M.L. 2014 Project Abstract
For the Period Ending June 30, 2017

PROJECT TITLE: Conserving Minnesota's Native Freshwater Mussels
PROJECT MANAGER: Jessica Kozarek
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 05k

APPROPRIATION AMOUNT: $350,000
AMOUNT SPENT: $350,000
AMOUNT REMAINING: $0

Overall Project Outcome and Results
Native freshwater mussels are a valuable part of Minnesota river ecosystems. Mussels can improve water clarity, enhance streambed stability, and create habitat for other aquatic organisms. Freshwater mussels are filter feeders that live within river bottom sediment and are sensitive to environmental changes including increased sediment loads, higher flood flows, or lower base flows. We investigated the interactions between mussels and their habitat using a combination of fieldwork in the Minnesota and the St. Croix watersheds and laboratory experiments in the Outdoor StreamLab and flumes at St. Anthony Falls Laboratory. We re-visited field sites previously sampled by MN DNR and evaluated mussel population change in abundance, diversity, life history traits and disturbance tolerance across a gradient of suspended sediment loads and agricultural impacts. We also evaluated growth rates and mussel energy stores (glycogen) within these watersheds. In general, as agricultural impacts (and sediment loads) increased, mussel abundance and diversity decreased, but growth rates and mussel energy stores increased, likely due to increased food availability from agricultural nutrient inputs. In addition, as agricultural impacts increased, mussel communities shifted toward more disturbance tolerant, opportunistic communities. In the laboratory, we evaluated mussel response to flow, suspended sediment, and streambed stability. Mussels did not stop feeding under high flows with increased sediment loads, and there was no measurable impact on mussel energy stores. However, mussels did increase their waste excretion behaviors. During flooding, when bed sediment was mobile, mussels anchored in place until flood waters receded. These experiments provide important evidence about how adult mussels respond to changing hydrology and sediment loads. However, sediment effects could not be isolated in the field and multiple stressors (hydrologic changes, sediment, nutrients, other pollutants, etc.) can affect sensitive mussel species and/or sensitive phases of the mussel life cycle. This research informs mussel conservation and re-introduction efforts.

Project Results Use and Dissemination
Through this project, we advocated cleaner and healthier Minnesota waters by studying the environmental conditions necessary to conserve and promote a diverse and sustainable native mussel population. This project impacted 1) the greater scientific community through the development of five peer-reviewed publications and presentations at scientific conferences (state, regional, and national); 2) water resources and wildlife professionals working towards freshwater mussel conservation through the

dissemination of results, and 3) the general public through public engagement strategies designed to illustrate ecosystem services provided by freshwater mussels and the linkages between mussels and clean water. In addition, this project provided training for the next generation of water resource professionals by incorporating twelve undergraduate student researchers in field, laboratory, and engagement activities.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan Final Report

Date of Report: August 15, 2018

Date of Next Status Update Report: Final Report

Date of Work Plan Approval: June 4, 2014

Project Completion Date: June 30, 2018

PROJECT TITLE: Conserving Minnesota's Native Freshwater Mussels

Project Manager: Jessica Kozarek

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Location: Minnesota River Basin; St. Croix River; Macalester College; St. Anthony Falls Laboratory, University of Minnesota

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$350,000**
	Amount Spent:	**$350,000**
	Balance:	**$0**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05k

Appropriation Language:
$350,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota in cooperation with Macalester College to document native freshwater mussel abundance and distribution, quantify environmental conditions necessary to conserve Minnesota's native freshwater mussels, and conduct outreach to local organizations and the public. This appropriation is available until June 30, 2018, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Conserving Minnesota's Native Freshwater Mussels

II. PROJECT STATEMENT:

Native freshwater mussels are a valuable part of our river ecosystems but mussel populations have declined in Minnesota (MN) due to widespread habitat destruction, pollution, land-use change, over-harvesting, and/or the introduction of exotic species. For example, in the Minnesota River, where mussel diversity was once greater than that of the St. Croix River, nearly half of the mussel fauna has been lost in the past 50 years. These declines have led to the initiation of programs to propagate and reintroduce rare mussels to maintain the ecosystem services that freshwater mussels provide and to preserve historical biodiversity. Mussels filter an enormous quantity of water each day removing suspended material. The physical presence of both living mussels and their empty shells stabilizes sediment, and creates habitat for other aquatic life including fishes, amphibians, insect larvae, and algae. Large aggregations of mussels can improve water clarity and enhance streambed stability, decrease sediment re-suspension during high flows and reduce downstream transport of target contaminants such as excess nutrients, suspended solids, and bacteria.

Freshwater mussel abundance and distribution are inherently linked with their habitat through sediment transport processes in moving waters (i.e. suspended sediment or bed stability). This project seeks to quantify the complex interactions between mussels and their habitat using a combination of field data collection in the Minnesota River Basin and the St. Croix River and controlled laboratory experiments in the Outdoor StreamLab (OSL) and flumes at St. Anthony Falls Laboratory (SAFL). This information is critical to MN's ability to 1) maintain ecosystem services proved by mussels (e.g. improved water clarity and river bed stability), 2) use mussel monitoring as an indicator for changes in water quality, 3) to evaluate the suitability of potential mussel reintroduction sites, and 4) to define specific habitat criteria for restoration planning (e.g. pinpoint areas where bank stabilization and decreased sediment load will have the greatest impact on retaining or reintroducing mussels to their historic range).

While native mussels are an integral and fascinating part of MN's aquatic ecosystems, they live on the bottom of our rivers, and are fairly unknown to most people. The importance of native mussels and river habitat will be disseminated to Minnesotans through a mussel display at the MN State Fair as part of a broad-based and dynamic set of strategies to reach public audiences. This project integrates Foundational Natural Resource Data and Information and Water Resources research with a public engagement strategy that will supplement ongoing mussel restoration, reintroduction, and rehabilitation efforts where the success of these projects is dependent on the public's understanding of the importance of native mussels to our aquatic resources (e.g. for swimming and fishing).

III. PROJECT STATUS UPDATES:

Project Status as of January 1, 2015: The project kickoff meeting was scheduled for January 8, 2015 and was attended by J. Kozarek and A. Hansen (SAFL), M. Hove, K. Macgregor, and D. Hornbach (Macalester), P. Nunnally (River Life), and M. Davis and B. Sietman (MN DNR). The goals of this meeting were 1) to introduce all members of the team, 2) to discuss the integration of Activities 1 and 2 with the public engagement (Activity 3), 3) to select sites and mussel species for Activity 1 with input from MN DNR.

Project Status as of July 1, 2015**:** The Macalester research team including Hornbach, Hove, MacGregor and four Macalester undergraduate students began field data collection for Activities 1 and 2. Field sites include three sub- watersheds in the Minnesota River Basin (Chippewa, Le Sueur, and Cottonwood) in the Minnesota River Basin and in the Snake River sub-watershed in the St. Croix watershed that were previously sampled for freshwater mussels by MN DNR. The research team met with MN DNR employees to ensure that field methods would be comparable between past data and the current project. This field campaign is ongoing and has undergone minor delays due to high water levels.

Project Status as of January 1, 2016**:** The first year of mussel sampling was completed in three sub-watersheds in the Minnesota River Basin (23 sites) and in the Snake River sub-watershed in the St. Croix River watershed (13 sites) as part of Activity 1. Glycogen samples were collected from two species at each of these sites to measure the physiological response of mussels to the environmental conditions in each sub-watershed (Activity 2). Student researchers developed a display for the Minnesota State Fair DNR building and created a blog to tell the story of their research (http://mnmusselsatmac.blogspot.com/) as part of Activity 3. Preparations are underway for experiments at St. Anthony Falls this summer (Activity 2)

Amendment Request (1/11/16): LCCMR Amendment Approval 1-14-2016
To complete an agreement with the UMN Sponsored Projects Administration and USGS UMEC, the University of Minnesota needs to move the $4,800 budgeted under "Other" for laboratory fees to a Professional Service Contract to the USGS Upper Midwest Environmental Sciences Center. The total budget will remain the same, but this change is necessary to complete the funds transfer to USGS UMEC.

Completion date of Activity 2, Outcome 2, "Physiological response of mussels to suspended sediment" needs to be changed to April 2017 (combined with Activity 2, Outcome 3). This will ensure that researchers can conduct experiments in appropriate stream temperatures and that experiments can last the appropriate length of time. Based on Activity 1, elevated suspended sediment concentrations recorded in the Minnesota River lasted much longer than previously expected and experiments need to account for this.

Project Status as of July 1, 2016**:** Experiments are underway at St. Anthony Falls Laboratory (SAFL). Lead by project manager, J. Kozarek, the research team including Hornbach, Hove, MacGregor and six undergraduate student researchers are conducting experiments in the Outdoor StreamLab (OSL) and a flume at SAFL to quantify mussel response to bed instability (OSL) and suspended sediment loads (flume) as part of Activity 2.

Project Status as of January 1, 2017**:** Experiments were completed at SAFL in August 2016 (Activity 2) to quantify mussel response to bed instability (OSL) and suspended sediment loads. Data analysis is ongoing. Undergraduate student researchers led a freshwater mussel display at the MN State Fair (Activity 3), and research results were presented by undergraduate and senior researchers. Planning is underway for a second season of field work (Activity 1).

Project Status as of July 1, 2017**:** Data processing from the 2015 summer sampling is complete while data processing from the 2016 experiments is ongoing due to the large amount of data collected. The second season of fieldwork is underway. For this season, focus will be on quantitative sediment grainsize and mussel population sampling in two watersheds: the Cottonwood and the Snake. In addition, mussel growth rates of two species: Lampsilis Cardium and Ampema Plicata will be measured across watersheds: Snake, Chippewa, Cottonwood and Le Sueur.

Amendment Request (11/16/17): LCCMR Amendment Approval 12/8/17
Completion dates of Activity 1, Outcome 3 (Report), and Activity 2, Outcomes 2 and 3 need to be moved to the end of the project (June 30, 2018) to allow researchers to complete data analysis necessary for reporting.

Project Status as of January 1, 2018**:** The second year of field data collection was completed focusing on quantitative methods to quantify mussel populations and sediment grain size. Gape sensors were installed in the field to verify the results from the flume studies in 2016. Undergraduate students involved in this research collaborated on an article with River Life detailing their experiences.

Amendment Request (1/2/18):
Request $9,361 to be moved to personnel to fund final reporting, data analysis and manuscript preparation. This total includes $7,453 from supplies, $534 from printing, and $1,374 from in-state travel.

Overall Project Outcomes and Results:
Native freshwater mussels are a valuable part of Minnesota river ecosystems. Mussels can improve water clarity, enhance streambed stability, and create habitat for other aquatic organisms. Freshwater mussels are filter feeders that live within river bottom sediment and are sensitive to environmental changes including increased sediment loads, higher flood flows, or lower base flows. We investigated the interactions between mussels and their habitat using a combination of fieldwork in the Minnesota and the St. Croix watersheds and laboratory experiments in the Outdoor StreamLab and flumes at St. Anthony Falls Laboratory. We re-visited field sites previously sampled by MN DNR and evaluated mussel population change in abundance, diversity, life history traits and disturbance tolerance across a gradient of suspended sediment loads and agricultural impacts. We also evaluated growth rates and mussel energy stores (glycogen) within these watersheds. In general, as agricultural impacts (and sediment loads) increased, mussel abundance and diversity decreased, but growth rates and mussel energy stores increased, likely due to increased food availability from agricultural nutrient inputs. In addition, as agricultural impacts increased, mussel communities shifted toward more disturbance tolerant, opportunistic communities. In the laboratory, we evaluated mussel response to flow, suspended sediment, and streambed stability. Mussels did not stop feeding under high flows with increased sediment loads, and there was no measurable impact on mussel energy stores. However, mussels did increase their waste excretion behaviors. During flooding, when bed sediment was mobile, mussels anchored in place until flood waters receded. These experiments provide important evidence about how adult mussels respond to changing hydrology and sediment loads. However, sediment effects could not be isolated in the field and multiple stressors (hydrologic changes, sediment, nutrients, other pollutants, etc.) can affect sensitive mussel species and/or sensitive phases of the mussel life cycle. This research informs mussel conservation and re-introduction efforts.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Strategic Resampling of Survey Sites: Quantifying Environmental Conditions
Description: This activity focuses on quantifying mussel population response to changing environmental conditions. A strategic plan will be developed to resample a subset of sites previously sampled by the MN DNR (DNR) as part of the Statewide Mussel Survey (http://www.dnr.state.mn.us/nhnrp/mussel_survey/index.html) across a gradient of water quality and habitat conditions in the Minnesota River Basin (MRB). The St. Croix River will serve as a reference or 'baseline' for comparison to a known healthy and diverse mussel community. Mussel species diversity in the MRB has declined compared to historical levels while the St. Croix serves as a refuge for state and federally endangered mussel populations. Spatial data including the DNR statewide mussel survey data, existing information on stream flow and water quality will be used to select field sites across a gradient of high, moderate, and low impact of recent environmental alterations. Sites will be selected in consultation with the DNR. Field data collection will focus on mussel surveys, flow and sediment stability, and important habitat variables in explaining mussel abundance, diversity and distribution. Mussel surveys will be conducted per DNR protocol surveying a large area and a variety of habitats. Additional detailed field surveys will be used to understand the current relationship between mussel diversity/community dynamics and bed conditions. This information will be used to constrain laboratory experiments in Activity 2. Our methodology and resampling plan will be disseminated to DNR as a model to apply to other MN watersheds to detect changes in native mussel populations due to changes in environmental conditions.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 164,773**
Amount Spent: $ 164,773
Balance: $ 0

Activity Completion Date: December 31, 2018

Outcome	Completion Date	Budget
1. Spatial Data Collection (water quality, flow rate, land use, etc. from DNR, PCA, USGS)	April 30, 2015	$ 16,746

2. Resampling to document environmental conditions and mussel populations in MRB and St. Croix.	September 30, 2017	$ 123,580
3. Report detailing the changes in mussel populations and environmental variables in each watershed. Results will be presented in Activity 3.	End of Project	$ 24,447

Activity Status as of January 1, 2015**:** The project kickoff meeting was scheduled for January 8, 2015. A plan was developed at this meeting to select sites and mussel species for Activity 1 with input from MN DNR.

Activity Status as of July 1, 2015**:** The Macalester research team including Hornbach, Hove, MacGregor and four undergraduate students, have been revisited the selected research sites for resampling. The selected sites include the Snake River in the St. Croix watershed (which serves as a reference site) and sites on the Chippewa River, Cottonwood River, and Le Sueur River in the Minnesota River Basin (MRB). The MRB sites represent a gradient of suspended sediment concentration versus discharge curves based on work by Hansen et al. (in Press). Selection of these sites was based on: 1) the presence of MN DNR mussel sampling data, 2) a USGS flow gaging station, and 3) a sufficient number of suspended sediment concentration measurements. Field data collection is ongoing and will be completed by the end of this summer. At each site a timed effort mussel survey is conducted (following MN DNR procedures) to compare changes in mussel populations between the previous MN Statewide Mussel Survey and the current survey. In addition, sediment samples and velocity profiles are collected over areas of relatively high mussel density and low mussel density. Due to the unusually wet summer, some field data collection has been delayed. Additional delays may be incurred if water levels remain high. Note that the charges from Macalester College will be applied after July 1, 2015.

Hansen, A.T., J.A. Czuba, J. Schwenk, A. Longjas, M. Danesh-Yazdi, D. Hornbach and E. Foufoula-Georgiou (In Press) Coupling ecology and river dynamics using a simplified interaction model. *Freshwater Science*

Activity Status as of January 1, 2016**:** The Macalester research team including Hornbach, Hove, MacGregor and undergraduate researchers collected freshwater mussel data in four watersheds (Snake, Chippewa, Cottonwood, Le Sueur). The Snake River served as a control, or good water quality site, while the other three watersheds were across a gradient of suspended sediment concentrations in the Minnesota River Basin (Chippewa – low, Cottonwood – moderate, LeSueur – high) that were all an order of magnitude larger than the annual suspended sediment loads in the Snake River. Despite high water throughout much of the summer, the research team was able to visit a total of 36 sites previously sampled by the MN DNR as part of the statewide mussel survey (Table 1). Results from this summer sampling show a general trend of decreasing catch per unit effort (proxy for abundance) as sediment loads increased (Figure 1).

Table 1. Sites sampled in each watershed.

Watershed	Number of Sites Sampled
Snake	13
Chippewa	9
Cottonwood	7
Le Sueur	7

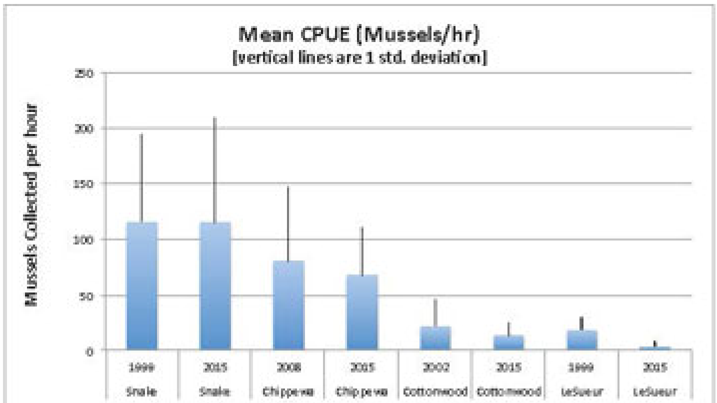


Figure 1. Mean catch per unit effort in each watershed by year.

Activity Status as of July 1, 2016**:** Data collected from Activity 1 from 2015 were used to set up experiments at SAFL in 2016. Based on experimental results from SAFL, field sites will be revisited in the 2017 summer field season.

Activity Status as of January 1, 2017**:** No new activity. Planning is underway for the 2017 field season.

Activity Status as of July 1, 2017**:** 2017 field season is underway. Four undergraduate students from Macalester College are assisting the research team in data collection.

Activity Status as of January 1, 2018**:** The Macalester research team including Hove, MacGregor, Hornbach and four undergraduate students conducted quantitative sampling in the Snake and Cottonwood Rivers (see Figure 1) in 2017 to evaluate whether our Catch per Unit Effort (CPUE) measures of abundance were robust. We randomly chose 10 locations on each river from locations earlier sampled semi-quantitatively by the MN DNR. At each location we used ArcGIS to randomly select 25 sites within a 200 m stretch of the river. At each site we placed a 0.25 m^2 metal frame on the bottom of the stream and excavated the river bottom to a depth of 15 cm. We ran the sediment through a sieve (Figure 2) and removed all living and dead mussels. Individuals were identified to species and live specimens shell lengths (anterior-posterior) were measured with calipers to the closest 1.0 mm. Dead shells were classified as either fresh dead (demonstrating a shiny nacreous layer and intact periostracum), weathered dead (dull nacreous layer and some periostracum still intact) or subfossil (nacreous layer and periostracum very weathered).

Figure 1. Summer 2017: Snake River (left) and Cottonwood River (right).

Figure 2. Mussel sampling in the Snake River, Summer 2017.

We calculated the density of mussels for each quadrat and compared the river systems using nested analysis of variance (quadrats nested within sites and sites nested within each river). Density values were $\log_{10}$(density + 1) transformed before analysis to improve normality. We also calculated the dead:live ratio for each river using the mean number of live or fresh dead mussels. Ratios were arcsine square root transformed before analysis.

Quantitative Sampling

The mean density in the Snake River was 2.74 mussels/m^2 and was significantly higher than the 0.14 mussels/m^2 found in the Cottonwood (Nested ANOVA on log transformed density: $F_{1,18} = 29.9$, $p<0.0001$). In the quantitative sampling we collected 9 species of live mussels in the Cottonwood compared to 13 species in the Snake. An average of 92% of the mussels collected from the Cottonwood River were dead compared to 64% from the Snake River (t-test: $t_{17} = 4.2$, $p=0.0006$)

Mussel Growth

We used external shell measurements to assess the growth of *Lampsilis cardium*. We collected approximately 25 individuals from each of 3 areas (upper, middle and lower reaches) of each river. We also assessed growth of *Amblema plicata* in two of the rivers (Chippewa and Snake). We measured the anterior to posterior length of presumptive annuli with a caliper to the nearest 1 mm. Internal ring counts have been used widely to estimate mussel age (Haag & Commens- Carson, 2008). However the use of internal rings requires the sacrifice of animals that we did not have the permits to accomplish. Despite differences in internal and external age estimates, growth appraisals have been found to be consistent between the two methods (Sansom et al., 2013). In our study, because of the erosion of the umbo many shells, age determination was impossible.

Preliminary data analysis indicates that *Lampsilis cardium* grew fastest in the Le Sueur River with slower growth rates in the Cottonwood, Chippewa and Snake Rivers, respectively. A similar analysis for *Amblema plicata* showed that growth rates were also higher in the Chippewa as compared to the Snake River. *L. cardium* had higher growth rates than A. plicata. There was a latitudinal difference in mussel growth rates among sites that could result in different temperatures experienced by the river systems. We are accounting for this by including air temperatures as surrogates for water temperature within the analysis.

The field data collection in Summer 2017 also focused on quantitative and semi-quantitative measures of sediment within each river system that will supplement the research efforts in 2015 and 2017. The research team is currently compiling information into manuscripts for submission as peer-reviewed scientific journals.

Final Report Summary: A total of five scientific manuscripts are in preparation from this research study. The first describes the population sampling conducted in Activity 1 in the Minnesota River Basin (MRB) and St. Croix watershed (SCW; Figure 1). The MRB was historically home to dense and diverse assemblages of freshwater mussels. Of the 37 species that occurred there, 46% have been extirpated since 1908. The SCW in Minnesota/Wisconsin, in contrast, has maintained a dense and diverse mussel community, likely due to the maintenance of a higher quality ecosystem. The Snake River in the SCW had low levels of suspended sediment and was surrounded mostly by forest and some developed (e.g., rural and agricultural) land. The Chippewa, Cottonwood, and Le Sueur Rivers in the MRB have significantly higher annual suspended sediment loads and highly agricultural basins (Figure 2). High suspended sediment loads often associated with intensive agriculture are suspected to negatively impact freshwater mussels. While the MRB rivers had higher suspended sediment loads, increased agricultural landuse in these watersheds also led to higher nutrient concentrations resulting in more food (measured as chlorphyll a).

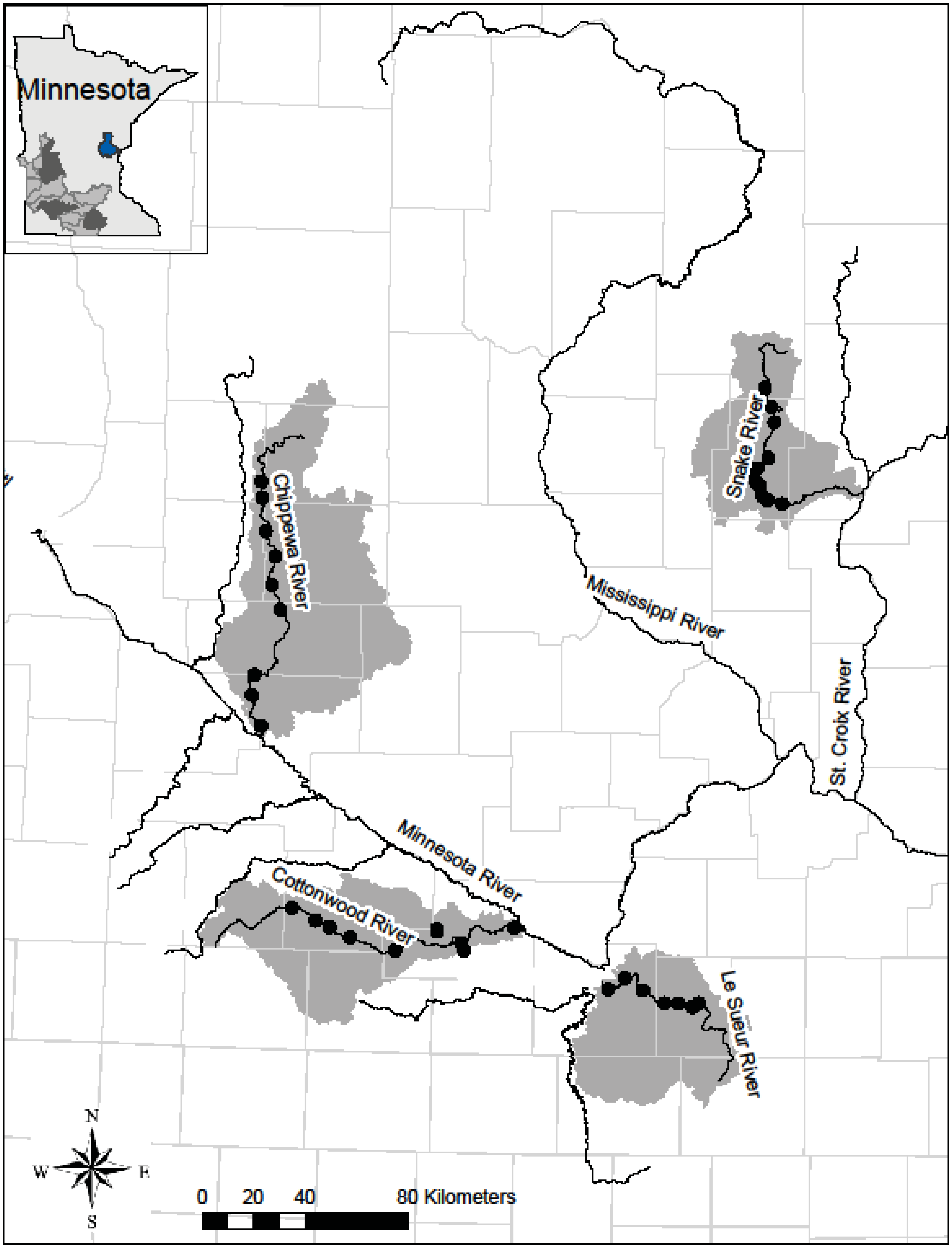


Figure 1. Re-sampling sites for freshwater mussel populations**.**

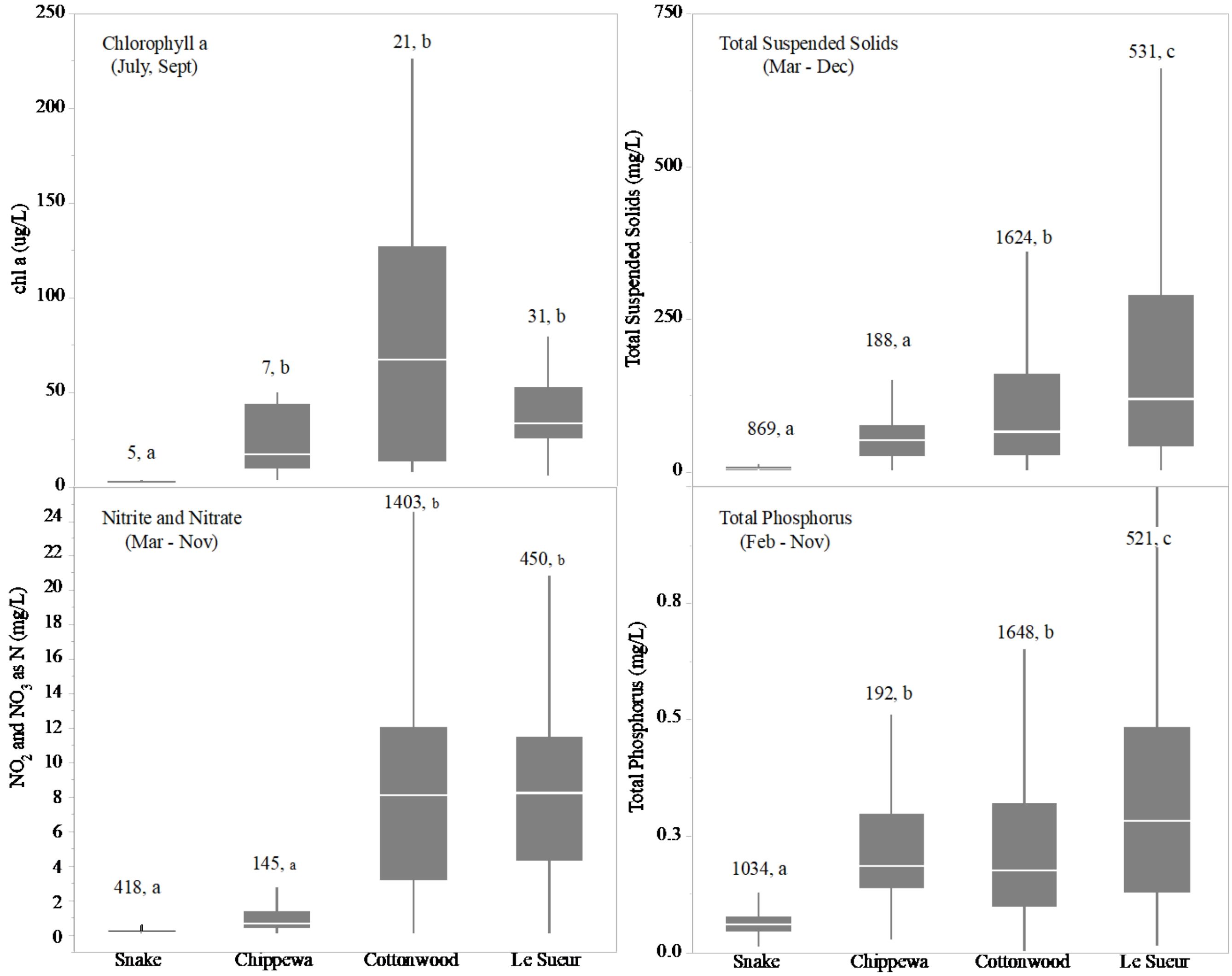


Figure 2. Box plots of chl a, nitrite and nitrate, total phosphorus and total suspended solids for four rivers in Minnesota. The numbers above the bars are the sample sizes and bars with the same letter are not significantly different. Suspended sediment loads increase in the following order: Snake>Chippewa>Cottonwood>Le Sueur.

Following MN Department of Natural Resources (DNR) mussel sampling protocol, we conducted timed searches at 7-9 locations in each of 3 subbasins of the MRB, and 13 locations in one subbasin in the SCW in 2015. These locations had been sampled previously by the DNR. Mussel abundance and richness was significantly lower in the MRB compared to the SCW (see Activity Status as of January 1, 2016). We found negligible changes in mussel density in the SCW, while abundances declined 17-83% in the MRB over periods of 7 to 16 years. Rates of decline were greatest for rivers with higher annual sediment loads. Individuals of species that inhabited both watersheds were larger in size in tributaries that had higher sediment loads (and nutrient concentrations).

In addition to the analysis of the changes in mussel abundance we found that there were shifts in the community structure with tributaries having increased sediment loads harboring species that displayed opportunistic (low life span and age at maturity coupled with high fecundity) and periodic life history traits (moderate to high growth rates, low to intermediate fecundity, life span and age at maturity) compared to the SCW communities which had greater percentages of mussels displaying equilibrium life history traits (long lifespan, late maturity and low reproductive effort) (Figure 3). Also, rivers with higher amounts of suspended sediment contained more species classified as disturbance tolerant (Figure 4).

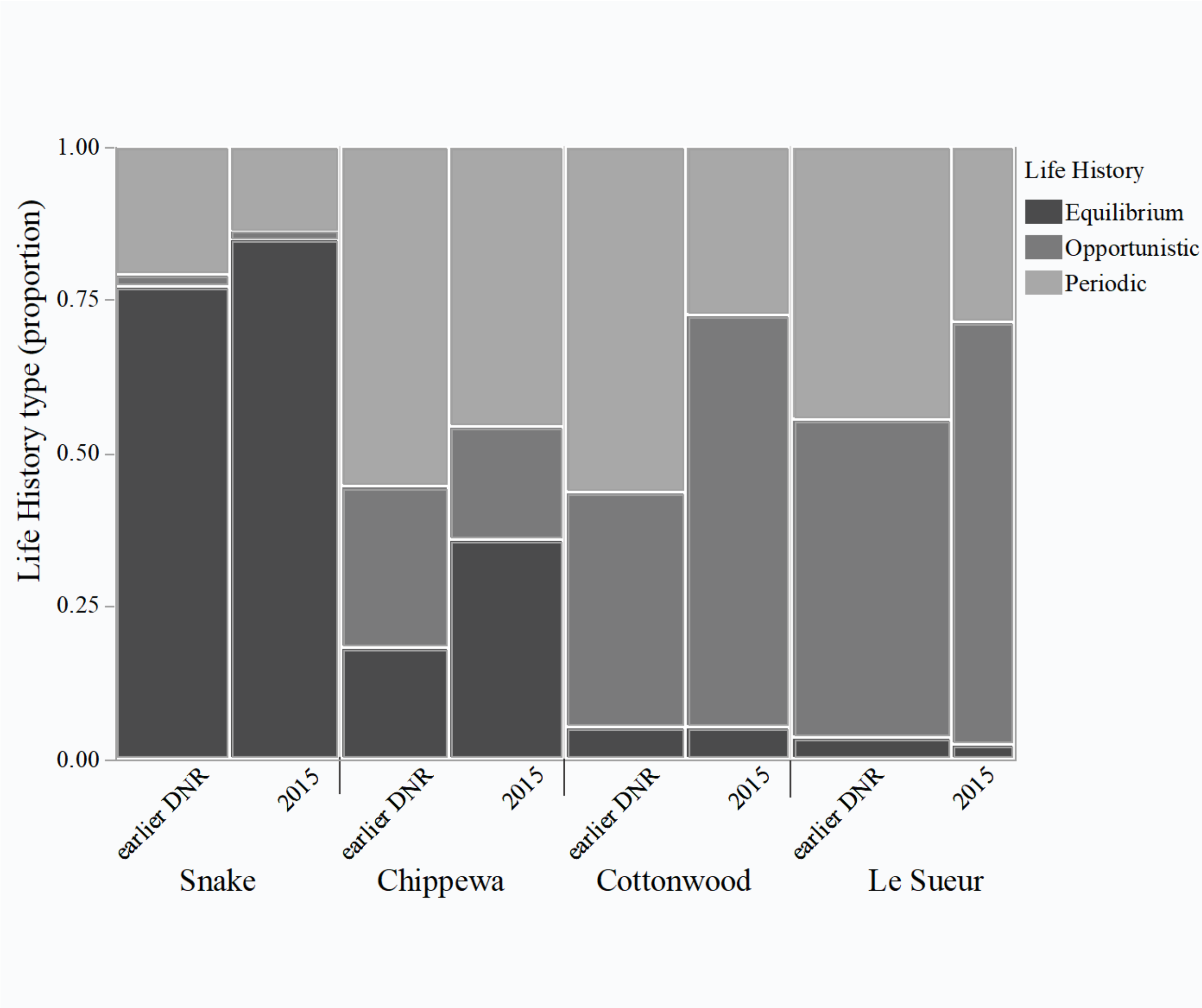


Figure 3. Changes in life history type in the four rivers sampled.

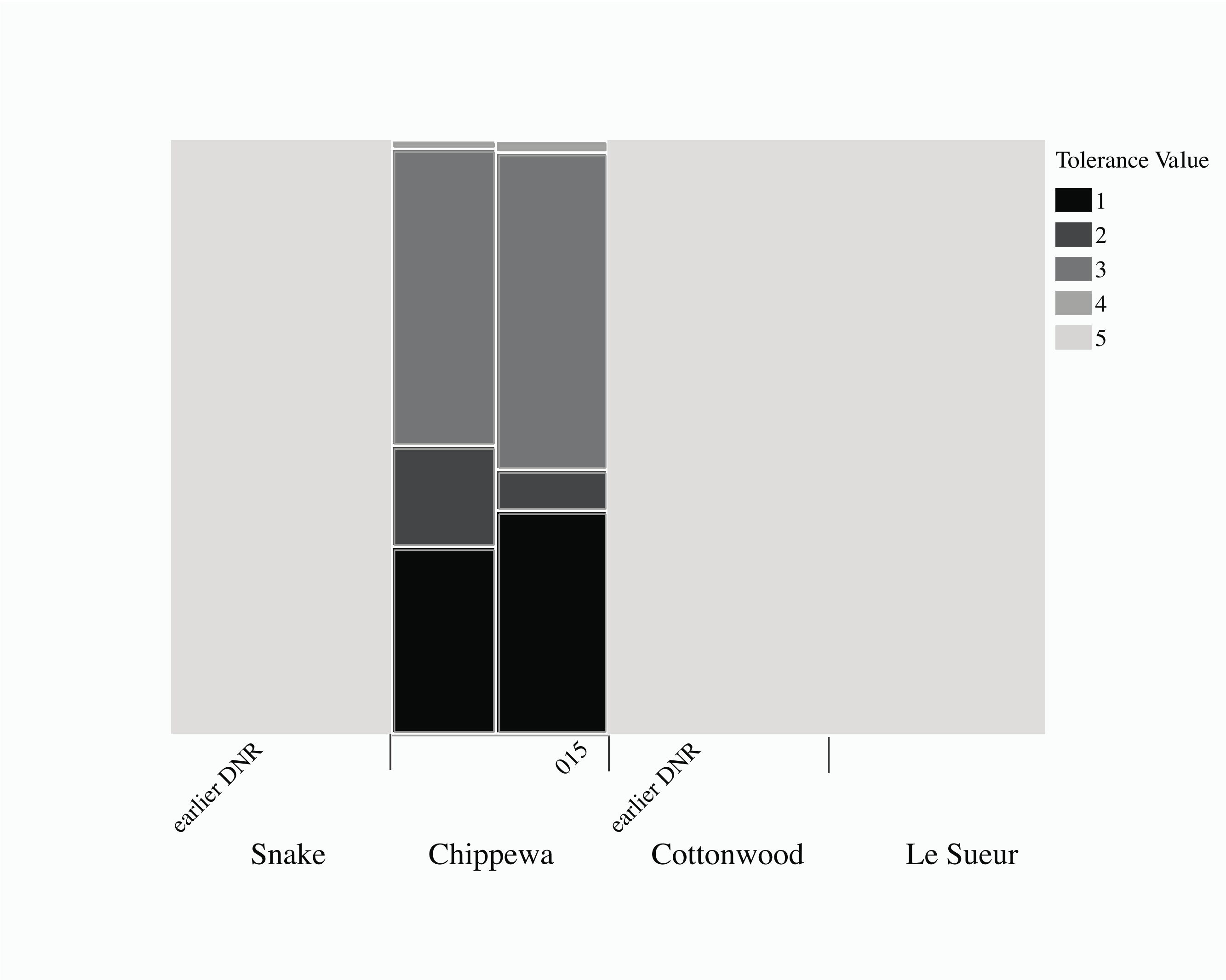


Figure 4. Pollution tolerance values for mussel species collected from four rivers.

Significance: Our study supports others that demonstrate increased levels of agricultural land use correlated with increased sediment load and nutrient input significantly influence mussel abundance, richness and community structure.

Insights:

- While many studies have indicated that sedimentation is responsible for mussel community changes, it is not possible to separate sediment effects from other stressors (ammonia, pesticides, etc.) present in agricultural systems when analyzing mussel population changes. Thus, the mechanism for mussel decline in these watersheds is likely to the combination of stressors to different mussel life stages and both water quality and habitat likely need to be addressed when evaluating potential mussel conservation efforts.
- While mussel abundance and richness declined with greater agricultural impact, the maximum length of mussels increased, indicating that for mussels that survived, increased food availability from increased nutrient loads led to greater growth rates.
- There were measurable declines over a 7-16 year period in mussel abundance and richness (supported by more recently dead shells) in the MRB; however, the power of analysis for catch per unit effort (CPUE) methods is low and these declines were not statistically significant. This should be taken into account when developing studies to re-visit sites sampled by the MN DNR.

ACTIVITY 2: Quantifying Mussel Response to Changes in Environmental Conditions
Description: To quantify native mussel responses to a range of environmental conditions in the MRB and St. Croix, laboratory experiments will examine the physiological response and physical reaction (changes in feeding, movement, burial, etc.) of mussels to different levels of suspended sediment and bed instability over a range of flow rates. Experiments will be conducted in the Outdoor StreamLab and flumes at St. Anthony Falls Laboratory at the University of Minnesota. The Outdoor StreamLab is a unique outdoor experimental stream channel located across the Mississippi River from downtown Minneapolis. This experimental stream allows for direct manipulation of environmental conditions in a field-scale channel while collecting laboratory quality measurements. Laboratory experiments will focus on mussel response to suspended sediment (water quality) and bed instability (increased flows or siltation). To gather background information on mussel response to altered environmental conditions, growth rates and physiological stress (e.g., tissue glycogen, enzymatic biomarkers) will be measured for two species at the MRB and St. Croix field sites.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 161,680**
Amount Spent: $ 161,680
Balance: $ 0

Activity Completion Date: December 31, 2018

Outcome	**Completion Date**	**Budget**
1. Physiological response of mussels in the MRB and St. Croix (as a report and Activity 3)	October 2015	$ 30,000
2. Physiological response of mussels to suspended sediment (as a report and Activity 3)	End of Project	$ 65,840
3. Physical reaction of mussels to bed stability (as a report and Activity 3)	End of Project	$ 65,840

Activity Status as of January 1, 2015**:** No activity to date.

Activity Status as of July 1, 2015**:** All field sites have been visited in preparation the glycogen analysis to determine the physiological response of mussels in the MRB and St. Croix. The glycogen samples will all be collected within a short (~ 2 week window) on the target species (plain pocketbook, *Lampsilis cardium*; threeridge, *Amblema plicata;* White heelsplitter (*Lasmigona complanata*). Preliminary work, as part of Activity 1, was conducted aggregate the mussel species of interest and select two of the three species of interest with sufficient numbers in the MRB and St. Croix sites to use this species for glycogen comparison. As water levels come down in the Le Sueur River, this data collection is planned for August 2015.

Activity Status as of January 1, 2016**:** Glycogen samples were collected in early September on the target species (plain pocketbook, *Lampsilis cardium and* White heelsplitter (*Lasmigona complanata*) at all sites. Samples are currently being analyzed.

Activity Status as of July 1, 2016**:** Glycogen samples have been analyzed for mussels sampled in September 2015. Data processing is ongoing and these results will be compared to the glycogen samples in the flume experiments at SAFL.

Experiments are underway at SAFL in the Outdoor StreamLab (OSL) and a flow-through flume to be completed in August 2016. In experiments in the OSL, mussel response to bed instability will be tracked in a series of experiments with aggrading, degrading, mobile, and immobile bed sediment. Three species of mussels were collected for these experiments (collected from the Mississippi River watershed under permit from the MN DNR): *A. plicata* (threeridge), *L. cardium* (plain pocketbook), and *L. complanata* (white heelsplitter). Comparisons will be made between mussel species' response to differing bed stability characteristics. In addition to the research team, a total of six undergraduate students worked on the OSL mussel project during the 2016 research season. Flume experiments at SAFL are focusing on the response of mussels to suspended sediment. The flume setup is complete including gape sensors to measure mussel gape as a surrogate for filtration. Flume experiments will be conducted within a two week period in August to minimize differences due to temperature and time of year. Mussels in the flume will be sampled for glycogen content as a function of suspended sediment loads.

Figure 1. Outdoor StreamLab research team collecting mussel habitat data post-flood.

Figure 2. Flume setup for testing mussel response to suspended sediment. Gape sensors (right) will be attached to mussels to measure filtering response as a function of suspended sediment load.

Activity Status as of January 1, 2017**:** Experimental data collection in the OSL and flume at SAFL were completed in August 2016. These experiments evaluated mussel response to sediment loads by investigating bed load (e.g. sandy material that moves along a river bed as migrating dunes) and suspended sediment load (e.g. fine silt and clay material that is transported in suspension) separately. Bed load experiments were conducted in the sand-bedded OSL, and suspended load experiments were conducted in an indoor flume. Data analysis is ongoing, but the following provides a summary of preliminary results.

Outdoor StreamLab (OSL) Experiments:

The OSL experiments tracked mussel response to bed load in a series of experiments with aggrading, degrading, mobile, and immobile bed sediment. We used three species of mussels in these experiments: *A. plicata* (threeridge), *L. cardium* (plain pocketbook), and *L. complanata* (white heelsplitter). A summary of OSL experiments is shown in Table 1. Experiments were broken down into flooding experiments (high velocities and mobile bed) and low flow (low velocities and immobile bed) experiments. Flooding experiments were conducted for all mussel species (density of ~ 4 mussels/m^2) and a baseline (no mussel) case under quasi-equilibrium (steady state flow and sediment transport). *A. plicata* (density of ~ 4 mussels/m^2) and baseline (no mussel) experiments were conducted under all of the above sediment transport conditions. Additional flooding experiments were conducted with *A. plicata* to under aggrading and degrading bed elevation conditions (burial and exposure) and to investigate the effect of mussel density with 8 mussels/m^2. Low flow (non-flooding) experiments were conducted with *A. plicata* and tested the effect of depth and slope on mussel response in a meandering channel.

Table 1. Summary of Outdoor StreamLab experiments.

Start Date	Run	Name	Mussel	Flood (L/s)	Flood Sed (kg/min)	Low (L/s)
Flood Experiments:						
6/16/2016	0	Baseline	none	201	4.3	28
6/28/2016	1	AP equil.	*A. plicata*	201	4.3	27
7/1/2016	2	Baseline 2	none	207	4.3	30
7/6/2016	3	AP degrad.	*A. plicata*	201	2.1	31
7/11/2016	4	LCard equil.	*L. cardium*	203	4.3	30
7/14/2016	5	Baseline degrad.	none	200	2.1	35
7/18/2016	6	AP agg.	*A. plicata*	201	4.2	28
7/25/2016	7	Lcomp equil.	*L. complanata*	200	3.9	31
7/29/2016	8	Baseline agg.	none	202	4.2	28
8/9/2016	9	AP x 2 equil.	*A. plicata*	201	4.2	30
Low Flow Experiments:						
6/20/2016	Low1	AP Low flow (bar)	*A. plicata*	NA	-	31
8/1/2016	Low2	AP Low flow (flat)	*A. plicata*	NA	-	29

Mussel Characteristics:
The three species of mussels used in OSL experiments were selected because they varied in shell morphology. *A. plicata* were relative short and round with ridges on their shell. *L. cardium* were longer, relative to their width and had a smooth shell, and *L. complanata* were long and thin with a thin fin extending from their shell. Figure3 shows the relative lengths of the mussels used in this study by species. These shell morphologies are expected to influence a mussels ability to move, or maintain location under different flow conditions. Similarly, the density of mussels (Figure 4) influence how easily mussels can be dislodged.

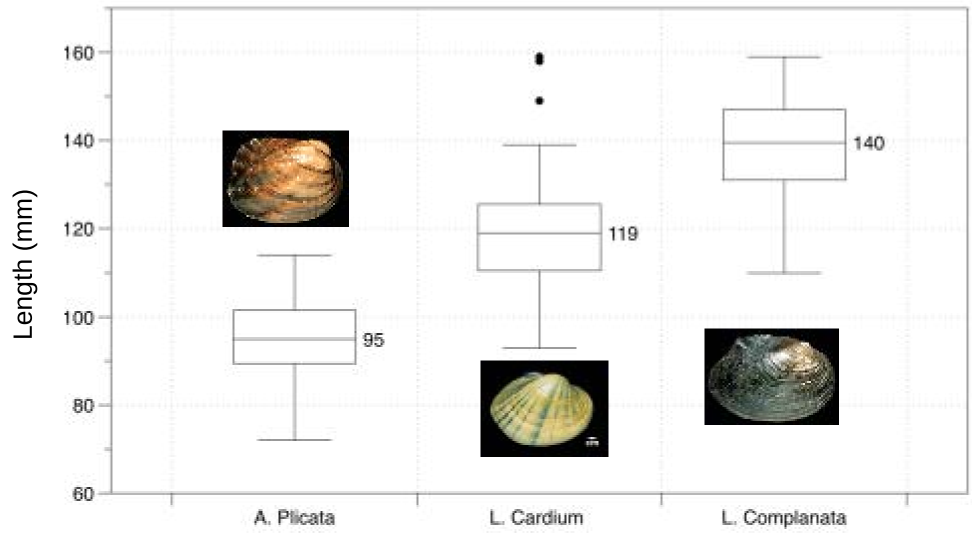


Figure 3. Length (mm) of each mussel species used in OSL experiments.

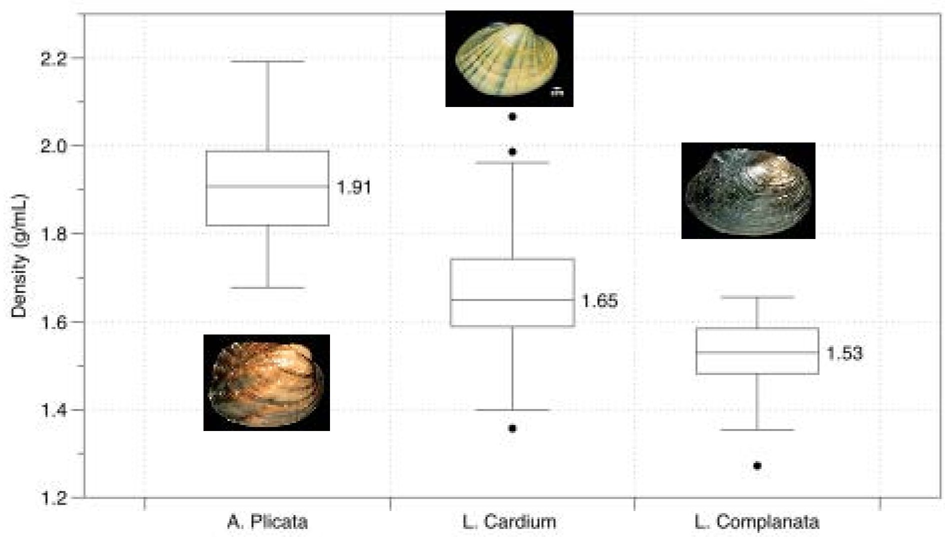


Figure 4. Density (mass/volume) of each mussel species used in OSL experiments

OSL Flood Experiments:

Each flooding experiment started with randomly placing mussels in the OSL on a gridded pattern. Individual mussels were identified using a combination of colored sequins and a length of floating fishing line (Figure 5). The floating line was used to find mussels that were buried in the sediment and estimate the depth of burial. Mussels were also painted white to observe their movement during high flow events. The test section of the OSL in in a meander with a shallow point bar and deeper thalweg. Mussels were allowed to settle in (but not move significantly) before a flood commenced. Each flood lasted approximately seven hours during which velocity was collected with an acoustic Doppler velocimeter (ADV), bed form movement was recorded using a computer controlled cart with sonar, and bed elevation was monitored at permanent cross sections using a point gauge. Velocity patterns were similar in all flooding events (Figure 6) with maximum velocities equal to 65 cm/s. Near bed shear stresses during the floods were >1.4 – 8 times the critical shear stress of the sandy sediment in the OSL (indicating mobile sediment). Bedform characteristics were extracted from repeat sonar scans (Figure 7). Typical bedform height was four cm with maximum heights of 10 – 12 cm occurring near the shoulder of the point bar. Mussels were buried and unburied by the passage of bedforms during the flood.

Figure 5. Mussels were identified by uniquely colored sequins and a length of floating fishing line.

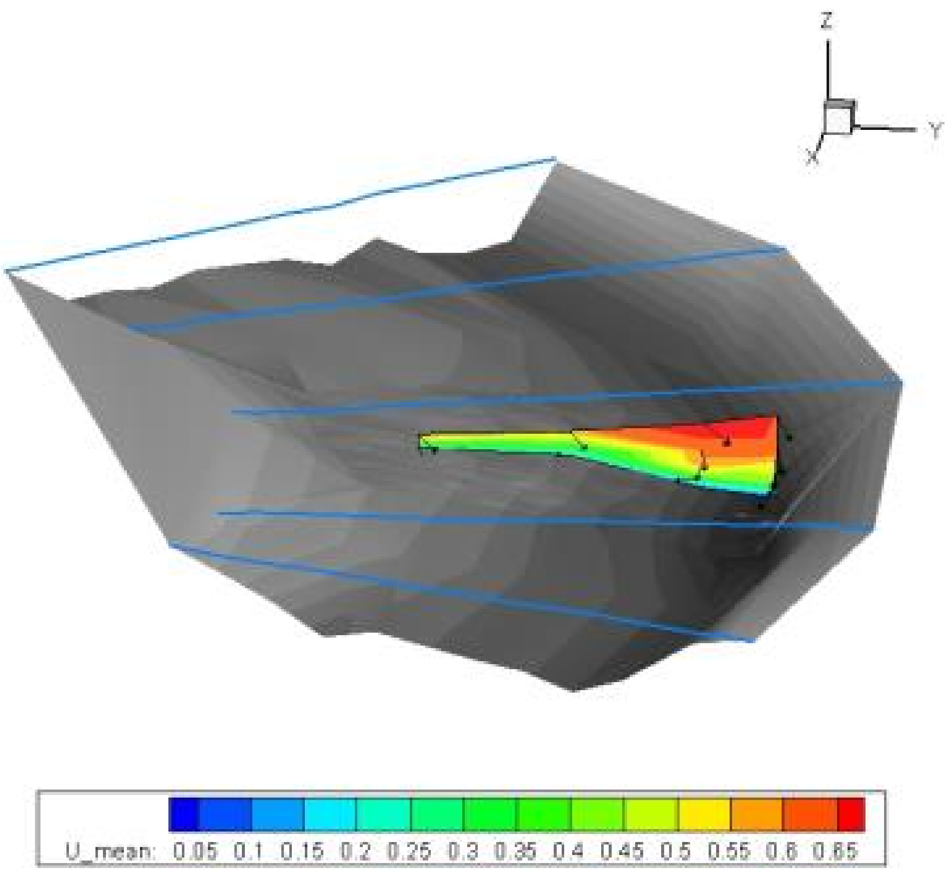


Figure 6. Velocity patterns in the mussel test section of the OSL (Umean, m/s). Flow is from top to bottom and blue lines indicate water surface. Highest velocities (up to 65 cm/s) and highest shear stresses were at the outside of the meander.

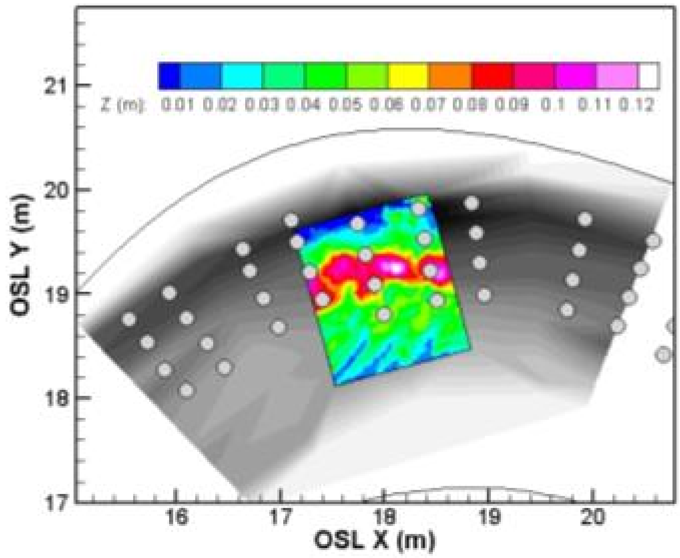


Figure 7. Initial location of mussels in 4 mussels/m^2 experiments (white dots). The colormap shows the range of bed form heights in the OSL test section. Typical bedform height was 4 cm and maximum bedform height was approximately 10-12 cm. Flow is from left to right.

Immediately after each flood, mussel location was measured using a total station, mussel protrusion or burial, and the orientation of each mussel to the oncoming flow was recorded. These measurements were repeated the next morning, and two days post flood. Mussel locations at each of these time steps are shown in Figure 8. Mussels moved little (1-2 cm/hr) during the flood, but moved significantly (up to 5 cm/hr) after the flood. Once mussels reached the thalweg mussel movement slowed (0.4 – 1 cm.hr).

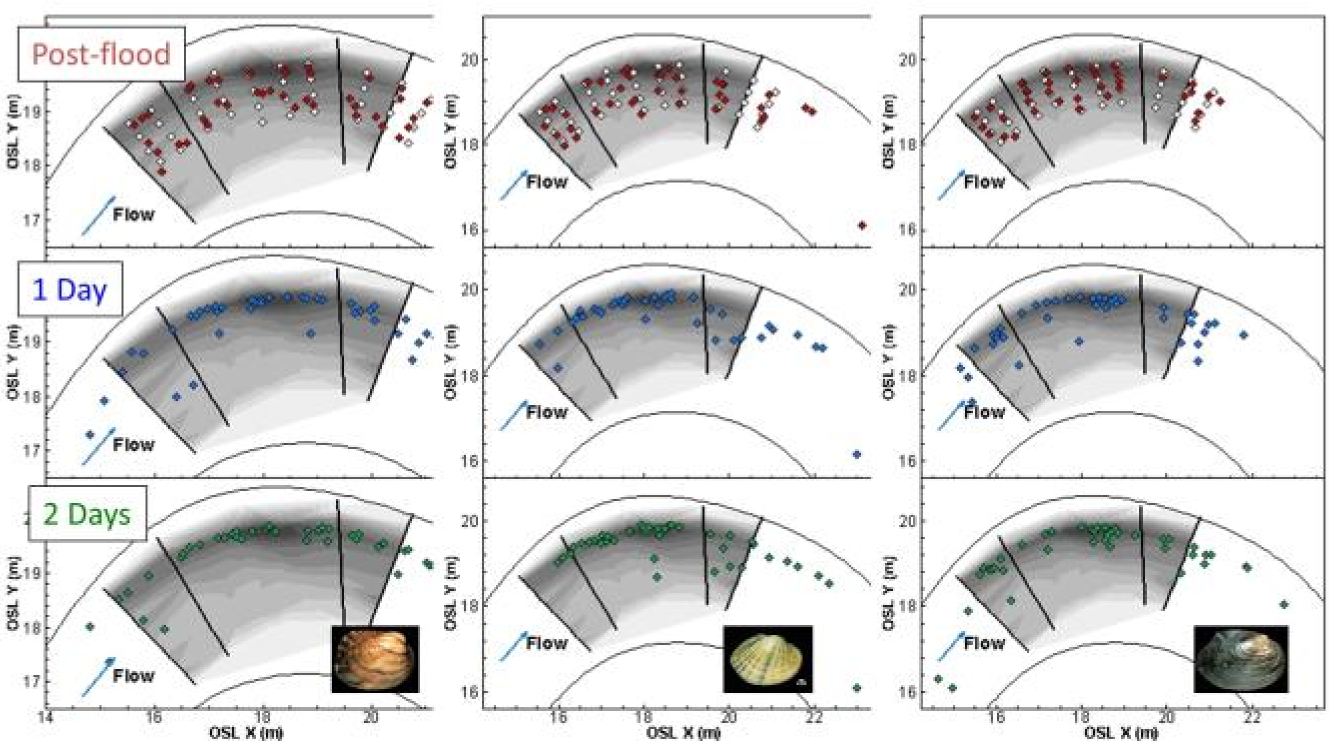


Figure 8. *A. plicata*, *L. cardium*, and *L. complanata* mussel locations at start of flood (white), post-flood (red), one day post-flood (blue) and two days post-flood (green).

Measurements of mussel protrusion before and after each flood indicate that mussels were buried by bedforms (up to 20 cm), were able to extract themselves by the morning after the flood (Figure 9). Similar to horizontal movement, the mussels were able to adjust their vertical position in the time between the end of the flood and the day after the flood.

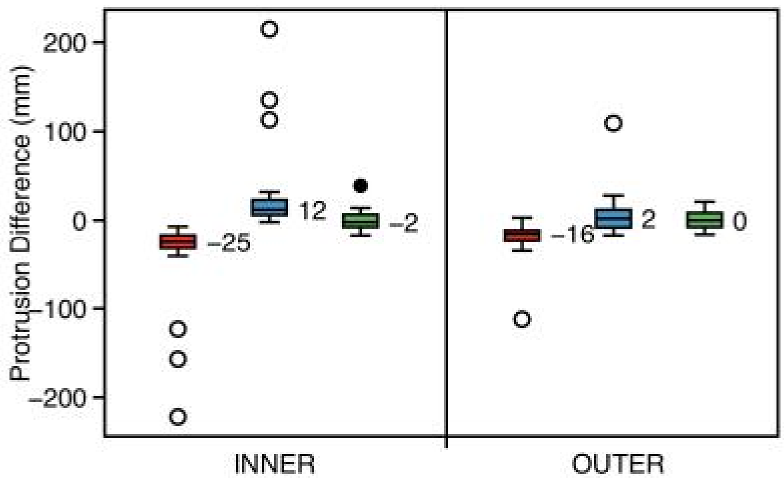


Figure 9. Difference in protrusion during the aggrading experiment from pre to post-flood (red), post-flood to one day post flood (blue), and one day post-flood to two days post-flood (green). Measurements are separated in the mussels that started on the inner bar and those that started on the outer bar. Negative numbers indicate a mussel moved down relative to the bed surface and positive numbers indicate a mussel moved up relative to the bed surface.

OSL Low Flow Experiments:

Because most mussel movement occurred at low flows (after the flood), two experiments were conducted at low flows allowing mussels to move for four days. Results from the first experiment replicated the post-flood movement where mussels moved within a day toward the outer thalweg, or down slope (Figure 10, left). As the thalweg is the area of the stream with the deepest, fastest water, it is difficult to tease out whether this movement was triggered by velocity or depth. Therefore a second experiment was conducted where the bed was raked flat to remove the deeper flow. In this case, mussel movement was random, indicating that depth or slope were likely the driver for the direction of mussel movement (Figure 10, right).

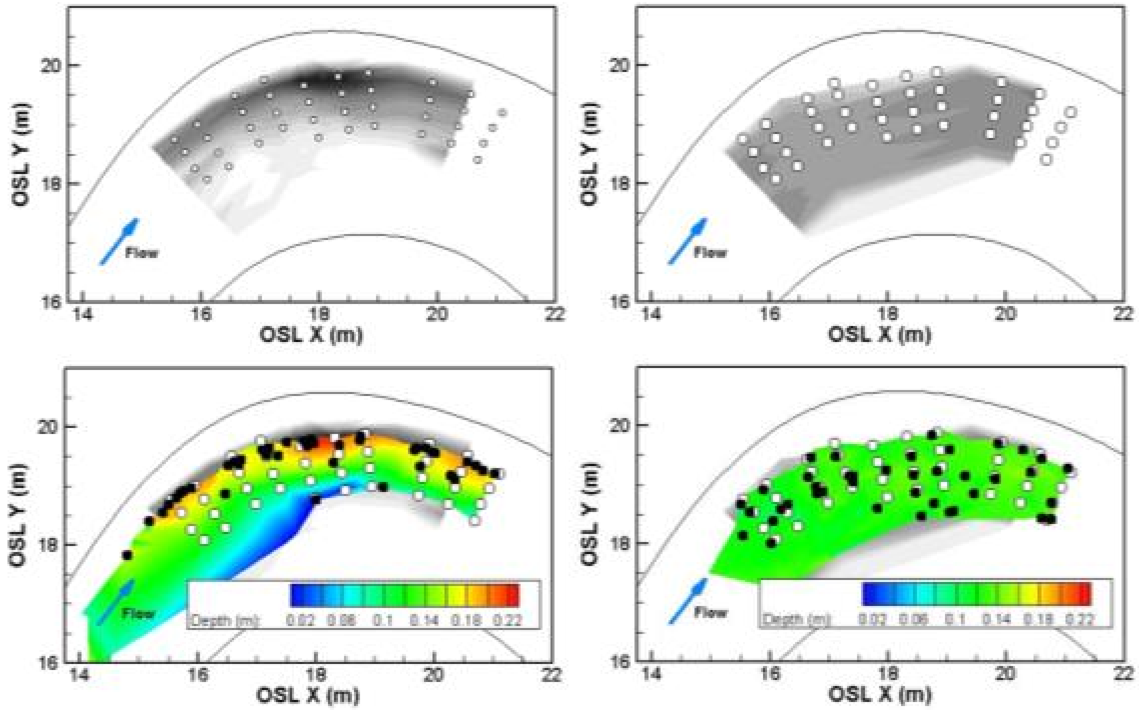


Figure 10. Low flow mussel movement (after one day). White dots are initial mussel location and black dots are the location after one day. Right: low flow movement with a typical bar, Left: low flow movement when the bar is raked flat.

Effect of Mussels on Channel Morphology:

A complementary question to the mussel response to bed load and channel morphology is the channel morphology response to the presence of mussels (e.g. does the presence of mussels change the sediment transport patterns such that the channel shape changes). We used the results from the *A. plicata* experiments with two different densities (4 and 8 mussels/m^2) to explore this question (Figure 11). The effect of mussel presence on the bar shape was small indicating that mussels at these densities did not provide enough roughness in the channel to dramatically alter the sediment transport patterns. The mussel densities used in these experiments were selected to be representative of densities at our field sites; however, with greater mussel densities, the effect of mussels on the channel morphology may be greater. The effect of mussel presence on bedform movement will be further investigated using the repeat sonar scans collected during the flood.

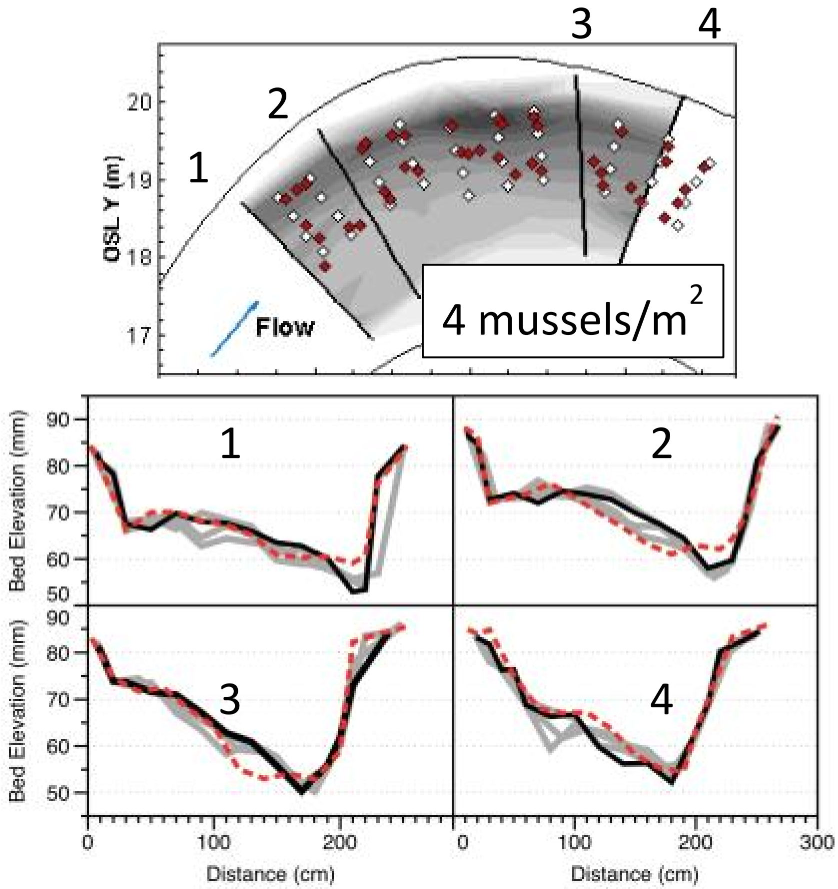


Figure 11. Bed elevation (cm) at the four cross sections shown in the upper figure for 4 and 8 mussels/m^2 densities. In the cross section plots, gray is the baseline (no mussel) bed elevation, black is the 4 mussels/m^2 bed elevation and the red dashed line is the 8 mussels/m^2 bed elevation.

OSL Experiment Preliminary Findings Summary:
Findings from the OSL experiments illustrate mussel behavior during and after flooding events. This is significant because these behaviors have implications for mussel health and these behaviors are difficult or impossible to observe in the field. For example, mussels were able to respond (hold their location and unbury) in response to a single flooding event, but mussel energy expenditure could be great if mussels were subjected to repeat events. Five key points can be summarized based on our preliminary observations:

- Mussels anchored/moved little during flooding events
- Mussels moved significantly (up to 5 cm/hr) post flood
- Mussels were able to unbury (up to 20 cm) post flood
- Mussel movement was primarily down slope during low flows
- Mussel movement was random without a change in depth

One of the undergraduate researchers who worked in the OSL this summer has received a UROP (Undergraduate Research Opportunity) grant from the UMN to continue data processing to further analyze the effect of mussels on channel morphology.

Flume Experiments:
Flume experiments were used to test the dual effect of increased velocity and suspended sediment on mussel feeding behavior. Two species were used in these experiments: *A. plicata* and *L. cardium*. Mussel response was measured using a gape sensor glued to the mussel opening. This sensor reported voltage at one Hz (one sample per second) that decreased as the mussel shell closed and approached 2500 mV as the mussel shell opened (Figure 12). From video and observation of mussel behavior, three behavior patterns can be extracted from the signal: long closure, movement, and high frequency short closure events. The long closure events occurred when the mussel closed its shell and remained closed for hours resulting in a flat dip in voltage (Figure 12a). Movement events occurred when mussels were actively moving (crawling) and resulted in a noisy and high frequency signal (Figure 12b). High frequency, short closure event were associated on video with pseudo-feces production (or expelling material before it reaches the mussel digestion tract. These patterns have not been previously seen in gape sensor studies with mussels, likely because the frequency of data logging was too slow (~one measurement/minute) or the short closure events were filtered out. We believe these events may be important in understanding the effect of increased suspended sediment loads on mussels and are awaiting the results from our tissue glycogen tests to examine the correlation between these behaviors and glycogen levels.

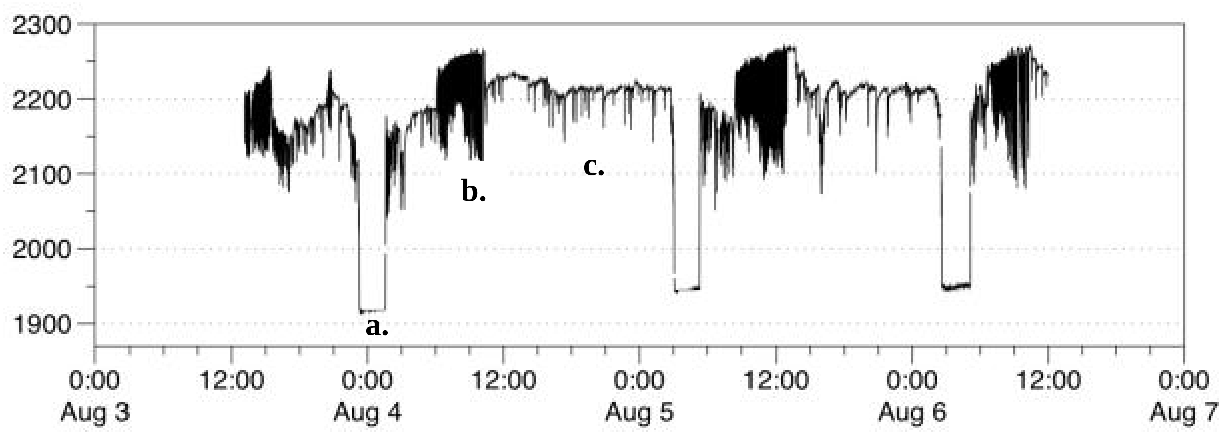


Figure 12. Voltage (mV) recorded from mussel gape sensor showing three distinct patterns: a) long closure events, b) movement events, and c) high frequency short closure events.

Four control/treatment experiments were conducted in a flume in at SAFL to investigate the effect of suspended sediment on mussel gape (Table 2). The flume was divided into two sections, an upstream control section and a treatment section. Suspended sediment (a 50/50 mix of silt and clay) was added to the treatment section downstream of the mussels in the control. In each experiment, four mussels of each species were instrumented with gape sensors in the control and treatment sections, respectively. Glycogen samples were collected from an additional three *L. complanata* and one *A. plicata* in each section for each experiment.

Table 2. Experimental matrix for flume experiments to measure mussel response to water velocity (vel) and suspended sediment (sed).

Run	Mussels Placed	Target Sediment Feed mg/L	Velocity m/s
low vel/high sed	8/3/2016	200	0.25
low vel/low sed	8/6/2016	100	0.25
high vel/high sed	8/9/2016	200	0.6
high vel/low sed	8/15/2016	100	0.6

Preliminary results indicate that *A. plicata* displayed a longer total time closed when exposed to suspended sediment, but that this response was not observed in *L. complanata* (Figure 13).

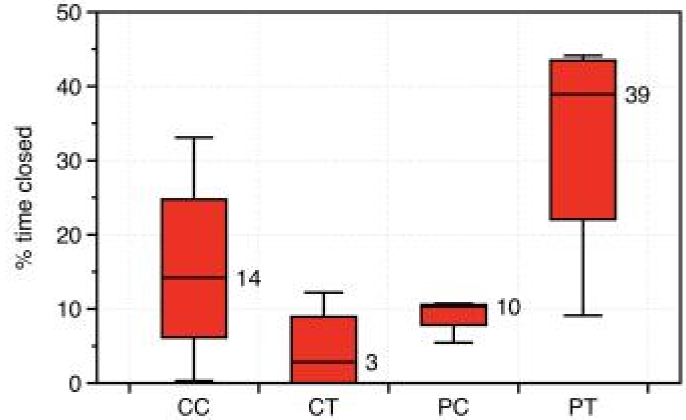


Figure 13. Percent time closed for *L. complanata* (C) control (C) and treatment (T), and *A. plicata* (P) control (C) and treatment (T).

Both species of mussels, however, exhibited a change in behavior in the frequency of short closure events. The time between these events decreased (Figure 14) as mussels had to deal with more sediment in the water.

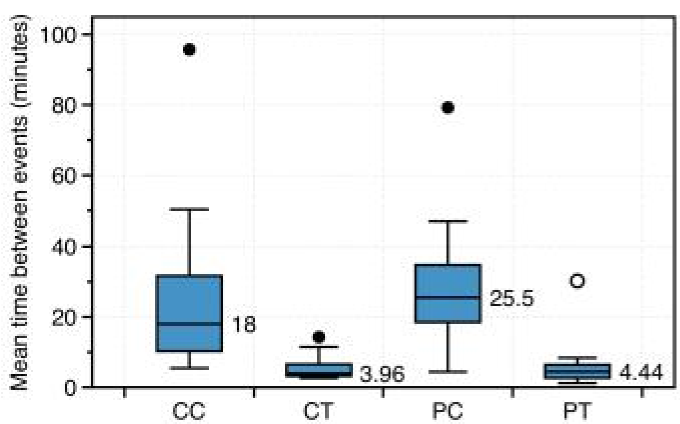


Figure 14. Mean time between short events for *L. complanata* (C) control (C) and treatment (T), and *A. plicata* (P) control (C) and treatment (T).

Flume Experiment Preliminary Findings Summary:

Findings from the flume experiments illustrate mussel behavior during high flow and high suspended sediment loads. These experiments focused on mussel feeding behavior, by measuring gape. From the preliminary data, two different types of response were observed:

- Long closure events where mussels fully closed for hours: There were few differences between these behaviors in control and treatment groups across species.
- High frequency short closure events: Mussels partially closed for short durations (seconds) at a higher frequency during high suspended sediment treatments. These events coincided with pseudo-feces excretion, or removal of sediment from the digestive tract.

The effect of these behaviors on mussel wellbeing will be verified using glycogen testing. Testing is underway for glycogen concentrations from mussel tissues from flume experiments. A Macalester undergraduate student is continuing to work on the data processing from these experiments.

Activity Status as of July 1, 2017**:** Data analysis is ongoing and planning is underway to deploy gape sensors in the field to verify flume results.

Activity Status as of January 1, 2018**:** Data from the 2016 OSL and flume experiments are being compiled into manuscripts for publication in peer-reviewed journals. Gape sensors were installed on six mussels in the Chippewa River for two weeks in September 2017. Sensors were attached to two *Lampsilus cardium* and four *Ambema plicata* similar to the flume experiments (Figure 1). Results from this field installation are being used to verify the mussel behavior in the 48 hour flume experiments (Figure 2).

Figure 1. Hall effect sensor attached to *Lampsilus cardium* used to measure mussel gape.

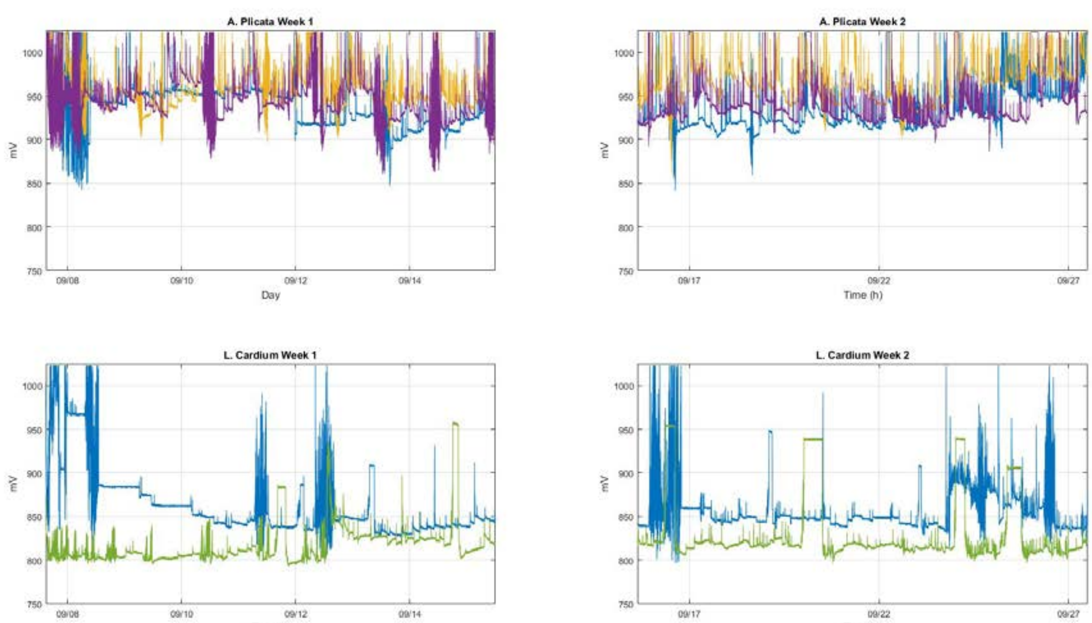


Figure 2. Unfiltered output (voltage) from gape sensors installed in Chippewa River September 2017.

Final Report Summary: In addition to the mussel population manuscript from Activity 1, four additional peer-reviewed publications are in preparation from the results from Activity 2 to investigate the impact of water quality (specifically sediment) and habitat (water flow and bed stability) on mussel behavior. The second peer-reviewed manuscript, in collaboration with United States Geological Survey (USGS) researchers, uses energy stores (glycogen) and growth rates to investigate the differences in mussel health between watersheds (Figure 1).

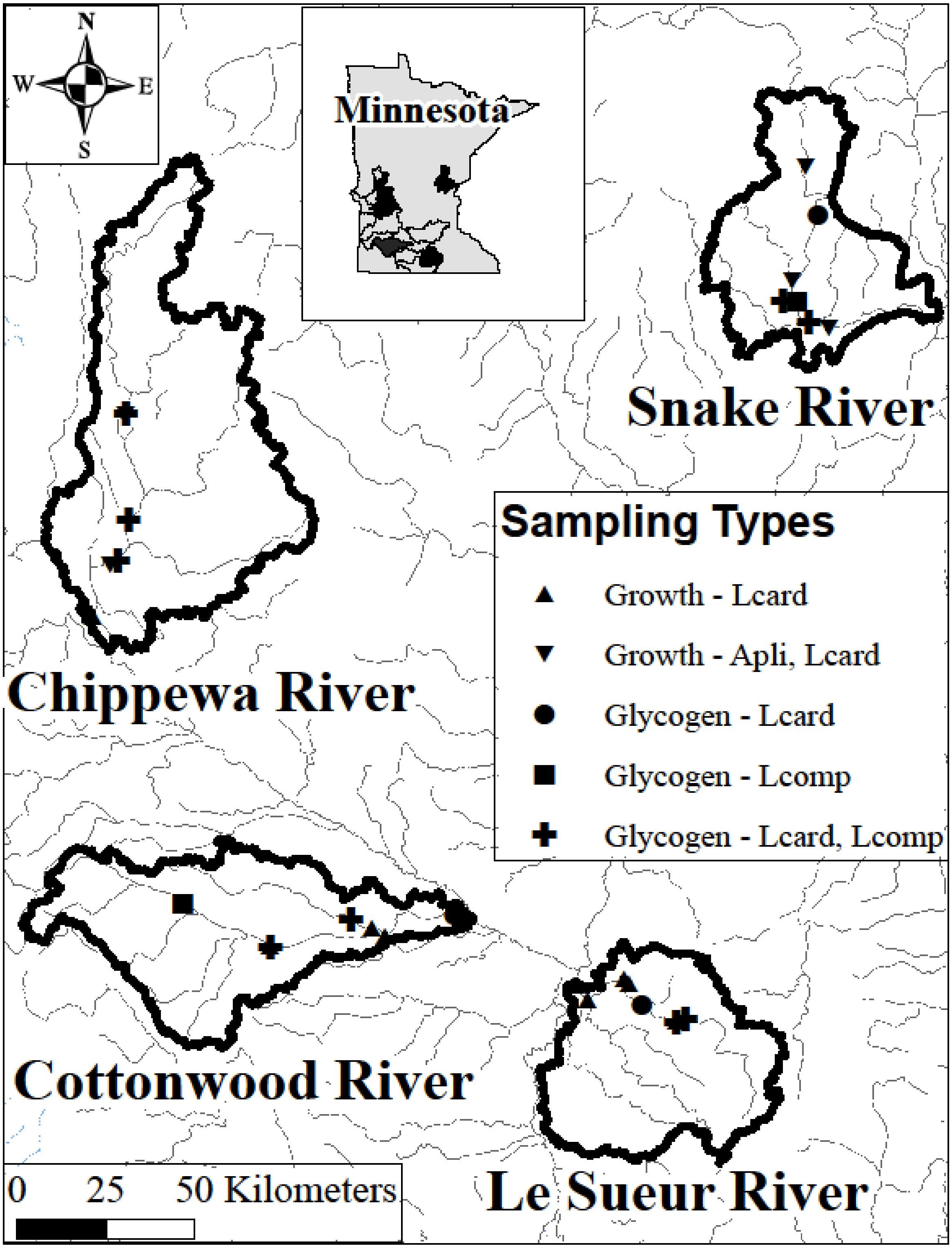


Figure 1. Sampling sites for glycogen and growth.

Freshwater mussels face threats from climate change and changing land use that are dramatically altering their habitat. The health of mussel populations and the state of current and past environmental conditions can be monitored by measuring mussel growth and glycogen level. In this study we measured growth rate and glycogen levels in mussels from two river basins impacted by different land uses. The Snake River in the St. Croix watershed (SCW) had low levels of suspended sediment and was surrounded mostly by forest and some developed (e.g., rural and agricultural) land. The Chippewa, Cottonwood, and Le Sueur Rivers in the Minnesota River basin (MRB) have significantly higher annual suspended sediment loads and highly agricultural basins (see Activity 1). Foot glycogen levels measured in the summer in mussels from the MRB rivers all had higher glycogen concentration compared to the Snake River. These patterns were similar for two mussel species, suggesting that environmental conditions are likely determining growth rates (Figure 2).

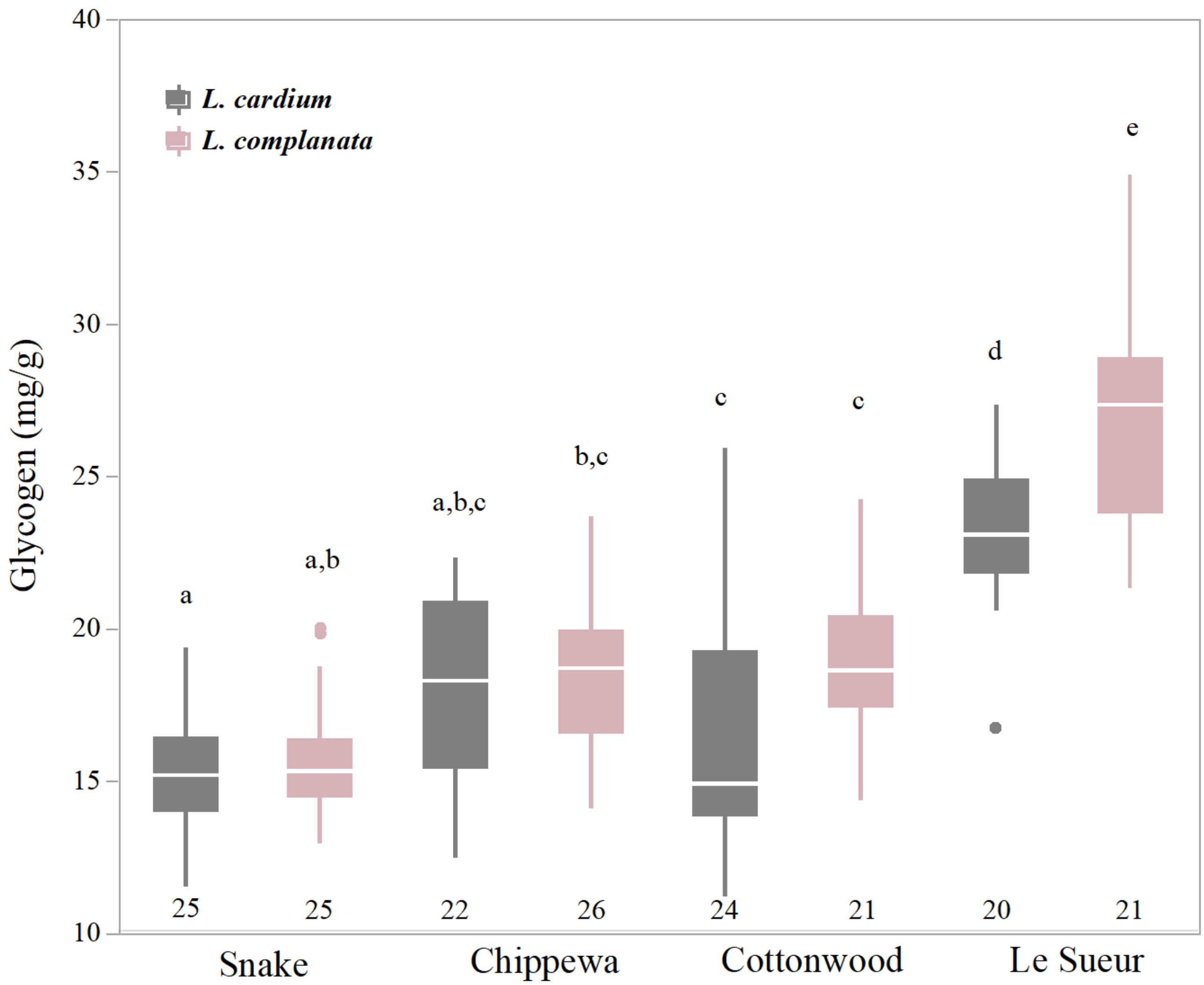


Figure 2. Box plots of glycogen concentration (in mg/g wet weight) of two species of mussels, Lampsilis cardium and Lasmigona complanata from four rivers in Minnesota. Suspended sediment loads increase from the Snake through the Le Sueur River. Bars with the same letters are not significantly different. Numbers below bars are sample sizes.

Mussel growth rates were highest in the Le Sueur and Cottonwood rivers followed by the Chippewa and the Snake rivers, which had the slowest growth rates (Figure 3).

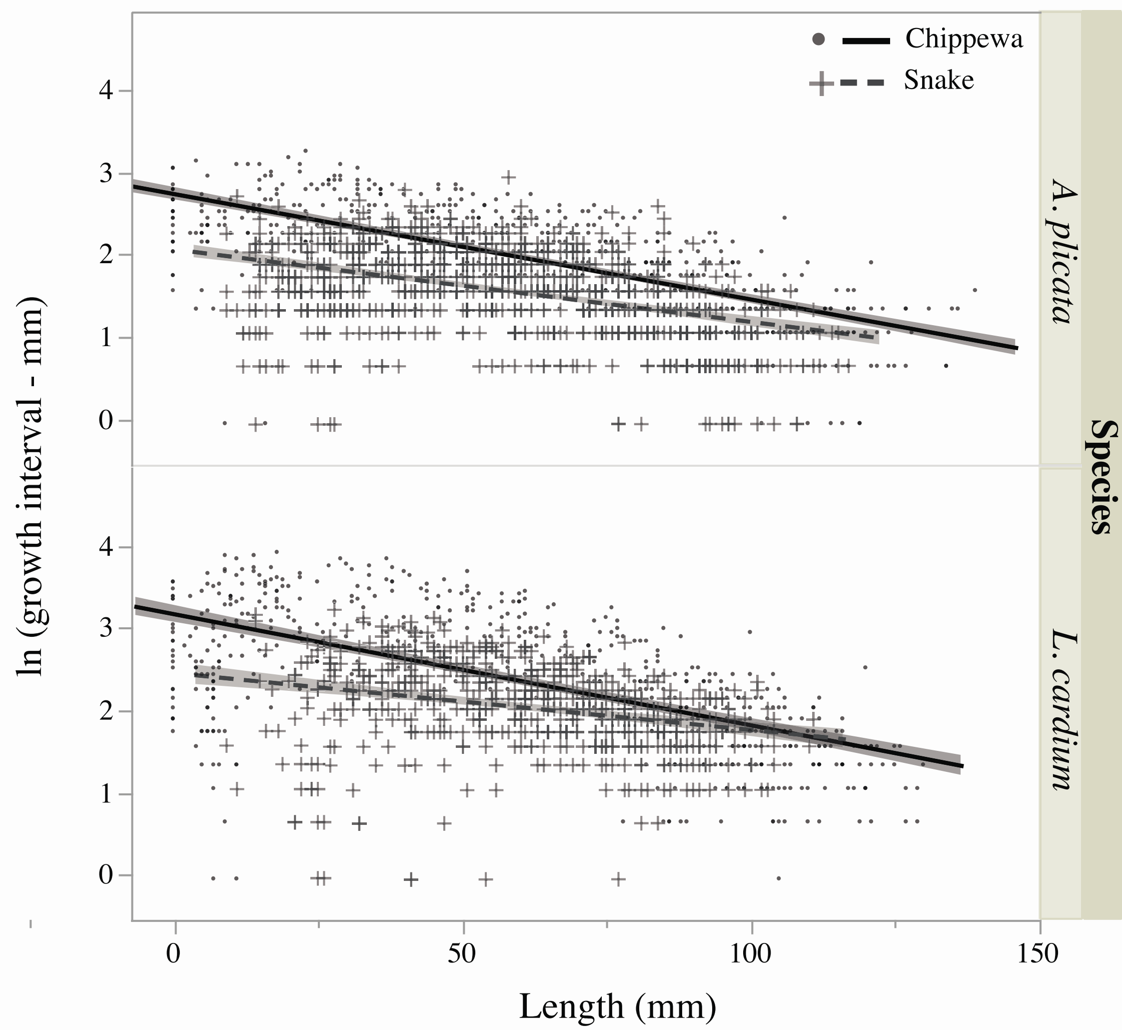


Figure 3. Change in Lampsilis cardium growth rates (natural log of the growth interval) with size (shell length) among four rivers in Minnesota. Suspended sediment loads increase in the following order: Snake>Chippewa>Cottonwood>Le Sueur. Shaded areas are 95% confidence limits.

The difference in land use provides a potential explanation for these differences in mussel condition and populations through differences in nutrient levels (see Figure 2, Final Report Summary for Activity 1). Although agriculture appears to have a negative effect on mussel population abundance and diversity, the resulting food availability has a positive effect on growth rates and glycogen level. These results are important to consider when determining watershed management policies.

The third and fourth papers will present flume studies at St. Anthony Falls Laboratory that investigate the impact of suspended sediment and water flow rate on mussel feeding (measured as mussel gape) and glycogen content. Particle image velocimetry (PIV) was used to measure the flow fields around individual mussels in different orientations (facing upstream and facing downstream) at different flow rates (high and low; Figure 4). There were significant differences between mussel behavior (measured as gape) and flow fields (Figure 5) depending on mussel orientation, giving insight into the interactions between flow, food delivery, and mussel behavior.

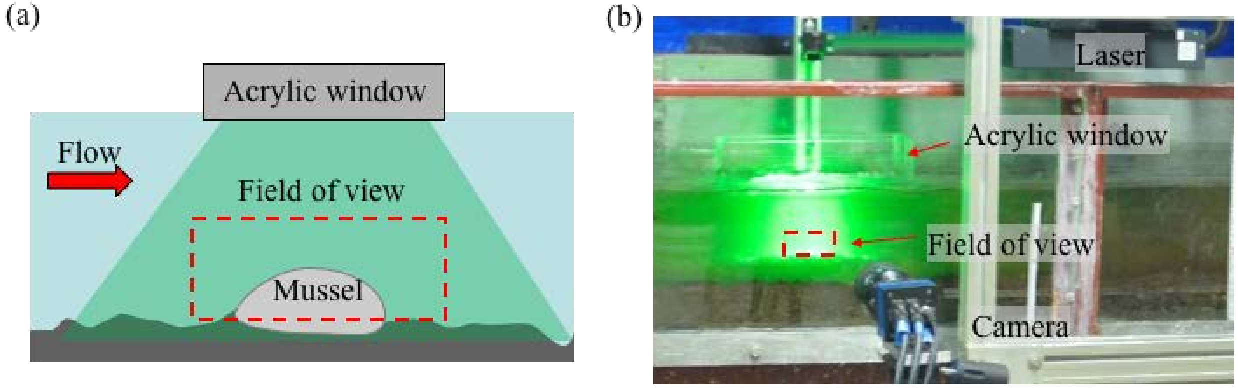


Figure 4. (a) Schematic of experimental setup showing the mussel, the captured field of view and the acrylic window (provide approximate dimensions for the red rectangle) . (b) Experimental setup with the PIV system consisting of the laser and a camera (indicate sediment bed and the water surface).

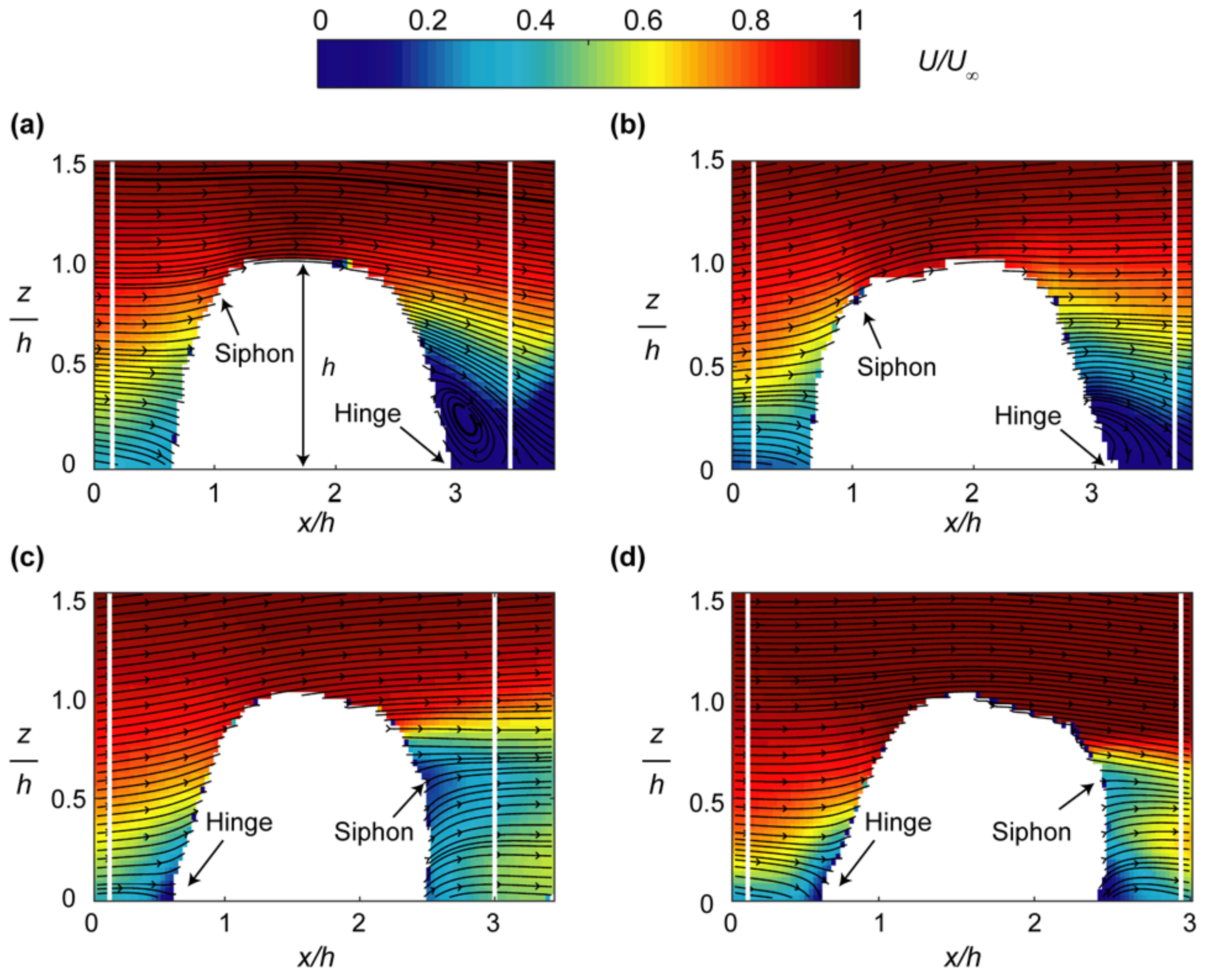


Figure 5. Flow patterns around mussels with different orientations and flow velocities. Contours of mean streamwise velocity normalized by the free stream velocity for (a) low flow, upstream orientation (b) high flow, upstream orientation (c) low flow, downstream orientation (d) high flow, downstream orientation cases, with vertical and horizontal axes non-dimensionalized by the exposed height of the mussel (h).

In a separate set of experiments, mussel feeding (gape) was measured as a function of suspended sediment concentration and flow rate (Figure 6). Three parameters were measured, % time closed, frequency of short closure events, and % time moving. The biggest impact of sediment was on the frequency of short closure events. Under high sediment loads, mussels tended to remove waste more frequently, which was measured as a short closure. However, there was no measureable impact of these events on glycogen content. Gape sensors were deployed in the field to verify that mussel gape measured in the lab was representative of field behavior (Figure 7).

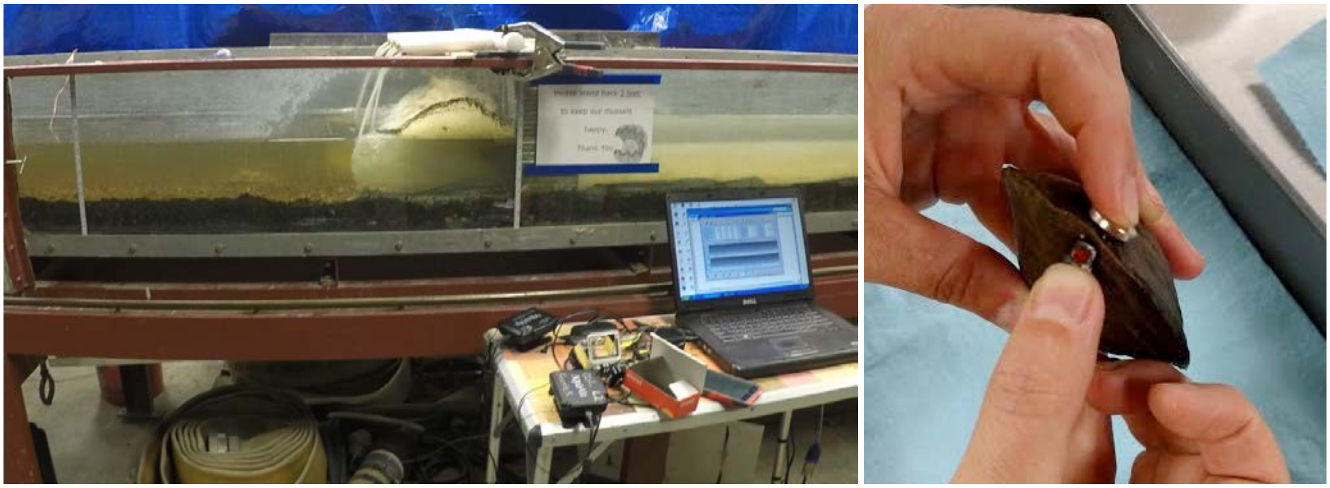


Figure 6. Paired control-treatment flume setup to measure mussel response to suspended sediment and flow rate. Mussel response was measured as gape (proxy for feeding) and through glycogen content.

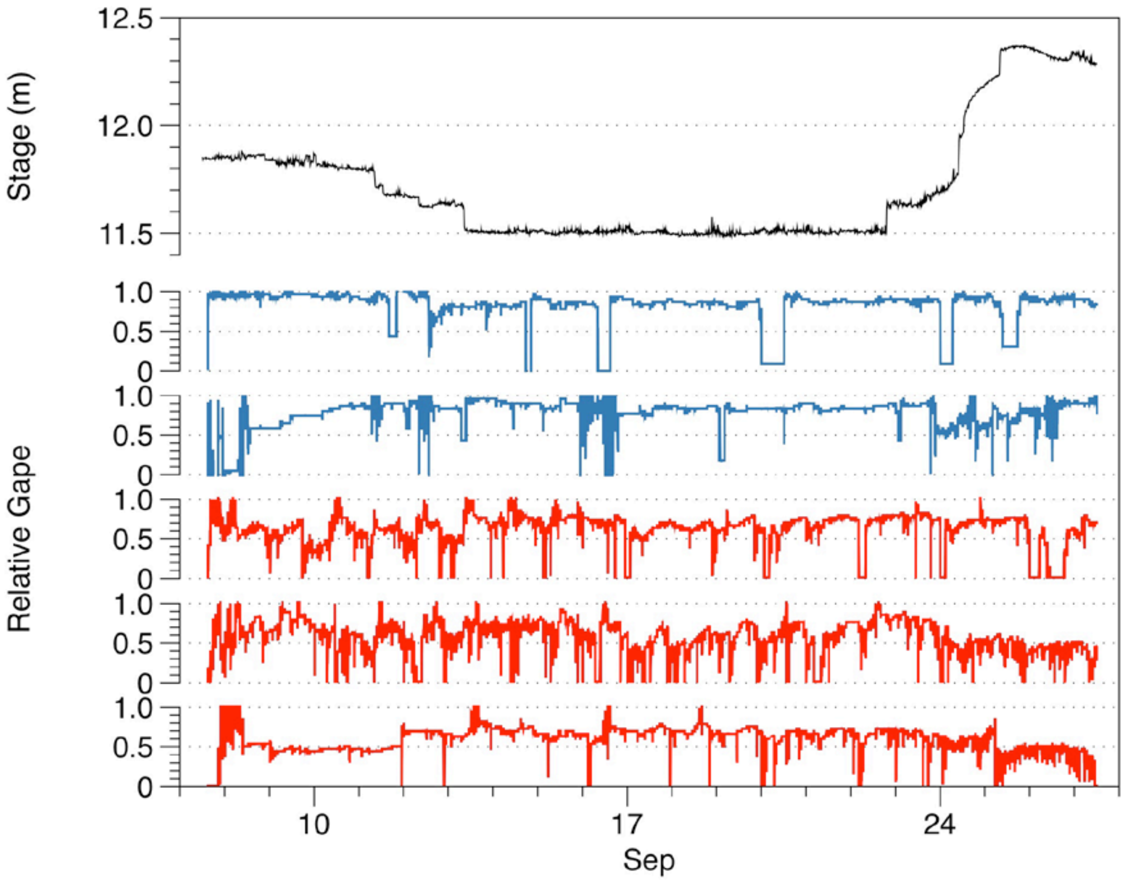


Figure 7. Mussel gape measured in the Chippewa River in September 2017. There were three phases of flow, falling stage, stable low flow, and rising stage. Red is *Amblema Plicata*, and blue is *Lampsilus Cardium*.

The fifth paper presents results from experiments in the Outdoor StreamLab at SAFL. Mussel response to bed instability was measured by tracking mussel movement (laterally and vertically), before, during and after a flood event. In general, mussels were able to respond to bed movement by anchoring temporarily during flood events, allowing bedforms to pass overtop (Figure 9), then moving to deeper water as floods receded (see Activity 2 status as of January 2017).

Figure 8. Mussel response to bed instability was observed in the Outdoor StreamLab at SAFL. Mussel movement was tracked using unique identifiers.

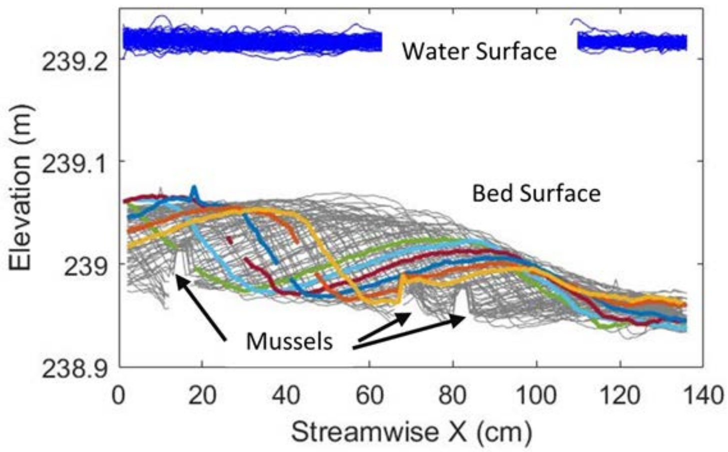


Figure 9. Repeat scan of bed and water surface elevation showing bedforms moving over mussels. Colored scans are approximately 5 minutes apart.

Significance: Growth rates and energy stores (glycogen) were greater in watersheds with greater agricultural impacts. The increased nutrient loading within these watersheds correlated with greater chlorphyll a concentrations indicating greater food availability. Although agricultural impacts appear to have a negative effect on mussel population abundance and diversity, there is a positive effect on growth rates and glycogen level. These results are important to consider when determining management policies for land use around rivers.

Laboratory experiments were used to isolate the impact of sediment on mussel behavior that 1) cannot be easily observed in the field, and 2) is often complicated by interacting stressors. Mussel gape and filtering behavior was influenced by flow rate, suspended sediment concentrations and mussel orientation to flow. The frequency of short closures (waste excretion) increased with less ideal orientation (siphons downstream), at high flows and with high suspended sediment concentrations. This behavior did not result in a difference in energy stores (glycogen), however. Mussels responded to bed instability by anchoring in place and allowing bedforms (sand waves) to pass overtop during high flows. When mussels were placed in shallow water, or when water levels receded quickly, they moved downslope to deeper water. Adult mussels displayed behaviors that allowed them to react to changes in flow, suspended sediment, and bed stability.

Insights:

- We expected growth rates and mussel energy stores to be less in rivers with greater sediment and agricultural impact; however, the opposite trends were observed for adult mussels. Juvenile mussels are likely more sensitive to both sediment impacts and other water quality stressors.

- While gape sensors are increasingly being used in ecotoxicology studies to measure non-lethal response to water contaminants, in this study, mussels did not behave as expected, by closing their valves, during high sediment events. The increase in frequency of short closures, however, was observed to correspond with waste excretion in video images. Gape sensors had not previously been used to record these behaviors, in part, because these behaviors were often masked in signal filtering of 5-10 minutes or greater and we recorded data at 1 Hz. While we were unable to measure a change in energy stores (glycogen) associated with increased sediment, it is unknown how the filtering rate correlates with gape as previous studies have indicated a decrease in filtering rate with increased suspended sediment.

- Our study of mussel response to flood flows and bed instability was conducted in the Outdoor StreamLab at SAFL. This allowed us to collect detailed information about mussel movement, bed mobility, and water velocities and turbulence that would be difficult or impossible to observe in the field. There were tradeoffs, however, as the habitat in the OSL is much shallower than the habitat these mussels are usually found in. Future studies should make use of other deeper facilities (such as the main channel at SAFL) to replicate depths and bedform heights found in large rivers such as the Mississippi.

ACTIVITY 3: Engaging the MN Public in Native Mussel Conservation
Description: Through the collaboration with the River Life program at the University of Minnesota, we seek to engage the public in water quality issues, broadly, and freshwater mussel conservation, specifically. River Life is a program of the Institute for Advanced Study at the University of Minnesota that works to build communities of knowledge and practice that develop new understandings of systems of people, land, and water. They work through student programs (training the next generation), develop collaborative cross-disciplinary research agendas (science to humanities) and develop digital (social media) and face-to-face programs. Efforts will be monitored with metrics designed to measure reach, engagement, and conversations.

We will 1) equip our student researchers to give talks to the public (including place oriented groups such as local civic and religious institutions), 2) generate digital content through social media platforms (i.e. River Talk blog (http://riverlife.umn.edu/rivertalk/, Facebook and Twitter), and 3) actively develop a network of networks to engage directly with programs such as the ENTRF funded Urban Wilderness Canoe Adventure to have the results and significance of our research reach the audiences that have already been developed.

Researchers and students will present the results from our project to Minnesota public through an extension of the DNR's popular Historical DNR Building at the State Fair. We will help develop interpretation for the indoor fish aquaria, present project results, as well as provide general information about mussels and the importance of water and habitat quality, to DNR building visitors.

Summary Budget Information for Activity 3:		
	ENRTF Budget:	**$ 23,547**
	Amount Spent:	**$ 23,547**
	Balance:	**$ 0**

Activity Completion Date: December 31, 2018

Outcome	Completion Date	Budget
1. Reach 20,000+ people per day at the MN State Fair Historical DNR Building with a native mussel display led by student researchers	September 2017	$ 7,849
2. Directly reach 50+ people in place-oriented groups and others indirectly through word of mouth. Students serve as teachers by giving 3 public talks.	September 2017	$ 7,849
3. Records of engagement and virality, the sharing and discussion of posted information in Social Media (measure incoming links and visits to blog posts, Twitter mentions, etc.)	End of project	$ 7,849

Activity Status as of January 1, 2015**:** No activity to date.

Activity Status as of July 1, 2015**:** No activity to date.

Activity Status as of January 1, 2016**:** Researchers visited the DNR building during the State Fair on September 6, 2015 (Figure 1). This display, led by undergraduate researchers, told the story of freshwater mussels and their habitat (sediment). Students also created a blog about their summer research experiences (available at http://mnmusselsatmac.blogspot.com/p/about-project.html). Kelly MacGregor summarized this summer's research in a public presentation at Sip of Science at the Aster Café in Minneapolis.

Figure 1. Macalester students talk to State Fair visitors about freshwater mussels.

Activity Status as of July 1, 2016**:** No new activity to date.

Activity Status as of January 1, 2017**:** Researchers again visited the DNR building during the State Fair on September 4, 2016 (Figure 2). This display, led by undergraduate researchers, told the story of freshwater mussels and their habitat (sediment). Students discussed their experiments at St. Anthony Falls Lab to quantify mussel habitat.

Figure 3. Macalester and UMN students talk to State Fair visitors about freshwater mussels, Sept. 4, 2016.

Activity Status as of July 1, 2017**:** No new activities. Project featured by the Partnership for River Restoration in the Upper Midwest:
http://prrsum.dl.umn.edu/SAFLmussels

Activity Status as of January 1, 2018**:** Macalester students from the 2017 field season collaborated on a publication for Open Rivers a joint project of River Life (Patrick Nunally and Joanne Richardson, partners in this project), the University of Minnesota Institute for Advanced Study, and University of Minnesota Libraries. *Open Rivers* is an interdisciplinary online journal that recognizes the Mississippi River as a space for timely and critical conversations about people, community, water, and place. This article details their summer field experience including engagement with local communities while in the field.

Final Report Summary: Twelve undergraduate student researchers across a range of disciplines were integrated into both research and public engagement on water quality and freshwater mussel conservation. Students presented to a range of audiences including student research fairs, the St. Croix River Research Rendezvous, the Upper Midwest Stream Restoration Symposium, and the Minnesota State Fair. For the 2015 field season, students developed a blog about their experiences, and in 2017, students worked with River Life at the University of Minnesota to develop an article for publication in the Open Rivers online journal. In addition, researchers presented project results at national conferences (Society for Freshwater Science, American Geophysical Union, and Geological Society of America), and to the public at Sip of Science at the Aster Café. A full list of presentations and public outreach activities is included in the dissemination section of this report. In addition, a report detailing the **significance** and **insights** of the social media campaign from River Life is included as Appendix A at the end of this report.

Undergraduate Student Researchers (12 total):
2015

Maya Agata, Clara Friedman, Molly Guiney, Brooke Hunter – Macalester College

2016

Lea Davidson, Brooke Hunter – Macalester College
Patrick Buffington, Tahni Jungst – University of Minnesota
Samantha Beck, Gabriela Martinez – National Science Foundation Research Experience for Undergraduates (NSF REU)

2017

Lea Davidson, James Doherty, Laura Gould, Hayley Stutzman – Macalester College
Tahni Jungst – University of Minnesota Undergraduate Research Opportunity (UROP)

Student Papers:
2016

Samantha Beck, Gabriela Martinez –NSF REU Final Reports

2017

Brooke Hunter – Macalester College Honors Thesis
Tahni Jungst – UMN UROP Final Report

V. DISSEMINATION:

Description: We will present the results from our project through a number of deliverables. Scientific results from Activities 1 and 2 will be submitted for publication in peer-reviewed journals as well as presented in local (e.g., St. Croix River Research Rendezvous) and national (e.g., Society of Freshwater Science, Freshwater Mollusk Conservation Society) meetings of natural resource professionals. We will also meet with biologists in charge of Minnesota mussel conservation efforts (i.e., Mike Davis and Bernard Sietman, DNR) to discuss our results and offer ideas to improve mussel community resampling methodology to detect changes in native mussel populations due to changes in environmental conditions. We are also excited to present the results from our project to Minnesota public through a range of public engagement strategies including an extension of the DNR's popular Historical DNR Building at the State Fair (Activity 3). Project results and general information about mussels and the importance of water and habitat quality will be shared by researchers and students through public presentations, and social media (Activity 3). A comprehensive report of results and analyses from this project will be submitted to the LCCMR by December 31, 2017.

Activity Status as of January 1, 2015**:** No activity to date.

Status as of July 1, 2015**:** No activity to date.

Status as of January 1, 2016**:** 2015 research results were disseminated at both at local and regional conferences and through public outreach. Undergraduate student researchers presented their research results in a poster and oral presentation at the 2015 St. Croix River Research Rendezvous and at the Midstates Consortium for Science and Math at Washington University in St. Louis. Students also created a blog about their summer research experiences (http://mnmusselsatmac.blogspot.com/p/about-project.html) and hosted a half day exhibit at the MN DNR booth at the State Fair to talk to visitors about freshwater mussels and sediment. Kelly MacGregor summarized this summer's research in a public presentation at Sip of Science at the Aster Café in Minneapolis.

Agata, M., and Friedman, C. (2015) Species Richness, Diversity, and Impact of Life History Strategies on Distribution of Freshwater Mussels, Midstates Consortium for Science and Math, Washington University, St. Louis, MO, November 7, 2015.

Agata, M., Friedman, C., Hornbach, D., Hove, M., MacGregor, K. (2015). Species Richness, Diversity, and Impact of Life History Strategies on Distribution of Freshwater Mussels in the Snake River. St. Croix River Research Rendezvous, October 20, 2015.

Guiney, M., Hunter, B., MacGregor, K., Hornbach, D., and Hove, M., (2015) Bed sediment composition and mussel population dynamics on the Snake River, St. Croix River Research Rendezvous, October 20, 2015, St. Croix Watershed Research Station, Marine on St. Croix, MN.

MacGregor, K. (2015) Ask me about my mussels! The relationship between sediment and native river mussels in Minnesota, Sip of Science, Aster Café, Minneapolis, MN.

Status as of July 1, 2016**:** Research results from 2015 were presented as a poster by Dan Hornbach at the Society for Freshwater Science Annual Meeting.

Hornbach, D.J., Hove, M.C., MacGregor, K.R., Agata, M., Friedman, C., Guiney, M., Hunter, B., and Kozarek, J.L. (2016) Impact of suspended sediment load on freshwater mussel assemblages: a comparison of two Minnesota watersheds. Society for Freshwater Science Annual Meeting, May 21-26, 2016, Sacramento, CA.

Status as of January 1, 2017**:** Students presented their research results at local poster sessions including the Research Experience for Undergraduates (REU) Site on Sustainable Land and Water Resources Poster Session held at SAFL at the University of Minnesota, and the Macalester College Student Poster Presentations. Research results from the experiments at SAFL were presented by Jessica Kozarek at the American Geophysical Union Fall meeting in San Francisco, CA.

Martinez, G. (2016) Freshwater mussel gape behavior in response to total suspended sediment. REU Site on Sustainable Land and Water Resources Poster Session, August 19, 2016, SAFL, Minneapolis, MN.

Beck, S. (2016) Water velocity, depth, and unionid mussel habitat interactions. REU Site on Sustainable Land and Water Resources Poster Session, August 19, 2016, SAFL, Minneapolis, MN.

Hunter, B., Davidson, L., Kozarek, J., MacGregor, K., Hornbach, D., Hove, M. The impact of flooding and suspended sediment on native mussel behavior in flume experiments. Macalester College Student Poster Presentations, October 2016.

Kozarek, J.L, K. MacGregor, D. Hornbach, M. Hove (2016) Quantifying habitat interactions: sediment transport and freshwater mussels. AGU Fall Meeting, December 12-16, 2016, San Francisco, CA.

This project was featured on the Macalester College website:
https://www.macalester.edu/news/2016/10/mighty-mussels/

and on the SAFL website:
http://www.safl.umn.edu/featured-project-response-native-mussels-changing-river-conditions-flume-experiments-st-anthony-fall

Jessica Kozarek published an article about freshwater mussels in Open Rivers, a joint project of River Life (Patrick Nunally and Joanne Richardson, partners in this project), the University of Minnesota Institute for Advanced Study, and University of Minnesota Libraries. *Open Rivers* is an interdisciplinary online journal that recognizes the Mississippi River as a space for timely and critical conversations about people, community, water, and place.

Kozarek, Jessica. 2016. “What do you see when you look at a river?” Open Rivers: Rethinking the Mississippi, no. 4. http://editions.lib.umn.edu/openrivers/article/what-do-you-see-when-you-look-at-a-river/

Status as of July 1, 2017**:** Students presented their research results at local poster sessions including the University of Minnesota Undergraduate Research Symposium. Research results from the experiments at SAFL were presented by Dan Hornbach and Jessica Kozarek at the Society for Freshwater Science Annual Meeting and Upper Midwest Stream Restoration Symposium, respectively.

Hornbach, D.J., M.C. Hove, K.R. MacGregor and J. Kozarek (2017) The response of freshwater mussels to bedload transport: experimental stream studies. Freshwater Science Annual Meeting, June 12-16, 2017, Raleigh, NC.

Jungst*, T. (2017) Effect of freshwater mussels on stream bed morphology. Undergraduate Research Symposium. April 20, 2017, University of Minnesota, Minneapolis, MN.

Kozarek, J.L, K. MacGregor, D. Hornbach, and M. Hove (2017) Freshwater mussel response to habitat alterations. Upper Midwest Stream Restoration Symposium. February 26-March 1, 2017, LaCrosse, WI.

Status as of January 1, 2018**:** Students presented their research results at local poster sessions including the St. Croix River Research Rendezvous. Research results from the experiments at SAFL were presented by Jessica Kozarek at the American Geophysical Union Annual Meeting.

Hunter*, B., J. Kozarek, K. MacGregor and D. Hornbach (2017) Freshwater river mussel gaping response behavior to increased water velocity and total suspended solids. Geological Society of America Meeting, October 22-25, 2017, Seattle, WA.

Kozarek, J.L., K.R. MacGregor, D. Hornbach, M. Hove (2017) Freshwater mussel response to bedform movement: experimental stream studies. AGU Fall Meeting, December 11-15, 2017, New Orleans, LA.

L. Davidson*, J. Doherty*, L. Gould*, H. Stutzman*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Land use change, sediment and mussels: a study of ecological interactions between sediment bedload and native freshwater mussels in Minnesota and St. Croix River basins. St. Croix River Research Rendezvous, October 10, 2017, St. Croix Watershed Research Station, Marine on St. Croix, Minnesota.

L. Davidson*, J. Doherty*, L. Gould*, H. Stutzman*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Land use change, sediment and mussels: a study of ecological interactions between sediment bedload and native freshwater mussels in Minnesota and St. Croix River basins. Macalester College Student Research Fair, October 2017, St. Paul, Minnesota.

L. Gould*, H. Stutzman*, L. Davidson*, J. Doherty*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Mussel growth in the St. Croix and Minnesota River basins. St. Croix River Research Rendezvous, October 10, 2017, St. Croix Watershed Research Station, Marine on St. Croix, Minnesota.

L. Gould*, H. Stutzman*, L. Davidson*, J. Doherty*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Mussel growth in the St. Croix and Minnesota River basins. Macalester College Student Research Fair, October 2017, St. Paul, Minnesota.

Final Report Summary: Through this project, we advocated cleaner and healthier Minnesota waters by studying the environmental conditions necessary to conserve and promote a diverse and sustainable native mussel population. This project impacted 1) the greater scientific community through the development of five peer-reviewed publications and presentations at scientific conferences (state, regional, and national); 2) water resources and wildlife professionals working towards freshwater mussel conservation through the dissemination of results, and 3) the general public through public engagement strategies designed to illustrate ecosystem services provided by freshwater mussels and the linkages between mussels and clean water. In addition, this project provided training for the next generation of water resource professionals by incorporating twelve undergraduate student researchers in field, laboratory, and engagement activities.

Scientific results from the field and laboratory studies are being submitted for publication as five separate manuscripts to peer-reviewed journals. These results were shared with Minnesota DNR and USGS scientists who also serve as co-authors. Project results were presented at national conferences (Society for Freshwater Science; American Geophysical Union; and Geological Society of America), regional conferences (St. Croix Watershed Research Rendezvous and Upper Midwest Stream Restoration Symposium), and local venues (Macalester College Student Research Fair and UMN Undergraduate Research Symposium).

We presented the results from our project to the Minnesota public through a range of public engagement strategies including presentations in 2015 and 2016 at the DNR's popular Historical DNR Building at the MN State Fair. Project results and general information about mussels and the importance of water and habitat quality were shared by researchers and students through public presentations (Sip of Science at the Aster Café), a blog about the 2015 field experience, and development of an article for the digital journal, Open Rivers. *Open Rivers: Rethinking Water, Place & Community* is an interdisciplinary online journal developed by River Life at the University of Minnesota that recognizes rivers in general, and the Mississippi River in particular, as space for timely and critical conversations about the intersections between biophysical systems and human systems.

Below is a full listing of dissemination activities related to this project. A copy of the public presentation at the Aster Café is included in Appendix B. Copies of student-led and researcher-led presentations are included in Appendices C and D, respectively.

Peer-Reviewed Publications:

Kumar, S., J.L. Kozarek, D. Hornbach, M. Hondzo, and J. Hong (in Review) Experimental investigation of turbulent flow over live mussels, Submitted to Environmental Fluid Mechanics

Hornbach, D.J., M.C. Hove, K. MacGregor, J.L. Kozarek, B. Sietman, and M. Davis (in Review) Impact of suspended sediment load on freshwater mussel assemblages: a comparison of two Minnesota watersheds, Submitted to Aquatic Conservation: Marine and Freshwater Ecosystems

Hornbach, D.J., H. Stutzman, M.C. Hove, J.L. Kozarek, K. MacGregor, T. Newton, and P. Ries (in Prep) Influence of Surrounding Land-Use on Mussel Growth Rate and Glycogen Levels in the St. Croix and Minnesota River Basins

Kozarek, J.L., M.C. Hove, D. Hornbach, and K. MacGregor (in Prep) Title: TBD. Presenting results from flume study at SAFL

Kozarek, J.L., M.C. Hove, K. MacGregor, and D. Hornbach (in Prep) Title: TBD. Presenting results from OSL study at SAFL

Project Dissemination/Outreach/Engagement Efforts:

*Presentations (*student):*

2015

Agata*, M., and C. Friedman* (2015) Species richness, diversity, and impact of life history strategies on distribution of freshwater mussels. Midstates Consortium for Science and Math, November 7, 2015, Washington University, St. Louis, MO.

Agata*, M., C. Friedman*, D. Hornbach, M. Hove, and K. MacGregor (2015) Species richness, diversity, and impact of life history strategies on distribution of freshwater mussels in the Snake River. Macalester College Student Research Fair, October, 2015, St. Paul, Minnesota.

Agata*, M., C. Friedman*, D. Hornbach, M. Hove, K. MacGregor (2015). Species richness, diversity, and impact of life history strategies on distribution of freshwater mussels in the Snake River. St. Croix River Research Rendezvous, October 20, 2015, St. Croix Watershed Research Station, Marine on St. Croix, MN.

Guiney*, M., B. Hunter*, K. MacGregor, D. Hornbach, and M. Hove (2015) Bed sediment composition and mussel population dynamics on the Snake River. Macalester College Student Research Fair, October, 2015, St. Paul, Minnesota.

Guiney*, M., Hunter*, B., MacGregor, K., Hornbach, D., and Hove, M., (2015) Bed sediment composition and mussel population dynamics on the Snake River. St. Croix River Research Rendezvous, October 20, 2015, St. Croix Watershed Research Station, Marine on St. Croix, MN.

2016

Beck*, S. (2016) Water velocity, depth, and unionid mussel habitat interactions. REU Site on Sustainable Land and Water Resources Poster Session, August 19, 2016, SAFL, Minneapolis, MN.

Hornbach, D.J., M.C. Hove, K.R. MacGregor, M. Agata*, C. Friedman*, M. Guiney*, B. Hunter*, and J.L. Kozarek (2016) Impact of suspended sediment load on freshwater mussel assemblages: a comparison of two Minnesota watersheds. Society for Freshwater Science Annual Meeting, May 21-26, 2016, Sacramento, CA.

Hunter*, B., L. Davidson*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2016) The impact of flooding and suspended sediment on native mussel behavior in flume experiments. Macalester College Student Poster Presentations, October, 2016, St. Paul, Minnesota.

Kozarek, J.L, K. MacGregor, D. Hornbach, and M. Hove (2016) Quantifying habitat interactions: sediment transport and freshwater mussels. AGU Fall Meeting, December 12-16, 2016, San Francisco, CA.

Martinez*, G. (2016) Freshwater mussel gape behavior in response to total suspended sediment. REU Site on Sustainable Land and Water Resources Poster Session, August 19, 2016, SAFL, Minneapolis, MN.

2017

Hornbach, D.J., M.C. Hove, K.R. MacGregor and J. Kozarek (2017) The response of freshwater mussels to bedload transport: experimental stream studies. Freshwater Science Annual Meeting, June 12-16, 2017, Raleigh, NC.

Hunter*, B., J. Kozarek, K. MacGregor and D. Hornbach (2017) Freshwater river mussel gaping response behavior to increased water velocity and total suspended solids. Geological Society of America Meeting, October 22-25, 2017, Seattle, WA.

Jungst*, T. (2017) Effect of freshwater mussels on stream bed morphology. Undergraduate Research Symposium. April 20, 2017, University of Minnesota, Minneapolis, MN.

Jungst*, T., J.L. Kozarek, D. Hornbach, M. Hove, and K. MacGregor (2017) Effect of freshwater mussels on stream bed morphology (3rd Place Student Poster Competition). Upper Midwest Stream Restoration Symposium. February 26-March 1, 2017, LaCrosse, WI.

Kozarek, J.L, K. MacGregor, D. Hornbach, and M. Hove (2017) Freshwater mussel response to habitat alterations. Upper Midwest Stream Restoration Symposium. February 26-March 1, 2017, LaCrosse, WI.

Kozarek, J.L., K.R. MacGregor, D. Hornbach, M. Hove (2017) Freshwater mussel response to bedform movement: experimental stream studies. AGU Fall Meeting, December 11-15, 2017, New Orleans, LA.

L. Davidson*, J. Doherty*, L. Gould*, H. Stutzman*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Land use change, sediment and mussels: a study of ecological interactions between sediment bedload and native freshwater mussels in Minnesota and St. Croix River basins. St. Croix River Research Rendezvous, October 10, 2017, St. Croix Watershed Research Station, Marine on St. Croix, Minnesota.

L. Davidson*, J. Doherty*, L. Gould*, H. Stutzman*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Land use change, sediment and mussels: a study of ecological interactions between sediment bedload and native freshwater mussels in Minnesota and St. Croix River basins. Macalester College Student Research Fair, October 2017, St. Paul, Minnesota.

L. Gould*, H. Stutzman*, L. Davidson*, J. Doherty*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Mussel growth in the St. Croix and Minnesota River basins. St. Croix River Research Rendezvous, October 10, 2017, St. Croix Watershed Research Station, Marine on St. Croix, Minnesota.

L. Gould*, H. Stutzman*, L. Davidson*, J. Doherty*, J. Kozarek, K. MacGregor, D. Hornbach, and M. Hove (2017) Mussel growth in the St. Croix and Minnesota River basins. Macalester College Student Research Fair, October 2017, St. Paul, Minnesota.

2018

Hornbach, D.J., M.C. Hove, K.R. MacGregor, J. Kozarek, P. Ries, and T. Newton (2018) Mussel Growth and Energy Storage in Rivers with Differing Amounts of Agricultural Impact. Freshwater Science Annual Meeting, May 20-24, 2018, Detroit, MI.

Outreach Activities:

MacGregor, K. (2015) Ask me about my mussels! The relationship between sediment and native river mussels in Minnesota. Sip of Science, September 9, 2015, Aster Café, Minneapolis, MN.

Hand's on demonstration at the MN State Fair DNR Building:

September 6, 2015
September 4, 2016

Macalester mussel blog: http://mnmusselsatmac.blogspot.com/p/about-project.html

Dan Hornbach's Research Page: https://www.macalester.edu/~hornbach/

Publicity:

- https://www.macalester.edu/news/2015/07/fat-mussels/
- https://www.macalester.edu/news/2015/09/what-mussels-tell/
- https://www.macalester.edu/news/2016/10/mighty-mussels/
- http://www.safl.umn.edu/featured-project-response-native-mussels-changing-river-conditions-flume-experiments-st-anthony-fall
- http://www.presspubs.com/st_croix/news/article_76ab6130-bfe4-11e7-9d29-fb2931aaa7a8.htmlMention in St. Croix River

River Life Publications:

Kozarek, J. (2016) "What do you see when you look at a river?" Open Rivers: Rethinking the Mississippi, no. 4. http://editions.lib.umn.edu/openrivers/article/what-do-you-see-when-you-look-at-a-river/

Davidson, Lea, James Doherty, Laura Gould, and Hayley Stutzman. (2018) "Mosquitoes, Muck, and Mussels: A Look Into Scientific Research." Open Rivers: Rethinking Water, Place & Community, no. 9. http://editions.lib.umn.edu/openrivers/article/mosquitoes-muck-and-mussels-a-look-into-scientific-research/

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$158,227	1 project manager at 25% FTE for 4 yrs; 1 research advisor at 3.8% FTE 2 yrs; 1 instrumentation specialist at 3.3% FTE for 2 yrs; 1 technician at 2% time for 3 yrs; 4 undergraduate research assistants at 23% FTE for 1 yr; River Life coordinator at 2% for 3 yrs; 1 info tech professional at 6% for 2 yrs
Professional/Technical/Service Contracts:	$177,051	contract with Macalester College for field data collection, research collaboration, and public engagement: **Personnel** (70% of contract): 2 co-PIs at 8% FTE for 2 yrs; 1 research associate at 21% FTE for 3 yrs; 3 students at 20% FTE for 2 yrs; **Travel Expenses in MN** (11% of contract): travel to field sites including mileage, lodging and meals (MRB, St. Croix), misc. travel for equipment repair, etc., mileage, lodging, registration fees, meals for student presentations; **Equipment/Tools/Supplies** (5% of contract): field equipment maintenance, new equipment replacement; **Other**: laboratory assays (14% of contract to USGS Upper Midwest Environmental Sciences – T. Newton's Laboratory); outreach costs (1% of contract)
	$4,800	Contract for laboratory fees for mussel assays (USGS Upper Midwest Environmental Sciences Center – T. Newton's Laboratory was the only laboratory identified capable of analyzing glycogen levels in mussel tissue)
Equipment/Tools/Supplies:	$8,855	Sediment laboratory supplies; OSL supplies, equipment, and maintenance; materials for film/video and handouts
Printing:	$466	handout and outreach material printing
Travel Expenses in MN:	$601	mileage, lodging, meals
TOTAL ENRTF BUDGET:	**$350,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: N/A

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 2.65

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 2.15

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds

Non-state			
N/A	$	$	
State			
N/A	$	$	
TOTAL OTHER FUNDS:	**$**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

Project Partners Not Receiving Funds:

- MN DNR: Providing mussel data and serving an advisory role

Project Partners Receiving Funds

- Macalester College: $177,051 to conduct field data collection, research collaboration, and outreach activities
- USGS Upper Midwest Environmental Sciences Center: $4,800 to analyze glycogen levels in mussel tissue

B. Project Impact and Long-term Strategy:

We are advocating cleaner and healthier Minnesota waters by understanding environmental conditions necessary to conserve and promote a diverse and sustainable native mussel population. This project will impact 1) the greater scientific community through peer-reviewed publications and presentations at scientific conferences (state, regional, and national); 2) water resources and wildlife professionals working towards freshwater mussel conservation through the dissemination of results and resampling plan, and 3) the general public through public engagement strategies designed to illustrate ecosystem services provided by freshwater mussels and the linkages between mussels and clean water. In addition, this project educated and trained the next generation of water resource professionals by incorporating undergraduate student researchers in field, laboratory, and engagement activities. Quantifying the complex interactions between mussels and their habitat will assist in: 1) maintaining ecosystem services provided by mussel, 2) using long-term mussel monitoring as a biological indicator for changes in water quality, 3) evaluating the suitability of potential mussel reintroduction sites, and 4) defining specific mussel habitat criteria for restoration planning. This research is the result of at interdisciplinary meetings hosted by SAFL prior to the project start to discuss potential mussel research that will benefit ongoing mussel conservation efforts attended by academia, state and federal agencies MN DNR, US FWS, US ACE, NPS, and Macalester College. This proposal was developed in discussion with the MN DNR to supplement their freshwater mussel conservation efforts. Future funding is being sought to further examine the relationships between stream and river dynamics and freshwater mussel microhabitat and feeding, and reproduction.

C. Spending History:

Funding Source	**M.L. 1998 or FY99**	**M.L. 1999 or FY00**	**M.L. 2007 or FY08**
ENRTF appropriation, D. Hornbach and M. Hove (Macalester): Freshwater Mussel Resources in the St. Croix River. 7/1999-6/2001	$58,000		
National Park Service, M. Hove and D. Hornbach (Macalester) Community analysis of the mussel population downstream of the St. Croix Falls hydropower dam. 2000-2002.		$40,900	
National Park Service, M. Hove and D. Hornbach (University of Minnesota) Mussel communities in the St. Croix National Scenic Riverway community population monitoring and distribution surveys. 2000-2005.		$56,266	
National Park Service, K. MacGregor and D. Hornbach (Macalester): Monitoring Sediment Dynamics in the St. Croix River and the Impact on Federally Endangered Mussels. 4/2008-12/2010			$148,824

VIII. ACQUISITION/RESTORATION LIST: n/a

IX. VISUAL ELEMENT or MAP(S): See attached visual element.

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: n/a

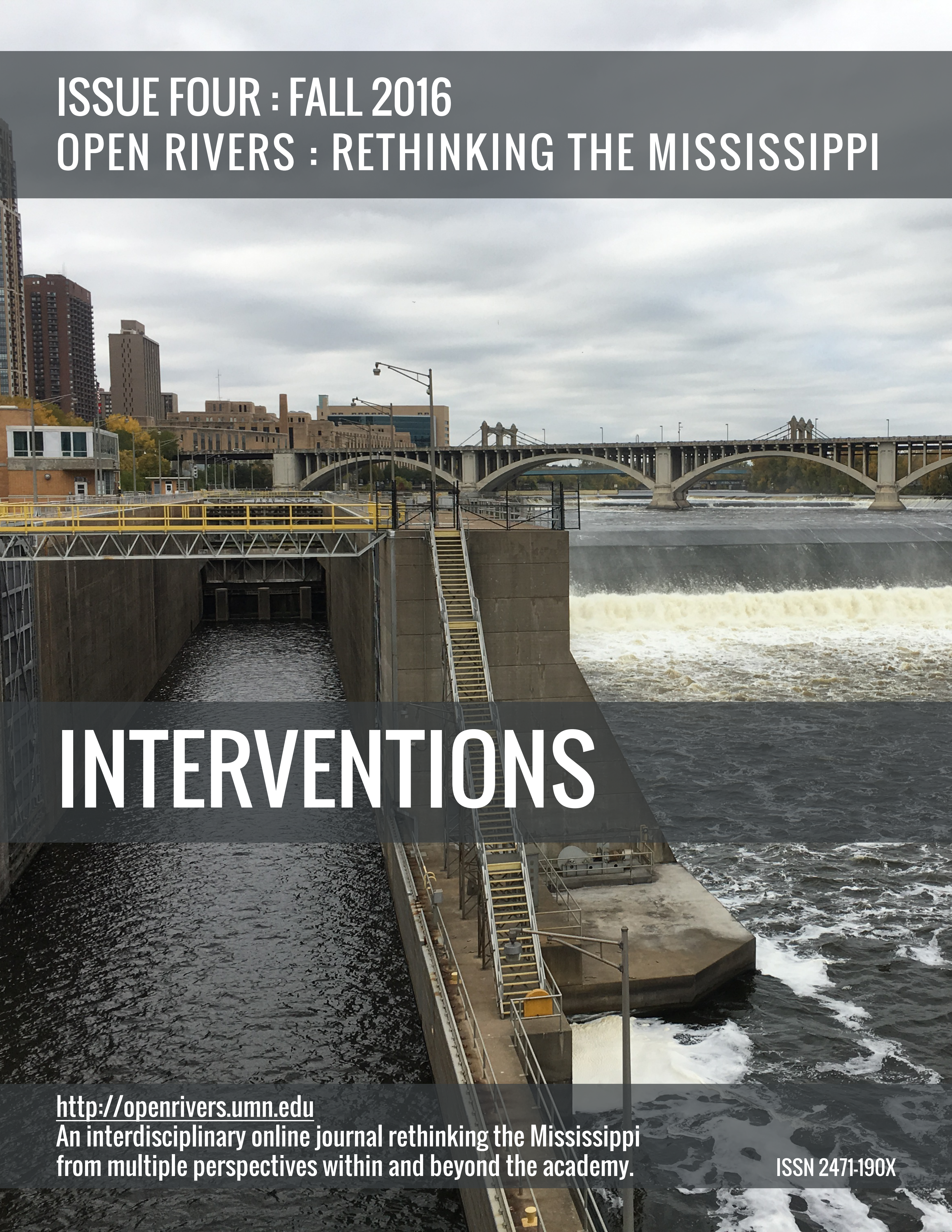
XI. RESEARCH ADDENDUM: See attached research addendum.

XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 1, 2015, July 1, 2015, January 1, 2016, July 1, 2016, January 1, 2017, July 1, 2017, and January 1, 2018. A final report and associated products will be submitted between June 30 and August 15, 2018.

Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: Conserving Minnesota's Native Freshwater Mussels
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05k
Project Manager: Jessica Kozarek
Organization: University of Minnesota
M.L. 2014 ENRTF Appropriation: $350,000
Project Length and Completion Date: 4 Years, June 30, 2018
Date of Report: Final

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Revised Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Revised Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Revised Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	**Strategic Resampling of Survey Sites: Quantifying Environmental Conditions**				**Quantifying Mussel Response to Changes in Environmental Conditions**				**Engaging the MN Public in Native Mussel Conservation**					
Personnel (Wages and Benefits)	~~$16,747~~	$18,121	$18,121	$0	~~$113,005~~	$118,025	$118,025	$0	~~$19,114~~	$22,081	$22,081	$0	$158,227	$0
Research Associate, Jessica Kozarek: ~~$61,942~~ $71,303 (33.6% benefits); 25% FTE for 3 yrs														
Professor, Miki Hondzo: $8,651 (33.6% benefits); 3.8% FTE for 1 yr														
Instrumentation Specialist: $13,400 (33.6% benefits); 8% FTE for 3 yrs														
Technician: $4,228 (36.8% benefits); 1.7% FTE for 3 yrs														
Researcher, Mark Hove: $16,747 (33.6% benefits); 10.5% FTE for 3 yrs														
Undergraduate research assistants: $24,784 (7.4% benefits); 25% FTE for 2 yrs; 70% FTE for 1 yr														
River Life Coordinator, Patrick Nunnally: $5,661 (33.6% benefits); 2% FTE for 3 yrs														
Info Tech Professional, Joanne Richardson: $13,453 (36.8% benefits); 6% FTE for 3 yrs														
Professional/Technical/Service Contracts														
Macalester College: field data collection, research collaboration, and public engagement: **Personnel** (70% of contract): 2 co-PIs at 8% FTE for 2 yrs; 1 research associate at 21% FTE for 3 yrs; 3 students at 20% FTE for 2 yrs; **Travel Expenses in MN** (11% of contract): travel to field sites including mileage, lodging and meals (MRB, St. Croix), misc. travel for equipment repair, etc., mileage, lodging, registration fees, meals for student presentations; **Equipment/Tools/Supplies** (5% of contract): field equipment maintenance, new equipment replacement; **Other**: laboratory assays (14% of contract to USGS Upper Midwest Environmental Sciences – T. Newton's Laboratory); outreach costs (1% of contract)	$146,051	$146,051	$146,051	$0	$30,000	$30,000	$30,000	$0	$1,000	$1,000	$1,000	$0	$177,051	$0
U.S. Geological Survey, a Bureau of the Department of the Interior, through the offices of its Upper Midwest Environmental Sciences Center (UMESC): laboratory work for mussel assays					$4,800	$4,800	$4,800	$0					$4,800	$0
Equipment/Tools/Supplies														
suspended sediment supplies					~~$3,875~~	$2,566	$2,566	$0					$2,566	$0
gape sensor supplies (magnets, proximity sensors)					~~$5,000~~	$3,792	$3,792	$0					$3,792	$0
OSL (sediment feeder maintenance, data acquisition)					~~$5,000~~	$2,497	$2,497	$0	~~$2,433~~	$0	$0	$0	$2,497	$0
Printing														
handout and outreach material printing									~~$1,000~~	$466	$466	$0	$466	$0
Travel expenses in Minnesota														
mileage, lodging, meals	~~$1,975~~	$601	$601	$0									$601	$0
COLUMN TOTAL	**$164,773**	**$164,773**	**$164,773**	**$0**	**$161,680**	**$161,680**	**$161,680**	**$0**	**$23,547**	**$23,547**	**$23,547**	**$0**	**$350,000**	**$0**



ISSUE FOUR : FALL 2016

OPEN RIVERS : RETHINKING THE MISSISSIPPI

INTERVENTIONS

http://openrivers.umn.edu

An interdisciplinary online journal rethinking the Mississippi from multiple perspectives within and beyond the academy.

ISSN 2471-190X

The cover image is of St. Anthony Falls Lock, closed in June 2015. Image courtesy River Life, University of Minnesota.

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Editorial Board

CONTENTS

FEATURE

WHAT DO YOU SEE WHEN YOU LOOK AT A RIVER?

By Jessica Kozarek

The Mississippi River in Minneapolis was the focus of a one-year study during 2015-16 to assess the current ecological condition of the river at the time of a major management event, the closure of the Upper St. Anthony Falls Lock (see Mazack, this issue).[1] From the compiled physical, chemical, and biological data, a baseline dataset was developed. Among other findings, the

Sauk River, upstream of the confluence with the Mississippi River at Sauk Rapids, MN. Image by Jessica Kozarek.

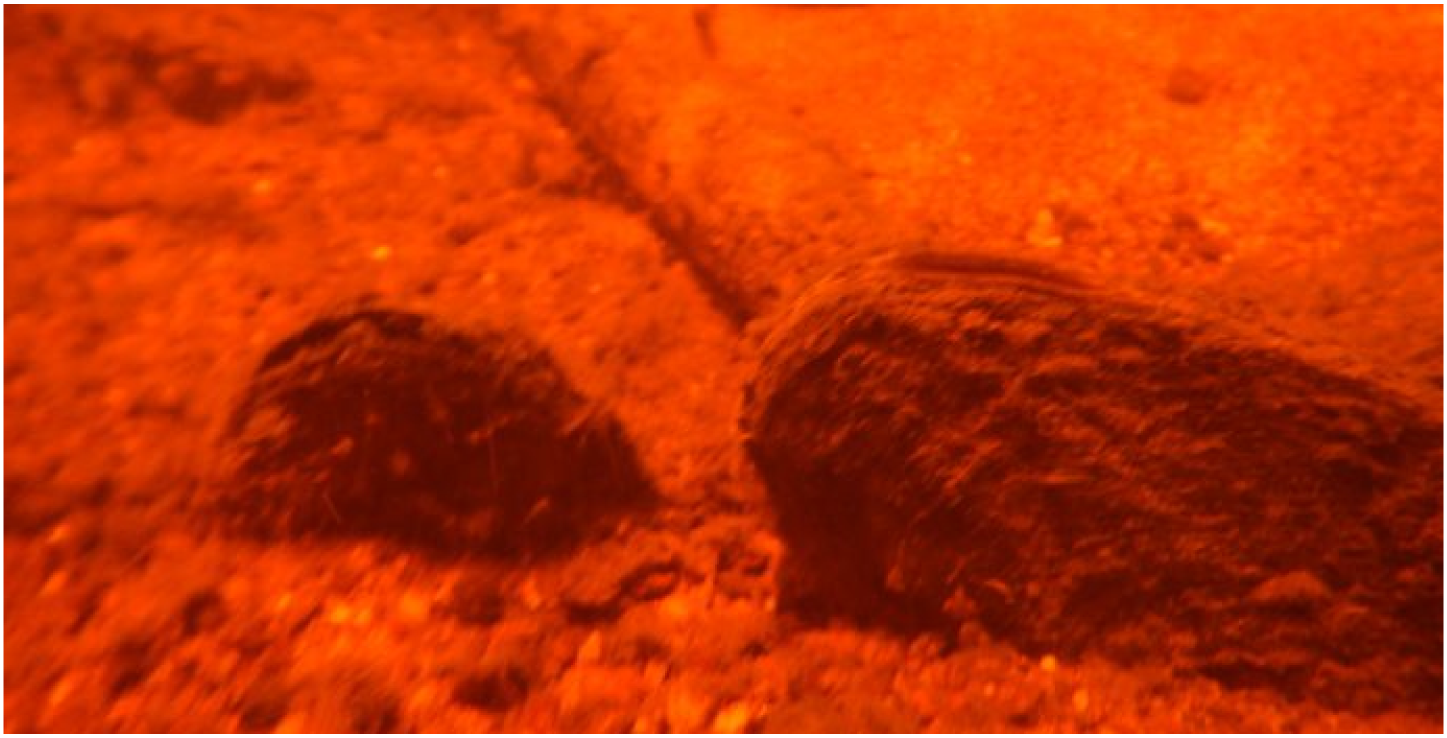
study determined that mussels are a significant component of the river's ecosystem. This article discusses mussels and mussel monitoring in more detail.

So, what do you see when you look at a river?

You might see physical characteristics of the water itself such as whirls from turbulence, waves, or water color and clarity. You might notice vegetation or birds and wildlife within the river. You might see large-scale river engineering projects: locks and dams, flood protection, bridges, or bank stabilization. All that you see and much that you likely can't see together compose the building blocks for an underwater ecosystem. These building blocks are all of the physical, chemical and biological conditions of the river that make it more or less livable for its underwater inhabitants. Physical habitat is the living space of aquatic biota represented by water currents and riverbed material. Physical river habitat is dynamic in space and time as water flow and sediment sources vary with weather patterns and land use practices. Chemical parameters of a river environment include: dissolved oxygen, temperature, nutrients, and pollutants. River water chemistry changes with season, rainfall, and land use practices. Biological parameters of a river habitat include: fish, aquatic wildlife and vegetation, macroinvertebrates (insect larvae, mussels), and microorganisms such as bacteria or algae. Together the physical and chemical environment with the biological community makes up the river ecosystem. By definition, a system is comprised of interconnected components or processes that make up a whole, and the physical, chemical, and biological processes within a river ecosystem are strongly interconnected.

Ecosystem Engineers

The interactions between the physical, chemical, and biological components of a river ecosystem are exemplified by those organisms that directly influence their physical habitat (which in turn affects the chemical and biological processes of the ecosystem). The concept of ecosystem engineering emerged in ecological literature in the 1990s (see review by Wright and Jones 2006). This concept generally refers to the modification of the physical features of ecosystems by a single species or collection of similar species. Human beings are the ultimate examples of ecosystem engineers, altering the physical habitat of rivers and landscapes to suit our needs by building dams, roads, cities, etc. that have cascading effects on the ecosystem in which we live. In the animal kingdom, one of the most visible ecosystem engineering species is the beaver whose dams extensively alter riverine habitat with dramatic effects on aquatic community structure and ecosystem functioning. Other examples of ecosystem engineers include elephants, gophers, and earthworms, all species that alter their physical surroundings. Even vegetation can be considered an ecosystem engineer under certain conditions, as it can significantly modify river flow and sediment characteristics altering the shape and form of a river. Less visible ecosystem engineering organisms that can have significant impacts on the physical structure of riverbed



Freshwater mussels in a river bed. Image by Jessica Kozarek.

Freshwater mussels in a mussel bed.
Source: Mike Davis, Minnesota Department of Natural Resources.

habitat are freshwater mussels. These organisms tend to aggregate in large groups called mussel beds. Mussel beds stabilize sediment and create habitat for aquatic insects, algae, and fish. Note the significant differences between the concept of ecosystem engineering—a community of organisms working together to engineer their habitat—and our human concept of engineering, namely intent. Beavers likely do intend to alter their physical habitat, but it could be argued that mussels' impact on riverbed habitat, while great, was not the intent of the mussels.

See video How Beavers Build Dams by PBS.

I will note at this point that I'm not an ecologist, nor am I a malacologist (a scientist who studies mollusks), and that my perspective on rivers is that of an engineer. I conduct research at St. Anthony Falls Laboratory at the University of Minnesota in a facility devoted to the study of the interactions between stream and river management and stream ecosystem response. This laboratory, dubbed the Outdoor StreamLab (OSL), is an experimental stream and floodplain designed to conduct experiments on a stream ecosystem such as the response of streambed composition, stream morphology, nutrient dynamics and/or biotic community to changes in water and sediment supply or engineering channel designs. Experiments conducted in the OSL during summer 2016 were focused on the feedbacks between mussels and channel morphology or how mussels respond to changing habitat and the impact of mussel presences on habitat in a changing environment.

The Outdoor StreamLab at St. Anthony Falls Laboratory at the University of Minnesota. Image by Jessica Kozarek.

Freshwater Mussels

Mussels are incredibly fascinating creatures that deserve some investigation. I've had the opportunity to learn about mussels from local experts in state and federal government agencies and from my colleagues in academia, who can speak much more accurately to mussel biology than I can, but I will enumerate some key points that make mussels worth thinking about. Mussels are much more than living rocks (although this is what they most resemble); mussel shells come in a wide variety of shapes, sizes, and surface textures. Adult mussel shell length ranges from 1 to 10 inches for different species (for a detailed discussion, see Haag 2012). With common names like "warty back," 'threeridge," "heelsplitter," or "pocketbook," you can imagine the shell sculpture for each of these species with bumps, ridges, wings, or smooth shells. Mussel shell morphology likely evolved to balance out the ability to maintain position without being scoured or dislodged, or to burrow (after dislodging or to avoid predation). Different morphology allows mussels to remain in riverbeds under different conditions. For example, a smooth-shelled mussel may be able to burrow faster, while a heavy, thick-shelled mussel with ridges or shell sculpture may be able to hold position in faster currents. Unfortunately, as mussels live on the bottoms of rivers, it is difficult to watch mussels during high flows, so it's hard to say what they actually do.

Freshwater mussels are abundant and diverse, but also highly imperiled. North America is home to approximately 300 species of mussels (Haag 2012); however, approximately 70 percent of these species are extinct, endangered, or otherwise of special concern. Mussel population decline cannot be attributed to a single factor, but rather a combination of often interacting factors from land use change (e.g., water quality degradation, habitat loss, altered streamflow, and sedimentation), direct channel modification (e.g., dam building), host fish availability (more on this later), and invasive species impacts (e.g., predation and zebra mussel infestation). Because mussels are long lived (some species can live 50 + years), relatively sedentary, and have a complicated life cycle that requires suitable host fish populations, they are often used as indicators of river ecosystem wellbeing. A kind of "canary in the coalmine" organism, mussel response to environmental conditions can signify an early warning for a degraded ecosystem. In fact, instrumented

The author holding a mussel collected from the Le Sueur River in Minnesota. Image used with permission from Amy Hansen.

mussels are being used as biomonitors for water quality. Mussels are filter feeders, and they have the ability to close their shells for a period of time when a contaminant is present. By monitoring mussel gape (i.e., the rate at which they open and close their shells), water resource managers can tell, for example, if all mussels close up quickly, that there is potentially harmful contamination.

Unlike fish, freshwater mussels are relatively sedentary and therefore subject to local environmental conditions. Mussels do have one foot, which allows them to anchor into sediment or crawl along slowly (generally inches to feet a day, at most). Unlike oysters or clams, freshwater mussels have a unique life cycle that depends on a parasitic relationship with a host fish. It is this relationship that allows mussels to spread throughout a river network. Female mussels release mussel larvae (called glochidia), which must attach to the gills of a suitable host where they will grow and develop for several weeks before dropping off of the fish as juvenile mussels. Many mussel species have evolved intricate methods to attract the appropriate fish host to ensure successful attachment of glochidia. These methods range from displaying elaborate lures that mimic fish, to developing packages of glochidia that resemble fish food, to physically capturing the unsuspecting fish host long enough

Diversity of mussel shell shapes and sizes in the Snake River, Minnesota. Image by Jessica Kozarek.

This illustration is from the booklet, "A Pocket Guide to Kansas Freshwater Mussels." It is reproduced with permission from the artist, Karen Couch.

to infest the fish with glochidia. These adaptations are next to impossible to observe in the wild without a snorkel, scuba gear, and/or lots of time and the expertise on when and where to look, but the curious can check out the array of videos online. As they grow, mussels can keep a record of the water chemistry and environmental conditions in their shells. Like trees, mussels develop rings as they grow. The size of each grow ring can show the mussels' growth, and a record of the river chemistry can be captured in the calcium carbonate that makes up the shell.

See videos of mussel lures at the Freshwater Mollusk Conservation Society.

Value of Freshwater Mussels

Descriptions of freshwater mussel diversity and abundance in the large rivers of the central U.S. prior to the 1900s evoked images of dense mussel beds hundreds of feet long and up to two or three feet thick in some areas (Haag 2012; Anfinson 2003). These beds provided the basis of a booming pearl button industry centered in Muscatine, Iowa in the late 1800s to early 1900s. Clammers dragged the Mississippi riverbed pulling up tens of thousands of tons of shells. In the same

Clammers standing atop a mound of mussels killed to make mother-of-pearl buttons. Source: US Fish and Wildlife Service, circa 1911.

time period, fortune seekers were on the hunt for elusive and valuable freshwater pearls. By the early 1900s, mussel beds had been depleted by the massive harvesting efforts and water quality was degrading due to growing human populations. Water pollution from agriculture and sewage made mussel population rejuvenation unlikely, and the button industry died out.

The New York Times published an article in 1902 about the end of the pearl mussel boom.

Modern wastewater treatment following the Clean Water Act of 1972 has greatly improved the water quality in our rivers, to the point that some mussel populations are beginning to recover. Today, freshwater mussels maintain a market as seed material for the cultured pearl industry but are illegal to collect in many states due to their threatened status. The non-market value of freshwater mussels today is more difficult to quantify, although they provide important ecosystem services. As mentioned above, the physical presence of a mussel bed can have a significant influence on riverbed habitat. But mussels influence more than just physical habitat. Mussels are filter feeders, passing gallons of water through a single mussel in a day, removing suspended material from the water column. In large enough numbers, mussels can greatly improve the water clarity. The unused nutrients and organic material that mussels filter out of the water while feeding are deposited in the riverbed stimulating the food web at the river bottom through algal growth and macroinvertebrate production. These processes can cascade up the food chain, ultimately providing more food for fish.

River Ecosystem Management in a Dynamic Environment

Freshwater mussel conservation efforts have shown some promise in rivers where water quality and physical habitat will support mussel populations; however, threats to freshwater mussels and causes for declining populations remain difficult to pin down, likely due, in part, to the interactions between many environmental stressors. Hansen and others published a modeling study in 2016 that provides an example of these interacting stressors in the heavily agricultural landscape in the Minnesota River basin. Land in this watershed is primarily used for row-crop agriculture (converted from a prairie-wetland system). Like much of the Midwest, extensive drainage practices (tile drains and ditches) and crop conversion compounded with changing precipitation patterns and earlier snowmelt have led to increased peak streamflows and suspended sediment concentrations. In turn, suspended sediment can shade or absorb the light and reduce the availability of algae, mussel's primary food. This model indicated that chronic exposure over many years to increased suspended sediment concentrations, combined with food limitation, were the primary factors controlling freshwater mussel population density in the watersheds which they examined. Other environmental stressors, such as pollutants or unstable habitat, may be more critical in river reaches in cities, for example.

I have used freshwater mussels as an example of how one component of a river ecosystem changes and is changed by its environment. This example illustrates that the interactions, feedbacks, and thresholds between components of a river ecosystem can be intertwined and should all be considered when maintaining, restoring, or otherwise managing a river to support life. Other less obvious, but non-structural components of river ecosystems can also drastically alter river ecosystems (see review by Corenblit et al. 2011). For example, feedbacks between hydrology, biogeochemistry (nutrient cycling), sediment transport, and vegetation growth can control river dimensions (width, depth, slope, etc.). As river management trends more toward restoration (see Open Rivers Issue 2) incorporating more environmental goals, understanding the interactions between the physical, chemical, and biological processes in a river becomes critical to successful management. And as the river adjusts to the lock closure and future river management, mussels will serve as indicators of the changes occurring in the river ecosystem.

For more information about freshwater mussels, see:

- http://dnr.state.mn.us/mussels/index.html
- https://www.fws.gov/midwest/mussel/index.html
- http://molluskconservation.org/MC_Ftpage.html

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Footnotes

[1] Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). Funding was awarded to the Minneapolis Riverfront Partnerships and work was completed in partnership with the Mississippi Watershed Management Organization, the Minnesota Department of Natural Resources, and the University of Minnesota's St. Anthony Falls Laboratory and River Life Program.

[2] Funding for this project, "Conserving Minnesota's Native Freshwater Mussells," was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

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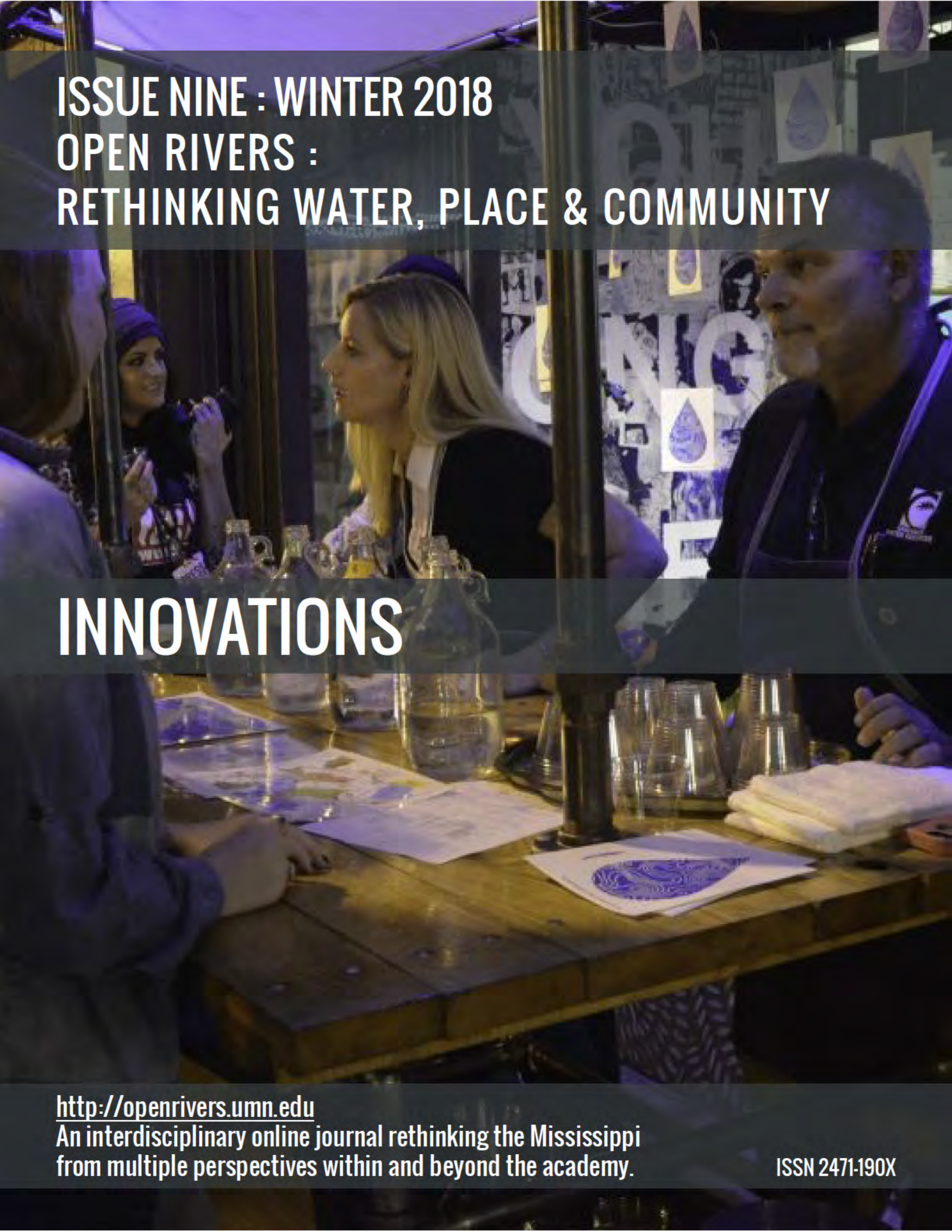
About the Author

Jess Kozarek leads ecogeomorphic research in the Outdoor StreamLab at St. Anthony Falls Laboratory. Jess' research links stream hydraulics to biological processes to develop guidance for stream and river management to protect and restore aquatic ecosystems.



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RETHINKING WATER, PLACE & COMMUNITY

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The cover image is of tending water and listening at Water Bar in Greensboro, North Carolina, courtesy Shanai Matteson, Works Progress, and Water Bar & Public Studio.

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Editorial Board

CONTENTS

TEACHING AND PRACTICE

MOSQUITOES, MUCK, AND MUSSELS: A LOOK INTO SCIENTIFIC RESEARCH

By Lea Davidson, James Doherty, Laura Gould, and Hayley Stutzman

In 2014, the University of Minnesota, Macalester College, and the Minnesota Department of Natural Resources began work on a multi-year study of mussel health in selected Minnesota rivers. The research, funded by the Legislative-Citizens Commission on Minnesota Resources, combined experimental study with field investigation to explore relationships between specific indicators of water quality and biological measures of the health of particular organisms. Mussels are bottom-dwelling filter feeders, and are therefore important "indicator species" of stream water quality. The work described in this article was a significant component of the broader, three year project.

– Patrick Nunnally, Editor

The aspiring young undergraduate scientists envision fieldwork as a romantic escape from the office cubicle, classroom desk, and seemingly endless pile of homework. Working alongside experts in their field, they anticipate working in the wildest regions of the world: dense tropical forests, remote mountain ranges, and distant glacial rivers. They see themselves on the forefront of groundbreaking discoveries: truly shattering the scientific community with a cure for Malaria, discovery of a new species, or theory of planetary evolution. Envisioning numerous publications and grad school offers, becoming leaders in their field and gaining tenure, the

Field work in the Minnesota basin differed from that of the St. Croix. The rivers were murkier and often lined by agricultural land. Image courtesy of Mark Hove.

undergraduate scientists see the ease and simplicity of a straightforward and successful career trajectory.

Spending a hot summer day clothed entirely in neoprene, amid swarms of mosquitoes, wading into the dark, murky brown waters of agricultural rivers, is not what young scientists have in mind when they envision cutting edge research. Though an extreme example, this was one of our many experiences conducting fieldwork throughout the rivers of southwestern Minnesota. As undergraduates at Macalester College, in Saint Paul, Minnesota, we worked alongside professors Dan Hornbach (an ecologist), Kelly Macgregor (a geomorphologist) and Mark Hove (a University of Minnesota and Macalester College biologist), studying the relationship between suspended bed sediment and native freshwater mussel populations. Geographically, our fieldwork spanned the Cottonwood, Le Sueur, and Chippewa Rivers, tributaries in the Minnesota River basin, as well as the Snake River of the St. Croix River basin. Searching for freshwater mussels, we measured mussel growth rings to gather information regarding growth rate and establishment success, while collecting sediment samples to inform our understanding of the composition of the riverbed.

This was hard work. But it was also important work. Monitoring of native freshwater mussel populations provides insight into the health of a river system. Without mussels, streams lose an important source of riverbed stability, because mussels anchor the sediment as they burrow. Mussels also filter the water column, converting suspended particulate matter into biodeposits. Furthermore, the data we collected on the state of mussel populations in these river systems contributed to an ongoing database of the Minnesota DNR.

Outside of Mora, Minnesota, students work together to gather quadrat data in the Snake River. Image courtesy of Mark Hove.

What exactly does a summer in the rivers of rural Minnesota look like? Each week in the field begins with the packing of Big Blue, our trusty transportation to our research sites across the state, with the tools and equipment we had Macgyvered: an inner tube covered in mesh for towing instruments, a net designed for aquatic insect capture reimagined for particulate sediment collection, pieces of pool noodle attached to dive weights to mark quadrat locations. Next we'd drive to a site, often stopping on the way to drop our belongings off at a local hotel, our new home for the next night or two. Upon arrival, we'd wriggle into our neoprene wetsuits, ideally in a windy area where the mosquitoes wouldn't find us, and securely tuck mosquito nets into our necklines as our final form of protection. With equipment in hand, we looked more like astronauts ready to step foot on the moon than undergrads about to go snorkeling for mussels.

A Day in the Field with Laura

The first time going underwater in the Snake River, where we began the summer, was a mix of experiences. For starters, it was breathtaking, both literally and figuratively. Before this summer, I had never snorkeled and had never seen a mussel filtering in a stream bed. The first *Lampsilis cardium* (the species of native mussel species, and honestly could only identify that species if I was lucky. As the summer progressed, allowing for countless opportunities to learn through exposure and from my brilliant professors, the world beneath the river's surface was no longer such a mystery. Despite an identical routine, the experience differed greatly in the

The research team wade their way downstream to their first quadrat point at a site along the Cottonwood River. Image courtesy of Mark Hove.

when they were right in front of our faces. It was the hottest days of summer, the rivers were smellier, and the fish more aggressive. Instead of exploring the underwater world with our snorkels, we pawed the ground blindly trying to feel the difference between rock and mussel. Here, we perfected the two-person digger technique, where in swift currents one member of the team braced themselves against the force of the water while the other used their leg as a guide and anchor to get enough leverage to dig up the sediment. By the time we finished gathering data at any site, we were always ready for a drink and snack to replenish our energy lost from swimming, digging, snorkeling, lugging equipment, and walking in weight belts, all under the summer sun. When we finished our last site of the day, we were itching to get out of our suits, wash off the river water, and fill our growling stomachs. There was nothing romantic about conducting fieldwork in rural Minnesota, yet it was truly an unforgettable and incredible experience. Spending time in ecosystems on the brink further reinforced the importance of conservation.

Crunching the Numbers

Most weeks we didn't spend more than three days in the field, and albeit exhausting, the other two days were spent in the lab at Macalester College. Here, we began the long process of sifting through and digitizing our data, requiring initial long hours using Excel before we could analyze our data in more interesting programs such as JMP and Gradistat.

Field work in the Minnesota basin differed from that of the St. Croix. The rivers were murkier and often lined by agricultural land. Image courtesy of Mark Hove.

Our sediment data required more physical manipulation. After hauling many bags of what appeared to be sand into the lab, we poured the sediment into metal pans to dry in an oven. We initially weighed, then sifted the sediment through sieves of various mesh sizes, before weighing the total amount of sediment collected in each one. This allowed us to understand specifically what sediment grain size was present at each research location, and connect this to our data on mussel density, species, and size at each site.

The main goals of our data analysis was to determine trends in mussel diversity, abundance, and growth in relation to sediment composition across the rivers. Our quadrat data confirmed findings from previous summers that mussel were more dense in the Snake River. This data was further inputted into the Minnesota DNR mussel database for future use in monitoring native freshwater mussel populations in these rivers. The measurements of growth rings and sex taken during our searches for *L. cardium* were used to compare trends in mussel growth rates and maximum growth size across the different rivers. Findings related to bed sediment composition provided representative information on mussel habitat, a factor influencing overall growth and population success.

After digging up everything in the quadrat, the load is lifted out of the water and dumped onto the mesh covered middle of the inner tube. Here, the sediment is thoroughly searched for mussels (live or dead) and shell fragments, and assessed for sediment composition. Image courtesy of Mark Hove.

Looking to the Future

While our work during summer 2017 produced many answers, it simultaneously opened the door to twice as many questions. We learned the “what”—what was happening to mussels, these benthic communities, and in the separate river basins as a whole. But what it left us with were the “whys”—what were the reasons behind these changes in bedform composition? Why were mussels in the Minnesota River basin initially growing more rapidly? And why were we seeing fewer mussels in the entirety of this system? Though our work allowed us to connect some of the dots, it produced more intriguing questions for pursuit. This is one of the main reasons many of us find science so exhilarating; the quest to find the answers never ceases.

The work we do continually sparks our own curiosity. It was exciting to share the interest in the fascinating workings of mussels with the greater public. We often interacted with locals while out in the field, knocking on front doors to ask if we could walk through fields and making conversation with passing fishermen. Many times people were amused to see us decked out in wetsuits, digging in the river, but simultaneously genuinely interested in the “clams” in their own backyards. They, too, are curious, about the details of the environment in which they live, and why these details could be interesting to strangers snorkeling in their river. For many of these communities, environmental issues are close to

Ready for a day in the field, the student researchers stand on the banks of the Snake River. Image courtesy of Mark Hove.

the heart, as their livelihoods centered around either farming or tourism in the form of outdoor recreation. Regardless of environmental protections, the Minnesota and St. Croix River basins have undergone varying levels of environmental alteration over the past century. Engagement with communities affected by change is often overlooked by those in power, but often these opinions and observations are among the most valuable. We not only gained important tips—like which sections of the river to avoid due to swarms of mosquitoes—but also learned about changes these communities have observed from many generations living on the banks of the Minnesota and the St. Croix Rivers.

Funding for this project, "Conserving Minnesota's Native Freshwater Mussels," was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

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About the Authors

Lea Davidson is a senior biology major and geology minor at Macalester College in Saint Paul, Minnesota. Her academic interests lie in human-environmental interaction, specifically via conservation biology and geomorphic processes.

James (Mac) Doherty is a junior geology major and data science minor at Macalester College in Saint Paul, Minnesota. He enjoys being outside, drinking good coffee, and learning about hydrogeologic issues.

Laura Gould is a senior environmental studies and geography double major at Macalester College in St. Paul, Minnesota. She loves learning about ways to better connect people with their environment, specifically through food and agriculture.

Hayley Stutzman is a senior biology major and statistics minor at Macalester College in St. Paul, Minnesota. She is interested in finding creative solutions to environmental problems and likes doing data analysis.