FY18 UMRR Science Proposals

The following are the UMRR LTRM management team recommendations regarding the use of FY2018 Science in Support of Management funds:

> Group I: Recommended for funding are seven full proposals, and selected components of two modular proposals.
>
> Group II: Recommended for reconsideration in FY2019 pending available funding, revisions to address questions and concerns raised during review, and an assessment of other science needs in FY 2019. These proposals address important topics, but were not judged to be of higher priority than any of the funded proposals and may need revision to be re-considered for funding.

Groups are identified in the attached Budget summary table. All of the proposals considered for funding are provided in the following section.

UMRR FY18 Science Proposals
Budget Summaries

Group ID	Proposal Title	PIs	FY18	FY19	FY20	FY21	Total
	Understanding changes in geomorphology						
I	*Conceptual Model and Hierarchical Classification of Hydrogeomorphic Settings in the UMRS*	Fitzpatrick	**$32,288**	**$75,747**	**$58,588**		**$166,623**
I	*Develop a better understanding of geomorphic changes through repeated measurement of bed elevation and overlay of land cover data*	Rogala	**$142,271**	**$98,300**	**$31,282**		**$271,853**
I	*Water Exchange Change in UMRS Channels and Backwaters, 1980 to Present*	Hendrickson	**$68,800**				**$68,800**
	Vegetation, Wildlife and Water Quality (Working Group 2)						
I	*Understanding constraints on submersed vegetation distribution in the UMRS: the role of water level fluctuations and clarity*	Kalas	**$6,645**	**$68,703**	**$21,280**		**$96,628**
I	*Effectiveness of Long Term Resource Monitoring vegetation data to quantify waterfowl habitat quality*	Winter, Straub and Schultz	**$99,879**	**$93,354**			**$193,233**
I	**Part A.** *Intrinsic and extrinsic regulation of water clarity over a 950-km longitudinal gradient of the UMRS*	Drake		**$12,103**	**$12,103**		**$24,206**
II	**Part B.** *Does nutrient supply limit algal growth and suspended particle quality, and ultimately drive water clarity in the UMRS?*	Drake and Strauss		**$77,443**	**$80,032**		**$157,475**
I	**Systemic analysis of hydrogeomorphic influences on native freshwater mussels**	Newton and Ries		**$178,411**	**$80,073**	**$99,786**	**$358,270**
	Understanding relationships among floodplain hydrogeomorphic patterns, vegetation and soil processes, and effects on wildlife habitat and nutrient export in the context of alternative management and environmental scenarios						
I	*Dendrochronology*	Vandermyde	**$90,971**	**$36,308**			**$127,279**
I	*Forest canopy gap dynamics*	Meier	**$122,612**	**$137,596**	**$47,350**		**$307,558**
II	*Reforesting UMRS forest canopy*	Guyon, Cosgriff		**$29,934**	**$28,990**		**$58,924**
II	**Woody Debris in the Upper Mississippi River System: its quantity, distribution, and ecological role**	Jankowski, Van Appledorn, and Sobotka					
	Option 1: Spatial distribution of woody debris linked to fisheries resources AND Experimentally placement of woody debris	Full proposal	**$11,961**	**$37,004**	**$264,326**	**$161,228**	**$474,519**
	Option 2: Spatial distribution of woody debris linked to fisheries resources	Partial work	**$4,086**	**$7,036**	**$214,413**	**$161,228**	**$386,763**
	Investigating vital rate drivers of UMRS fishes to support management and restoration	Bartels, Bouska, Phelps					
I	*Vital Rates*		**$61,660**	**$151,821**	**$47,446**	**$41,524**	**$302,451**
I	*Microchemistry*			**$56,588**	**$25,726**		**$82,314**
II	*Genetics*			**$148,962**	**$40,040**		**$189,002**
		GRAND TOTAL	**$637,087**	**$1,202,274**	**$737,236**	**$302,538**	**$2,879,135**
		Only includes option #1 of Woody Debris					

2018 UMRR Science Proposals

PROPOSED PROJECTS for

Focal area 1: Understanding changes in geomorphology.

There are three project proposals being submitted under the Geomorphic Change focal area for 2018 Science in Support of Management and Restoration funding. This document summarizes the connections between the three projects.

Project 1. Conceptual Model and Hierarchical Classification of Hydrogeomorphic Settings in the UMRS (PI: Faith Fitzpatrick).

Project 2. Develop a better understanding of geomorphic changes through repeated measurement of bed elevation and overlay of land cover data. (PI: Jim Rogala).

Project 3. Water Exchange Change in UMRS Channels and Backwaters, 1980 to Present. (PI: Jon Hendrickson)

Project 1 will develop a hierarchical classification system based on a conceptual model, and use that system to develop a GIS framework. This framework provides the structure to organize our state of knowledge on geomorphic change in a spatial manner as well as a structure for efficiently summarizing the data on geomorphic and hydrologic change produced by the other two projects. The current understanding and existing data of geomorphic change will be incorporated into the hierarchical framework at the appropriate resolution and scale dependent on the scope of the studies. The initial framework will likely include process-based classes defining form, stability, and origins of sediment deposition as well as an indication of level of hydraulic energy. The framework will specifically allow the products from Projects 2 and 3 to be entered into the framework by incorporating classes being measured in those projects. For example, Project 2 will document planform changes such as delta formation, and therefore the framework would include a delta class. Similarly, the framework will incorporate water exchange rate classes, and these would facilitate adding knowledge on those changes from findings from Project 3. This framework will provide a system-wide context for targeting research and monitoring efforts as well as for evaluating performance of past HREPs and improving the design of future HREPs.

The GIS framework will be a dynamic database, as we anticipate adding knowledge gained by Projects 2 and 3, and projects funded in the future, to the framework. Future investigations (including Projects 2 and 3) will provide input to the framework in terms of defining rates and location of change, but it will also suggest modifications to the framework as we better understand geomorphic change. For example, a class to capture likely locations and rates of future delta formations may be added based on findings from future studies.

Specific connections between projects:

Project 1 will include the types of geomorphic change being investigated in Project 2 and 3 into the classification systems and the resultant framework. These geomorphic changes include: side channel filling, backwater sedimentation, backwater delta formation, island gain/loss/dissection, and side channel meandering/widening/narrowing.

Project 2 and 3 will provide information on the location and rates of the geomorphic changes listed above. The planform analysis of change may add additional geomorphic changes information (e.g., main channel bank erosion). The information on location and rates of change attained in Projects 2 and 3 will be added to the GIS framework created in Project 1. For this reason, reports generated in Projects 2 and 3 will not include a set of maps describing the findings from those studies, but rather those “maps” will be part of the GIS framework. We anticipate an online tool will eventually be developed to make the framework easily accessible to resource managers and the public.

Projects 2 and 3 are related to each other because of geomorphic and hydrologic feedback loops. The rate of geomorphic change depends on the water exchange rate and degree of hydraulic energy which delivers or removes sediment depending on location. However, these same geomorphic processes which are driven by water exchange can eventually alter the water exchange rate through sediment deposition or secondary channel erosion. In an altered system like the UMRS these geomorphic and hydrologic rates are not in dynamic equilibrium, but vary spatially and temporally.

WG1

Conceptual Model and Hierarchical Classification of Hydrogeomorphic Settings in the UMRS

Previous LTRM project:
No

Name of Principal Investigator:
Faith Fitzpatrick, USGS Upper Mid Water Science Center, 608-821-4818, fafitzpa@usgs.gov

Collaborators (Who else is involved in completing the project):
Jim Rogala
Jon Hendrickson
Susannah Erwin
Lucie Sawyer
Jayme Stone

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., 2012), 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 datasets developed for use as indicators as part of a second habitat needs assessment (De Jager et al.; in review) and the UMRS Resilience Assessment (Bouska et al.; in review) 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 mapping units from De Jager et al. (in review). 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 mapping units from De Jager et al. (in review), 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.

Special needs/considerations, if any:

None

Budget:

The proposed budget includes salary for Faith Fitzpatrick (Umid WSC), Susannah Erwin (CERC), and Lucie Sawyer (USACE) for leading the team tasks and planning the workshop. The budget also includes GIS time for Jayme Stone and an assistant at UMESC. Jon Hendrickson (USACE) will provide technical expertise and management context. Technical expertise and research context will be provided by Jim Rogala (in kind). Travel costs are included for two team meetings and a workshop (including extra travel costs if needed for others on panel to attend). Publishing costs for a report are included.

Timeline:

Start date: July 1, 2018

Completion date: June 30, 2020

Expected milestones and products [with completion dates]:

- Workshop (Late Fall 2018)
- Summary of workshop findings and minutes (December 2018)
- 1st draft report on hydrogeomorphic conceptual model and hierarchical classification system (April 2019)
- Presentation to Focal Area 1 workgroup, LTRMP researchers, HREP designers, and state resource agency partners (August 2019)
- GIS data base (Dec 2019)
- Report USGS approval and submit for publishing (June 2020).

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Title of Project: 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:

<u>What's the issue or question?</u>

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.

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

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.

<u>Describe how the research addresses one or more of the 2018 Focal Areas:</u>

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.

<u>Determine geomorphic changes in selected side channels of selected reaches using hydroacoustics</u>

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.

<u>Establish a network of transects in backwaters to measure sedimentation</u>

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.

<u>Determine recent planform changes using UMRR LCU datasets</u>

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).

Special needs/considerations, if any:

None

Budget: (see budget spreadsheets for details)

<u>Determine geomorphic changes in selected side channels of selected reaches using hydroacoustics.</u> ~$121K

<u>Establish a network of transects in backwaters to measure sedimentation.</u> ~$87K

<u>Determine recent planform changes using UMRR LCU datasets.</u> ~$66K

Timeline:

Start date: As soon as funding is available in 2018
Completion date: September 30, 2020

WG1

Expected milestones and products [with completion dates]:

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

TIME FRAME	FIELD WORK PLANS	GIS, METHODS AND INTERPRETATION
2018	Field Work: Side channel surveys	Begin compilation of geodatabase. Explore methods for change detection.
2019	Field Work: Side channel surveys	Complete geodatabase and begin updating as needed. Begin developing and apply methods.
2020		Applying methods fully. Quality assuring the methods. Complete writing of report and summarizing the findings.

Establish a network of transects in backwaters to measure sedimentation

TIME FRAME	FIELD WORK PLANS	METHODS AND DATABASE
2018	Field Work: Begin setting monuments at existing transects. Establish, survey and monument new transects as needed	Establish methods. Determine database structure and begin entering data into database (including transect maps, description of monuments, etc.).
2019	Field Work: Continue 2018 field work	Continue entering data as transects are established and surveyed.
2020	Field Work: Complete setting monuments and surveying remaining transects	Complete database for all transects.

Determine recent planform changes using UMRR LCU datasets

TIME FRAME	GIS, METHODS AND INTERPRETATION
2018	Apply methods to detect delta formations systemically. Report on findings (could be delayed to contain these findings with other planform change findings). Begin developing methods for detection of other planform changes.
2019	Finalize methods and detect other planform changes systemically. Report on findings (in one or more reports).

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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.

All draft reports, publications, and manuscripts should be submitted to the UMRR UMESC LTRM Science Director. Products with USGS authors must undergo formal USGS review.

WG1

Title of Project: 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:

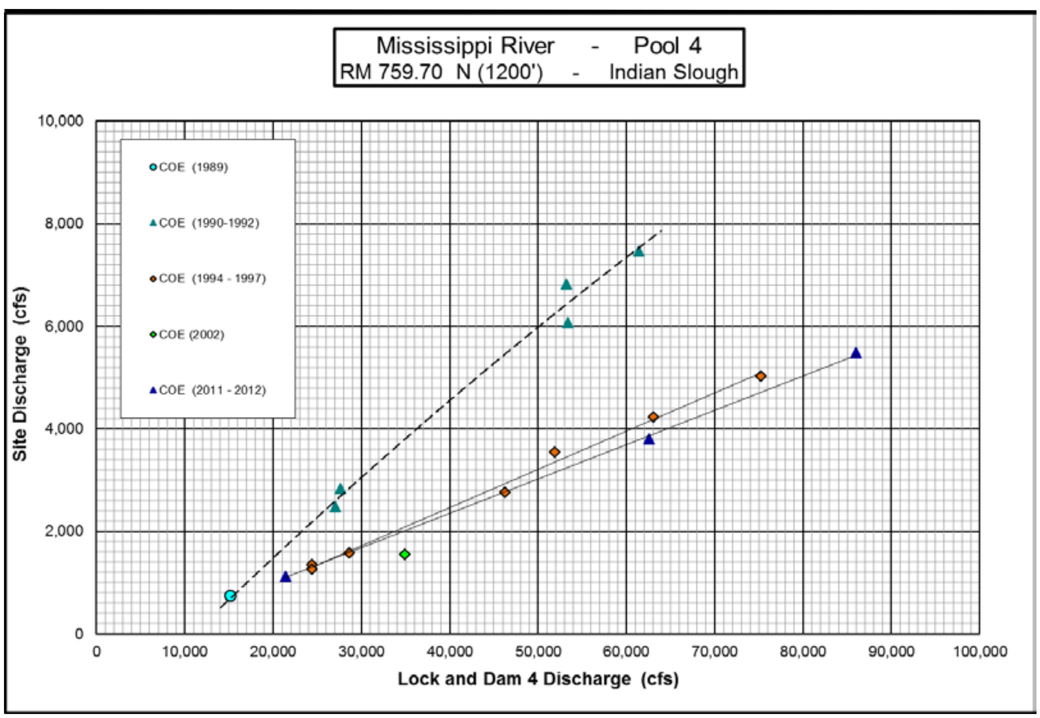
What's the issue or question?
Physical, chemical, and biological conditions in channels, off-channel areas, and floodplains of the Mississippi River are affected by water exchange rates between these water bodies. Transport of sediment, nutrients, and chemicals may have short-term seasonal effects on 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?

WG1

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 of 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.

WG1

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

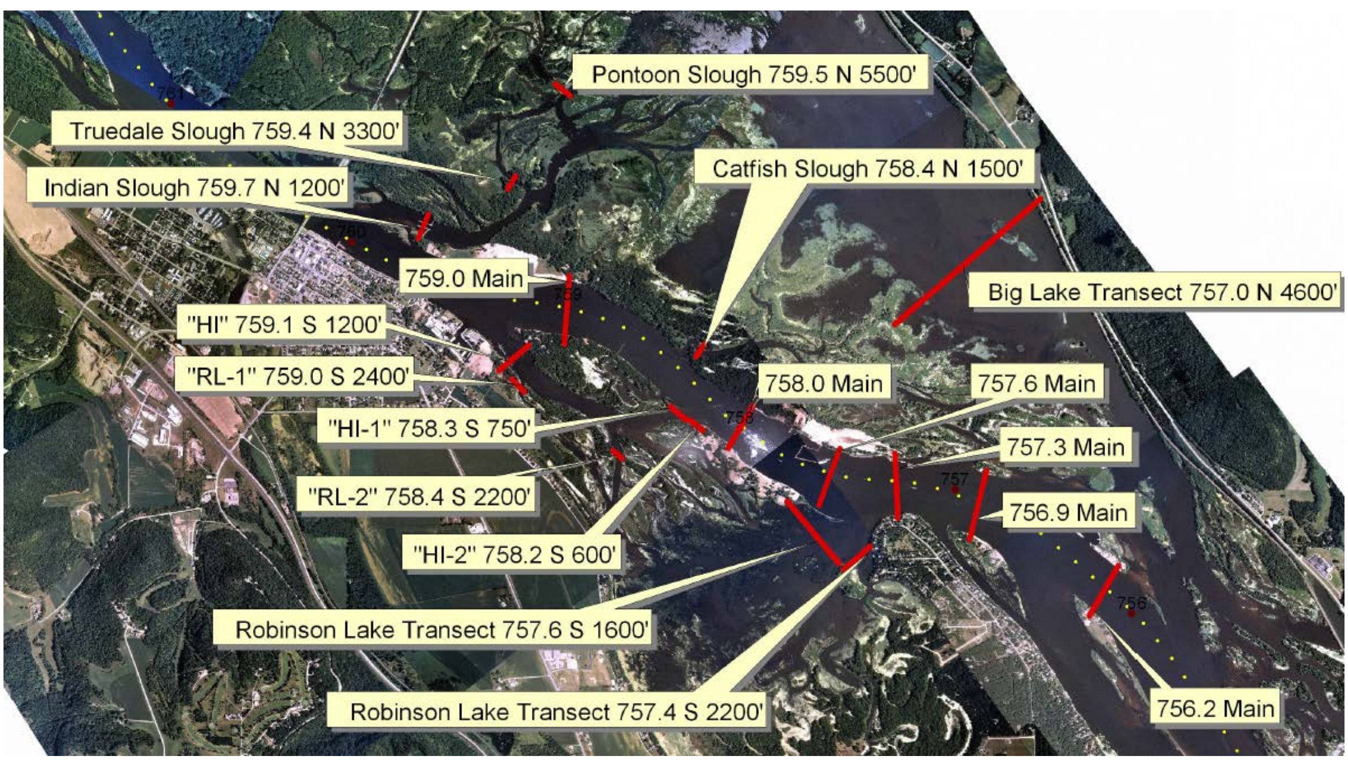
There is some confusion regarding water exchange rates, how they have changed in the past, the effects of projects on these rates, the future trajectory of these rates, and how they affect sediment deposition, nutrient processing, and habitat. The fact that a number of connectivity terms and methods 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.

<u>Describe how the research addresses one or more of the 2018 Focal Areas.</u>

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.



WG1

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.

Special needs/considerations, if any:

None

Budget:

Data analysis - $38,400

Develop maps showing measurement locations - $11,200

Write synthesis report - $19,200

Total - $68,800

Timeline:

Start Date: October 2018
Completion Date: September 2019

Expected milestones and products [with completion dates]:
Include a statement about the expected report content or how the product will be used.

WG1

For multi-year projects, please include a milestone in each year for an annual update.

A report and data base will be produced that will be a synthesis of the following information:

- Existing conditions water exchange rates versus total river discharge at all measurements sites in pools 2 through 10. Rating curves will be drawn if there is enough data to do this.
- Total inflow to backwaters will be determined
- Longitudinal changes to main channel flow
- Trajectory of water exchange rates at sites and backwater that have enough data

All draft reports, publications, and manuscripts should be submitted to the UMRR UMESC LTRM Science Director. Products with USGS authors must undergo formal USGS review.

WG2

Working Group #2 Vegetation, Wildlife and Water Quality

Summary

Collectively, the three proposals included in this package inform management by quantifying important functions of submersed aquatic vegetation (SAV) in the Upper Mississippi River System, and identifying areas where existing conditions may permit SAV restoration. Proposal 1 (Kalas and Carhart) delineates *potential* SAV distribution in Pools 3-26 and the Illinois River by identifying areas where water level variability and water clarity conditions do not preclude establishment of aquatic vegetation. Currently unvegetated areas where light and water level fluctuations are suitable for SAV establishment will be identified for possible restoration. Proposal 2 (Straub and others) quantifies the quality of migratory waterfowl habitat, and herbivory effects on SAV, in vegetated Key Pools (4, 8 and 13) through estimates of wildcelery (*Vallisneria americana)* winter bud production and seasonal biomass. The primary goal of this work is production of a model relating summer LTRM *V. americana* data to winter bud production. This will allow quantification of the bioenergetic value of waterfowl habitats and estimation of previous years' values. Quantifying the distribution and abundance of winter buds as a food resource for migratory waterfowl addresses management concerns regarding the support of these populations. Herbivory by waterfowl is also of considerable interest in understanding SAV-water clarity dynamics in the UMRS. Herbivore effects on wildcelery may be of particular importance because this species is often an early colonizer that facilitates development of SAV communities capable of regulating water clarity. The extent to which SAV modifies its own environment in the UMRS is a focus of Proposal 3 (Drake and others) which includes A) a retrospective study of LTRM data that builds on a previous study that focused on Pool 8 and investigated intrinsic biological controls (aquatic vegetation, common carp) and extrinsic physical controls (main channel and tributary inputs) on increasing water clarity since 1994, and B) a field study that will assess the role of nutrient limitation of algal growth in controlling water clarity. These studies extend the previous work on the interactions between vegetation and water clarity to Pools 4, 13 and 26, and incorporate new knowledge generated from Proposals 1 and 2 about SAV distribution limits and interactions between waterfowl herbivory and wildcelery.

Proposal 1. Understanding constraints on submersed vegetation distribution in the UMRS: the role of water level fluctuations and clarity

Principal Investigator:
John Kalas
Water Quality Specialist-LTRM
Wisconsin Department of Natural Resources
Phone: (608) 781-6365
Email: jkalas@usgs.gov

Collaborators:
Alicia Carhart
Mississippi River Water Resources Biologist-LTRM
Wisconsin Department of Natural Resources
2630 Fanta Reed Road, La Crosse, WI 54603
Phone: (608) 781-6378
Email: Alicia.Carhart@wisconsin.gov

Role: Assemble datasets, perform analyses and contribute to the interpretation and writing of the final manuscript.

Deanne Drake PhD
Vegetation Specialist-LTRM
Wisconsin Department of Natural Resources
2630 Fanta Reed Road, La Crosse, WI 54603
Phone: (608) 781-6363
Email: ddrake@usgs.gov

Role: Contribute to interpretation of the analyses and writing the final manuscript.

Jim Rogala
Support Scientist
USGS-UMESC
2630 Fanta Reed Road, La Crosse, WI 54603
Phone: (608) 781-6373
Email: jrogala@usgs.gov

Role: Provide assistance with data acquisition and methods.

Jason Rohweder
Spatial Applications Biologist
USGS-UMESC
2630 Fanta Reed Road, La Crosse, WI 54603
Phone: (608) 781-6228
Email: jrohweder@usgs.gov

Role: GIS support generating spatial coverages as needed to complete project.

Introduction/Background:

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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.

Expected outcomes

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1. A database containing water level fluctuation data will be made available on the LTRM website. This will provide an easily accessed, system-wide reference for water level fluctuations (descriptive statistics).
2. A database containing photic zone data will be made available on the LTRM website. This will provide an easily accessed, system-wide reference for photic zone depths, summarized annually by pool.
3. Spatial coverages generated from the analysis will be served as a web mapping application online. These will include annual coverages, by pool, similar to the existing submersed vegetation web modelling application. The total SAV band area will be quantified annually by pool.
4. Select spatial coverages will be compared to available LCU data (1989, 2000, 2010). Of particular interest will be areas where light and depth conditions appear suitable, but vegetation remains scarce. The unvegetated area within the SAV band will be quantified- this represents potential SAV restoration areas.
5. A database containing SAV band acreage information will be made available on the LTRM website.
6. LTRM programmatic report and peer reviewed manuscript- Understanding constraints on submersed vegetation distribution in the UMRS: the role of water level fluctuations and clarity.

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?

Timeline FY 2018-2020

Milestones and products: **WG2**

Tracking number	Products	Staff	Milestones
	Retrieve existing systemic datasets for elevation gages, topobathy and water clarity.	Kalas, Carhart, Rogala, Rohweder	30 October 2018
	Estimate/interpolate photic zone and generate predicted SAV bands systemically.	Kalas, Carhart, Rogala, Rohweder	30 March 2019
	Spatial coverages and databases complete, begin draft report.	Kalas, Carhart, Rohweder	30 August 2019
	LTRM programmatic report and peer reviewed manuscript- Understanding constraints on submersed vegetation distribution in the UMRS: the role of water level fluctuations and clarity. Webpage to house database information.	Kalas, Carhart, Drake, Rogala, Rohweder	30 March 2020

Budget- *see attached spreadsheet*

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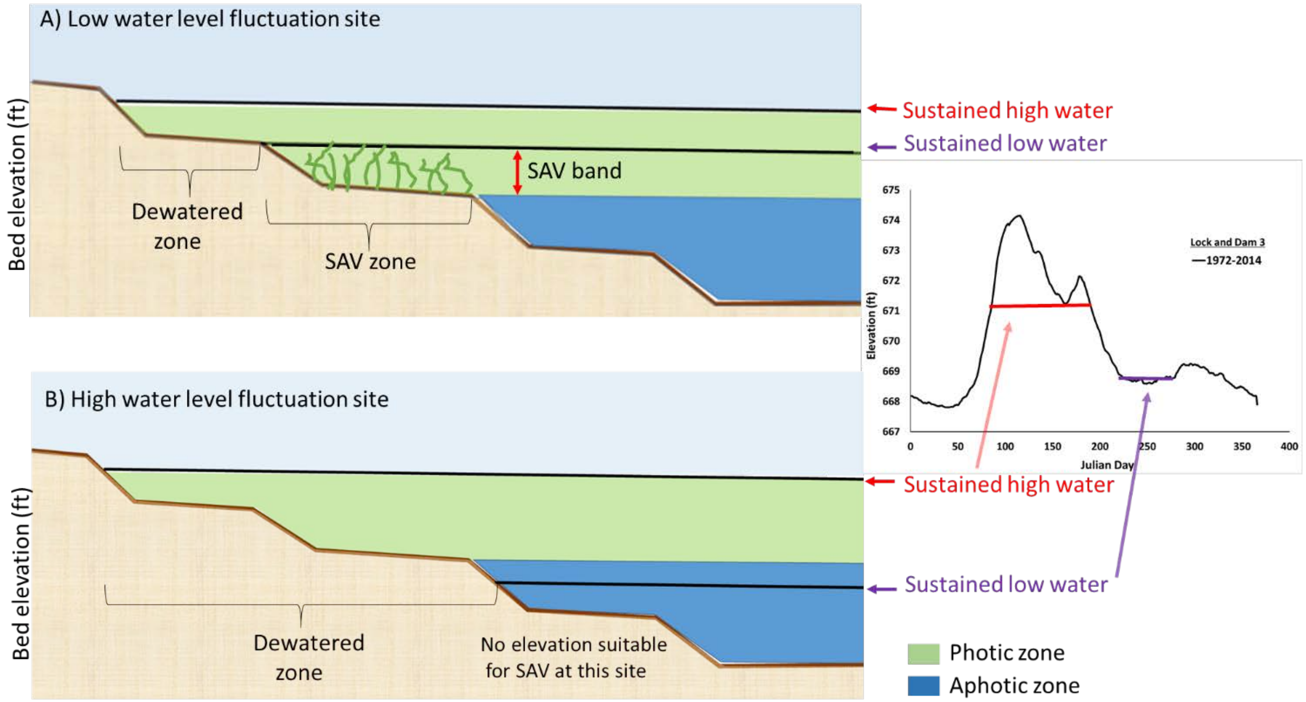

Figure 1. Conceptual illustration of the effects of the magnitude and duration of water level fluctuation on conditions for SAV. Shown are examples of a navigation pool with relatively small (A) and large (B) water level fluctuations (WLF). Water clarity, and therefore photic zone depth (PZ), is the 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*

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Proposal 2: Effectiveness of Long Term Resource Monitoring vegetation data to quantify waterfowl habitat quality

Previous LTRM project: N/A

Names of Principal Investigators:
Jacob Straub, Assistant Professor
Agency: University of Wisconsin-Stevens Point
Telephone: 715-346-3323
Email: Jacob.straub@uwsp.edu

Rachel Schultz, Wetland Scientist
Agency: University of Wisconsin-Stevens Point
Telephone: 715-346-3152
Email: Rachel.Schultz@uwsp.edu

Collaborators:
Stephen Winter, Wildlife Biologist
Agency: USFWS
Telephone: 507-494-6214
Email: stephen_winter@fws.gov
Role: technical assistance, assistance with the coordination and oversight of field sampling, review and assistance with report writing

Eric Lund, Deanne Drake, Kyle Bales - UMRR LTRM Vegetation Specialists
Agencies: MN DNR; WI DNR; IA DNR (respectively)
Telephone: 651-345-3331 ext. 223; 608-781-6363; 563-872-5495 (respectively)
Email: eric.lund@state.mn.us; ddrake@usgs.gov; kyle.bales@dnr.iowa.gov
Roles: technical assistance, coordination and oversight of field sampling, review and assistance with report writing

Scott Hygnstrom, Professor
Agency: University of Wisconsin-Stevens Point
Telephone: 715-346-2301
Email: scott.hygnstrom@uwsp.edu
Role: technical assistance, review and assistance with report writing

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.

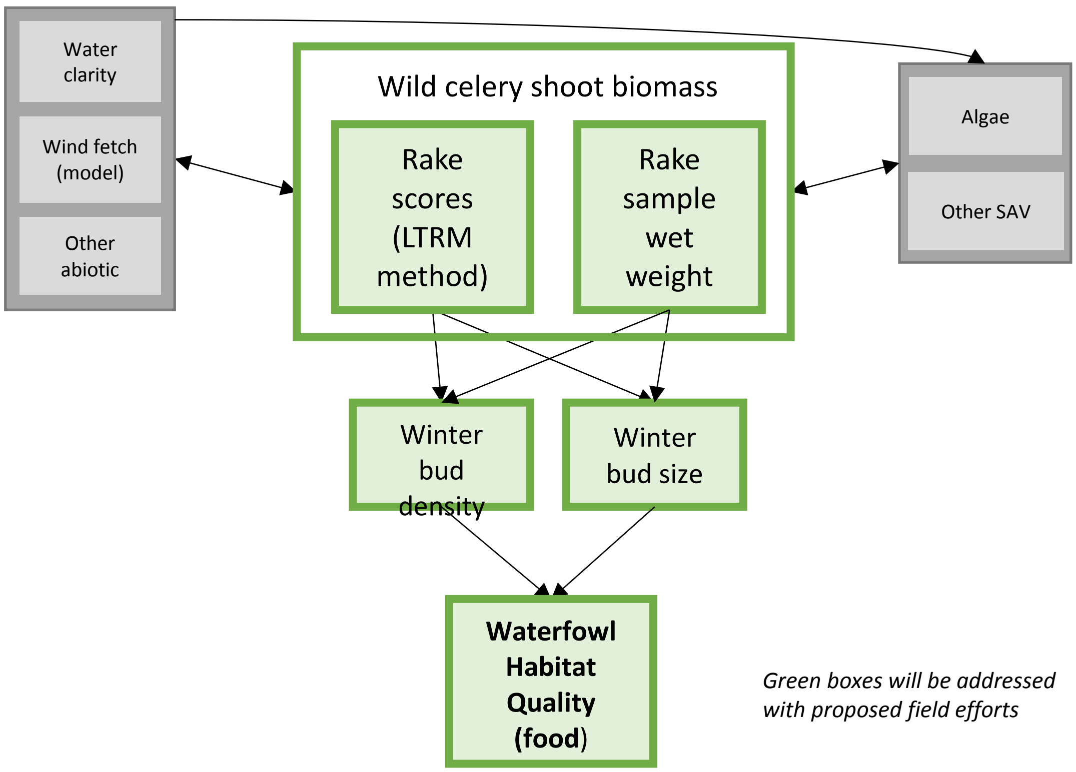

Figure 1. Conceptual model of interactions among abiotic variables, submerged aquatic vegetation (SAV), and waterfowl in the UMRS. Visual estimates for SAV using rake scores is the current LTRM method used to estimate SAV cover; current LTRM efforts are investigating whether the addition of fresh weights (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).

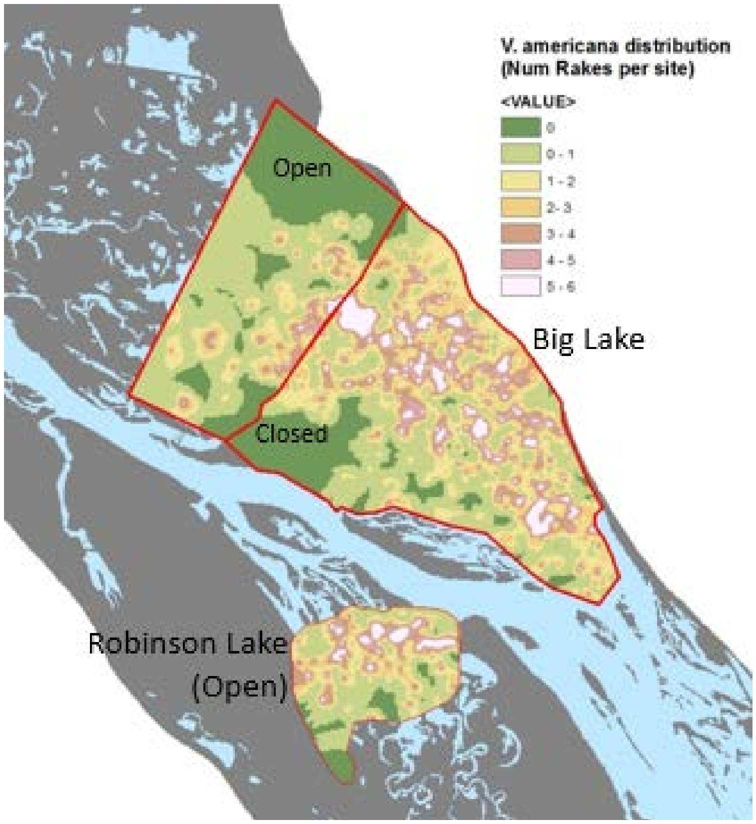

Figure 2. Distribution of wild celery (1998-2017) in lower Pool 4 of the Mississippi River in backwater areas open and closed to waterfowl hunting. Distribution is represented as a GIS interpolation based on the number of rakes (out of the six taken per site) on which *V. americana* was found during 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 February/March of 2019 to assess herbivory of waterfowl food resources during fall migration (mid-October) to just prior to spring migration (mid-March). 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.

Budget: Please see attached budget spreadsheet (P 30).

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Timeline

- July 2018 Project planning and initiation
- Aug 2018 Collect data in Pools 4, 8, 13 using LTRM rake and biomass methodology
- Oct 2018 Collect data in Pools 4, 8, 13 using benthic core sampling
- Feb 2019 Collect data in Pools 4, 8, 13 using benthic core sampling
- Spring 2019 Conduct preliminary analyses and write preliminary report
- July 2019 Second Field Season planning
- Aug 2019 Collect data in Pools 4, 8, 13 using LTRM methodology
- Oct 2019 Collect data in Pools 4, 8, 13 using benthic core sampling
- Winter 2019-2020 Conduct final analyses, write report and publication manuscripts

Expected milestones and products [with completion dates]:

- June 2019 – preliminary report with results from data collected in the summer and fall of 2018, and data collected in the winter of 2019.
- May 2020 – final report with results from data collected during the entire 2018–2019 period.
- May 2020 – manuscript(s) submitted for publication.

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WG2

Proposal 3. **Part A.** 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?

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:

Deanne Drake
Wisconsin Department of Natural Resources
(608) 781-6363
ddrake@usgs.gov

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
University of Wisconsin - La Crosse estrauss@uwlax.edu

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 *biomas*s 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)

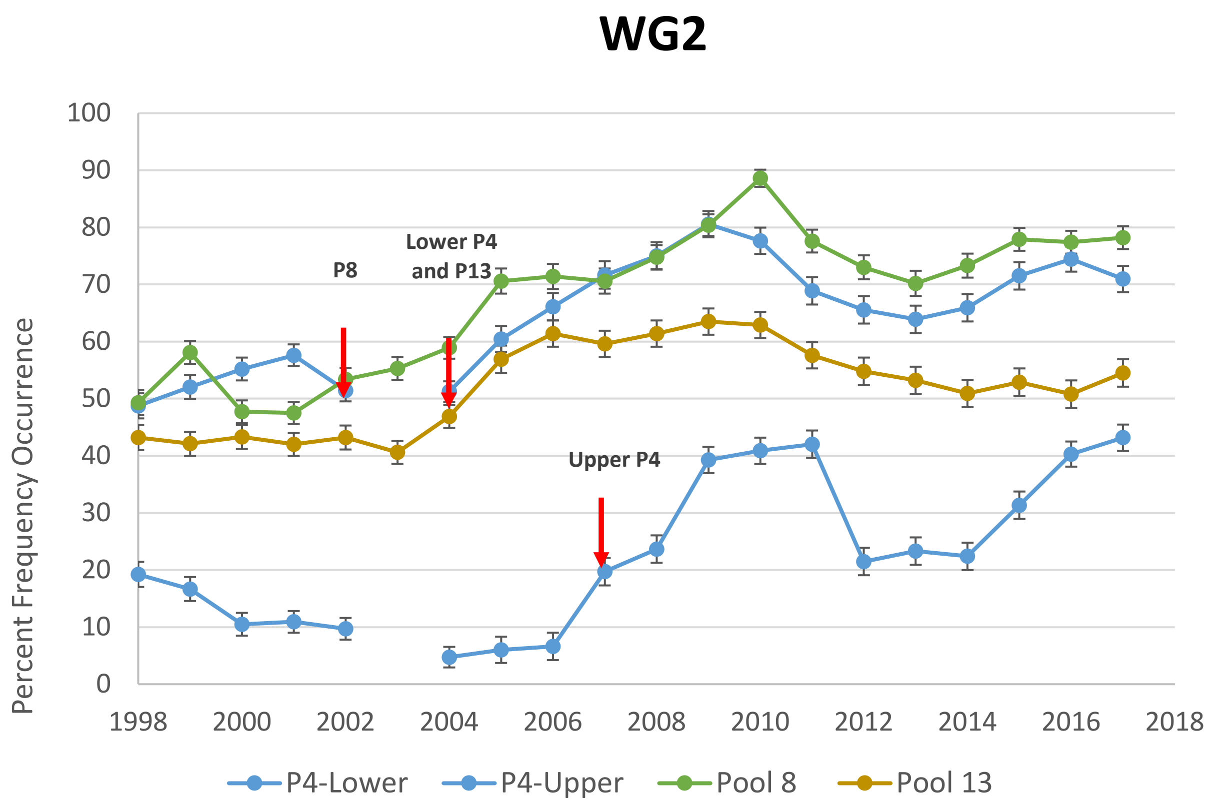

Figure 1. Prevalence of SAV (pool-wide mean percent frequency occurrence) has increased over time in all three vegetated Key Pools, but sustained, positive trends began (indicated by red arrows) during different years in each pool. Pool 4 SAV prevalence is separated into Upper and Lower Pool means, and 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.

WG2

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 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.

WG2

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 (Part A):

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	

Timeline A: January 2019 – November 2020

Expected milestones and products A:

Tracking number	Products	Staff	Milestones
	Database complete	Carhart, Drake, others	April 2019
	Draft analysis	Drake, Carhart and others	December 2019
	Draft manuscript	Drake, Carhart and others	March 2020
	Final manuscript	Drake, Carhart and others	November 2020

Methods (Part B)

Monitoring

The existing LTRM program will be used as a source of spatial and temporal data and as a structure to collect new information about nutrient concentrations, seston, and periphyton. More specifically, we will use the SRS samples collected from pools 4 and 8 by LTRM personnel to obtain data on concentrations of TSS/VSS, Total N, NOx, NHx, Total P, Soluble Reactive P (SRP), and Chlorophyll a. In addition, we will use the stratified random sampling structure to collect additional water and seston for assessment of DOC, color, and seston/periphyton quality and activity. This will require collection of 1-liter, whole water samples from a subset of SRS sites in backwaters and main channel strata, in spring, summer and fall quarters. We will request that LTRM water quality personnel collect an estimated 50-100 samples per key pool per quarter during normal SRS field work currently and, and in exchange the graduate students will be available to assist in the field or laboratory. If it not possible for LTRM staff to accommodate this, students can access SRS sites independently or with the help of D. Drake. The additional biological samples will be used to determine total CNP content, bacterial secondary production via incorporation of [methyl-^{3}H] Thymidine into DNA, and phosphorus limitation via alkaline phosphatase activity. All analyses (other than standard SRS analyses) will be conducted UWL River Studies Center Water Quality Lab.

Experimentation

Nutrient limitation of algal communities will be determined seasonally in bioassays conducted in both pools 4 and 8. In general, algal communities will be exposed for several days to ambient nutrient levels or elevated levels of N, P, or N &P. These bioassays are often conducted using nutrient diffusing substrates (NDS) for periphyton communities or carboys for planktonic communities (Biggs and Kilroy 2000). The specific details and level of replication of these experiments will be planned as part of the students' proposal development process to meet our primary goals of understanding seasonal patterns in nutrient limitation and how water-residence-time may affects nutrient limitation. Thus NDS deployment will be conducted in spring, summer and fall (coinciding with LTRM SRS episodes) and split between channel and off-channel habitats.

This study will be split into two Master's degree projects, both addressing nutrient limitation of algal production. One student will be responsible for the research objectives and work associated with the periphyton analysis and the second will be associated with the seston objectives. Although the two student projects are distinct, it will be likely (and encouraged) that the students will work together to coordinate sampling and processing of samples that will be useful to both projects. Both students will be enrolled in the Aquatic Science program in the Department of Biology at the University of Wisconsin – La Crosse and will be officially advised by Professor Strauss. Dr. Drake will serve on the Thesis committee of both students, facilitate LTRM collaboration, and be the primary research advisor for the student focused on the periphyton research. Professor Strauss will be the primary research advisor for the student focused on the seston research.

Timeline B January 2019 – December 2021 or June 2019 – June 2021

Milestones and products B:

Tracking number	Products	Staff	Milestones
	MSc proposals	UWL students	6 months after contract initiation
	Draft analysis and reports	UWL students	20 months after contract initiation
	MSc theses	UWL Students Drake, Strauss	24 months after contract initiation

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WG3

WG3: Systemic analysis of hydrogeomorphic influences on native freshwater mussels

Previous LTRM project: No.

Name of Principal Investigators:

Teresa Newton, USGS, Upper Midwest Environmental Sciences Center, La Crosse, WI, 608-781-6217, tnewton@usgs.gov

Patty Ries, USGS, Upper Midwest Environmental Sciences Center, La Crosse, WI, 608-781-6288, pries@usgs.gov

Collaborators:

Mike Davis, Minnesota Department of Natural Resources, Lake City, MN, 507-251-4116, mike.davis@state.mn.us; ROLE: pool-wide mussel sample collection, data entry

Nathan De Jager, USGS, Upper Midwest Environmental Sciences Center, La Crosse, WI, 608-781-6232, ndejager@usgs.gov ; ROLE: in-kind contribution with spatial analysis

Dan Kelner, USACE, St. Paul District, St. Paul, MN, 651-290-5277, Daniel.E.Kelner@usace.army.mil; ROLE: in-kind contribution of field work support

Catherine Murphy, USACE, Engineer Research and Development Center, Vicksburg, MS, 601-634-3246, Catherine.E.Murphy@usace.army.mil; ROLE: multivariate data analysis

Jim Rogala, USGS, Upper Midwest Environmental Sciences Center, La Crosse, WI, 608-781-6373, jrogala@usgs.gov; ROLE: experimental design for pool-wide mussel sample collection and estimation of pool-wide population sizes

Jason Rohweder, USGS, Upper Midwest Environmental Sciences Center, La Crosse, WI, 608-781-6228, jrohweder@usgs.gov; ROLE: assistance with aquatic areas geomorphic analyses, redefining geomorphic metrics, development of geospatial maps, data synthesis

Sara Schmuecker, USFWS, Rock Island Field Office, Moline, IL, 309-757-5800 ext 203, sara_schmuecker@fws.gov; ROLE: in-kind contribution of field work support

Lori Soeken-Gittinger, Illinois Natural History Survey, Alton, IL, 217-300-1036, soeken@illinois.edu; ROLE: in-kind contribution of field work support

Steve Zigler, USGS, Upper Midwest Environmental Sciences Center, La Crosse, WI, 608-781-6395, szigler@usgs.gov; ROLE: in-kind contribution of technical assistance, data synthesis

WG3

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.

Special needs/considerations, if any: No.

Budget: $358,270 (gross) across FY19-FY21. About 33% of the requested funds will go towards conducting pool-wide sampling for mussels in Pools 8 and 13; the remaining funds will go towards personnel to complete the mussel-geomorphic association analysis. USGS will also leverage about $30K in salaries.

Timeline:
- FY19: design pool-wide surveys in Pools 8 and 13, explore geomorphic indices within the aquatic areas data set that may influence mussel assemblages, assess correlations among select geomorphic variables, explore creation of additional geomorphic indices that may influence mussel assemblages, 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.
- FY20: 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
- FY21: complete statistical analyses, prepare geospatial maps, draft completion report

WG3

Expected milestones and products:

Products will include annual progress summaries (Dec 2019, Dec 2020), a draft completion report (Sep 2021), presentations at scientific and management forums, and at least one manuscript in the peer reviewed literature. The draft completion report will contain (1) summaries of mussel resources (e.g., distribution, abundance, diversity, recruitment) from the pool-wide surveys in Pools 8 and 13, (2) figures and/or tables of geomorphic variables, and their associated ranges, that contribute to dense and diverse mussels assemblages, and (3) geospatial models of geomorphic indices that are most likely to influence mussel assemblages.

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WG4

From: Focal Area 4 working group attendees: Jessica Bolser (USFWS), Robert Cosgriff, Michael Dougherty, Andy Meier, Ben Vandermyde (USACE), Lyle Guyon (NGRREC), Nathan De Jager, JC Nelson, Andrew Strassman, Annie McIntyre (UMESC)

Over the last decade, forested habitats within the Upper Mississippi River (UMR) floodplain have received increasing attention from management and research agencies within the UMRR partnership. One of the primary reasons for this increased attention is that many areas appear to lack sufficient tree regeneration to ensure a sustainable forest. Although floodplain forest regeneration is likely episodic, we lack historic baseline data on the scale and frequency of forest regeneration, and current information on the degree to which changes in hydrology or the presence of invasive species are affecting successional processes. As a result, there are concerns that the eventual loss of floodplain forest cover may be extensive and lead to a more savanna-like ecosystem, with cascading effects on fish and wildlife habitat and nutrient export to the UMR.

The degree to which floodplain forests are regenerating and the specific causes for declines in floodplain forest cover are unclear. In some cases, changes in the hydrological regime since the time of floodplain forest establishment may limit recruitment in the forest understory. In other cases, invasive herbaceous species may colonize small canopy gaps as individual trees reach their maximum lifespan and further expand as adjacent forests senesce. The current age structure of floodplain forests suggests that many of the dominant cohorts are nearing their longevity and additional non-native pests (Dutch elm disease and the emerald ash borer) may further increase the rate of forest loss.

Three project proposals were identified by working group 4, each focusing on improving our understanding of floodplain forest recruitment and growth in the context of alternative hydrological regimes and invasive species. The three projects build off of ongoing work to spatially and temporally represent flood inundation (Van Appledorn et al. In prep) and how it influences patterns of forest succession (De Jager et al. In prep). These three studies should lay the ground work for further research on how patterns of forest recruitment (or lack thereof) influence fish and wildlife habitat, nutrient export to the river, and the overall resilience of the UMR.

One project, “Using dendrochronology to understand historical forest growth, stand development, and gap dynamics,” takes a historical look at how floodplain forests have developed in the past in relation to multiple stressors.

Another project, “Forest canopy gap dynamics: quantifying forest gaps and understanding gap-level forest regeneration,” combines the use of remote sensing data (lidar and aerial photography) with field data collection to quantify patterns of gap creation and subsequent vegetation patterns within gaps.

Finally, “Reforesting UMRS forest canopy openings occupied by invasive species” seeks to develop novel methods to regenerate forest cover in gaps that have been invaded by a highly invasive species, Japanese hops.

Enclosed, please find each proposal with contact information for the principal investigators (PI’s). If you need any additional information on these proposals, please contact the PI’s.

WG4

Title of Project: 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).

Name of Principal Investigator:
Benjamin Vandermyde
Lead Forester
Mississippi River Project
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.

After all tree cores are crossdated, 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.

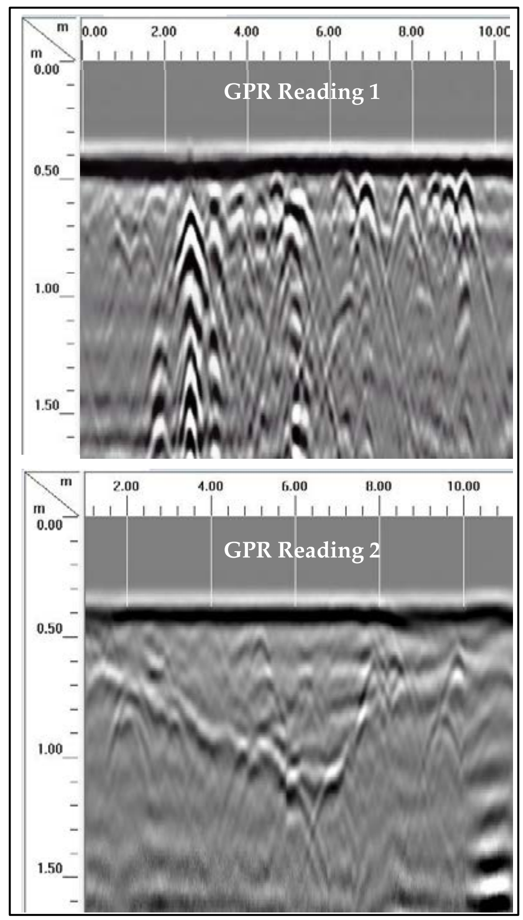

Figure 1. Example ground penetrating radar (GPR) schematic. Top: active return showing soil compression marks from 2.2 m to 9.8 m at the surface (surface calibration is 0.4 m) location. Bottom: showing the change in transmissivity along a diagonal from 0.60 m to 1.2 m depth between overlying unconfined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

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)

Budget:
The total estimated cost for this project is $123,720, spread across FY18 ($93,720) and FY19 ($30,000). A detailed budget spreadsheet is included with this proposal. Funding dispersal for master students at respected universities accounts for final report writing development in 2020; thus no itemized amount is estimated for 2020 for final projects. Oversight and review conducted by USACE staff for reports and writing products is expected to be minimal and will be funded through other sources.

Timeline:
All components of this project will be initiated July/August 2018. Data collection will be completed by June 2019. Report writing will be completed by June 2020. Dr. Harley, Dr. Maxwell, and corresponding master students will be providing the primary analysis, reports, and writing of manuscripts to be submitted to peer-reviewed journals by September 2020.

Expected milestones and products [with completion dates]:
-Annual report summarizing activities in 2018 and preliminary data summaries (December 2018)

—Growth-ring chronologies and forest vegetation demographic and biophysical data. Target completion: July 2019

—Plot-level 3-dimensional subsurface floodplain sedimentation maps for each study site. Target completion: July 2019

-Annual report summarizing results from field collection efforts and preliminary data processing summaries and milestones of dendrochronology results: Target completion December 2019.

—1 Master's thesis from the University of Idaho (supervised by Harley) focused on detailing results with regard to forest stand composition, structure, and biophysical data and disturbance history. Target completion: May 2020

—1 Master's thesis from Indiana University (supervised by Maxwell) focused on looking specifically at the growth trends and climate response of pecan. Target completion: May 2020

—Synopsis UMRR technical report summarizing the dendrochronology/forest stand dynamics and floodplain hydrogeomorphology component datasets with management recommendations. Target completion: June 2020

—Baseline dataset for promoting resilience of hard mast forest communities along the UMRS. Target completion: June 2020

—Submission of at least 2 peer-reviews manuscripts to the UMRR UMESC LTRM Science Director. Target completion: 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.

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WG4

Title of Project: 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).

Name of Principal Investigator:
Andy Meier, Forester, USACE-St. Paul District, 651.290.5899, Andrew.R.Meier@usace.army.mil

Collaborators (Who else is involved in completing the project):
Dr. Lyle Guyon, Terrestrial Ecologist, National Great Rivers Research and Education Center, One Confluence Way, East Alton, IL 62024, 618.468.2870, lguyon@lc.edu, lead report writing, lead field crews in lower pools, expertise in terrestrial and forest ecology.

Dr. Meredith Thomson, Professor of Biology, University of Wisconsin-La Crosse Biology Department, 1725 State Street, La Crosse, WI 54601, 608.785.8425, mthomsen@uwlax.edu, graduate student oversight, contribution to analysis and report writing, lead field data collection in upper pools, expertise in restoration of invaded habitats and effects on habitat fragmentation on community interactions.

Dr. Nathan R. De Jager, Research Ecologist, USGS Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Road, La Crosse, WI 54603, 608-781-6232, ndejager@usgs.gov, assistance with GIS analysis, expertise in landscape ecology.

Andrew Strassman, Biologist, USGS UMESC, 2630 Fanta Reed Road, La Crosse, WI 54603, 608.781.6386, astrassman@usgs.gov, lead and oversight of GIS analysis and database creation, expert in GIS, expertise in vegetation ecology.

Stephanie Sattler, Cartographic Technician, USGS UMESC, 2630 Fanta Reed Rd, La Crosse, WI 54603, 608.781.6272, ssattler@usgs.gov, lead in lidar analysis, lead in database creation.

Erin Hoy, Biologist, USGS UMESC, 2630 Fanta Reed Rd, La Crosse, WI 54603, 608.781.6384, ehoy@usgs.gov, lead in photo interpretation, expert in UMRS vegetation

Ben Vandermyde, Lead Forester, USACE-Rock Island District, PO Box 534, Pleasant Valley, IA 52767, 309.794.4522, ben.j.vandermyde@usace.army.mil, lead field crews in middle pools, site selection and project planning

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:
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?

WG4

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.

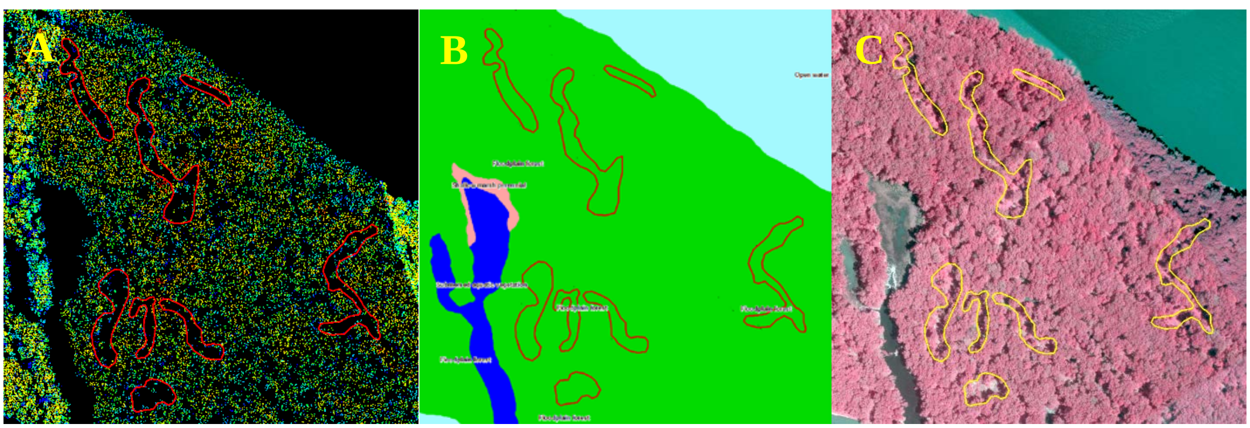

Figure 1: Tile A showing the lidar point cloud along the eastern shore of Railroad Island in Pool 13 with gaps delineated, Tile B showing how these gaps align with the existing 2010 systemic vegetation layer, and Tile C showing these same gaps in the 2010 systemic CIR imagery set.

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.

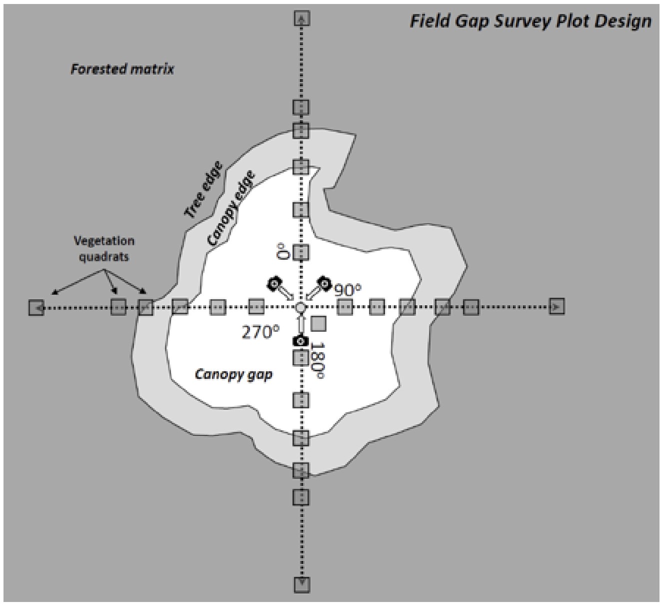

Figure 2. Generalized layout of field sampling in a hypothetical forest gap.

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).

Timeline:
The geospatial component of the project will be initiated in September 2018, with analysis completed by April of 2019 for use in the field component. The field component will be initiated in May 2019, with Data collection completed by October of 2019. Most analysis and report writing will be completed by September of 2020. Peer-reviewed article writing may stretch into 2021 or beyond, but no further funds will be requested beyond 2020.

Expected milestones and products [with completion dates]:

-Completion of polygon layer of canopy gaps for Study Area with associated tabular and FGDC-compliant metadata (Target completion – April 2019)

- Annual report summarizing activities in 2018 and describing geospatial methodology (Target completion – December 2018)

- Annual report summarizing activities in 2019 and preliminary data summaries (Target completion – December 2019)

- UMRR report detailing the methods used to create and attribute the gap layer along with lessons learned from the imagery interpretation process, including recommendation for use and further development (Target completion – April 2020)

- 1 MS thesis summarizing field collected data in upper pools (Target completion – May 2020)

- Summary UMRR technical report summarizing both the geospatial and field datasets with management recommendations (Target completion – September 2020)

- Baseline dataset for long-term forest gap study (Target completion – September 2020)

- 1 - 2 peer-reviewed journal articles (Target completion – September 2021)

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WG4

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WG4

Title of project:
Reforesting UMRS forest canopy openings occupied by invasive species

Previous LTRM project:
This project builds upon a previous non-LTRM study entitled "Japanese hops control and management," implemented by the USACE and the National Great Rivers Research and Education Center (NGRREC), and awarded through a cooperative agreement issued by the Great Rivers Cooperative Ecosystem Studies Unit (CESU) and ERDC. This new proposed study represents a second phase of a project focused on identifying cost effective methods for: 1) eradicating and controlling Japanese hops populations in UMRS floodplains; and 2) reforesting areas that have been heavily colonized by Japanese hops. The previous study identified effective herbicide treatments for treating Japanese hops in the field, and documented the role of periodic flooding in redistributing Japanese seeds and providing a mechanism for it to recolonize treated sites. Results also indicated that traditional tree planting methods using bare root seedlings and containerized saplings were likely to fail without additional intensive maintenance requirements. Study findings are documented in a final report.

Name of Principal Investigators:
Dr. Lyle Guyon, Terrestrial Ecologist, National Great Rivers Research & Education Center, One Confluence Way, East Alton, IL 62024; 618-468-2870; lguyon@lc.edu. Specific roles: project planning, implementation and oversight of monitoring activities, data analysis and report writing.

Robert Cosgriff, Lead Forester, USACE St. Louis District, 301 Riverlands Way, West Alton, MO 63386; 636.899.0074; robert.j.cosgriff@usace.army.mil. Specific roles: site selection, project planning and coordination, implementation and oversight of tree plantings and maintenance regimes.

Collaborators:
Ben Vandermyde, Lead Forester, USACE Rock Island District, PO Box 534, Pleasant Valley, IA 52767; 309.794.4522, ben.j.vandermyde@usace.army.mil. Specific roles: site selection, project planning, implementation and oversight of tree plantings and maintenance regimes.

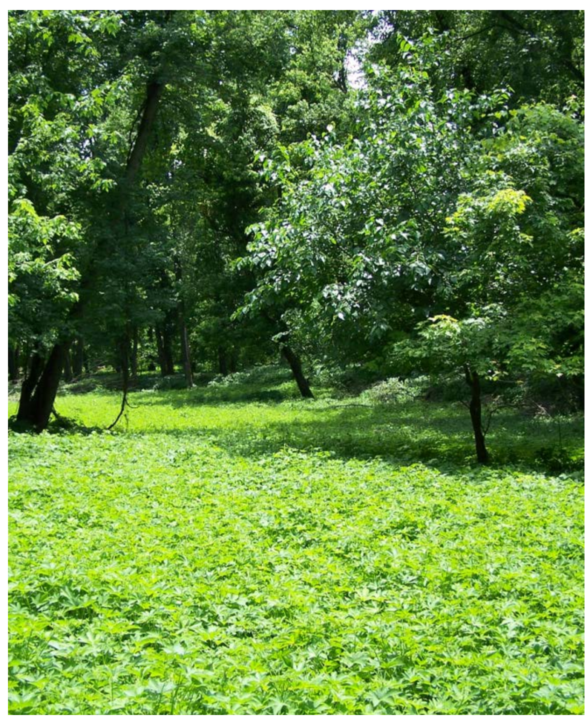
Andy Meier, Forester, USACE St. Paul District; 651.290.5899; Andrew.R.Meier@usace.army.mil. Specific roles: project coordination.

Introduction/Background:
Forest communities of the Upper Mississippi River System (UMRS) are highly productive, provide valuable habitat for many species of birds and wildlife, improve water quality, control erosion, and contribute to local and regional economies (Yin et al. 1997; Romano 2010; Guyon et al. 2012; Urich et al. 2002; Johnson et al., 2008). Currently, one of the biggest threats to the health and diversity of UMRS floodplain forests is invasive species. The Federal National Invasive Species Act (1996) and the USACE Invasive Species Policy (2009) state that one of the

missions of the USACE is to contain and reduce the spread of invasive species to minimize their harmful impacts.

Japanese hops (*Humulus japonicus*) is an invasive annual or weakly perennial vine species that has been spreading throughout the UMRS over the past 10-15 years. It readily establishes in forest canopy gaps and other open areas in riverine and riparian habitats, forms dense monocultures that inhibit the survival and growth of native species, and is particularly effective in suppressing tree and shrub regeneration. Japanese hops exhibits a growth pattern typical of trailing vine species, and can generally climb to a height of about 15 feet. When it forms dense stands it can overtop and quickly outcompete native vegetation. It has a high light requirement, and observations indicate that it rapidly colonizes edge areas and canopy gaps in forested floodplain settings where it can exploit full available sunlight. As a highly shade intolerant species, it cannot survive beneath a closed forest canopy.

Canopy gaps are a natural occurrence in floodplain forests, and are created as trees succumb to disturbance events (e.g., flooding and wind) or senescence. Forests of the UMRS are dominated by species such as silver maple (*Acer saccharinum*) and eastern cottonwood (*Populus deltoides*) that are reaching the end of their life cycle in many areas and can create large canopy gaps when they die. The 1993 flood event created significant canopy gaps where between 30-70% mortality occurred in mature trees (Yin et al. 1997; Cosgriff et al. 2007). Continued mortality has occurred due to more recent flooding and increased wind-throw from weakened canopy structure. An additional disturbance event that is likely only a decade away from having a devastating impact in UMRS forests is Emerald Ash Borer (EAB). Green ash (*Fraxinus pennsylvanica*) is the second most dominant tree species within USACE St. Louis District Rivers Project Office floodplain forests. As green ash succumbs to EAB, additional canopy gaps will be created providing further opportunity for invasive species such as Japanese hops to become even more widespread.



Impacts on native plant communities are therefore an immediate cause for concern. Since it readily takes over canopy gaps and open areas within floodplain forests that would otherwise be colonized by native tree regeneration, Japanese hops may have a long term negative impact on the extent of forest cover in the floodplain landscape. This issue is especially troublesome in Upper Mississippi River floodplains where large canopy gaps are commonly created following significant floods.

Relevance of research to UMRR:

Control and management of Japanese hops is necessary to prevent further degradation and maintain the health and sustainability of terrestrial floodplain habitat in the UMRS. The overarching goal of this specific project is to identify effective reforestation methods, with and without traditional tree planting maintenance practices (e.g., herbicides, mowing), for use as a cultural treatment in the control and management of Japanese hops populations in UMRS floodplain forest habitats.

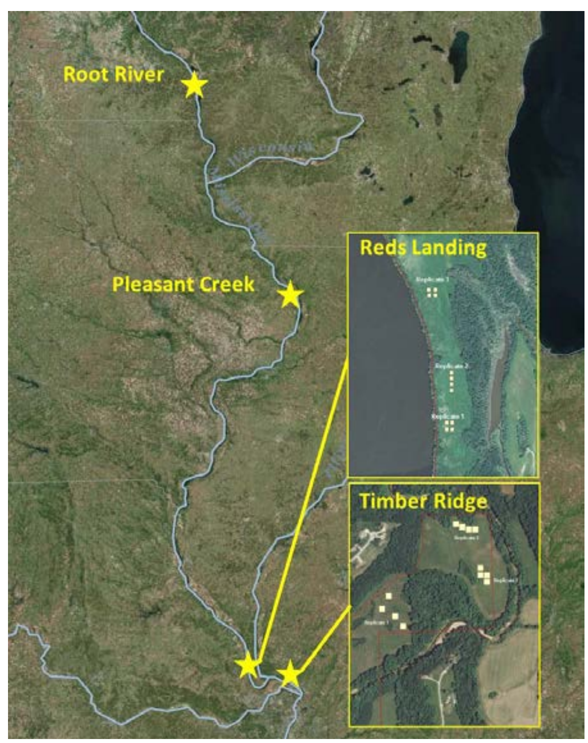
Specifically, this study will address the following questions:

1) Can artificial reforestation be used as a technique to close canopy gaps and reduce the abundance of invasive species such as Japanese hops?
2) What is the most cost-effective planting density to achieve expedient canopy closure with minimal maintenance requirements?
3) Can early successional species be used to replace green ash following the establishment and spread of emerald ash borer throughout the UMRS floodplain?

This project will inform river restoration and management by determining planting densities and maintenance regimens necessary to control Japanese hops and rapidly establish floodplain forest canopy cover in impacted areas. It addresses sections vi and viii of 2018 Focal Area 4.2, Understand and Quantify Floodplain Vegetation Dynamics, by investigating the impacts of active forest management practices on invasive species and forest regeneration.

Methods:

The project will occur at four different study sites and have three replicates per location. Each study site is under a slightly different resource management regime but is significantly impacted by Japanese hops. Reds Landing in Pool 25 is an active 110 acre reforestation site that was first planted in 2013. This site had minimal Japanese hops present until a flooding event in 2014 brought in seed. Currently the site has a dense population of Japanese hops that is affecting survivorship and growth of tree seedlings. The Timber Ridge Site is a 35 acre wetland restoration and reforestation site located along lower Piasa Creek, a tributary of the Mississippi River in Pool 26. This site also contains dense Japanese hops and reed canary grass populations. The third study site is located in Rock Island District near Bellevue, IA, adjacent to the confluence of the Maquoketa and Mississippi Rivers. The fourth study site will be located in St. Paul District near the confluence of the Root and Mississippi Rivers.



Within each replicate, there will be there will be four 1/10th acre study plots containing three planting densities and one control treatment. The study will have a split plot design where half of each treatment (1/20th acre) will receive maintenance and the other half will not. Due to the remote location of many Japanese hops populations, annual maintenance following planting will not be feasible in many areas, and this will hopefully allow us to identify a threshold for planting density that effectively eliminates the need for maintenance. In the study plots, we will compare survivorship and growth of large black willow cuttings planted at two different densities (4x8 ft and 8x8 ft) and 3 gallon eastern cottonwood and American sycamore (*Platanus occidentalis*) trees planted at one density (16x16 ft). Long term survivorship of trees is contingent on their ability to grow taller than competing herbaceous vegetation, and large cuttings should provide a size and growth advantage. Cuttings will be planted to a depth of approximately three feet using a hydro-spade, which utilizes high-pressure water to hydro-drill a planting hole for large diameter cuttings. Annual maintenance activities will include three mowing treatments, one pre-emergent herbicide (sulfometuron) application and one post-emergent herbicide (glyphosate) application. Each treatment block will be mowed around it to reduce the potential for lateral growth of Japanese hops into the plots.

Japanese hops, other naturally occurring ground-layer vegetation, and planted trees within each study plot will be monitored twice a year over the course of the study. Initial sampling will occur prior to the first mowing each year to get a baseline assessment of hops and vegetation coverage at the sites. 100% of the trees planted in each treatment will also be measured at this time to determine over-wintering and flood survivorship. An additional monitoring effort will occur 2-4 weeks after the second maintenance treatment to determine seasonal hops and herbaceous plant production, coverage, and frequency of occurrence. 100% of the trees planted at each treatment will be measured again at this time to determine survivorship and seasonal growth rates.

Quantifiable data will be collected from ten 0.5 m^2 quadrats randomly located within each $1/20^{th}$ acre split plot. Coverage of Japanese hops in each quadrat will be measured on a percent scale. Additional herbaceous layer vegetation will be recorded by species and percent cover. Subsequent to on-site measurements conducted during the second seasonal monitoring effort, aboveground Japanese hops biomass will be collected from three randomly selected quadrats in each split plot and brought back to NGRREC's laboratory to determine oven-dry weight. The dbh (diameter at breast height) and height of all planted trees at each study site will be recorded by species. Any naturally occurring tree regeneration greater than 1.37 m in height in the quadrats will also be tallied and recorded by species and size class (dbh and height).

Data analysis will follow a split plot experimental design testing for the effects of planting density and maintenance on several quantifiable measures of vegetation response including Japanese hops coverage and biomass, total vegetation species richness, diversity and coverage, and survivorship and growth of planted trees.

Special needs/considerations:
None

Budget:
The USACE has secured an alternate source of funding for the tree planting and maintenance portion of the project.

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Timeline:
The proposed period of performance is April 1, 2019 – September 30, 2020.

Expected milestones and products:

1. Annual progress reports will be submitted following completion of yearly work cycles. These reports will contain detailed information about work completed over the course of the entire year, data analyses, a summary of results to date, and annual expenditures.
2. A final technical report containing detailed information about work completed over the course of the project, data analyses and summaries, final results, a discussion of the implications of the results of the study, and recommendations for Japanese hops control and management strategies throughout the UMRS. Completion date: September, 2020.
3. One peer-reviewed manuscript. Completion date: September, 2021.

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WG5

Woody Debris in the Upper Mississippi River System: its quantity, distribution, and ecological role

Principal Investigators:
KathiJo Jankowski, Research Ecologist; USGS UMESC, 2630 Fanta Reed Road, La Crosse, WI 54603; Phone: 608-781-6242; Email: kjankowski@usgs.gov

Molly Sobotka, Systems Ecologist; Big Rivers and Wetlands Field Station; Missouri Department of Conservation, 3815 E Jackson Boulevard, Jackson, MO 63755; Phone: 573-290-5858; Email: Molly.Sobotka@mdc.mo.gov

Molly Van Appledorn, Ecologist; USGS UMESC, 2630 Fanta Reed Road, La Crosse, WI 54603; Phone: 608-781-6323; Email: mvanappledorn@usgs.gov

Collaborators:
Jayme Stone, Cartographic Technician; USGS UMESC, 2630 Fanta Reed Road, La Crosse, WI 54603; Phone: 608-783-6290; Email: jmstone@usgs.gov

Jenny Hanson, Biologist; USGS UMESC, 2630 Fanta Reed Road, La Crosse, WI 54603; Phone: 608-781-6372; Email: jhanson@usgs.gov

John H. Chick, Field Station Director; Great Rivers Field Station, Illinois Natural History Survey, 918 Union Street, Alton, IL 62002; Phone: 217-300-3844; Email: chick@illinois.edu

Roger Haro, Associate Dean and Professor; Dean's Office, 105E Graff Main Hall, University of Wisconsin-La Crosse, La Crosse, WI 54601; Phone: 608-785-6970; Email: rharo@uwlax.edu

Faculty member, Southeastern Missouri University

LTRM fisheries specialists and Other Personnel:
Steve DeLain (MN DNR – Lake City)
Andy Bartels (WI DNR – La Crosse)
Mel Bowler (IA DNR - Bellevue)
Kristopher Maxson (INHS – Illinois River)
Ben Lubinski (INHS - Great Rivers)
John West (MDC - Big Rivers & Wetlands)
Postdoctoral Associate, USGS UMESC
MS Student, University of Wisconsin-La Crosse
MS Student, Southeastern Missouri University

Introduction/Background:
Woody debris has long been recognized as an important component of stream and river ecosystems. It provides a direct link between terrestrial and aquatic environments and plays a variety of significant geomorphic and ecological roles (Gregory et al. 2003, Wohl 2017). For example, submerged woody debris can change channel geometry and bedforms by affecting sediment scour and deposition patterns, influence local inundation and sediment dynamics on the

floodplain via log jam formation, and affect hyporheic flow and associated biophysical processes. Woody debris can also provide important habitat for aquatic and terrestrial organisms, influence biogeochemical cycling rates, and serve as germination sites for plant propagules on the floodplain and on floating log rafts.

To date there has been very little research on woody debris in great rivers, including the Upper Mississippi River System (UMRS; see Lehtinen et al. 1997, Angradi et al. 2004, 2010), despite recognition of its key role in geomorphic and ecological processes in other ecosystems. The majority of wood research has been undertaken on river reaches with much smaller drainage areas (<500km^2) and from a relatively limited geographic region (primarily the Pacific Northwest of North America; see Wohl 2017 for a review). The interest in, and use of, woody debris as a restoration tool in North American rivers has also generally been restricted to these geographic areas and catchment sizes (Roni et al. 2015). More information on woody debris in great rivers would substantially improve our understanding of these systems and expand our methods of habitat restoration and management in these systems.

Limited information on the distribution and role of wood in the UMRS exists. Our understanding of its distribution primarily comes from two sources: 1) a system-wide survey of channel border habitats done from 2004 to 2006 by Angradi et al. (2010) and 2) LTRM electrofishing surveys that have documented wood presence/absence across a subset of aquatic areas in six study reaches. These data show several notable patterns. First, Angradi et al. (2010) found that although there were no obvious longitudinal trends in wood abundance along the channel border, wood abundance in the UMRS was much lower than in other streams and rivers. Wood was more abundant along forested than revetted, agricultural, or urban shorelines, suggesting that remaining floodplain forests are critical sources of wood to the river. Second, an analysis of LTRM fisheries data showed notable differences in wood occurrence among aquatic habitat types and over time. Although there were no differences among study reaches in the frequency of wood occurrence, backwater shorelines consistently had the highest abundance of wood (Figure 1A). These analyses also show a notable decline in the frequency of wood occurrence over time (Figure 1B), which suggests that wood inputs or storage may have changed since the beginning of the LTRM program.

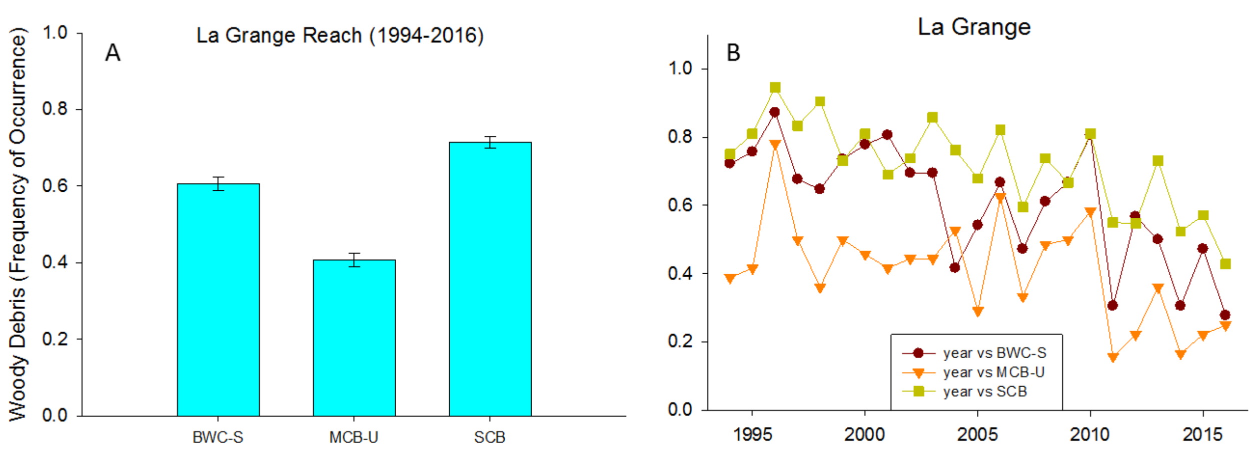

Figure 1. Example of pattern of frequency of occurrence of woody debris (A) across habitats and (B) over time in the La Grange reach of the Illinois River. “BWC-S” = contiguous backwater shoreline, “MCB-U” = main channel border – unstructured, and “SCB” = side channel border.

There are several important limitations to our understanding of wood distribution based on these datasets. Although Angradi et al. (2010) covered the entire length of the Upper Mississippi River and provided quantitative information on wood abundance and characteristics, the survey provides no information on wood distribution across habitat types other than the main channel border, does not include the Illinois River, and represents a single snapshot in time. The LTRM data do provide more information about the spatial distribution of wood across habitats and time because wood presence is reported in each 200x30 meter electrofishing sampling site which are distributed in all six LTRM key reaches, including the La Grange reach of the Illinois River. However, no information about the quantity, size, or structural characteristics of woody debris is reported and exact location of wood occurrences within the sampling area is unknown. Furthermore, both datasets are limited to wood observed above the surface of the water and do not give any information on the abundance of submerged wood, which could be substantial in some habitats and critical for understanding its geomorphic role and ecological impacts on aquatic organisms.

There have been even fewer studies of the biophysical role of woody debris in great rivers (Gregory et al. 2003) and in the UMRS in particular (but see Angradi et al. 2004 and Lehtinen et al. 1997). In the UMRS, fish were more frequently associated with wood structure more often in fast-flowing habitats such as the channel border than in lower flow side channels and backwaters (Lehtinen et al. 1997). A preliminary analysis of LTRM fisheries data showed a small but significant difference in fish communities associated with the presence of wood and suggested that this may differ among habitats (J. Chick, pers. comm.). Furthermore, AHAG 2.0 models suggest that there is variation in the degree to which UMRS fish species associate with woody debris (Ickes et al. 2014). Although these studies provide useful information, they are still limited in scope and extent, rely on wood frequency of occurrence data, and provide no information on other vertebrates (e.g., waterfowl, turtles; Obbard and Brooks 1978, Lindeman 1999), invertebrates, or periphyton. As a result, we do not know whether wood is a factor that limits habitat for species that use the UMRS and whether that varies spatially. Based on work on smaller river systems, wood can fill a diverse set of biophysical roles depending on its geophysical setting, from altering local sediment dynamics to providing substrate for macroinvertebrate colonization and fish refuge from high flow and predators. Thus, we expect that the biophysical role and importance of woody debris could vary widely throughout the UMRS.

The limited information we have about woody debris hinders our ability to anticipate and respond to changes in the UMRS watershed that may directly impact woody debris dynamics. For example, there may be large-scale changes to wood recruitment dynamics in response to the arrival of Emerald Ash Borer and even-aged silver maple stands reaching their longevity. We currently do not have a way to anticipate how these terrestrial impacts may affect aquatic wood distributions, or know how long-lasting these effects may be. The distribution and transport of woody debris may shift in response to altered hydrologic regimes associated with watershed development, climate change, and management actions. How flow alterations impact the distribution and availability of woody debris is largely unknown in the UMR. Furthermore, there is a growing interest in understanding the contemporary distribution, recruitment and transport dynamics, and potential of woody debris as a restoration tool in the UMR. There remain many questions to answer in order to enhance our understanding and ability to utilize wood effectively in habitat restoration projects.

Our project aims to improve our understanding of the abundance, distribution and ecological role of woody debris in the UMRS. Such information can inform future HREP selection and design by documenting relationships among woody debris, aquatic organisms, and local habitat conditions. The results will also provide a foundational for future studies of transport and retention dynamics of woody debris across the UMRS, including the development of process-based models of how changes to terrestrial environments and hydrology may impact the availability of woody debris and influence aquatic organisms – all of which could contribute to diversifying the techniques available for habitat restoration in the UMRS.

Our proposed research will address the following two questions:

1) What is the current distribution of submerged and partially submerged woody debris in LTRM study reaches?
2) What is the biophysical role of woody debris in the UMR and how does it vary across hydrogeomorphic settings?

To address these questions, we first will enhance existing woody debris data collection efforts by LTRM fisheries teams to estimate the abundance and distribution of woody debris in the six LTRM study reaches. These efforts will generate finer-scale information on woody debris distribution patterns across aquatic habitats in the UMRS. Second, we will investigate the functional role of wood from three key tree species using an analysis of fish and wood data from the LTRM fisheries surveys and through experimental field wood incubations. The proposed research would fill a fundamental knowledge gap and lay the foundation for future studies of woody debris transport and recruitment, hydrogeomorphic role, broader ecological impacts, and the utility of wood in HREP design in the UMRS.

Approach and Methods:

Research Question 1) *What is the current distribution of submerged and partially submerged woody debris in LTRM study reaches?*

Documenting the abundance and distribution of woody debris in the UMRS is a primary step toward understanding important drivers/constraints of these patterns. The abundance of woody debris is expected to be a dynamic component of the UMRS river-floodplain ecosystem that changes over time in ways that reflect patterns of wood recruitment, storage, and transport (Figure 2). At any given time, the amount and distribution of aquatic woody debris in a stretch of river is a function of wood inputs from upstream and tributary sources, internal recruitment from riparian forests, transport dynamics, and loss of woody debris via export downstream or decomposition. Currently, we have very little understanding on how wood is distributed across riverine habitats within the UMRS.

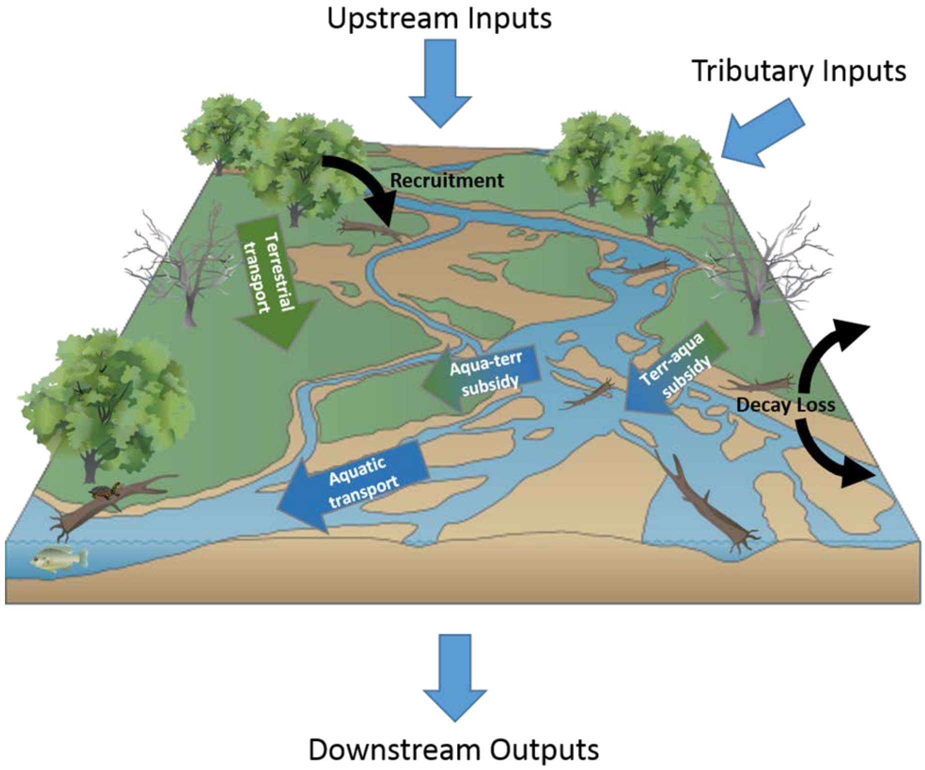

Figure 2. A conceptual model of woody debris dynamics in a stretch of river. Important inputs, outputs and material transfers are labeled.

We will document the abundance and distribution of aquatic woody debris in the UMRS by enhancing existing LTRM data collection efforts in two ways:

1) *Enhanced Visual Surveys:* We will develop a standardized, quantitative visual assessment protocol for inventorying "emergent" woody debris by LTRM fisheries teams during routine sampling efforts. Fisheries teams already gather information on the presence or absence of woody debris associated with fish collections of various gear types. We will develop an enhanced protocol with the assistance of the fisheries teams to collect quantitative information on woody debris in standardized sampling areas. This protocol will primarily be focused on electrofishing surveys, but we will explore the possibility of collecting additional woody debris information along with other gear types. We anticipate these protocols will include two additional pieces of information: 1) a categorical wood abundance estimate and 2) an estimate of percent cover. We will work with the LTRM database manager at UMESC to develop new fields in the Fish App to include these more quantitative data. We will retain the collection of the presence/absence data and associated field in the database to allow for direct comparisons between existing woody debris datasets and the new, enhanced woody debris inventory.
2) *Mapping submerged woody debris:* We will develop maps of submerged woody debris by interpreting imagery from side-scanning sonar. Work by the UMESC spatial branch has shown that side-scanning sonar is capable of capturing high-resolution images of submerged woody debris that can be analyzed to calculate abundance and quantify simple measures of wood complexity such as exposed length, diameter, orientation, branching complexity, presence of root wads, etc. (Figure 3). Side-scanning sonars with technical

specifications appropriate for mapping woody debris are already in use by most LTRM fisheries teams to detect potential obstructions during routine sampling. We will leverage existing equipment where possible and equip fisheries teams with new sonar equipment where appropriate (see budget for specifics). Image collection will occur during a second pass through electrofishing sampling locations upon completion of the electrofishing survey. Although boating speed must not exceed 5 mph to ensure high resolution image capture, fisheries teams do not anticipate the sonar surveys to be substantial time investments. Images will be downloaded, post-processed, and interpreted by USGS UMESC Geospatial branch members (coordinated by J. Stone and J. Hanson). A shapefile of point locations of woody debris will be produced that includes information about debris size, orientation, and complexity. A pilot study of these new visual and sonar survey methods will be done in summer 2018 during LTRM fisheries surveys, evaluated, revised if necessary, and applied in 2019.

The analysis of data from the enhanced visual surveys and submerged woody debris maps will be led by the post-doctoral research assistant with supervision by Van Appledorn. First, data from the enhanced visual surveys will be compared to presence/absence surveys collected at the same time to characterize the sampling error and variability of past LTRM woody debris records. The results of this comparison should guide the application of previous records in ecological studies. Second, the abundance and distribution of woody debris will be summarized across and within each LTRM key pool to understand longitudinal variability in the abundance of aquatic woody debris, and to understand how aquatic woody debris may vary across aquatic habitat types. Third, spatial distributions of woody debris will be analyzed in conjunction with geospatial measures of river morphology and bathymetry to identify potential drivers of woody debris distributions (e.g., tributary inputs, bed complexity, channel connectivity, terrestrial land cover, etc.). The results of these analyses will collectively document spatial patterns of woody debris abundance across the UMR and identify potential drivers of these distributions, ultimately producing testable hypotheses about processes that contribute to woody debris dynamics.

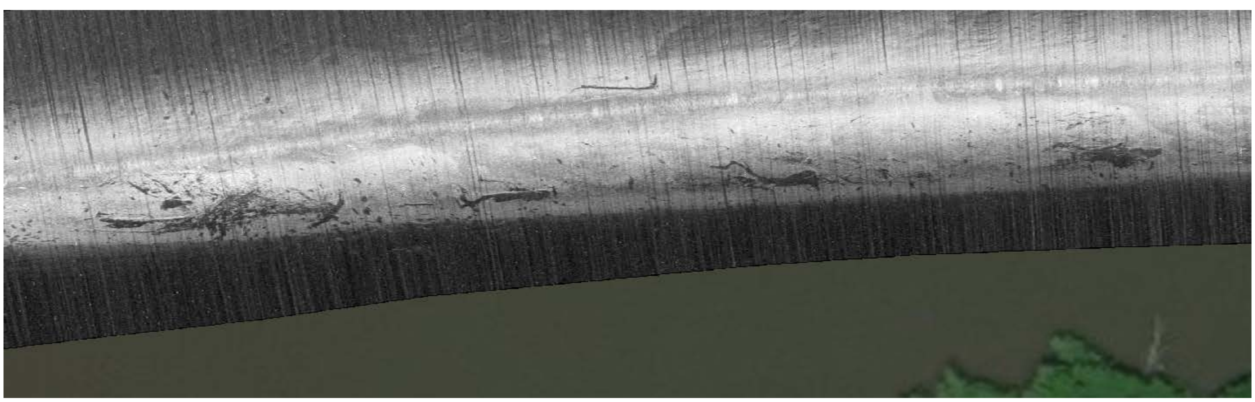

Figure 3. Google Earth satellite image overlain by black-and-white image of the underwater substrate collected from side scanning sonar in the Illinois River. Basic attributes such as size class, shape, and orientation of woody debris pieces can be extracted from the sonar imagery.

The scope of the proposed research and magnitude of new data generated requires someone for whom this project is the primary responsibility (i.e., term (post-doctoral) scientist). The newly generated spatial datasets of submerged and emergent woody debris will be large and complicated. We anticipate the organization, integration with historical LTRM data, and analytical time will be substantial and require proper quantitative skill sets. In addition, the post-doctoral assistant will take a lead role in integrating these spatial datasets with fish community data as described below.

Research Question 2) *What is the biophysical role of woody debris in the UMR and how does it vary across hydrogeomorphic settings?*

Understanding the importance of woody debris to fundamental ecological processes that support secondary and tertiary production such as decomposition, periphyton growth, and macroinvertebrate colonization and consumption will help managers and scientists anticipate how perturbations may impact the broader UMRS ecosystem. Given the simple disparity in the size of woody debris relative to the size of the channel in a system as large as the UMRS, the capacity of woody debris to substantially alter physical, chemical and biological processes is much lower than in small streams and rivers (Bilby and Ward 1989, Piegay et al. 2003, Wohl et al 2017). However, the UMRS is a mix of diverse habitats that range in depth, velocity and riparian forest cover, thus, woody debris is likely to play a more critical role as substrate and habitat in some areas than others. Gaining an understanding of how wood functions differently across aquatic habitat types will be important for its effective use in restoration projects.

Subquestion 2.1: Does fish abundance or community composition vary in association with the quantity or characteristics of woody debris?

Previous work in Pool 6 has showed that the composition of fish communities associated with wood varies (Lehtinen et al. 1997). In addition, LTRM electrofishing surveys already provide a basic assessment of the presence or absence of woody debris in each pass that suggests that these relationships may hold true on a broader scale (Ickes et al. 2014, J. Chick, pers. comm.). To more fully answer these questions, we will use the information generated by the enhanced LTRM Fisheries surveys of woody debris outlined in Objective 1 to assess patterns in fish use associated with woody debris across study reaches and habitats. We also will also be able to use the wood complexity metrics generated from the sonar data to assess whether wood complexity is related to fish use. This will allow us to more closely relate these quantitative estimates of wood abundance and characteristics to fisheries data than has been possible with presence/absence estimates.

Statistical analyses will focus on the following two goals: 1) relating wood abundance and complexity across habitats and LTRM study reaches to fish community composition, 2) comparing our findings with our historical presence/absence estimates. The analyses will be largely based on data collected to address Research Question 1 by LTRM Fisheries crews as described previously as well as existing LTRM fisheries datasets. Statistical analyses will be led by the post-doctoral researcher with guidance from Chick, Jankowski, and Sobotka. No additional equipment is needed beyond that detailed above.

Subquestion 2.2: Do decomposition and colonization rates by periphyton and macroinvertebrates vary among tree species, aquatic habitat types, or river reaches?

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We will examine how three key tree species – black locust, green ash and silver maple – vary in their decomposition rate, as substrate for periphyton growth, and in their colonization and consumption by macroinvertebrates. We will focus on these three species for a number of reasons. Black locust is a common species used to provide woody structure (e.g., loafing structures) in restoration projects on the UMRS (Baker et al. 2012), and we anticipate these data will be of interest to restoration planners in understanding how this species decomposes and serves as habitat for primary and secondary producers. Green ash and silver maples are both currently substantial components of floodplain forest communities, but mortality of both species is anticipated to increase in the near term with the arrival of Emerald Ash Borers and the nearness of single-age Silver Maple stands to their longevity.

Figure 4. Hester-Dendy sampler (image: Forestry Suppliers.

Our experimental design uses modified "Hester-Dendy" samplers (Figure 4) that will be installed under water across contrasting hydrogeomorphic areas in Pool 8 and the Open River reach. We will construct these samplers using standardized wood pieces of the three species of interest. We will distribute the samplers across nine sites in each river reach – three sites for each of three habitat types specific to each reach. In Pool 8, we will sample three backwaters, three side channel and three channel border sites. In the Open River Reach, we will sample three wing dike scour hole, three side channel and three channel border sites. We will use three replicate samplers for each tree species at each site for a total of 81 samplers per river reach. We will deploy samplers in early June and collect them 16 weeks later. Mass loss has been observed over this time period in other studies (R. Haro, pers. comm.). We will assess periphyton biomass at the time of collection by scraping a known area of each plate and collecting the periphyton onto a filter to be later run for chlorophyll content at UMESC.

We will quantify macroinvertebrate abundance on each plate at the time of collection, and specimens will be preserved for identification. Periphyton and macroinvertebrate biomass per unit of wood surface area will be scaled to estimated areas of large wood size categories used in the woody debris mapping effort (Research Question 1). After periphyton and macroinvertebrates have been removed, we will dry and weigh each plate to quantify mass loss and decomposition rate.

This project will provide an estimate of decomposition rates of three key tree species to inform our understanding of wood loss rates across different riverine conditions. We intend to compile the data from both reaches into manuscript(s) that compares decomposition, periphyton and macroinvertebrate colonization across habitats, species and river reaches. This project will be led in Pool 8 by a graduate student at the University of Wisconsin-La Crosse (UWL) under the guidance of Jankowski and Roger Haro (UWL). The Open River Reach portion of this project will be led by a graduate student at Southeastern Missouri University (SEMO) with supervision by Sobotka and Jankowski.

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We will construct 162 Hester-dendy samplers at UWL. Chlorophyll analysis will be done by the LTRM Water Quality Lab at UMESC. Macroinvertebrate identification will be done by graduate students with the oversight of Roger Haro and faculty at SEMO.

Relevance of research to UMRR:
The lack of information on woody debris in great rivers, and the UMR in particular, represents a significant gap in our understanding of large floodplain rivers. The proposed work will contribute fundamental knowledge about the distribution of woody debris across a range of aquatic habitat types and longitudinally within the UMRS, what factors drive or constrain spatial patterns of woody debris storage, and the relationships with aquatic biota.

Woody debris is commonly used for habitat restoration in streams and rivers across the United States, and although wood elements have been incorporated into some HREP designs, woody debris has not been widely used in habitat restoration projects in the UMRS (D. Potter and J. Hendrickson, pers. comm.). This project will provide information that will inform the use of wood in HREP projects in a number of ways. First, we will generate data on the current natural supply and drivers of woody debris abundance in all LTRM reaches of UMR. This will allow us to estimate how wood loads compare among and within reaches of the UMR and with other rivers. Second, we will generate data on how fish use woody debris, which can inform our understanding of whether and under what conditions added wood provides additional habitat for certain fish species. Third, we will generate estimates of the decomposition and macroinvertebrate colonization rates (fish food sources) of wood of three key tree species that are either used in restoration projects (black locust) or are expected be a large proportion of the woody debris budget of the UMR in the future (silver maple and green ash).

This project addresses the following Focal Areas: **Focal area 3** Interactions and associations of hydrogeomorphology with biota and water quality and **Subarea 3.4**: Associations between hydrogeomorphology and the quantity, distribution and biophysical role of woody debris in the UMR.

Timeline

	FY18	**FY19**			**FY 20**			**FY 21**		
Task	**SU**	**FA**	**SP**	**SU**	**FA**	**SP**	**SU**	**FA**	**SP**	**SU**
Objective 1:										
Enhanced Visual Surveys	Pilot			X	X		X	X		
Side-scan Mapping	Pilot			X	X					
Analysis		X	X			X	X		X	X
GIS layers of woody debris distribution										X
Draft manuscript										X
Objective 2:										
Fish abundance/community	Pilot			X	X					
Periphyton/Macroinverts/Decomposition	Pilot			X						
Analysis					X	X	X			
Manuscript draft										X

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Title of Project: 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.

Name of Principal Investigators:

Andy Bartels
WDNR Field Station
2630 Fanta Reed Road
La Crosse, WI 54603
608-781-6361
abartels@usgs.gov

Kristen Bouska
USGS UMESC
2630 Fanta Reed Road
La Crosse, WI 54603
608-781-6344
kbouska@usgs.gov

Quinton Phelps
West Virginia University
Percival Hall
Morgantown, WV 26506
304-293-2216
Quinton.phelps@mail.wvu.edu

Collaborators:
The following LTRM field station staff will collect and store fish specimens for the project:

Steve DeLain, MNDNR, steve.delain@state.mn.us
Kraig Hoff, WIDNR, khoff@usgs.gov
Mel Bowler, IADNR, melvin.bowler@dnr.iowa.gov
Eric Ratcliff, INHS, eratclif@illinois.edu
Eric Gittinger, INHS, egitting@illinois.edu
John West, MDOC, John.West@mdc.mo.gov
Levi Solomon, INHS, soloml@illinois.edu
Kris Maxson, INHS, kmaxs87@illinois.edu

The following UMESC, USGS staff will provide data management support:

Ben Schlifer, USGS, bschlifer@usgs.gov

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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

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.

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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?

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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

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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 $Lt = L\infty(1\text{-}e(\text{-}K(t\text{-}t0)))$; where, Length infinity ($L\infty$) is the theoretical maximum length that a fish can achieve, K is the growth constant or growth rate of the population, and t0 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.

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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 and genetic analyses 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.

Genomic analysis will be conducted on a subset of each of the six system-wide species (n=50 adults) from each LTRM reach and will be led by Dr. Wes Larson and a masters student. 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. We will use restriction site-associated DNA (RAD) sequencing to genotype thousands of genetic markers per species. RAD sequencing employs a restriction enzyme (in this case *SbfI*) to fragment the genome into thousands of small pieces, which are then sequenced on a high-throughput platform, such as the HiSeq4000 (Illumina, San Diego, CA). Single-nucleotide polymorphisms (SNPs) are then discovered and genotyped from the sequence data. RAD sequencing is currently the most commonly employed technique to genotype thousands of SNPs in non-model organisms and was a significant catalyst for the genomics revolution in these organisms (Andrews et al. 2016). RAD sequencing will be conducted using the "Best RAD" method described in Ali et al. (2015). Dr. Wes Larson has previously used this method to RAD sequence yellow perch and cisco and found it produces robust data with a higher proportion of on-target reads compared to traditional RAD methods that do not incorporate an additional restriction site selection step. We will use the program STACKS (Catchen et al. 2013) to identify and genotype SNPs from RAD data, and SNP filtering will be conducted using the methods outlined in Larson et al. (2014) to produce a final dataset of high-quality SNPs. We will then conduct individual- and population-based analyses to quantify genetic differentiation among sampling sites, estimate genetic diversity, and investigate adaptive differentiation (Table 1).

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Special needs/considerations, if any: In addition to the costs requested as part of this proposal, Dr. Greg Whitledge will provide two years of a PhD student's salary and fringe through other funding sources for the otolith microchemistry component. If other proposals require effort from the LTRM fish specialists, additional funds may be requested to support an additional field assistant.

Budget:
The attached budget spreadsheet includes a breakdown of costs for all project components. We estimate the 4-year vital rates component to cost approximately $300,000, the otolith microchemistry component to cost roughly $80,000, and the genetic component to cost approximately $184,000. With all components together, the project cost is estimated to be $564,000.

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

		2018		2019			2020			2021		
	Task	Sum	Fall	Spr	Sum	Fall	Spr	Sum	Fall	Spr	Sum	Fall
Vital Rates	LTRM Fish collection	■			■			■				
	Otolith processing		■			■			■			
	Vital rate quantification			■			■			■		
	Data QA/QC										■	
	Vital Rate Final Report/Manuscripts											■
	Annual age-0 length estimation	■										
	Development of independent variables	■	■									
	Statistical analysis: test drivers of vital rate variability			■	■		■	■		■	■	
Microchemistry	Laboratory analysis			■	■	■						
	Statistical analysis						■	■	■			
	Microchemistry Final Report/Manuscripts									■	■	■
Genetics	Laboratory analysis			■	■	■						
	Statistical analysis						■	■	■			
	Genetics Final Report/Manuscripts									■	■	■
All	Annual report				■			■				■

Timeline:
A timeline table is provided with project tasks and estimated dates of completion (Table 3). Data collection will occur during regular LTRM fish field sampling in 2018, 2019, and 2020. Processing of samples will occur from late 2018 through 2021. Data QA/QC will occur in late 2021. Data set will be provided to UMESC when QA/QC is complete. Analysis and reporting will occur annually with the final report due in late 2021.

Expected milestones and products:
A dataset of all age, growth, recruitment, and mortality information will be assembled and made available to the UMRR program following QA/QC. The dataset will be linked to the LTRM database through barcode numbers and will be coordinated with Ben Schlifer. Following completion of the project, otoliths will be organized by barcode and stored at the Big Rivers and Wetlands Field Station.

Revisions of age-0 growth data will be made to the LTRM Fish Life History database following completion of annual age-0 length estimates from LTRM fish data.

Annual progress reports will be provided in the summer of each year. At the completion of this project, there will be multiple manuscripts and reports prepared, published, and shared with the partnership. All manuscripts will be submitted no later than December 2021. These products will come in the form of written documents, power point presentations (i.e., at UMRCC, MRRC and component meetings), and potential new additions to graphical browsers (e.g, length at age for biologists and anglers).

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