, the range of WLF is greater than PZ, and there is no area suitable for SAV.

Table 1. Pool statistics during the growing season (May-September): 2005-2014

		Pool 8	**Pool 26**
Upper Pool	Minimum stage (ft) ± sd	630.6 ± 0.37	420.6 ± 1.97
	Maximum stage (ft) ± sd	637.7 ± 2.63	436.2 ± 5.77
	Fluctuation (ft)	*7.1*	*15.6*
Lower Pool	Minimum stage (ft) ± sd	629.2 ± 0.06	414.3 ± 0.99
	Maximum stage (ft) ± sd	631.0 ± 0.99	423.5 ± 4.29
	Fluctuation (ft)	*1.8*	*9.2*

Systemic analysis of hydrogeomorphic influences on native freshwater mussels

Previous LTRM project: No.

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Introduction

What's the issue or question? Geomorphic and hydrophysical conditions strongly influence aquatic communities in rivers (Statzner et al. 1988, Gore 1996). Physiology, behavior, and life history strategies determine species tolerances to geomorphic conditions and allow populations to persist in these dynamic environments. For benthic organisms, distributions are often responsive to heterogeneous physical and hydraulic conditions near the sediment-water interface that result from spatial and temporal variation in discharge and geomorphology (Rempel et al. 2000, Merigoux and Doledec 2004). Interest in understanding physical, hydraulic, and geomorphic factors that might drive the distribution and abundance of freshwater mussels has been increasing due to their precipitous decline throughout North America. Native freshwater mussels are a group of organisms that appear responsive to variation in hydrophysical conditions (Steuer et al. 2008, Zigler et al. 2008), but comparatively less is known about how variation in geomorphic features might influence mussel assemblages. In support of the Upper

Mississippi River Restoration (UMRR) Program's second Habitat Needs Assessment (HNA-II, 2017), the Upper Midwest Environmental Sciences Center (UMESC) has recently created a system-wide GIS data set (aquatic areas) that could be used to evaluate linkages among specific geomorphic metrics and mussel resources. In HNA-I (2000), mussels were largely represented as locations on a map where expert opinion suggested that dense or diverse mussel assemblages might exist. Since HNA-I, large-scale systematic surveys for mussels have been completed in Pools 3, 5, 6, and 18. With the addition of the new aquatic areas GIS dataset, which provides a better characterization of the physicochemical and ecological conditions than previous classifications, and the large-scale systematic mussel surveys, it should be possible to better understand and quantify broad-scale spatial relationships among mussel communities and hydrogeomorphic conditions within the Upper Mississippi River System (UMRS).

What do we already know about it? Prior studies of mussel distributions often relied on physical variables (i.e., current velocity, substrate type) to predict suitable mussel habitat with limited success (e.g., Holland-Bartels 1990, Strayer and Ralley 1993, Brim Box et al. 2002). Recent studies have provided evidence that mussel occurrence is often related to complex hydraulic variables such as shear stress and Froude number (Hardison and Layzer 2001, Howard and Cuffey 2003). In the Upper Mississippi River (UMR), studies suggest that hydrophysical conditions account for a substantial portion of the variability in mussel distributions (Steuer et al. 2008, Zigler et al. 2008). For example, models developed at UMESC used a suite of complex hydraulic and physical variables to successfully predict ~74% of presence and absence of mussels in Pool 8 (Zigler et al. 2008). These models predicted few mussels in poorly connected backwaters and the navigation channel; whereas channel borders with high geomorphic complexity and side channels were favorable to mussels. Ries et al. (2016) quantified patterns in patchiness of mussel distributions in the UMR and hypothesized that geomorphic patterns may have contributed to the observed differences in spatial patterning of mussels among river reaches. These studies suggest that the interaction of geomorphology and discharge produces a template of conditions that could be manipulated by managers to conserve or benefit native mussels. However, the utility of geomorphic variables as large scale predictors of mussel distribution and abundance, across the UMRS, are virtually unknown. We propose testing whether geomorphic predictors of mussel habitat from the aquatic areas data set (HNA-II) can be used to predict the distribution, abundance, diversity, and recruitment of mussels using existing pool-wide data (Pools 3, 5, 6, and 18), and new data collected as part of this project (Pools 8 and 13). Conducting two additional pool-wide surveys may expand the range of geomorphic conditions across the study pools and leverage extensive existing data in LTRM pools that may be included in these analyses.

Why is it important? Freshwater mussels are a group of highly imperiled animals that serve as biological indicators of water quality, provide important ecosystem services, and historically supported large commercial fisheries. Ecosystem services provided by mussels include nutrient recycling and storage, structural habitat, substrate and food web modification, use as environmental monitors, and water purification (Vaughn 2017). Over the past 50 years, about 20 species have been lost or greatly diminished from the UMRS, and overall abundance of mussels has substantially declined in many portions of the river (Havlik and Sauer 2000). Where mussels remain abundant, they are vital components of the riverine ecosystem. For example, surveys for native mussels across three reaches of the UMR (Pools 5, 6, and 18) documented communities composed of 16-23 species and 61-212 million individuals (Newton et al. 2011). Mussels filtered a significant amount of water over this reach, amounting to their processing of up to 12% of the river discharge during low flows. Collectively, these data suggest that mussels play an integral role in the UMR ecosystem by retaining suspended materials that can be used by other benthic organisms. Mussels also provide critical links in the riverine food web, both indirectly as physical habitat for invertebrates and fish, and directly as food sources for many organisms. Because of their critically imperiled status, native mussels are a significant resource of concern to the U.S. Fish and Wildlife Service, the National Park Service, state natural resource agencies, and non-governmental organizations. The lack of information on metrics to predict the distribution, abundance, diversity, and recruitment of native mussels makes it difficult for resource managers to understand what constitutes mussel habitat in large rivers and to evaluate the effects of management actions (e.g., habitat rehabilitation and enhancement projects [HREPs], drawdowns) on this imperiled faunal group.

If work involves an HREP, name it. A primary objective of the HNA effort was to assess habitat needs and guide HREP planning at moderate to large scales. Despite their ecological importance, mussels have not been included in those analyses in part because linkages between mussel habitat and those HNA geomorphic metrics have not been established. A better understanding of the geomorphic metrics that associate with dense and diverse mussel assemblages can guide the designs of future HREPs to support mussel assemblages and may provide new and improved habitats for mussels. Identification of the geomorphic drivers that influence the distribution and abundance of native mussels can be used across HREPs to predict the occurrence of mussels so that future HREPs can minimize adverse effects on existing mussel assemblages or areas with threatened and endangered species. Furthermore, the USACE is planning to use routine water level drawdowns in Pool 8 to improve aquatic habitat. Obtaining systematic, pool-wide data on native mussels in Pool 8 will serve as baseline information on mussel resources associated with this management action. Similarly, Pool 13 has been proposed by UMR managers as a location for a future water level drawdown and pool-wide population estimates will significantly enhance our knowledge of mussel resources in this pool.

Relevance of research to UMRR:

Objectives: (1) Estimate the distribution, abundance, diversity, and recruitment of native mussels in two pools (Pools 8 and 13) of the UMR; (2) Identify geomorphic gradients using physical habitat metrics across six navigation pools of the UMR; (3) Assess if geomorphic indices are predictive of the distribution, abundance, diversity, and recruitment of native mussels across six pools in the UMR.

Relevance (demonstrate scientific and/or management value). Freshwater mussels are the most imperiled faunal group in North America and they are of significant management concern to States, Federal agencies, and non-governmental organizations. Maintaining and restoring adequate habitat for these animals is critical to their conservation. Conservation and restoration actions depend, in part, on understanding what constitutes habitat for mussels in large rivers. While our hydrophysical models have greatly contributed to this understanding, there is still unexplained variability in mussel distributions in the UMRS that may relate to broader, geomorphic indices of physical habitat. This project seeks to assess the potential for geomorphic indices to predict the distribution, abundance, diversity, and recruitment of native mussels across a large extent (Pools 3-18) of the UMRS.

How will the results inform river restoration and management? From prior research, we know that about 60% of the mussels in Pools 5, 6, and 18 reside in only about 10% of the aquatic area (Newton et al. 2011). If the primary variables structuring mussel assemblages are related to geomorphology (which is reasonable given the importance of geomorphic complexity in recent UMESC modelling efforts), then these features can be manipulated by resource managers to benefit native mussel assemblages. Successful restoration efforts for native mussels will depend on knowledge of where mussels occur, where the highest density areas occur, and which geomorphic indices have strong associations with mussels. Quantifying associations between geomorphology and mussels will help us answer these questions and may lead to informed HREP planning at the system, reach, and pool scales. In addition, if mussel assemblages differ among aquatic area types or navigation pools, then these data could help refine management goals and actions for mussel resources in the UMRS that are inclusive of this variation. Data generated from this project may also provide additional data layers for the USACE UMR Mussel Community Model (Todd Swannack, ERDC).

Linkages to 2018 Focal Areas. This work directly or indirectly addresses three of the five focal areas developed by the UMRR. Specifically, (1) What are the patterns of mussel distribution and abundance and their key habitat drivers across a hierarchy of scales in the UMRS; (2) What are the effects of hydrogeomorphic regime on the distribution and abundance of UMRS mussel populations; and (3) What are the differences and annual variation in population-level characteristics (e.g., recruitment) across species with varying life histories? The proposed research also supports question 1a (What are the spatial and temporal patterns in mussel assemblages in the UMRS?) of the "Scientific Framework for Research on Unionid Mussels in the UMRS" (Newton et al. 2010).

Methods

A systematic sampling design will be used to sample mussels in Navigation Pools 8 and 13 of the UMRS, similar to experimental designs used in Pools 3, 5, 6, and 18 (Newton et al. 2011, T.J. Newton, unpublished data). These pools are ~8,850 (Pool 8) and ~11,100 ha (Pool 13) in aquatic area, and contain main channel, side channels, backwater lakes, and impounded region habitat types. Briefly, sample sites will be chosen systematically using a north–south aligned square grid; about 300 sites will be sampled in each pool (image to the right depicts the 359 sites that were sampled in Pool 5 in 2006). About 20 closely situated sites will be grouped together in a block—the typical estimated workload for a single day of sampling. The blocks will be sampled in random order between July and October 2019. At each site, divers will place two 0.25 m^2 aluminum quadrat frames on the river bottom. The duplicate quadrats, which will be placed 10 m apart in an upstream to downstream direction, will be used to increase the area sampled at each site and increase the effectiveness of this design (i.e., by increasing within-site heterogeneity). Divers will excavate substrates to a depth of ~15 cm and all materials will be placed into a 6 mm mesh bag. Mussels will be identified to species, aged via external annuli, measured for shell length, and sexed (in species with external sexual dimorphism). Pool-wide survey data will be used to estimate a suite of response variables in mussels including: presence-absence, total and species-specific abundance, abundance of adults and juveniles (≤ 5 y of age), age, length, diversity, and evidence of recent recruitment (percent of population ≤ 5 y of age). Pool-wide population estimates will be derived using survey sampling statistical software (PROC SURVEYMEANS, SAS Institute Inc., 2014).

Using existing pool-wide data in Pool 3, 5, 6, and 18, and the newly collected data in Pools 8 and 13, we will begin to explore associations between a suite of geomorphic indices and a suite of mussel response variables. We may also use recently obtained mussel survey data in Pool 15 which was sampled systematically but only in main channel border areas. First, we will explore recently developed metrics related to sinuosity, shoreline complexity, water depth, connectivity, topographic position, and river training structures in the aquatic areas coverages and identify those metrics that are likely to influence mussels. We will also explore creating additional metrics that are suitable for assessing patterns in mussel populations and re-computing existing geomorphic metrics (e.g., sinuosity, shoreline complexity) across a range of geomorphic scales using buffers around sample points. Second, we will look for collinearity among geomorphic metrics, and strongly correlated variables ($r \geq 0.70$) will be excluded (Moore and McCabe 1993, Dormann et al. 2013). Generalized linear mixed models will be used to assess patterns in univariate responses (e.g., presence, abundance, diversity) across a gradient of geomorphic conditions (PROC GLIMMIX, SAS Institute Inc., 2014). Multivariate analyses (e.g., principal components analysis, non-metric multidimensional scaling) will be used to look at associations of mussel assemblages across the geomorphic gradient within and among pools (PRIMER-E Ltd., Clarke and Warwick 2001). Results from these analyses may inform geospatial models of those geomorphic metrics that are most likely to influence mussel assemblages. Once important geomorphic metrics are identified, and depending on the strength of the associations, we may be able to map the distribution of suitable mussel habitat across the UMRS.

Milestones and products

Tracking number	Products	Staff	Milestones
2019FM1	Design pool-wide surveys in Pools 8 and 13, begin assessing patterns in mussel assemblages across a gradient of geomorphic conditions in existing data (Pools 3, 5, 6, and 18), conduct pool-wide surveys for mussels in Pools 8 and 13	Mike Davis, Teresa Newton, Jim Rogala, Jason Rohweder	30 September 2019
2019FM2	Annual progress summary	Teresa Newton	31 December 2019
2019FM3	Calculate pool-wide population estimates of native mussels in Pools 8 and 13, finish assessing patterns in mussel assemblages across a gradient of geomorphic indices (all pools), begin conducting statistical analyses	Catherine Murphy, Teresa Newton, Jim Rogala, Jason Rohweder	30 September 2020
2019FM4	Annual progress summary	Teresa Newton	31 December 2020
2019FM5	Complete statistical analyses, prepare geospatial maps, Submit draft LTRM completion report	Teresa Newton	30 September 2021
2019FM6	Submit Final LTRM completion report	Teresa Newton	30 March 2020

References

Brim Box, J., R.M. Dorazio, and W.D. Liddell. 2002. Relationships between streambed substrate characteristics and freshwater mussels (Bivalvia: Unionidae) in coastal plain streams. Journal of the North American Benthological Society 21:253–260.

Clarke, K.R. and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation. Plymouth, UK, PRIMER-E. 172 pp.

Dormann, C.F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J.R.G. Marquéz, B. Gruber, B. Lafourcade, P.J. Leitão, and T. Münkemüller. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36:27–46.

Gore, J.A. 1996. Responses of aquatic biota to hydrological change. Pages 209–230 in Petts, G.E. and P. Calow (eds), River biota: diversity and dynamics. Blackwell Science, Oxford.

Hardison, R.B. and J.B. Layzer. 2001. Relations between complex hydraulics and the localized distribution of mussels in three regulated rivers. Regulated Rivers Research and Management 17:77–84.

Havlik, M.E. and J.S. Sauer. 2000. Native freshwater mussels of the Upper Mississippi River System. USGS Upper Midwest Environmental Sciences Center Project Status Report 2000-04.

Holland-Bartels, L.E. 1990. Physical factors and their influence on the mussel fauna of a main channel border habitat of the Upper Mississippi River. Journal of the North American Benthological Society 9:327–335.

Howard, J.K. and K.M. Cuffey. 2003. Freshwater mussels in a California North Coast Range river: occurrence, distribution, and controls. Journal of the North American Benthological Society 22:63–77.

Merigoux, S. and S. Doledec. 2004. Hydraulic requirements of stream communities: a case study on invertebrates. Freshwater Biology 49:600–613.

Moore, D.S. and G.P. McCabe. 1993. Introduction to the practice of statistics. W.H. Freeman and Co., NY.

Newton, T.J., S.J. Zigler, W. Haag, J. Duyvejonck, and M. Davis. 2010. Scientific framework for research on unionid mussels in the Upper Mississippi River System. Prepared for the Upper Mississippi River Restoration Program. 7 pp.

Newton, T.J., S.J. Zigler, J.T. Rogala, B.R. Gray, and M. Davis. 2011. Population assessment and potential functional roles of native mussels in the Upper Mississippi River. Aquatic Conservation: Marine and Freshwater Ecosystems 21:122–131.

Rempel, L.L., J.S. Richardson, and M.C. Healey. 2000. Macroinvertebrate community structure along gradients of hydraulic and sedimentary conditions in a large gravel-bed river. Freshwater Biology 45:57–73.

Ries, P.R., N.R. De Jager, S.J. Zigler, and T.J. Newton. 2016. Spatial patterns of native freshwater mussels in the Upper Mississippi River. Freshwater Science 35:934–947.

SAS Institute. 2014. SAS OnlineDocs 9.4. SAS Institute, Cary, NC.

Statzner, B., J.A. Gore, and V.H. Resh. 1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Society 7:307–360.

Strayer, D.L. and J. Ralley. 1993. Microhabitat use by an assemblage of stream-dwelling unionaceans (Bivalvia), including two rare species of *Alasmidonta*. Journal of the North American Benthological Society 12:247–258.

Steuer, J.J., T.J. Newton, and S.J. Zigler. 2008. Use of complex hydraulic variables to predict the distribution and density of unionids in the Upper Mississippi River. Hydrobiologia 610:67–82.

Vaughn, C.C. 2017. Ecosystem services provided by freshwater mussels. Hydrobiologia. doi:10.1007/s10750-017-3139-x.

Zigler, S.J., T.J. Newton, J.J. Steuer, M.R. Bartsch, and J. Sauer. 2008. Importance of physical and hydraulic characteristics to unionid mussels: a retrospective analysis in a large river reach. Hydrobiologia 598:343–360.

Using dendrochronology to understand historical forest growth, stand development, and gap dynamics

Previous LTRM project:

The plot-level forest biophysical data (i.e., establishment and growth rates) from the 15 study sites can be used to calibrate and validate a newly-developed forest succession model covering forest dynamics across St. Paul, Rock Island and St. Louis Districts (De Jager et al. Unpublished).

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Rock Island District - USACE

Collaborators:

Dr. Grant Harley, Assistant Professor, University of Idaho, Geography Department, 875 Perimeter Dr, MS 3021, Moscow, ID 83844, 208.885.0905, gharley@uidaho.edu, lead report writing, lead field data collection for dendrochronology plot sampling, graduate student oversight, expertise in dendrochronology and ground penetrating radar.

Dr. Justin Maxwell, Assistant Professor, Indiana University, Department of Geography, Student Bldg. 120, 701 E. Kirkwood Ave., Bloomington, IN 47405, 812.855.5557, maxweljt@indiana.edu, contribution to analysis and report writing, graduate student oversight, lead field data collection for canopy dominant trees, expertise in dendrochronology and hydroclimate variability.

Robert Cosgriff, Lead Forester, USACE-St. Louis District, 301 Riverlands Way, West Alton, MO 63386, 636.899.0074, robert.j.cosgriff@usace.army.mil, site selection and project planning

Introduction/Background:

Current and impending changes to temperature and precipitation regimes make it critical to assess existing forest health and better understand the decline of vegetation community diversity during the 20th and 21st centuries. In riparian, bottomland forests, there is a need to understand the longterm response of tree species to physical (flood inundation and sedimentation) and climatic (drought, snow melt) drivers through techniques of dendrochronology. Hard mast forest communities have declined in abundance and diversity in the Eastern United States over the past *ca.* 150 years (*e.g.* Braun 1950; Whitney 1996; Healy et al. 1997; Abrams 2003). The proposed study will focus on [1] the interactions among flood inundation, geomorphic patterns and processes and floodplain vegetation dynamics and [2] the effects of floodplain hydrogeomorphology and vegetation on soil distributions and dynamics within hard mast communities along the Upper Mississippi River. We propose to use northern pecan (*Carya illinoinensis*) to capture trends, patterns, and growth associations over the past century to refine forest management and planning activities and increase the success of forest restoration efforts that promote resilience of hard mast communities along the Upper Mississippi River System (UMRS). Disturbances, those initiated naturally or by humans, impart change in many ecosystems by impacting community dynamics or the composition, structure, and successional trajectories of forest systems through time. Floods and droughts can have significant impacts on tree growth. Radial growth in trees has been shown to be adversely affected both during and immediately following drought events, while overstory trees also exhibit longer post-drought growth reductions (Orwig and Abrams 1997). Soil inundation due to flooding leads to less oxygen available to roots and negatively affects height, leaf, cambial, and reproductive growth of trees (Kozlowski 1985). Topography is one of the most important predictors of vegetation composition within a given region (Danz et al. 2011), especially within bottomland ecosystems prone to periodic flooding. The frequency and intensity of disturbance regimes can have varying effects on communities with regard to fine-scale elevation variance and local-scale topographic conditions (Sousa 1984, Foster 1988, Hylander 2005, Åström et al. 2007). The influence of disturbance on vegetation dynamics is well understood for many upland communities in the northeast (*e.g.* Lorimer 1977; Seymour et al. 2002), mid-Atlantic (*e.g.* Brose et al. 2008), and Southeast (*e.g.* Hart et al. 2008, 2011; Buchanan and Hart 2012; Harley et al. 2015) United States (US). Yet, the role that disturbance (*e.g.* floods, drought, ice storms, insect outbreaks) plays in bottomland hardwood forests, specifically along the UMRS, is less understood. Although baseline information exists regarding the relationship between the annual flooding regime and forest compositional dynamics along the UMRS (DeJager and Rohweder 2011; DeJager 2012; DeJager et al. 2012), dendrochronological information on the composition, structure, and disturbance dynamics is needed in order to develop silvicultural tools for managing and restoring hard mast bottomland forests.

The results from this research will directly influence the silvicultural prescriptions for the forest timber stand improvement features of the Steamboat Island HREP and adaptive management influence to the forest treatment features of the Beaver Island HREP and Keithsburg HREP.   Additionally, this data will provide regional guidance on silvicultural prescriptions to all future UMRR-HREP sites that include forest health and structure development objectives.

Relevance of research to UMRR:

We will use multiple, interdisciplinary methods to refine forest management and planning activities and increase the success of forest restoration efforts that promote resilience of hard mast communities along the UMRS. Specifically, we will address the following research questions:

[1] What are the trends in forest growth that have occurred over the past 150+ years within UMRS floodplain forests and how do those trends relate to forest health?

[2] How are past trends in flood, drought, and sedimentation associated with forest recruitment and growth patterns?

[3] What are the most appropriate stocking densities required for sustainable forest growth and overall forest resilience for multiple floodplain forest communities?

[4] Where will the current UMRS floodplain support hard mast forest communities and resilient stand dynamics for other wetland forest communities?

This research directly addresses Focal Area 4, Subarea 4.2: Understand and quantify floodplain vegetation dynamics, by using dendrochronology methods to understand forest stand dynamics.

Methods:

Dendrochronology and Stand Dynamics Component

Dendrochronology (or tree-ring science) is the science that dates the annual growth rings in trees to their exact calendar year of formation to study processes that affect tree populations. The precisely-dated, high temporal resolution (e.g. annual), and well-replicated nature of techniques of dendrochronology make it a powerful tool within the context of forestry and ecological studies. We will install forest dynamics plots and collect a wide variety of common forestry data (*e.g.* increment cores for tree age and patterns of growth releases and suppressions, crown class, tree height and diameter at breast height (dbh), species type and abundance of seedlings/saplings, size and decay class of dead/downed woody material, stem density/basal area/spatial distribution, canopy crown maps). We will target 15 known old-growth pecan forest stands (sites) across the Rock Island and St. Louis Districts. At each site, we will install a 50 x 100 m rectangular plot within which to collect all forestry data. Within each plot, we will use 4.3 mm interior diameter increment borers to collect 2 cores from the base of each individual tree > 5 cm dbh, as well as target at least 25 canopy dominant pecan individuals within and adjacent to each site for dendrochronological analysis. We will record the location of all stems using a Trimble GPS unit (which typically has accuracy on the order of millimeters). To characterize richness of the sapling layer, all saplings > 1 m tall but < 5 cm dbh will be recorded by species. We will tally by the species the number of seedlings (< 1.5 m height) in smaller, nested 10 m x 20 m plots. Tree canopy crown class was assigned using the following categories: suppressed, intermediate, co-dominant, and dominant and was based on the amount and direction of intercepted light (Oliver and Larson 1996). All data will be collected digitally using an open data kit (ODK) system, as this reduces human error in recording plot-level information and efficiently captures a range of important metadata. The ODK also promotes an easy and efficient method for sharing data with USACE. Tree cores will be mounted, sanded, and crossdated using methods standard to the science of dendrochronology (Stokes and Smiley 1968; Speer 2010). These laboratory procedures will yield a wood surface with clearly discernable cellular features.

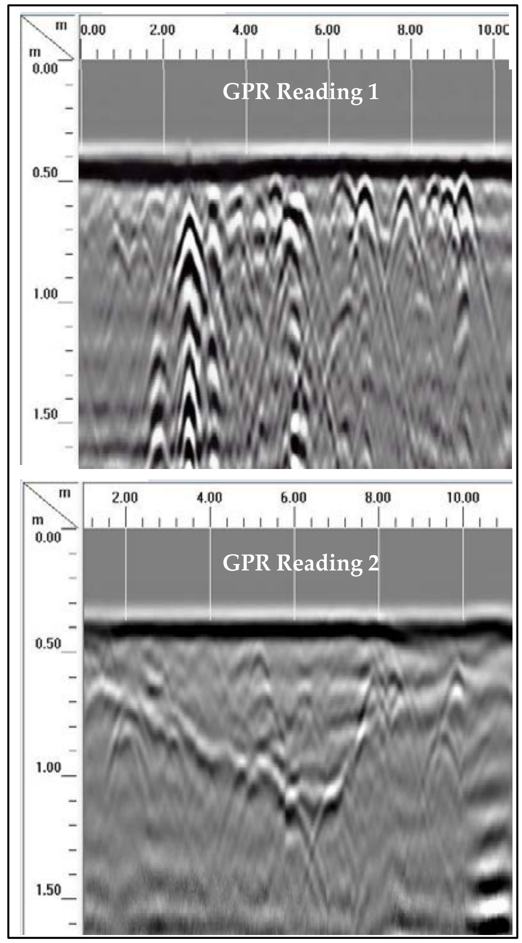

Figure 1. Example ground penetrating radar (GPR) schematic. Top: active return showing soil compression marks from 2.2 m to 9.8 m at the surface (surface calibration is 0.4 m) location. Bottom: showing the change in transmissivity along a diagonal from 0.60 m to 1.2 m depth between overlying unconfined sediments (mud and organic layers) and underlying compacted soil. Figure adapted from Harley et al. (2017).

After all tree cores are cross dated, we will analyze changes in raw ring widths with respect to the running mean of the previous and subsequent 10 years (Nowacki and Abrams 1997). Release (suppression) events will be identified as periods in which raw ring width was ≥ (≤) 25% (minor) or ≥ (≤) 50% (major) of the 10-year preceding and subsequent mean, sustained for a minimum of 3 years (*e.g.* Hart and Grissino-Mayer 2008). We will also develop species-specific ring-width chronologies for climate analysis. We will use Pearson correlation analysis to better understand the relationship between tree growth and climate variables (monthly indices of temperature, precipitation, and drought) during the period 1895–2018. We will also use the North American Drought Atlas (*e.g.* Cook et al. 1999) to analyze the influence of past droughts on tree growth and forest stand dynamics (e.g. establishment, recruitment, mortality) over the past several centuries.

Floodplain Hydrogeomorphology Component

Obtaining the exact germination year when coring a tree (hence, true tree age) requires collecting an increment core sample at the root-shoot interface. Yet, this is an issue in frequently-flooded landscapes, such that the current ground level is likely above the actual root-shoot interface given sediment aggradation from successive flood events. We will use ground-penetrating radar (GPR) to survey and map floodplain sediments within each plot. We will use GPR techniques to acquire data on fluvial sediment depth above compacted soil level, which will, in turn, inform us on coring height for each individual tree (*e.g.* Figure 1). We will then use these data on actual coring height to apply an error term to the coring age in order to achieve the most accurate information on tree age (e.g. Liu 1986).

We will survey the immediate subsurface using a GPR GSSI model SIR-3000 with a 400 MHz antenna mounted on a tri-wheel carriage, which measures return rates of transmissivity variance at the interfaces between materials with different physical and chemical properties (Jol 2008; Conyers 2013). The depth range will be set with a geological media material dielectric constant to match the soil type found at each site, and we will calibrate the linear distance by an attached survey wheel connected to the receiving antenna (Conyers 2006; Goodman and Piro 2013). Each plot will be transected in 1 m intervals using the plot orientation and survey flagging for direction control.

We plan to take advantage of past and on-going USACE research focused on modeling floodplain sediment transport and forest community composition across the Rock Island and St. Louis Districts. We will generate forest health and resilience data that can be used to assess recent modelled applications of forest community diversity and vigor. These data can be used as a way to ground-truth these models in order to make them more accurate and robust.

Special needs/considerations, if any: (e.g., funding needs to be received by 30 January)

Milestones and products

Tracking number	Products		Staff		Milestones

2019DD1	Annual progress summary	Dr. Harley, Dr. Maxwell, MS students, Ben Vandermyde	31 December 2018
2019DD2	Data collection	Dr. Harley, Dr. Maxwell, MS students, Ben Vandermyde, Robert Cosgriff	31 November 2018
2019DD3	Growth-ring chronologies and forest vegetation demographic and biophysical data	Dr. Harley, MS students	31 July 2019
2019DD4	Plot-level 3-dimensional subsurface floodplain sedimentation maps for each study site	Dr. Maxwell, MS students	31 July 2019
2020DD5	Annual progress summary	Dr. Harley, Dr. Maxwell, MS students, Ben Vandermyde	31 December 2019
2020DD6	Baseline dataset for promoting resilience of hard mast forest communities along the UMRS	Dr. Harley, Dr. Maxwell, MS students	30 June 2020
2020D8	Submit draft manuscript	Dr. Harley, Dr. Maxwell, MS students	30 September 2020

We will use these products to increase our systemic understanding of general riparian forest health and the causal mechanisms in the decline of hard mast forest community diversity over the past *ca.* 150 years. The applied nature of the proposed work will aid the USACE in efficient restoration planning efforts. Hard mast forest community types have declined rapidly throughout the Upper Mississippi River corridor. We will use a combination of the primary products to identify the environmental stressor signals in tree growth and forest stand dynamics to better understand this decline and inform methods with which to mitigate the decline. In addition, the plot-level forest biophysical data from the 15 study sites can be used to validate a newly-developed UMRS forest succession model developed for the St. Paul, Rock Island and St. Louis Districts (De Jager et al. Unpublished), as well as link to current dendrochronology studies being conducted in the St. Paul District.

References

Abrams, M.D., 2003. Where has all the white oak gone? *BioScience*, *53*(10), pp.927-939.

Åström, M., Dynesius, M., Hylander, K. and Nilsson, C., 2007. Slope aspect modifies community responses to clear-cutting in boreal forests. *Ecology*, *88*(3), pp.749-758.

Braun, E.L., 1950. Deciduous forests of eastern North America. *Deciduous forests of Eastern North America.*

Brose, P.H., K.W. Gottschalk, S.B. Horsley, P.D. Knopp, J.N. Kochenderfer, B.J. McGuinness, G.W. Miller, T.E. Ristau, S.H. Stoleson, S.L. Stout. 2008. Prescribing regeneration treatments for mixed-oak

forests in the Mid-Atlantic region. Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 100 p.
Buchanan, M.L. and Hart, J.L., 2012. Canopy disturbance history of old-growth Quercus alba sites in the eastern United States: examination of long-term trends and broad-scale patterns. *Forest Ecology and Management*, *267*, pp.28-39.
Conyers, Lawrence B., 2006. Ground-penetrating Radar Techniques to Discover and Map Historic Graves. Historical Archaeology, 64-73.
Conyers, Lawrence B., 2013. Ground-penetrating Radar for Archeology. Altamira Press.
Cook, E.R., Meko, D.M., Stahle, D.W. and Cleaveland, M.K., 1999. Drought reconstructions for the continental United States. *Journal of Climate*, *12*(4), pp.1145-1162.
Danz, N.P., Reich, P.B., Frelich, L.E. and Niemi, G.J., 2011. Vegetation controls vary across space and spatial scale in a historic grassland-forest biome boundary. *Ecography*, *34*(3), pp.402-414.
DeJager, N.R. and J.J. Rohweder. 2011. Spatial scaling of core and dominant forest cover in the Upper Mississippi and Illinois River floodplains, USA. Landscape Ecology 26:697-708.
DeJager, N.R. 2012. Effects of flood frequency and duration on the allometry of community-level stem size-density distributions in a floodplain forest. American Journal of Botany 99:1572-1576.
DeJager, N.R., M. Thomsen and Y. Yin. 2012. Threshold effects of flood duration on the vegetation and soils of the Upper Missississippi River floodplain, USA. Forest Ecology and Management 270: 135-146.
Goodman, Dean and Salvatore Piro, 2013., GPR Remote Sensing in Archaeology. Springer.
Harley, G.L., Maxwell, J.T. and Raber, G.T., 2015. Elevation promotes long-term survival of Pinus elliottii var. densa, a foundation species of the endangered pine rockland ecosystem in the Florida Keys. *Endangered Species Research*, *29*(2), pp.117-130.
Harley, G.L., Maxwell, J.T., Holt, D. and Speagle, C.B., 2017. Construction history of the Deason House, Jones County, Mississippi. *Dendrochronologia*, *43*, pp.50-58.
Hart, J.L. and Grissino-Mayer, H.D., 2008. Vegetation patterns and dendroecology of a mixed hardwood forest on the Cumberland Plateau: implications for stand development. *Forest Ecology and Management*, *255*(5-6), pp.1960-1975.
Hart, J.L., van de Gevel, S.L. and Grissino-Mayer, H.D., 2008. Forest dynamics in a natural area of the southern Ridge and Valley, Tennessee. *Natural Areas Journal*, *28*(3), pp.275-289.
Hart, J.L., Bhuta, A.A. and Schneider, R.M., 2011. Canopy disturbance patterns in secondary hardwood stands on the Highland Rim of Alabama. *Castanea*, *76*(1), pp.55-63.
Healy, W.M., Gottschalk, K.W., Long, R.P. and Wargo, P.M., 1997, March. Changes in Eastern Forests: Chesnut is Gone, Are the Oaks Far Behind? In *Transactions of the North American Wildlife and Natural Resources Conference* (Vol. 62, pp. 249-263). Wildlife Management Institute.
Hylander, K., Dynesius, M., Jonsson, B.G. and Nilsson, C., 2005. Substrate form determines the fate of bryophytes in riparian buffer strips. *Ecological Applications*, *15*(2), pp.674-688.
Foster, D.R., 1988. Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah Forest, south-western New Hampshire, USA. *The Journal of Ecology*, pp.105-134.
Jol, Harry M., ed., 2008. Ground Penetrating Radar Theory and Applications. Elsevier.
Kozlowski, T.T., 1985. Soil aeration, flooding, and tree growth. *Journal of Arboriculture*.
Liu, C.J., 1986. Rectifying radii on off-center increment cores. *Forest science*, *32*(4), pp.1058-1061.
Lorimer, C.G., 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. *Ecology*, *58*(1), pp.139-148.
Nowacki, G.J. and Abrams, M.D., 1997. Radial-growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. *Ecological Monographs*, *67*(2), pp.225-249.
Oliver, C.D. and Larson, B.C., 1996. *Forest stand dynamics: updated edition*. John Wiley and sons.

Orwig, D.A. and Abrams, M.D., 1997. Variation in radial growth responses to drought among species, site, and canopy strata. *Trees*, *11*(8), pp.474-484.

Seymour, R.S. and White, A.S., 2002. Natural disturbance regimes in northeastern North America—evaluating silvicultural systems using natural scales and frequencies. *Forest Ecology and Management*, *155*(1-3), pp.357-367.

Sousa, W.P., 1984. The role of disturbance in natural communities. *Annual review of ecology and systematics*, *15*(1), pp.353-391.

Speer, J.H., 2010. *Fundamentals of tree-ring research*. University of Arizona Press.

Stokes, M.A. and Smiley, T.L., 1968. Tree-ring dating. *Tree-ring dating*.

Whitney, G.G., 1996. From coastal wilderness to fruited plain: a history of environmental change in temperate North America from 1500 to the present. Cambridge University Press. Vancouver.

Forest canopy gap dynamics: quantifying forest gaps and understanding gap – level forest regeneration

Previous LTRM project: This project will create new data, the forest gap layer, based entirely off of existing UMRR and other available data. The primary datasets used for this purpose will be the lidar point clouds used to create the UMRS systemic DEM and the 2010/11 UMRS systemic imagery. Ancillary datasets will include: the 1890 LCU and 2010 LCU, 2015/16 state NAIP imagery, USACE forest inventory dataset, and USDA soils data (SSURGO).

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Introduction/Background:

The current conditions and future trajectory of extant floodplain forest (FF) has received increasing attention from Upper Mississippi River System (UMRS) managers in recent years. A primary concern is the potential for conversion of forest to non-forested systems dominated by herbaceous species, especially the invasive reed canarygrass (*Phalaris arundinacea*, RCG). Independent of the specific threat from RCG, there are likely to be trends toward forest decline as current overstory trees age. There appears to be a pattern of insufficient natural forest regeneration in many areas of the UMRS, potentially resulting in a failure to recruit future cohorts of forest trees. Tree mortality caused by invasive pests, especially Dutch elm disease (*Ophiostoma ulmi* and *O. novo-ulmi*) and emerald ash borer (*Agrilus planipennis*) has and will continue to increase the rate of forest canopy loss.

Forest regeneration is inherently a function of forest disturbance (Runkle 1982, Oliver and Larson 1996), which often increases the availability of resources, such as sunlight and nutrients, for tree seedlings and saplings. Different tree species are adapted to different levels of disturbance but all require some level of disturbance to establish as seedlings and to grow into the canopy. However, regeneration dynamics are also directly impacted by a wide range of site- and landscape-level factors, including soil moisture, light availability, regeneration substrate, herbivory, historic land use, and seed dispersal (Sousa 1984, Kern et al. 2017). The loss of canopy trees, or gap formation, is a discrete disturbance event that should create the necessary conditions for the establishment of a new cohort of seedlings or the release of already established saplings (Kern et al. 2017). In the presence of adverse site- or landscape-level conditions, these gaps may fail to regenerate back to trees, potentially leading to a “demographic disequilibrium” that “triggers forest cover loss” across the landscape (Barrette et al. 2017).

In upland forests, the impact of many of these factors on forest regeneration dynamics are well understood and silvicultural treatments have been designed to promote regeneration of desirable species (e.g. Brose et al. 2008, Leak et al. 2014, Poznanovic et al. 2014). In addition, there is a broad literature base describing landscape-level disturbance dynamics in many of these systems (e.g. Lorimer 1977, Runkle 1982, Frelich and Graumlich 1994, Oliver and Larson 1996, Seymour et al. 2002). Significant work has also been done on restoration techniques in bottomland forests of the southeastern United States (Hodges 1997, Allen et al. 2004, Stanturf et al. 2009). In contrast, bottomland forest systems in the UMRS have been the subject of only a small amount of basic and applied research, thus limiting the applicability of current ecological understanding and silvicultural tools developed in other systems. Though there are many ecological similarities between southeastern bottomland forests and bottomland forests of the UMRS, southeastern forests differ substantially in tree species composition, hydrology and land use history from those of the UMRS. Basic research in the UMRS describing bottomland forest spatial pattern (DeJager and Rohweder 2011), forest compositional dynamics in the context of annual inundation duration (DeJager 2012, DeJager et al. 2012), and herbivory and non-native plant invasion (Thomsen et al. 2012, DeJager et al. 2013, Cogger et al. 2014) is available. However, very little information is available related to the extent or frequency of gap formation in floodplain forests and the rate at which forest gaps are converting to non-forested cover types or returning to forest cover. Further, no comprehensive, system-wide field data are available to document gap-scale drivers of regeneration success or failure.

Relevance of research to UMRR:

In recent years, multiple Habitat Rehabilitation and Enhancement Projects (HREP) have been proposed or initiated with an emphasis on forest rehabilitation at large scales (e.g Reno Bottoms (Pool 9) and Beaver Island (Pool 14)), and future projects promise to place an even greater emphasis on enhancement of existing forest. This study will provide critical information for the selection of project areas and the design of management activities, a quantitative understanding of the drivers of forest loss, indicators of future forest decline, and metrics for assessing the effectiveness of various management actions. At a broad scale, this study will also directly increase our understanding of the relationship between floodplain hydrogeomorphic patterns, forest gap formation, and floodplain forest regeneration in the UMRS.

In particular, this study will ask the following questions:

1. What is the current abundance and distribution of forest canopy gaps in the UMRS, and what proportion of these gaps have been re-colonized by forest tree species relative to herbaceous plants?

2. What site and landscape level variables (e.g., gap size, flood dynamics, soils, surrounding forest) are associated with herbaceous invasion versus forest reestablishment? Is there an association between reestablishment and health and successional dynamics in the surrounding forest?

3. Are there associations between the spatial arrangement of forest gaps and the health of surrounding forests? By integrating geospatial and field-collected data, is it possible to identify forest areas that are most vulnerable to canopy loss in the near-term?

This research directly addresses Focal Area 4, Subarea 4.2: Understand and quantify floodplain vegetation dynamics, specifically sections vi – vii, by using a combination of geospatial and field-based data to map and quantify floodplain forest regeneration dynamics associated with the formation and distribution of canopy gaps across the UMRS landscape.

Methods:

Geospatial component

Creation of a forest gap layer will proceed in two phases: lidar analysis followed by aerial imagery interpretation (Figure 1). The geospatial analysis will use the 2010/11 systemic lidar and imagery dataset to identify all forest canopy gaps between 0.05 ha and 1.0 ha. All floodplain areas (including lowland, floodplain, and swamp) in Pools 8, 9, 13, 21, 24, 26 (through Maple Island just south of L&D 26), and the lower 32 miles of the Illinois River from its confluence with the Mississippi River to Kampsville, IL will be included in the analysis. The maximum gap size of 1.0 ha is set by the existing minimum mapping unit of the 2010 LTRM systemic LCU. Any gap greater than 1.0 ha should already be mapped within the 2010 LCU layer and will be integrated later in the process.

The lidar analysis will use the 2010/11 lidar point cloud to create a surface for the study area in floodplain forest. The surface will show the difference between the first return and the ground elevation (Figure 1.A), revealing where canopy gaps exist. A neighborhood analysis of the difference in surrounding elevation will be conducted to identify the area of each gap. The analysis will identify areas in the floodplain forest where there is minimal difference between the bare earth (ground elevation) and lidar first return (forest canopy top) as compared to the surrounding forest, which has a large difference between the ground elevation and the first return. The resulting surface showing areas of minimal difference will be converted into a forest gap polygon layer with all gaps <0.05 ha and >1.0 ha removed. As a final step, the existing 2010 systemic land cover layer will be analyzed for non-forested polygons <5.0 ha, entirely surrounded by forest, that are composed of vegetation classified as seasonally flooded and drier and these will be included in the gap layer.

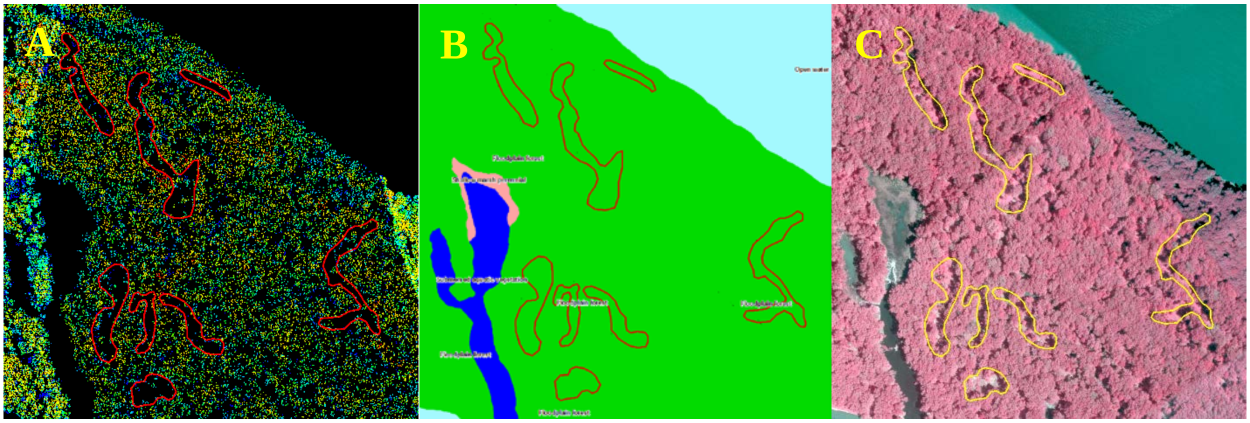

Figure 1: Tile A showing the lidar point cloud along the eastern shore of Railroad Island in Pool 13 with gaps delineated, Tile B showing how these gaps align with the existing 2010 systemic vegetation layer, and Tile C showing these same gaps in the 2010 systemic CIR imagery set.

The initial polygon layer will then be populated with GIS-derived gap metrics (Figure 1.B) for each gap updated from the following layers: 1890 LCU landcover (assuming it is covered), 2010 LCU surrounding forest type(s), distance to nearest neighboring gap (edge to edge), distance to nearest non-forest vegetation and type of non-forest vegetation (edge to edge) using the 2010 LCU, distance to open water (edge to edge) using the 2010 LCU, flooding dynamics (derived flood inundation from M. Van Appledorn, in prep), area of the surrounding forest using the 2010 LCU, gap perimeter-to-area ratio, average forest height in the 10m surrounding each gap, underlying SSURGO soil type (when available), and gap area to 2010 LCU forest polygon area ratio.

Following population of the polygon layer with GIS-derived metrics and ancillary data, it will undergo a rigorous review using the 2010/11 systemic imagery (Figure 1.C). Each gap will be reviewed in stereo to ensure that it is a gap and the image interpreter will attempt to determine the ground cover in the gap (bare earth, vegetation, water, shrubs, trees, unknown), noting that this may not be possible in many instances because of shadows from an overhanging canopy.

Field component

To assess site-level characteristics of forest gaps with and without viable forest regeneration, a subset of gaps will be selected from the gap layer developed in questions 1 and 2. Within each USACE district, a minimum of 27 gaps will be surveyed. Gaps will be selected from the geospatial Study Area and stratified based on the flooding regime (classified as Low, Medium and High utilizing datasets from Van Appledorn et. al 2018 to define flooding regime) and gap size (classified as Small, Medium and Large based on the gap inventory dataset), for a total of nine flooding and gap size combinations. Gaps will not be stratified based on forest type, but forest type will be included as a random effect in the analysis to account for differences in forest composition. Within each category, gaps will be randomly selected for field analysis; inaccessible gaps will be replaced by a randomly selected alternate from the same set. It is anticipated that gaps selected for this study will continue to be monitored over time and reassessed at 5-10 year intervals, so access is an important consideration. Field sampling will occur between June and September of one field season to capture maximum development of vegetation.

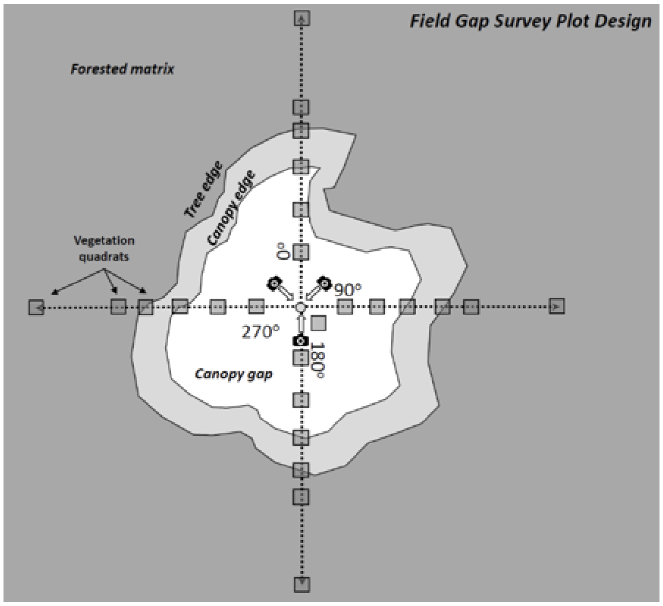

Figure 2. Generalized layout of field sampling in a hypothetical forest gap.

Sampling of selected gaps will be oriented from the GIS derived gap centroid (Figure 2). Prior to sampling, a metal t-post will be placed at the centroid to monument the gap center, and three photos will be taken. At a location offset from the centroid by 2 meters and at a random azimuth from the centroid, a 1 square meter vegetation quadrat will be placed to assess woody and herbaceous vegetation and percent forest canopy. Additional vegetation quadrats will be placed on 4 transects oriented in each cardinal direction (0°, 90°, 180° and 270°) from the centroid. These transects will traverse the gap from centroid to gap edge, then continue 25 meters into the adjacent forested matrix. Along each transect six quadrats will be placed such that: the first and second are equally spaced between the gap centroid and the canopy edge, the third is at the canopy edge, the fourth is at the tree edge (defined as an imaginary line drawn from the gap-ward surface of each tree trunk at the forest edge, see figure 2), the fifth is 5m from the tree edge, and the sixth is 25m from the tree edge.

At each quadrat, the following variables will be recorded: height, species and root collar diameter (and dbh if available) of tallest woody stem, count of all woody stems taller than 0.5 meters by species and height class, an index of stem density of woody species less than 0.5 meters tall, an index of browsing intensity by woody plant species, cover class and average height of native herbaceous vegetation by species, cover class and average height of non-native herbaceous vegetation by species, and a densiometer measurement to quantify canopy density.

Soil texture, percent organic matter, and carbon-to-nitrogen ratio will be analyzed in each gap and the forest matrix adjacent to each gap. Soil samples will be collected at the gap centroid and at one random quadrat along each transect inside of the gap then aggregated for a gap soil sample. One soil sample will also be taken at one of the two quadrats in the forest outside of the gap on each transect and these will be aggregated for a forest matrix soil sample. In total, five soil samples will be collected within the gap and four will be collected in the surrounding forest.

To assess forest conditions in the matrix surrounding selected gaps, and to determine whether any characteristics of the surrounding forest are related to the vegetation inside forest gaps, a combination of remotely sensed LTRM data, the geospatial gap analysis in this study, and previously collected USACE and USFWS forest inventory (FI) data will be summarized for the forested area adjacent to gaps and compared to gap level vegetation data. Within a neighborhood of 150 meters of the outermost edge of each study gap the 1989 and 2010 USGS Landcover/Land Use (LC/LU) layers will be joined with the average change in canopy cover between datasets and the 2010 average canopy cover summarized for the neighborhood. FI plots within the same neighborhood will be summarized based on field-collected tree basal area, canopy cover, regeneration rating, and presence of invasive species, per the standard USACE FI protocol. If established forest inventory plots are not available in the area surrounding the gap, new pseudo-inventory plots will be placed in a location on the established FI grid where forest inventory plots would occur. The new pseudo-inventory plots will not include a full forest inventory sample. Instead, the summary variables described above will be recorded for the new plots.

Two sets of data analyses will be conducted to quantify associations between canopy gap formation and forest regeneration. The first set of analyses will be conducted at the canopy-gap scale. We will calculate a series of patch-based metrics, including size, perimeter, and perimeter-area fractal dimension. These metrics will then be used to quantify associations between gap-level characteristics and field measurements (e.g., woody stem densities, herbaceous cover, presence and percent cover of invasive species). The second set of analyses will be conducted at the landscape scale. We will calculate a series of landscape-based metrics, such as mean patch size, landscape shape index, landscape cohesion. Such metrics provide indices of the degree of landscape-scale fragmentation, based on the amount, size, and distribution of individual canopy gaps that exist within the landscape. These metrics will most likely be calculated at the scale of the individual navigation pool and then be related to the patch-scale field measurements aggregated at the pool scale (e.g., mean and variance of woody stem densities, herbaceous cover, presence and percent cover of invasive species).

Products and Milestones

Tracking number	Products	Staff	Milestones
2019FG1	Completion of polygon layer of canopy gaps for Study Area with associated tabular and FGDC-compliant metadata	Strassman, Sattler, Hoy	30 April 2019
2020FG2	Annual progress summary	Meier, Strassman	31 December 2018
2020FG3	Data collection	Thomsen, Vandermyde, Guyon	31 October 2019
2020FG4	Annual progress summary	Meier, Strassman	31 December 2019

2020FG5	Submit draft LTRM Completion Report	Guyon, Thomsen, Meier, Strassman	30 September 2020
2020FG6	Baseline dataset complete	Guyon, Thomsen, Meier, Strassman, DeJager	30 September 2020
2020FG7	Submit draft manuscript	Guyon, Thomsen, Meier, Strassman, DeJager	30 September 2021

References:

Allen, J.A., B.D. Keeland, J.A. Stanturf, A.F Clewell, and H.E. Kennedy, Jr. 2001 (revised 2004). A guide to bottomland hardwood restoration. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD/ITR–2000-0011, U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS–40, 132 p.

Barrette, M., L. Bélanger, L. De Grandpré, and A.A. Royo. 2017. Demographic disequilibrium caused by canopy gap expansion and recruitment failure triggers forest cover loss.

Brose, P.H., K.W. Gottschalk, S.B. Horsley, P.D. Knopp, J.N. Kochenderfer, B.J. McGuinness, G.W. Miller, T.E. Ristau, S.H. Stoleson, S.L. Stout. 2008. Prescribing regeneration treatments for mixed-oak forests in the Mid-Atlantic region. Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 100 p.

Cogger, B.J., N.R. DeJager, M. Thomsen, C. Reinhardt-Adams. 2014. Winter browse selection by white-tailed deer and implications for bottomland forest restoration in the Upper Mississippi River Valley, USA. Natural Areas Journal 34: 144-153.

DeJager, N.R. and J.J. Rohweder. 2011. Spatial scaling of core and dominant forest cover in the Upper Mississippi and Illinois River floodplains, USA. Landscape Ecology 26:697-708.

DeJager, N.R. 2012. Effects of flood frequency and duration on the allometry of community-level stem size-density distributions in a floodplain forest. American Journal of Botany 99:1572-1576.

DeJager, N.R., M. Thomsen and Y. Yin. 2012. Threshold effects of flood duration on the vegetation and soils of the Upper Missississippi River floodplain, USA. Forest Ecology and Management 270: 135-146.

DeJager, N.R., B.J. Cogger, and M.A. Thomsen. 2013. Interactive effects of flooding and deer (*Odocoileus virginianus*) browsing on floodplain forest recruitment. Forest Ecology and Management 303: 11-19.

Frelich, L.E. and L.J. Graumlich. 1994. Age-class distribution and spatial patterns in an old-growth hemlock-hardwood forest. Can. J. For. Res. 24: 1939-1947.

Hodges, J.D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management 90: 117-125.

Kern, C.C., J.I. Burton, P. Raymond, A.W. D'Amato, W.S. Keeton, A.A. Royo, M.B. Walters, C.R. Webster and J.L. Willis. 2017. Challenges facing gap-based silviculture and possible solutions for mesic norther forests in North America. Forestry 90: 4-17.

Leak, W.B., M. Yamasaki, R. Holleran. 2014. Silvicultural guide for northern hardwoods in the northeast. Gen. Tech. Rep. NRS-132. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 46 p.

Oliver, C.D. and B.C. Larson. 1996. Forest Stand Dynamics. John Wiley & Sons, Inc., New York, New York. 520 pp.

Lorimer, C.G. 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. Ecology 58: 139-148.

Poznanovic, S.K., A.J. Poznanovic, C.R. Webster and J.K. Bump. 2014. Spatial patterning of underrepresented tree species in canopy gaps 9 years after group selection cutting. Forest Ecology and Management 331: 1-11.

Runkle, J.R. 1982. Patterns of disturbance in some old-growth mesic forest of eastern North America. Ecology 63: 1533-1546.

Seymour, R.S., A.S. White and P.G. deMaynadier. 2002. Natural disturbance regimes in northeastern North America—evaluating silvicultural systems using natural scales and frequencies. Forest Ecology and Management 155: 357-367.

Sousa, W.P. 1984. The role of disturbance in natural communities. Annual Review of Ecology and Systematics 15: 353-391.

Stanturf, J.A., E.S. Gardiner, J.P. Shepard, C.J. Schweitzer, C.J. Portwood, and L.C. Dorris, Jr. 2009. Restoration of bottomland hardwood forests across a treatment intensity gradient. Forest Ecology and Management 2009: 1803-1814.

Thomsen, M, K. Brownell, M. Groshek, E. Kirsch. 2012. Control of reed canarygrass promotes wetland herb and tree seedling establishment in an Upper Mississippi River floodplain forest. Wetlands 32: 543-555.

Investigating vital rate drivers of UMRS fishes to support management and restoration

Previous LTRM project:

Recently, there have been a number of LTRM projects investigating age and growth, including *Smallmouth Buffalo population demographics of the Upper Mississippi River Basin* (2018SMBF, Levi Solomon), *Collection and archiving of age and growth structure for selected species in the La Grange Reach of the Illinois River* (2016B7, Levi Solomon), *Sex-Specific Age Structure, Growth, and Mortality of Black and White Crappie in Pool 13 of the Upper Mississippi River* (2014, Mel Bowler), age and growth of common carp, grass carp, silver carp, and bighead carp (Michael Wolf and Quinton Phelps), age and growth of black crappie (Tyler Ham and Quinton Phelps), and quantification of Freshwater drum vital rates from otoliths collected from across the system in the early 1990's (Special Project M-006), conducted by Josh Abner and Quinton Phelps.

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The following UMESC, USGS staff will provide data management support:
Ben Schlifer, USGS, bschlifer@usgs.gov

The following individuals will oversee project components, conduct data analyses, and write manuscripts:

Vital rates – Quinton Phelps and two MS students (Hae Kim)

Microchemistry – Greg Whitledge (SIU, gwhit@siu.edu) and PhD student

(Genetics – Wes Larson (Assistant Unit Leader, USGS Coop Unit, UW-SP, wes.larson@uwsp.edu) and MS student Not Funded)

Introduction/Background:

Vital rates (i.e., recruitment, growth, and mortality) are the processes responsible for changes in abundance and biomass of a population through time. Knowledge of vital rates can therefore provide critical information in determining why fish population abundances increase or decrease across time and space. For example, high mortality, low recruitment and a shift toward older individuals in shovelnose sturgeon populations of the Middle Mississippi River indicated future population losses in the absence of management actions (Colombo et al. 2007; Tripp et al. 2009). Unlike catch-per-unit-effort data, measurements of vital rates are relatively unaffected by gear efficiency and selectivity, and often reflect immediate responses to driving forces. In river systems, fish population dynamics are commonly driven by abiotic drivers, such as temperature and river flow, more so than biotic drivers (Van Den Avyle and Hayward 1999). Understanding the factors that contribute to inter-annual variability in recruitment, growth, and mortality is critical to understand population dynamics in the Upper Mississippi River System.

A number of ecological theories provide insight into the likely factors important to fish population dynamics in large rivers. For example, the flood pulse concept (FPC) postulates that fishes that are adapted to predictable flood pulses make efficient use of the aquatic/terrestrial transition zone (Junk et al. 1989). Under this concept, it is hypothesized that appropriately-timed flood events support enhanced growth in flood-adapted fishes. However, differential growth rates across species suggests that growth response to flood pulses may partially depend upon trophic position (Gutreuter et al. 1999). Further, a critical assumption of this hypothesis is that the aquatic/terrestrial transition zone provides shallow, warm, productive, low-velocity habitats with submersed terrestrial vegetation, which may not occur in all river reaches given the present-day channel geometry. To evaluate patterns in vital rates and improve our understanding of the underlying factors that influence population dynamics, our primary research questions are: 1) Are there patterns of vital rates within and among species across time or space in the UMRS? and 2) How are vital rates within and across species associated with differences in abiotic and biotic drivers in LTRM reaches? With respect to UMRR, improved understanding of the role of hydrogeomorphic conditions (i.e., flow, temperature, habitat availability) on vital rates can provide insight into how river restoration can more effectively influence fish populations and communities.

Similar to analysis of growth rings on a tree, vital rates are determined through analysis of growth rings on select hard structures (e.g., otoliths) from sampled fish. Additional analyses can be performed on the collected specimens to advance our understanding of vital rate findings, contribute to the overall understanding of patterns and trends among fishes in the UMRS, and inform UMRR program themes and focal areas. Thus, we present two additional project components below: otolith microchemistry and genetic analysis. Since the collection of otoliths from fishes requires sacrificing fish; we believe the inclusion of the two additional components exercises good stewardship of the resource and fiscal responsibility by maximizing the information extracted from the collected specimens.

Otolith microchemistry is a technique to reconstruct the environmental history of fishes (i.e., the areas of the river where they have spent substantial time). As fish grow, the elemental and stable isotopic composition of the water body they inhabit is transcribed into otoliths, fin rays and spines. Environmental history can then be reconstructed by associating changes in chemical composition with respect to locations of annual growth marks in these structures. This technique is particularly useful for identifying natal environments where fish spend their early life history, the scarcity of which is thought to limit fish populations in highly channelized rivers. Within the UMRS, microchemistry has been used to identify natal origins for bigheaded carps, *Scaphirhynchus* sturgeons, channel catfish, and blue catfish (Phelps et al. 2010; Norman and Whitledge 2015; Laughlin et al. 2016; Porreca et al. 2016). The majority of this work has been conducted in the Illinois River, the Unimpounded Reach (i.e., Middle Mississippi River) and the Lower Impounded Reach (Pools 14-26), and is generally able to provide resolution at the floodplain reach scale; this method has not yet been used extensively in the Upper Impounded Reach. A library of UMRS water samples (2006-2014) indicate water chemistry signatures for the Middle Mississippi River and tributaries are relatively stable across time (Laughlin et al. 2016). Research questions proposed to complement the vital rates proposal through the use of otolith microchemistry are: 1) to what extent are spatial and temporal patterns in recruitment/year class strength driven by "local" recruits vs. immigrants from other reaches of the river? and 2) are there particular natal environments that consistently support strong year classes? Through spatially and temporally understanding source and sink dynamics, we can improve our understanding of relationships between hydrogeomorphology and recruitment.

Genetic analyses can be used to examine genetic population structure, genetic diversity, connectivity, and adaptive divergence among populations. Historically, genetic analyses of freshwater fish, have utilized data from 10-100 neutral genetic markers (e.g. microsatellites). These markers can provide important information on connectivity (intermixing populations) and genetic diversity that can be used to construct genetic management units with the goal of protecting discrete stocks. Recently, significant advances in sequencing technology have led to a "genomic revolution" that has made it possible to quickly and affordably genotype thousands of markers in nearly any species. These technological advances have made it possible to genotype orders of magnitude more neutral markers as well as investigate markers under selection that reflect adaptive divergence across populations. Pairing data from neutral markers and markers under selection can provide a much more complete picture of how populations use and adapt to their environment (Funk et al. 2012).

Genetic analysis has only been conducted on a few species across the UMRS and genomic analyses have not been conducted on any native species in this area to the best of our knowledge. One previous study conducted in this region indicated that genetic structure of blue sucker, which are highly migratory, large river specialists, has not been significantly impacted by lock and dams in the UMRS (Bessert and Orti 2008). However, it is likely that fish with different life histories will display different patterns of genetic structure (e.g. Blanchet et al. 2010).

We expect a spectrum of genetic isolation to occur from lotic to lentic species in the UMRS, especially across gradients of life history strategy. For example, we expect that nest building lentic fishes, such as centrarchids, will display higher levels of genetic differentiation among reaches than pelagic spawning lotic fishes, such as freshwater drum (e.g. Stepien et al. 2007). Once genetic structure is determined, these data can be paired with vital rates to determine how rates correspond to genetic stock boundaries and paired with microchemistry data to investigate patterns of connectivity across multiple timescales. Genetics research questions include: 1) what is the population structure and diversity of UMRS fishes?, 2) do different genetic stocks of the same species exhibit differences in vital rates?, and 3) are there indications of adaptive differentiation across populations and are these patterns congruent across species?

Table 1. Primary research questions and lead investigators of the proposed project components.

Project component	**Research Question**	**Lead Investigator**
Vital Rates	1) Are there patterns of vital rates within and among species across time or space in the UMRS?	Dr. Quinton Phelps (WVU) and two masters students
	2) How are vital rates within and across species associated with differences in abiotic and biotic drivers in LTRM reaches?	Dr. Kristen Bouska (UMESC)
Microchemistry	1) To what extent are spatial and temporal patterns in recruitment/year class strength driven by "local" recruits vs. immigrants from other reaches of the river?	Dr. Greg Whitledge (SIU) and a doctoral student
	2) Are there particular natal environments that consistently support strong year classes?	
Genetics	1) What is the population structure and diversity of UMRS fishes?	Dr. Wes Larson (UWSP) and a masters student
	2) Do different genetic stocks of the same species exhibit differences in vital rates?	
	3) Are there indications of adaptive differentiation across populations and are these patterns congruent across species?	

Relevance of research to UMRR:

The proposed research addresses Focal Area 3 (Interactions and associations of hydrogeomorphology with biota and water quality) and Focal Area 5 (Vital rates of biotic communities) of the 2018 Focal Areas for UMRR Science in Support of Management.

Age, growth, recruitment and mortality data provide managers with information to improve their understanding of the probable causes of changes in fish abundance and community structure. This study will provide vital rate snapshots for thirteen different species to inform their specific population status. The development of a stand-alone vital rates database of UMRS fishes will provide a reference point that will allow a better understanding of future changes in the river. For example, the impact of HREPs, disturbance events, or long-term ecological trends can be quantified by evaluating changes in vital rates.

While species-specific information is critical for understanding the ecology and management of individual species, a life history perspective allows for understanding broader patterns in the fish community (Winemiller and Rose 1992). Species for this study were selected to represent the diversity of known life history strategies of freshwater fish. By investigating the role of abiotic drivers on population dynamics across a spectrum of life history strategies, we can evaluate the applicability of predominant ecological theories (e.g., FPC) to the UMRS. Selection of systemically abundant species further allows for assessment of these theories across a gradient of hydrogeomorphic conditions.

Microchemistry and genetics analyses provide additional, complementary information on natal origin and genetic structure that will lead to a more complete understanding of the spatial ecology of riverine fishes (Campana and Thorrold 2001; Collins et al. 2013). Specifically, microchemistry provides data on where fish reside in their early life history, which represents an important step towards understanding the habitats that support early life stages. Microchemistry may inform where restoration of nursery habitats may be beneficial. Genetic analysis provides data on the spatial extent and rate that populations exchange migrants over evolutionary timescales (100s to 1000s of years). Pairing microchemistry and genetics techniques offers the potential for greater resolution in assessing population boundaries and intermixing. As a result, the identification of isolated fish populations and their place(s) of origin may support the development of relevant management units (Porreca et al. 2016) and identify biologically-meaningful scales at which to assess habitat availability.

Methods:

We carefully selected candidate species (Table 2) based on 1) life history strategy, 2) systemic and regional distribution, and 3) the ability of LTRM field stations to collect the majority of samples during regular LTRM field sampling. Further, candidate species represent a mix of game, commercial, non-game, and an invasive species.

We propose three consecutive years of fish collection for vital rates, starting in summer 2018 (Table 2). The LTRM fish specialists will lead data collection from their respective pools. For each species, the target goal is to collect 10 individuals of each centimeter length group from each LTRM pool annually. If a species is usually represented by fewer than ten length groups or is seldom caught in large enough numbers to fill most length bins, then we will attempt to collect a minimum of 100 individuals for that species, regardless of length. Samples will be collected from pool 4 (Lake City, Minnesota, RKM 1210-1283), pool 8 (La Crosse, Wisconsin, RKM 1092-1131), pool 13 (Bellevue, Iowa, RKM 841-896), pool 26 (Alton, Illinois, RKM 325-389), La Grange Pool (Illinois River, RKM 80-158) and the open river (Cape Girardeau, Missouri, RKM 47-129). Individuals of each species will be collected using the same gear (Table 2) across all reaches. Standardized LTRM protocols will be followed in the collection of all species, whether collected during regular LTRM sampling or in targeted sampling (Ratcliff et al. 2014). Upon collection, total length and weight will be recorded from each fish. Individual fish will then be bagged with a unique individual fish barcode affixed, and frozen for storage until dissection. Barcodes will used to track all fish from collection through analysis. Individual fish barcodes will be linked to the LTRM sample barcodes within the fish data entry application. Fish hard parts (e.g., otoliths) will be removed from the fishes, sectioned and aged to determine population age structure. Age estimates will be determined by two independent readers. In the event of a disagreement, a third reader will be used to resolve discrepancies. Otoliths will be organized by barcode and stored at the Big Rivers and Wetlands Field Station after processing. For each fish population sample, we will quantify vital rates (recruitment, growth, and mortality; see below).

Table 2. Species selected for estimation of vital rates, microchemistry (MC) and genetic (GE) analyses.

Species	**Trophic Guild**	**Life history strategy**	**Method**	**Vital rate years sampled**	**MC and GE years sampled**
System-wide					
Emerald shiner	Herbivore	Opportunistic	Electrofishing	1, 2, 3	1
Bullhead minnow	Herbivore	Opportunistic	Mini-fyke	1, 2, 3	1
Channel catfish	Omnivore	Equilibrium	Hoop nets	1, 2, 3	1
Freshwater drum	Invertivore/carnivore	Periodic	Electrofishing	1, 2, 3	1
Bluegill	Invertivore	Equilibrium	Electrofishing	1, 2, 3	1
Gizzard shad	Herbivore	Periodic	Electrofishing	1, 2, 3	1
Pools 4/8/13					
Bowfin	Carnivore	Equilibrium	Fyke nets	2, 3	
Yellow perch	Invertivore/carnivore	Periodic	Electrofishing	2, 3	
Shorthead redhorse	Invertivore	Periodic	Electrofishing	2, 3	
Sauger	Carnivore	Periodic	Electrofishing	2, 3	
Pools 26/IWW/Open River					
Silver carp	Herbivore	Periodic	Electrofishing	2, 3	
Orangespotted sunfish	Invertivore	Equilibrium	Electrofishing	2, 3	
River carpsucker	Planktivore/detritivore	Periodic	Electrofishing	2, 3	

Dr. Quinton Phelps will oversee two graduate students in the quantification of vital rates. To determine the relative number of fish that are entering (i.e., recruiting) the system each year, the number of fish in each year class will be quantified. Ages derived from fish hard parts will be used to determine recruitment patterns. For each age class present in all six river reaches, we will quantify the relative strength or weakness of each cohort within each reach using the residual method (Maceina 1997). Specifically, positive residual values from the regression would indicate a relatively strong year class while negative residuals would indicate weak year classes. Recruitment variability will be quantitatively analyzed using recruitment coefficient of determination (Isermann et al. 2002).

Mortality rates of the individual species in the Mississippi River basin will be determined using a catch-curve approach (Ricker 1975). Catch curves will be generated by summing the number of fish caught per age class in each individual river reach. These data will allow for the development of individual regression models to estimate instantaneous mortality. Instantaneous mortality rate (Z), which will be used to determine the total annual mortality ($A = 1 - e^{-Z}$) for selected fishes from each river reach.

Gender-specific growth will be estimated for each species in each reach by determining the mean length-at-age. Mean length-at-age data will be incorporated into Fisheries Analysis and Modeling Simulator (Slipke and Maceina 2010) and will be used to model growth using a von Bertalanffy approach (von Bertalanffy 1938). The equation generated using the von Bertalanffy growth model is $L_t = L_\infty(1-e(-K(t-t_0))$; where, Length infinity (L_∞) is the theoretical maximum length that a fish can achieve, K is the growth constant or growth rate of the population, and t_0 is the theoretical length at time zero (i.e., age 0).

We will cross-correlate the relative strength or weakness of year classes (residual values) from the catch-curve regression from each individual reach for each of the selected species with all other reaches of the UMR. This will allow us to determine if recruitment patterns were similar among river reaches. To determine if differences in mortality occurred among reaches for selected fishes, we will compare the mortality rates among river reaches using the homogeneity of slopes test (i.e., test of interaction using ANCOVA). The overall growth curves generated for selected fishes at all river reaches will be compared using the residual sums of squares from the coinciding von Bertalanffy models. The individual parameters of the von Bertalanffy model will be used to descriptively compare among locations. Specifically, theoretical maximum length, and the Brody growth coefficient will be compared among sites.

Using LTRM data, period three age-0 length for each species will be estimated annually using linear regression with Julian day as an independent variable and length as a dependent variable (M. Bowler). Age-0 length estimates will be evaluated in response to a suite of abiotic and biotic variables using a mixed effects model (Weisberg et al. 2010). Similarly, annual growth estimates and year-class strength from the vital rates quantification will be assessed using a mixed effects model. Explanatory variables will include aspects of hydrology (e.g., mean annual discharge during growing season; number of days with discharge > 75^{th} percentile), temperature (e.g., growing degree days; number of days >15°C; number of days between ice-out and spawning temperature), terrestrial inundation (e.g., number of days of overbank flow; duration and extent of floodplain inundation) and habitat availability (e.g., nursery habitats could be approximated by perimeter of river edge/river mile; or area of shallow water/river mile; potential SAV growth zone [John Kalas, WDNR, pers. comm.).

Microchemistry will be conducted on six of the system-wide species: emerald shiner, bullhead minnow, channel catfish, bluegill, freshwater drum, and gizzard shad. Dr. Greg Whitledge and a doctoral student will lead the microchemistry component. Water samples will be collected from each LTRM reach and from nearby tributaries of the UMRS for analysis of strontium (Sr), barium (Ba) and calcium (Ca) concentrations. Water samples will be filtered in the field by LTRM crews (Shiller 2003) and analyzed using inductively coupled plasma mass spectrometry (ICPMS) by the doctoral student. Otolith microchemistry will be conducted on a subset of each species (n=50) from each LTRM reach. Sectioned otoliths (either those previously used for age estimation or a second otolith from each fish) will be analyzed for Sr:Ca and Ba:Ca using laser ablation-ICPMS. The laser will ablate a transect from the center of each otolith to the otolith edge to encompass the entire chronological record of each fish's environmental history. Natal environment will be inferred for each fish by comparing otolith core (the portion of the structure that reflects early life history) Sr:Ca and Ba:Ca to expected otolith chemical 'signatures' (Sr:Ca and Ba:Ca) of potential natal locations in the UMRS. Location-specific chemical 'signatures' will be calculated using water chemistry data (proposed collections and existing data) and relationships between otolith and water chemistry for the six species listed above (Zeigler and Whitledge 2010); Laughlin et al. 2016; Whitledge, unpublished). Data on natal environments contributing to each of the six fish species in each LTRM reach will be analyzed in relation to year class strength indices derived from the residual method. Movement patterns of fish among chemically-distinct locations in the UMRS will also be inferred from changes in Sr:Ca and Ba:Ca along laser ablation transects.

In 2018, fin clips of individual fish will be taken in the field, preserved in 95% non-denatured ethanol, labeled with appropriate barcode, and stored at room temperature. Genomic analysis will be conducted on a subset of each of the six system-wide species (n=50 adults) from each LTRM reach (when funding becomes available).

Table 3. A general timeline of all project components and tasks.

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<tr><th colspan="2" rowspan="2">Task</th><th colspan="2">2018</th><th colspan="3">2019</th><th colspan="3">2020</th><th colspan="3">2021</th></tr>
<tr><th>Sum</th><th>Fall</th><th>Spr</th><th>Sum</th><th>Fall</th><th>Spr</th><th>Sum</th><th>Fall</th><th>Spr</th><th>Sum</th><th>Fall</th></tr>
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<tr><td>Data QA/QC</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#c0c0c0"></td><td></td></tr>
<tr><td>Vital Rate Final Report/Manuscripts</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#c0c0c0"></td></tr>
<tr><td>Annual age-0 length estimation</td><td bgcolor="#c0c0c0"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Statistical analysis: test drivers of vital rate variability</td><td></td><td></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td></td></tr>
<tr><td rowspan="2">Microche mistry</td><td>Laboratory analysis</td><td></td><td></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Statistical analysis</td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td bgcolor="#c0c0c0"></td><td></td><td></td><td></td></tr>
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	Microchemistry Final Report/Manuscripts											
Genetics	Laboratory analysis											
	Sta											
	Genetics Final Report/Manuscripts											
All	Annual report											

Not Funded

Products and Milestones

Tracking number	Products	Staff	Milestones
2019VR1	Data collection will occur during regular LTRM fish field sampling	LTRM Fish Component Leads	15 October 2018
2019VR2	Processing of samples	Quinton Phelps. Greg Whitledge	2018 through 2021
2019VR3	Annual progress summary	Andy Bartels, Kristen Bouska, Quinton Phelps	31 December 2018
2019VR4	Data collection will occur during regular LTRM fish field sampling	LTRM Fish Component Leads	15 October 2019
2019VR5	Annual progress summary	Andy Bartels, Kristen Bouska, Quinton Phelps, Greg Whitledge	31 December 2019
2019VR6	Data collection will occur during regular LTRM fish field sampling	LTRM Fish Component Leads	15 October 2020
2019VR7	Annual progress summary	Andy Bartels, Kristen Bouska, Quinton Phelps, Greg Whitledge	31 December 2020
2019VR8	Data set complete (data delivered to Ben Schlifer, physical structures delivered to BRWFS)	Quinton Phelps	30 September 2021
2019VR9	Submit draft manuscript (Vital rates)	Quinton Phelps, Kristen Bouska	31 December 2021
2019VR10	Submit draft manuscript (Drivers of vital rates)	Quinton Phelps, Kristen Bouska	31 December 2021
2019VR11	Submit draft manuscript (Microchemistry)	Greg Whitledge	31 December 2021

Literature Cited

Ali, O. A., S. M. O'Rourke, S. J. Amish, M. H. Meek, G. Luikart, C. Jeffres & M. R. Miller, 2015. RAD capture (Rapture): flexible and efficient sequence-based genotyping. Genetics doi:10.1534/genetics.115.183665.

Andrews, K. R., J. M. Good, M. R. Miller, G. Luikart & P. A. Hohenlohe, 2016. Harnessing the power of RADseq for ecological and evolutionary genomics. Nat Rev Genet 17:81-92 doi:10.1038/nrg.2015.28 http://www.nature.com/nrg/journal/v17/n2/abs/nrg.2015.28.html#supplementary-information.

Bessert, M. L. & G. Orti, 2008. Genetic effects of habitat fragmentation on blue sucker populations in the upper Missouri River (Cycleptus elongatus Lesueur, 1918). Conserv Genet 9:821-832.

Blanchet, S., O. Rey, R. Etienne, S. Lek & G. Loot, 2010. Species-specific responses to landscape fragmentation: implications for management strategies. Evol Appl 3:291-304 doi:10.1111/j.1752-4571.2009.00110.x.

Campana, S. E. & S. R. Thorrold, 2001. Otoliths, increments, and elements: keys to a comprehensive understanding of fish populations? Can J Fish Aquat Sci 58:30-38.

Catchen, J., P. A. Hohenlohe, S. Bassham, A. Amores & W. A. Cresko, 2013. Stacks: an analysis tool set for population genomics. Mol Ecol 22:3124-3140 doi:10.1111/mec.12354.

Collins, S. M., N. Bickford, P. B. McIntyre, A. Coulon, A. J. Ulseth, D. C. Taphorn & A. S. Flecker, 2013. Population Structure of a Neotropical Migratory Fish: Contrasting Perspectives from Genetics and Otolith Microchemistry. T Am Fish Soc 142:1192-1201.

Colombo, R. E., J. E. Garvey, N. D. Jackson, R. Brooks, D. P. Herzog, R. A. Hrabik & T. W. Spier, 2007. Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse? J Appl Ichthyol 23:444-451.

Funk, W. C., J. K. McKay, P. A. Hohenlohe & F. W. Allendorf, 2012. Harnessing genomics for delineating conservation units. Trends in Ecology & Evolution 27:489-496 doi:10.1016/j.tree.2012.05.012.

Gutreuter, S., A. D. Bartels, K. Irons & M. B. Sandheinrich, 1999. Evaluation of the flood-pulse concept based on statistical models of growth of selected fishes of the Upper Mississippi River system. Can J Fish Aquat Sci 56:2282-2291.

Isermann, D. A., W. L. McKibbin & D. W. Willis, 2002. An analysis of methods for quantifying crappie recruitment variability. North American Journal of Fisheries Management 22:1124-1135.

Junk, W. J., P. B. Bayley & R. E. Sparks, The flood pulse concept in river-floodplain systems. In: Dodge, D. P. (ed) International Large River Symposium, Ottawa, Canada, 1989. vol 106. Canadian Special Publication of Fisheries and Aquatic Sciences, p 110-127.

Larson, W. A., L. W. Seeb, M. V. Everett, R. K. Waples, W. D. Templin & J. E. Seeb, 2014. Genotyping by sequencing resolves shallow population structure to inform conservation of Chinook salmon (*Oncorhynchus tshawytscha*). Evol Appl 7:355-369 doi:10.1111/eva.12128.

Laughlin, T. W., G. W. Whitledge, D. C. Oliver & N. P. Rude, 2016. Recruitment Sources of Channel and Blue Catfishes Inhabiting the Middle Mississippi River. River Res Appl 32:1808-1818.

Maceina, M. J., 1997. Simple application of using residuals from catch-curve regressions to assess year-class strength in fish. Fish Res 32:115-121.

Norman, J. D. & G. W. Whitledge, 2015. Recruitment sources of invasive Bighead carp (Hypopthalmichthys nobilis) and Silver carp (H-molitrix) inhabiting the Illinois River. Biol Invasions 17:2999-3014.

Phelps, Q. E., S. J. Tripp, J. E. Garvey, D. P. Herzog, D. E. Ostendorf, J. W. Ridings, J. W. Crites & R. A. Hrabik, 2010. Habitat use for age-0 shovelnose sturgeon and pallid sturgeon in a large river: interactions among abiotic factors, food, and energy intake. North American Journal of Fisheries Management 32:24-51.

Porreca, A. P., W. D. Hintz, G. W. Whitledge, N. P. Rude, E. J. Heist & J. E. Garvey, 2016. Establishing ecologically relevant management boundaries: linking movement ecology with the conservation of Scaphirhynchus sturgeon. Can J Fish Aquat Sci 73:877-884.

Ratcliff, E. N., E. J. Gittinger, T. M. O'Hara & B. S. Ickes, 2014. Long term resource monitoring program procedures: Fish monitoring. A program report submitted to the U.S. Army Corps of Engineers' Upper Mississippi River Restoration - Environmental Management Program, Program Report LTRM 2014-P001.

Ricker, W. E., 1975. Computations and interpretation of biological statistics of fish populations. Journal of the Fisheries Research Board of Canada 191.

Shiller, A. M., 2003. Syringe filtration methods for examining dissolved and colloidal trace element distributions in remote field locations. Environ Sci Technol 37:3953-3957.

Slipke, J. W. & M. J. Maceina, 2010. Fishery analysis and modeling simulator (FAMS). Auburn University, Department of Fisheries and Applied Aquaculture, Agricultural Experiment Station, Auburn, Alabama.

Stepien, C. A., D. J. Murphy & R. M. Strange, 2007. Broad- to fine-scale population genetic patterning in the smallmouth bass Micropterus dolomieu across the Laurentian Great Lakes and beyond: an interplay of behaviour and geography. Mol Ecol 16:1605-1624 doi:10.1111/j.1365-294X.2006.03168.x.

Tripp, S. J., R. E. Colombo & J. E. Garvey, 2009. Declining Recruitment and Growth of Shovelnose Sturgeon in the Middle Mississippi River: Implications for Conservation. T Am Fish Soc 138:416-422.

Van Den Avyle, M. J. & R. S. Hayward, 1999. Dynamics of exploited fish populations. In Kohler, C. C. & W. A. Hubert (eds) Inland Fisheries Management in North America. 2 edn. American Fisheries Society, Bethesda, MD.

von Bertalanffy, L., 1938. A quantitatie theory of organic growth. Human Biology 10:181-213.

Weisberg, S., G. Spangler & L. S. Richmond, 2010. Mixed effects models for fish growth. Can J Fish Aquat Sci 67:269-277.

Winemiller, K. O. & K. A. Rose, 1992. Patterns of Life-History Diversification in North-American Fishes - Implications for Population Regulation. Can J Fish Aquat Sci 49:2196-2218.

Zeigler, J. M. & G. W. Whitledge, 2010. Assessment of otolith chemistry for identifying source environment of fishes in the lower Illinois River, Illinois. Hydrobiologia 638:109-119.

UMRR Science in Support of Restoration and Management – On-going Tasks from FY14 and FY15

Tracking number	Milestone	Original Target Date	Modified Target Date	Date Completed	Comments	Lead
Development of Mussel Vital Rates						
2014MVR1	Brief summary report	30-Sep-15		30-Sep-15	completed, in UMESC review	Newton, Zigler, Davis
2014MVR2	Progress update	30-Sep-16		30-Sep-16		Newton, Zigler, Davis
2014MVR3	Completion report on a vital rates of native mussels at West Newton Chute, UMRS	30-Sep-17	30-Oct-17		Statistics took longer than anticipated. Reconciling comments.	Newton, Zigler, Davis
Effects of Nutrient Concentrations on Zoo- and Phytoplankton						
2014NC1	Counting of phytoplankton samples	13-Mar-15		2-Mar-15		Giblin, Campbell, Houser, Manier
2014NC2	Database completed and analysis completed	13-Mar-16	28-Feb-18		Working With UWL staff. Analysis partally complete.	Giblin, Campbell, Houser, Manier
2014NC3	Full manuscript completed	13-Mar-18				Giblin, Campbell, Houser, Manier
Plankton community dynamics in Lake Pepin						
2015LPP1	Phytoplankton processing; species composition, biovolume	30-Dec-15		22-Oct-15		Burdis
2015LPP2	draft manuscript: Plankton community dynamics in Lake Pepin	30-Sep-16	30-Mar-18		delayed due to field station staffing shortages and will also include data from 2015D15	Burdis
Predictive Aquative Cover Type Model - Phase 2						
2015AQ1	Develop 2-D hydraulic model of upper Pool 4	30-Sep-15		30-Sep-15		Libbey (MVP H&H)
2015AQ2	Apply model to Pool 4 and resolve discrepancies	31-Dec-15	31-Mar-16	31-Mar-16		Yin, Rogala
2015AQ3	Detailed summary of work for Phases I & II	31-Dec-15	31-Dec-17		Resolving model discrepancy took longer than anticipated. Last extension.	Yin, Rogala, Ingvalson