M.L. 2016, Chp. 186, Sec. 2, Subd. 03i Project Abstract
For the Period Ending June 30, 2018

PROJECT TITLE: Enhancing Understanding of Minnesota River Aquatic Ecosystem
PROJECT MANAGER: Tony Sindt
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2016, Chp. 186, Sec. 2, Subd. 03i

APPROPRIATION AMOUNT: $500,000
AMOUNT SPENT: $464,231
AMOUNT REMAINING: $35,769

Overall Project Outcome and Results

Land use practices, climate change, establishment of invasive species, conservation efforts, and other factors continually affect the Minnesota River ecosystem. This project accelerated collection of robust baseline datasets that provide a better understanding of plankton communities, physical habitat characteristics, backwater ecosystems, and sensitive fish species populations. These datasets provide the ability to better predict, measure, and understand future ecosystem changes. Specifically, we established a comprehensive understanding of lower trophic ecology in the Minnesota River by collecting 112 water chemistry, phytoplankton, and zooplankton samples across 7 sites and 16 months. We also quantified habitat features (e.g., longitudinal profiles, bathymetric maps) at 12 reaches along the Minnesota River and characterized fish communities inhabiting 12 unique backwater lakes. Lastly, we captured and tagged 85 Paddlefish and 391 Shovelnose Sturgeon from the Minnesota River providing an understanding of population dynamics (e.g., abundance, growth, recruitment, and mortality), habitat use, and movement patterns of these unique and understudied species. Our enhanced understanding of the Minnesota River ecosystem and information gained during this project will not only inform future monitoring efforts and guide management and restoration efforts, but also provide the critical ability to understand how the Minnesota River ecosystem responds to future changes. For instance, if invasive carps become established in the Minnesota River, we now have the ability to quantify consequent changes in plankton communities, displacement of backwater fish communities, and impacts on the Paddlefish population. Data collected during this project are publicly available for quantitative and qualitative analyses while accompanying in-depth reports for each project activity provide valuable context, interpretation, and comparisons with other aquatic ecosystems.

Project Results Use and Dissemination

Resulting from this project, we developed five comprehensive reports summarizing and analyzing the novel datasets we collected that provide important comparisons with other aquatic systems and discuss implications for future Minnesota River ecosystem monitoring and management (i.e., Activity 1 Final Report—Spatial and temporal trends of Minnesota River phytoplankton and zooplankton, Activity 2 Final Report—Evaluation of Minnesota River physical habitat features, Activity 3 Final Report—Minnesota River backwater fish communities, Activity 4A Final Report—Minnesota River Shovelnose Sturgeon: population dynamics and movement patterns, Activity 4B Final Report—Paddlefish inhabiting the Minnesota River). Condensed versions of the reports associated with activity one (e.g., plankton dynamics) and activity four (e.g., Shovelnose Sturgeon, Paddlefish) will be submitted for publication in open-access peer reviewed scientific journals (e.g., Journal of Fish and Wildlife Management; Journal of Freshwater Ecology). During the project, we provided project updates and preliminary results to scientific audiences at three annual meetings of the Minnesota Chapter of the American Fisheries Society and to members of the public at Hutchinson Area Avid Angler Meetings, Citizen Catfish Workgroup meetings, and a Minnesota River Congress meeting. Ultimately, we intend on providing data, project reports, and project summaries on the Minnesota River Fisheries page of the Minnesota Department of Natural Resources website (Minnesota River Fisheries Page). We are also seeking appropriate venues to present final project results with interested members of the public and other scientific and conservation entities as one of the most valuable outcomes of this project is the collection of novel datasets on important components of the Minnesota River ecosystem.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan Final Report

Date of Report: August 12, 2019

Final Report

Date of Work Plan Approval: June 7, 2016

Project Completion Date: June 30, 2019

PROJECT TITLE: Enhancing Understanding of Minnesota River Aquatic Ecosystem

Project Manager: Tony Sindt

Organization: Minnesota Department of Natural Resources

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Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$500,000**
	Amount Spent:	**$464,231**
	Balance:	**$35,769**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 03i

Appropriation Language:
$500,000 the second year is from the trust fund to the commissioner of natural resources to accelerate collection of baseline data to enhance understanding of the Minnesota River ecosystem, measure future impacts of changing climate and landscapes on the aquatic ecosystem, and guide future management efforts. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Enhancing understanding of the Minnesota River aquatic ecosystem

II. PROJECT STATEMENT:

The ecological health of the Minnesota River is being continually threatened by land conversion, population growth, climate change, and the establishment of aquatic invasive species. These factors likely have consequential impacts on lower trophic organisms (i.e., phytoplankton, zooplankton), physical habitat (e.g., channel dimensions, floodplain connectivity), backwater ecosystems, and sensitive fish species (e.g., Shovelnose Sturgeon, Paddlefish) among many other elements of the Minnesota River system. Additionally, conservation efforts within the Minnesota River watershed may have positive impacts on these elements and overall ecosystem health. Due to limited resources, current data on these elements are insufficient and diminishes the ability to measure change, understand important ecosystem functions, and monitor the ecological health of the Minnesota River. This project will accelerate collection of robust baseline data across all 320 miles of the Minnesota River to A) enhance fundamental understanding of the Minnesota River ecosystem; B) measure future impacts of land conversion, climate change, aquatic invasive species, and conservation efforts; C) inform monitoring of Minnesota River ecological health; and D) guide future management, restoration, and protection efforts. The Minnesota Department of Natural Resources (DNR) will use project funds to hire personnel, purchase supplies, and contract services necessary for accomplishing four specific project activities on the Minnesota River: 1) accelerating collection of baseline lower trophic data, 2) quantifying physical habitat characteristics, 3) inventorying backwater fish communities, and 4) evaluating population dynamics, movement, and habitat use of sensitive fish species. The DNR and other agencies will continue to build on the information gathered as part of this project and will utilize project outcomes to quantify future ecosystem changes and inform future management strategies that will ultimately benefit the ecological health of the Minnesota River.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 16, 2017:

During July 2016, a fisheries specialist and a fisheries technician were hired to accomplish the four project activities outlined in this work plan. Much of the work during the first few months involved familiarizing new personnel with the Minnesota River and project objectives, and selecting suitable survey sites for the four project activities. Above average river discharge during most of August–November limited the amount of field work that could be completed. Yet, as planned, lower trophic samples were collected monthly during August–October; four Minnesota River backwaters were surveyed; and acoustic tags were implanted in 26 Shovelnose Sturgeon and 4 Paddlefish. Sampling protocols and work plans are being developed and refined for all four project activities.

Project Status as of July 16, 2017:

Unfortunately, high water conditions during the first year of this project forced us to alter the sampling schedule and postpone some fieldwork. However, we utilized time efficiently by collecting all scheduled lower trophic and water chemistry samples (including extra sampled collected during April), conducting fish community assessments in five backwater habitats, and implanting acoustic transmitters into 36 Shovelnose Sturgeon and 11 Paddlefish. While high water conditions hampered our ability to conduct habitat surveys or Shovelnose Sturgeon assessments we have allocated extra effort towards sampling Paddlefish and actively tracking acoustic tagged fish.

Project Status as of January 16, 2018:

During summer of 2017, the fisheries specialist hired for this project left for a new job opportunity, and subsequently, the fisheries technician was promoted into the specialist position and a new technician was hired.

Although extended periods of high water continually delay scheduled work, most project activities are being completed on time. All scheduled lower trophic and water chemistry samples have been collected and all samples have been processed, except phytoplankton samples collected during 2017. Eight of 12 backwater fish community surveys and 3 of 12 habitat surveys have been completed. Three additional habitat surveys have been initiated, including creation of several bathymetric maps. During rare periods of low flow, three of five acoustic receivers were installed, and the remaining two will be installed during 2018. Although river conditions have not been conducive for the intensive Shovelnose Sturgeon sampling we planned, a total of 315 Shovelnose Sturgeon and 66 Paddlefish have been captured. Preliminary telemetry data indicate very interesting fish movements. We anticipate accomplishing all project activities prior to June 30, 2019.

Project Status as of July 16, 2018:
Unfortunately, unusually high water during spring and summer of 2018 has again limited our ability to conduct fieldwork associated with this project. Fortunately, the amount of fieldwork remaining will be very manageable once water levels recede to safe conditions. During May of 2018 the fisheries specialist hired for this project left for a permanent job opportunity and we are currently working towards filling the vacancy.

Despite these challenges, we have completed all scheduled water and plankton sample collections, completed two backwater fish community assessments, and made progress towards completing the remaining 9 habitat surveys during spring of 2018. Even during high water conditions, we were able to track acoustic tagged fish at all study sites and at additional sites downstream of Granite Falls Dam.

During the remainder of 2018 we will complete the remaining four water and plankton sample collections, three backwater assessments, 9 habitat surveys, and fall Shovelnose Sturgeon sampling. Additionally, we will continue tracking and monitoring movements of acoustic tagged Shovelnose Sturgeon and Paddlefish.

Amendment Request (07/06/2018)
We are requesting an amendment to the project budget due to greater than anticipated personnel and water chemistry analysis costs along with some lower than anticipated service, equipment, capital expense, and travel costs. We are requesting an amendment that allocates $21,966 more of the project funds for personnel (wages and benefits) in Activity 4 and $2,000 more of the project funds for the Minnesota Department of Agriculture (water chemistry analyses) service contract in Activity 1. Specifically allocating project funds away from phytoplankton analyses (-$13,104), zooplankton analyses (-$4,136), Activity 1 equipment (-$4,500), Activity 1 fleet (-$2,000), and Activity 4 capital expenditures (-$226).
Amendment Approved: [**07/26/2018**]

Project Status as of January 16, 2019:
During August 2018, project technician Michael Vaske was promoted into the specialist position and Kayla Stampfle was hired as the project technician. Kayala's last day was December 18th while Michael will remain in the specialist position for the remainder of the project (thru June 30th, 2019).

Most field work has been completed for this project, including: collection of water quality, phytoplankton, and zooplankton samples from seven sites across 16 months; quantifying physical habitat at 9 of 12 habitat sites; conducting fisheries assessments in 12 Minnesota River backwater habitats; assessing habitat use and movement patterns of 14 acoustic tagged Paddlefish and 36 acoustic tagged Shovelnose Sturgeon; and evaluation population dynamics of Shovelnose Sturgeon. Remaining fieldwork that will be completed during spring 2019 includes finishing habitat surveys at 3 sites and uploading telemetry data from the array of stationary acoustic receivers.

During the remainder of the project we will compile, analyze, summarize, and interpret collected data. We will create comprehensive final reports for each project activity and anticipate submitting manuscripts to peer-reviewed journals based on outcomes from project activities one and four. For now, we will refrain from making conclusive statements until all data are compiled and appropriately analyzed and interpreted.

Overall Project Outcomes and Results:

Land use practices, climate change, establishment of invasive species, conservation efforts, and other factors continually affect the Minnesota River ecosystem. This project accelerated collection of robust baseline datasets that provide a better understanding of plankton communities, physical habitat characteristics, backwater ecosystems, and sensitive fish species populations. These datasets provide the ability to better predict, measure, and understand future ecosystem changes. Specifically, we established a comprehensive understanding of lower trophic ecology in the Minnesota River by collecting 112 water chemistry, phytoplankton, and zooplankton samples across 7 sites and 16 months. We also quantified habitat features (e.g., longitudinal profiles, bathymetric maps) at 12 reaches along the Minnesota River and characterized fish communities inhabiting 12 unique backwater lakes. Lastly, we captured and tagged 85 Paddlefish and 391 Shovelnose Sturgeon from the Minnesota River providing an understanding of population dynamics (e.g., abundance, growth, recruitment, and mortality), habitat use, and movement patterns of these unique and understudied species. Our enhanced understanding of the Minnesota River ecosystem and information gained during this project will not only inform future monitoring efforts and guide management and restoration efforts, but also provide the critical ability to understand how the Minnesota River ecosystem responds to future changes. For instance, if invasive carps become established in the Minnesota River, we now have the ability to quantify consequent changes in plankton communities, displacement of backwater fish communities, and impacts on the Paddlefish population. Data collected during this project are publicly available for quantitative and qualitative analyses while accompanying in-depth reports for each project activity provide valuable context, interpretation, and comparisons with other aquatic ecosystems.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Accelerate collection of baseline Minnesota River lower trophic data

Description:

Lower trophic organisms (i.e., phytoplankton, zooplankton) are an important component of aquatic ecosystems. As primary producers, phytoplankton are the base of the aquatic food chain and are an important food source for zooplankton and other aquatic organisms. In turn, zooplankton are an important food source for many larger aquatic organisms including nearly all fish species. Abundance, composition, and timing of phytoplankton and zooplankton communities can have major impacts on aquatic ecosystems and can greatly influence survival, growth, and recruitment of fishes. Both phytoplankton and zooplankton communities are extremely sensitive to environmental change and are influenced by a variety of physical and biological factors including temperature, hydrology, turbidity, nutrients, competition, and predation. Thus, climate change, eutrophication, altered hydrology, and invasive species can have major impacts on lower trophic ecology, and consequently aquatic ecosystems.

Phytoplankton and zooplankton community dynamics have been extensively studied in lakes and oceans, but considerably less is known about lower trophic ecology in riverine systems such as the Minnesota River. Many native Minnesota River fishes including Bigmouth Buffalo *Ictiobus cyprinellus*, Emerald Shiner *Notropis atherinoides*, Gizzard Shad *Dorosoma depedianum*, and Paddlefish *Polydon spathula* rely on zooplankton as a primary food source. Unfortunately, limited knowledge and data restrict the ability to predict or quantify how changes in land use, climate, and hydrology within the Minnesota River basin affect the lower trophic ecology of the Minnesota River. The threat of invasive carps *Hypophthalmichthys spp.* and Zebra Mussel *Dreissena polymorpha* expansion into the Minnesota River is of further concern as they would have predatory impacts on plankton communities and consequently competitive impacts on native organisms such as Paddlefish and freshwater mussel species. For example, research conducted on the Illinois River showed that although zooplankton densities haven't been significantly impacted by the establishment of invasive carps, the zooplankton community has shifted towards smaller species (rotifers) resulting in a significant zooplankton biomass decline.

For this project activity, we will quantify spatial and temporal trends in Minnesota River phytoplankton and zooplankton communities and identify relationships between plankton communities and water chemistry parameters. Specifically, seven sites representing the spatial complexity of the Minnesota River will be selected and monthly phytoplankton, zooplankton, and water samples will be collected July–October 2016, May–October 2017, and May–October 2018. This results in a total of 112 sample collection events. Phytoplankton, zooplankton, and water samples will be collected using standard methodologies. Water samples will be processed and analyzed by the Minnesota Department of Agriculture. Phytoplankton samples will be processed and analyzed by contracted laboratories. Zooplankton samples will be processed and analyzed by DNR staff (Jodie Hirsch, Aquatic Biologist) but two additional replicate samples will be performed each month and sent to a contracted laboratory for analyses including biovolume measurements. Phytoplankton and zooplankton samples will be analyzed for taxa composition, density, and biovolume or biomass. Water samples will be analyzed for a suite of parameters including but not limited to total phosphorous, total Kjeldahl nitrogen, nitrite + nitrate, chlorophyll a, total suspended solids, total dissolved solids, ammonia-nitrogen, and silica.

Results of this project activity will establish a baseline understanding of Minnesota River phytoplankton and zooplankton communities. This knowledge will increase understanding of the Minnesota River ecosystem, and provide the ability to predict responses to various physical (e.g., hydrology), chemical (e.g., nutrients), and biological (e.g., invasive species) stressors. Additionally, continued monitoring efforts will be able to quantify changes to Minnesota River phytoplankton and zooplankton communities as they respond to an ever changing environment.

Activity 1 Timeline:

- <u>Prior to July 2016</u>: Seven study sites will be selected and contract bids will be solicited.
- <u>July 2016–October 2018</u>: Monthly phytoplankton, zooplankton, and water samples will be collected from study sites (May–October) and sent to contracted laboratories for analyses.
- <u>October 2018–June 2019</u>: Minnesota River lower trophic data will be summarized and analyzed. A final report for project activity 1 will be completed by July 2019.

Summary Budget Information for Activity 1:		
	Revised Budget:	**$ 145,698**
	Amount Spent:	**$ 132,365**
	Balance:	**$ 13,333**

Outcome	**Completion Date**
1. Quantify spatial and temporal variability of Minnesota River phytoplankton communities (7 sites, 16 months)	06-30-2019
2. Quantify spatial and temporal variability of Minnesota River zooplankton communities (7 sites, 16 months)	06-30-2019
3. Identify relationships between Minnesota River phytoplankton and zooplankton communities with water chemistry parameters	06-30-2019

Activity Status as of January 16, 2017:

Seven study sites were selected along the length of the Minnesota River where boat access was available, depth was adequate for sampling, and where it was presumed that adequate mixing of water would provide representative samples. From upstream to downstream, these sites include near Montevideo, downstream of Granite Falls, Brickyard Aquatic Management Area near Morton, Downstream of New Ulm, St. Peter, Chaska, and at the Interstate 35W bridge in Bloomington.

Samples were collected in August, September, and October during 2016. Immediately following sample collection, water samples were delivered to the Minnesota Department of Agriculture laboratory for water chemistry analyses and zooplankton samples were delivered to Jodie Hirsch at MN DNR Central Office for processing. Following the October sample collection, phytoplankton and replicate zooplankton samples were sent to BSA Environmental Services, Inc. in Beachwood, Ohio. Samples were not collected during July since some of the necessary sampling equipment was on backorder until August.

Activity Status as of July 16, 2017:
Water chemistry, phytoplankton, and zooplankton samples were collected from study sites during April, May, and June of 2017. Samples will also be collected monthly during July–October of 2017 and May–October of 2018. Results from previously collected samples are being compiled and preliminary analyses will be available during winter 2017–2018. One noteworthy discovery is the presence of Zebra Mussel veligers in zooplankton samples collected both upstream and downstream of Granite Falls Dam. In general, zooplankton densities have been low, but greatest at upstream sites.

Activity Status as of January 16, 2018:
Water chemistry, phytoplankton and zooplankton samples were collected at all seven study sites during July, August, September, and October of 2017 (Map 1). Immediately following sample collection, water samples were delivered to the Minnesota Department of Agriculture laboratory for water chemistry analyses and zooplankton samples were delivered to Jodie Hirsch at MN DNR Central Office for processing. Phytoplankton and replicate zooplankton samples collected during 2017 were shipped to BSA environmental and results are pending.

Preliminary analyses of 2016 and 2017 crustacean zooplankton data indicate generally low densities of zooplankton in the Minnesota River varying 0.0–144.0/liter, with the greatest densities occurring at upstream sites (Figure 1; Figure 2). Total crustacean zooplankton densities were greatest during August of 2016 (mean = 25.5/liter) and peaks in zooplankton densities were also observed at some sites during May–June and September–October of 2017. Greater zooplankton densities observed during September and October corresponded with heavy rain events that may have brought an influx of plankton and nutrients from backwaters, tributaries, and surface run-off.

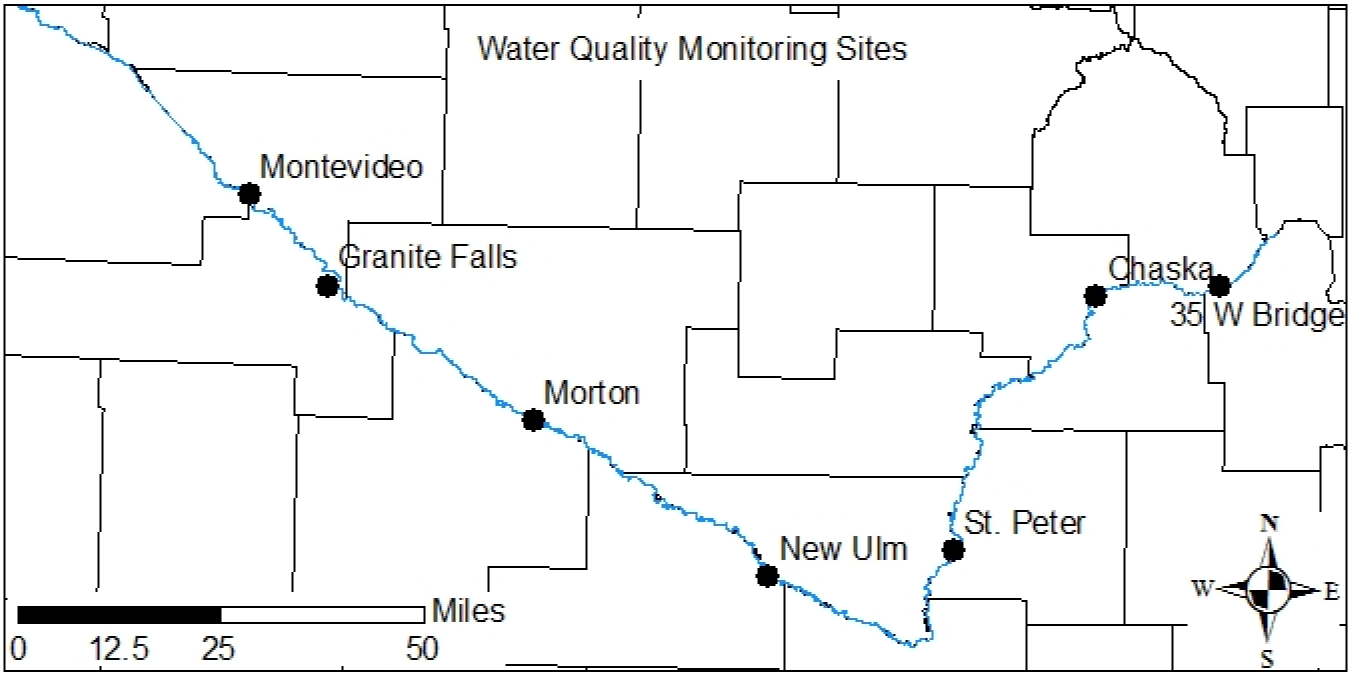
Unlike crustacean zooplankton, total rotifer densities were generally similar across all sample sites and sample periods varying 6.3–1,684.2/liter. Rotifer densities were also generally similar among years (2016 and 2017) with the exception of a large increase in densities observed across all sites during May of 2017 (Figure 3; Figure 4). Although rotifer densities were similar among sites, species composition differs between upstream (Montevideo, Granite Falls, Morton) and downstream sites (Chaska, I 35W Bridge). The most abundant rotifer genera across all sites was *Keratella spp.,* which accounted for a majority of rotifers sampled during 2017.

Zooplankton samples were also examined for Zebra Mussel veligers, which were found in samples from all sites, but not all sample events (Figure 5). Veliger counts were greatest at upstream reaches (Montevideo, Granite Falls, Morton) during spring and early summer months. We hypothesize that populations of adult Zebra Mussels upstream of Granite Falls Dam (e.g., Lac qui Parle) are the source of veligers found in the river. This hypothesis is supported by site-specific veliger counts and the corresponding hydrographs (Figure 6).

Preliminary analyses of water chemistry data will occur this winter. Some results have been summarized, including spatial and temporal trends in nitrate/nitrite and total phosphorus. Nitrogen and phosphorus are essential nutrients for plant growth, with phosphorus often the most limiting nutrient in fresh water systems. Nitrate/nitrite and total phosphorus concentrations varied among sample sites, but in general, both were greatest at downstream sites during both years. Nitrate/nitrite concentrations were greatest during September of 2016 (mean = 9.2 mg/L) and peaks in concentrations were observed during June and October of 2017 (Figure

7; Figure 8). Total Phosphorus concentrations declined from August to October during 2016 and were more variable during 2017 with increased concentrations observed at Montevideo, Granite Falls, Morton, and Chaska during July and August.

Lower trophic samples will be collected again at all seven sites during May–October of 2018. Future analyses will focus on identifying relationships between water chemistry parameters, hydrographs, and zooplankton and phytoplankton communities. Additionally, we will compare Minnesota River plankton communities with those reported for other large rivers, and discuss potential implications of establishment of Invasive Carps and Zebra Mussels.



Map 1. Minnesota River lower trophic and water quality sample sites.

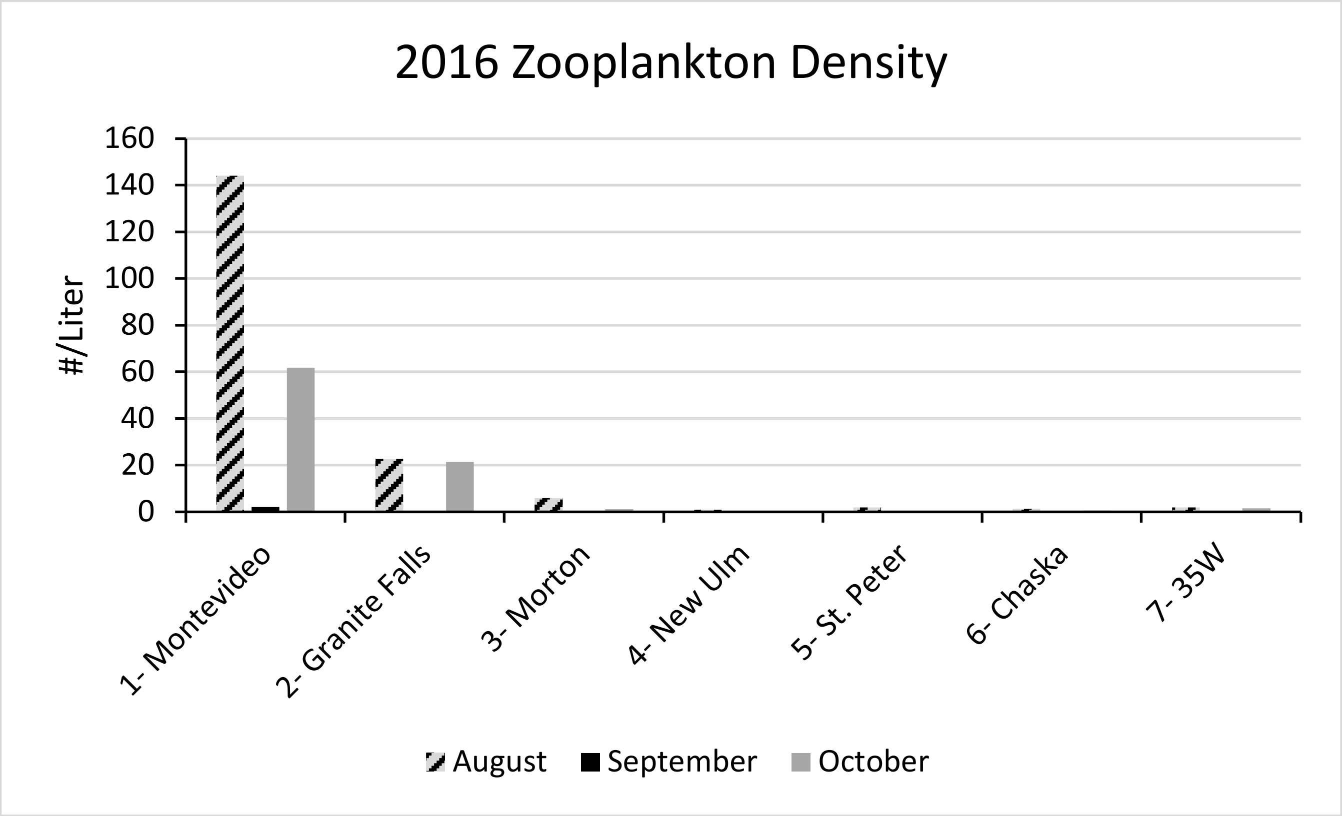


Figure 1. Monthly Minnesota River zooplankton densities at seven sample sites during 2016.

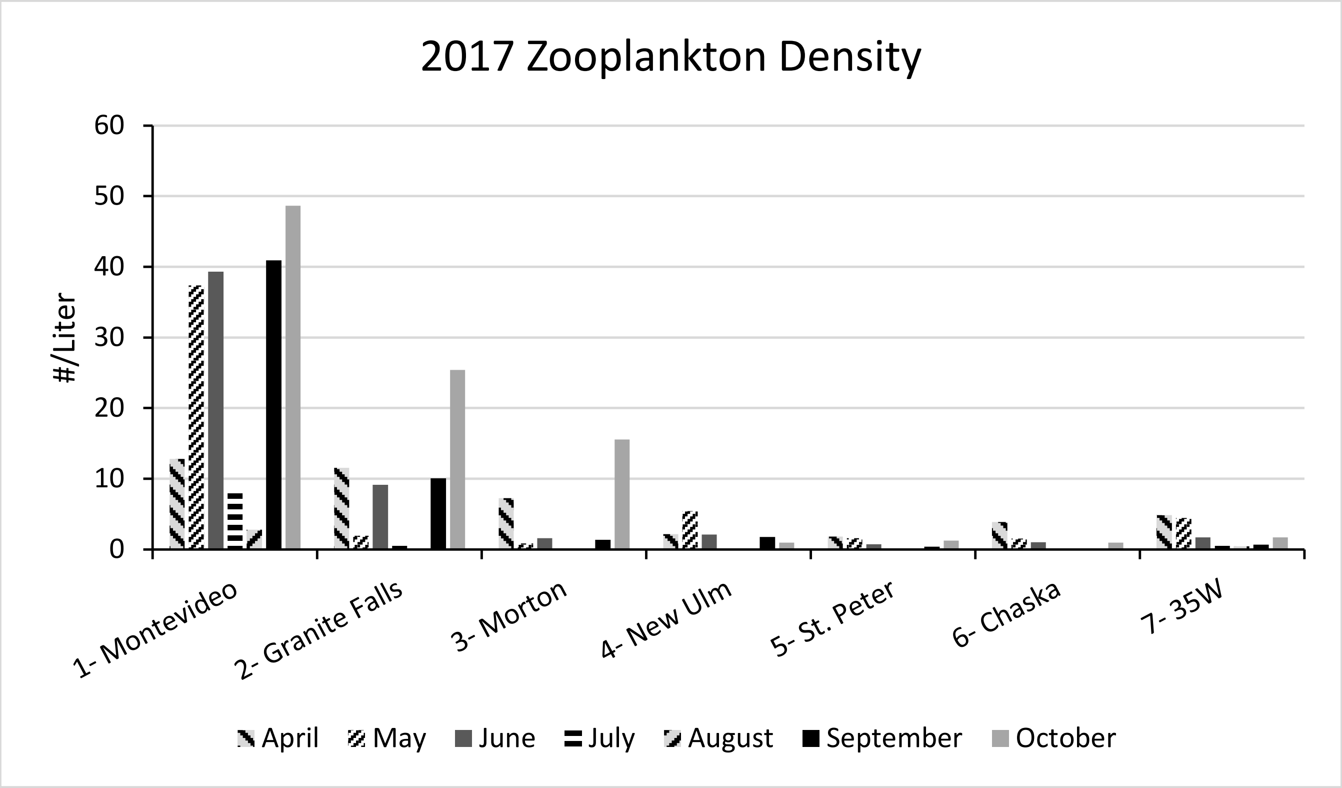


Figure 2. Monthly Minnesota River zooplankton densities at seven sample sites during 2017.

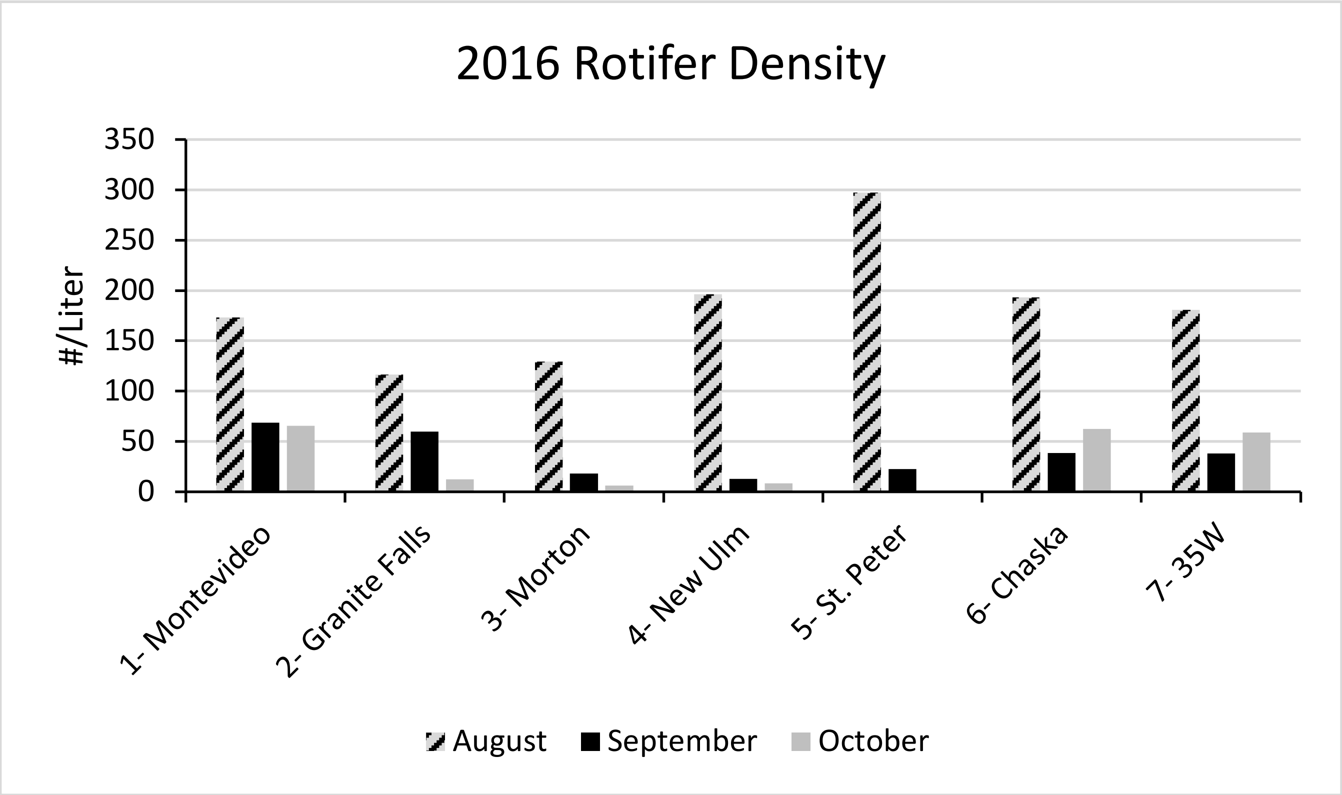


Figure 3. Monthly Minnesota River rotifer densities at seven sample sites during 2016.

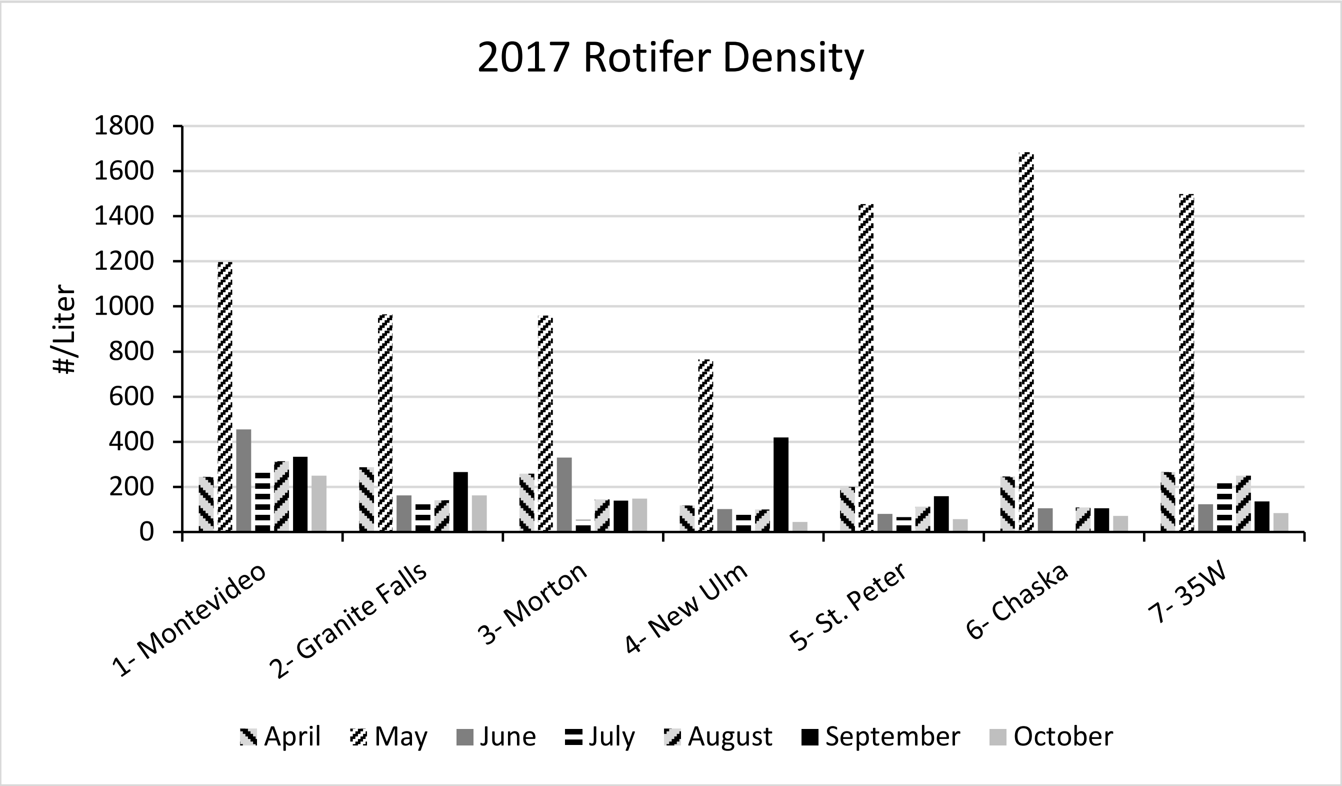


Figure 4. Monthly Minnesota River rotifer density at seven sample sites during 2017.

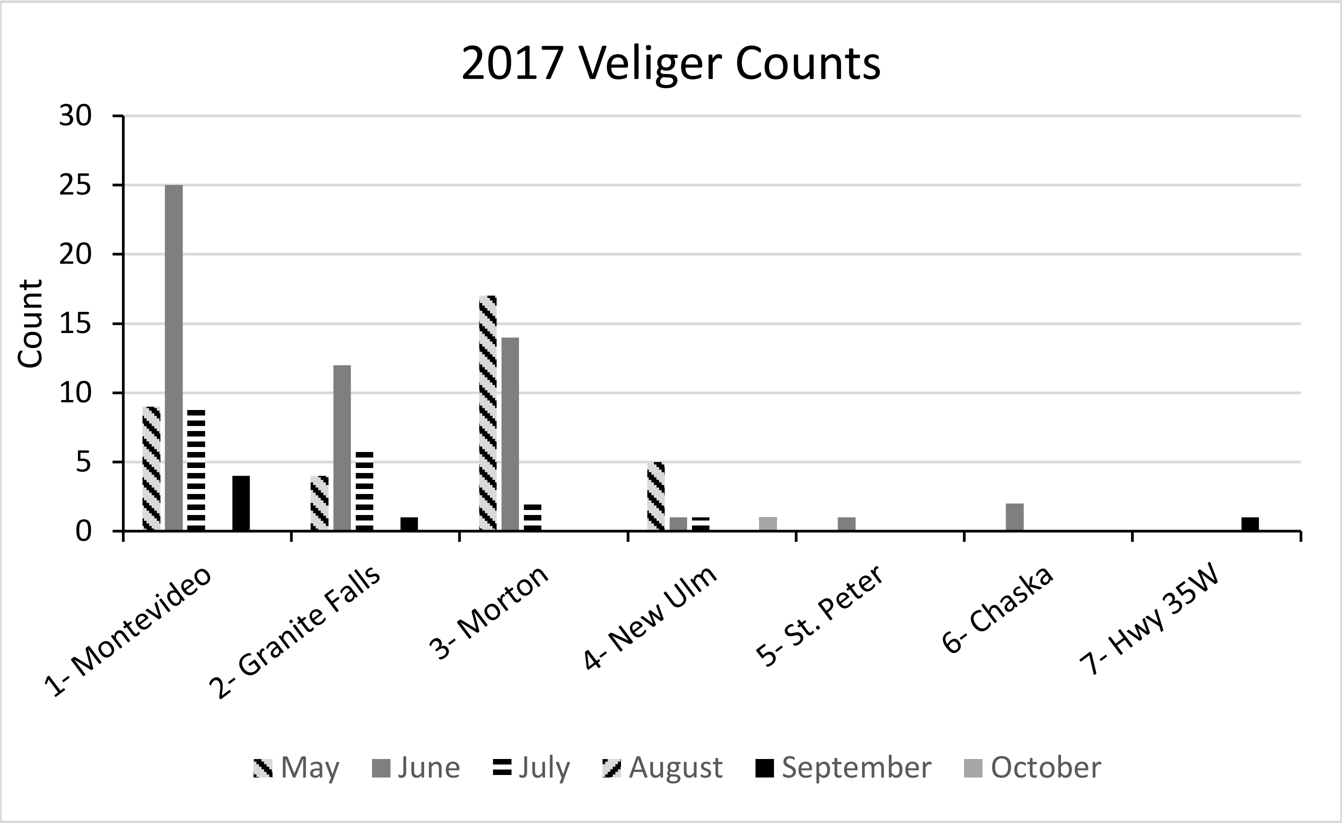


Figure 5. Monthly Minnesota River Zebra Mussel veliger counts from seven sample site during 2017.

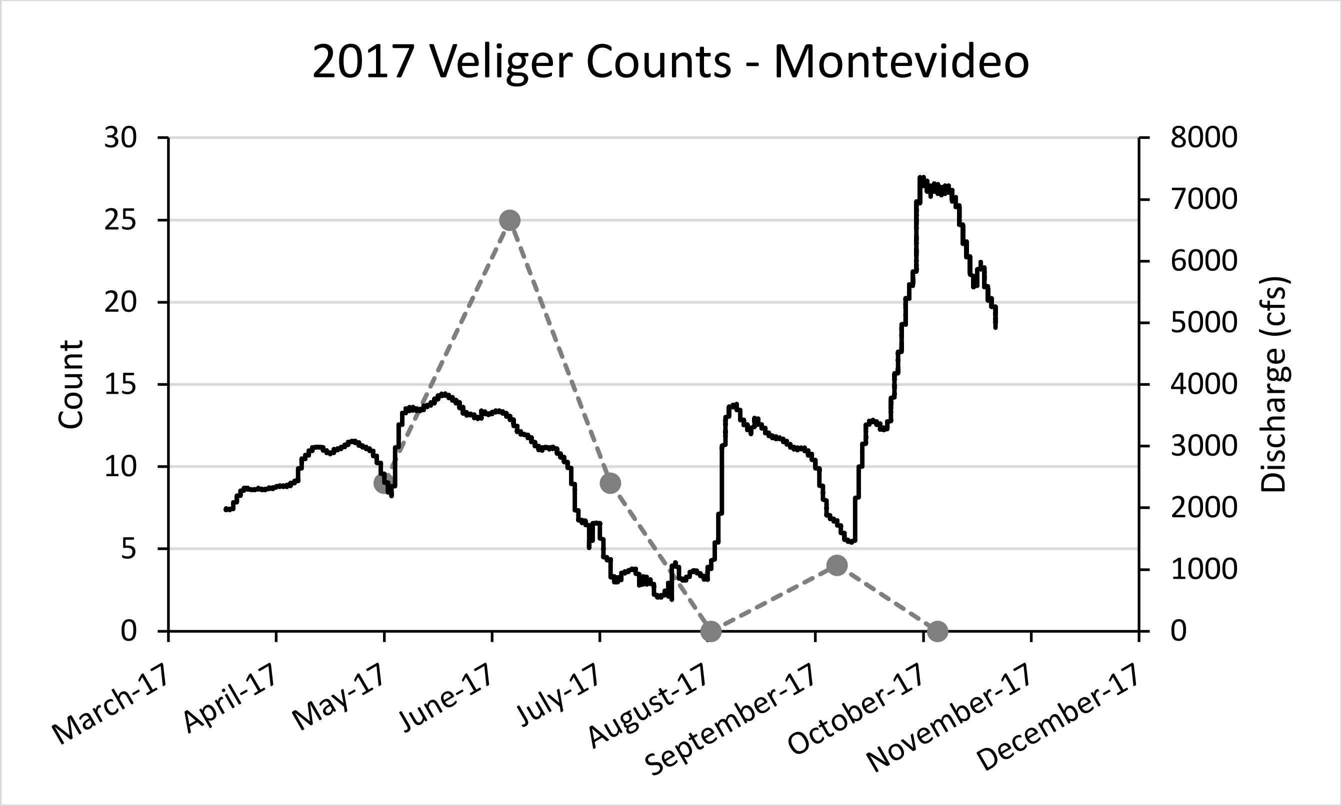


Figure 6. Minnesota River Zebra Mussel veliger counts and river discharge during 2017 at Montevideo, MN.

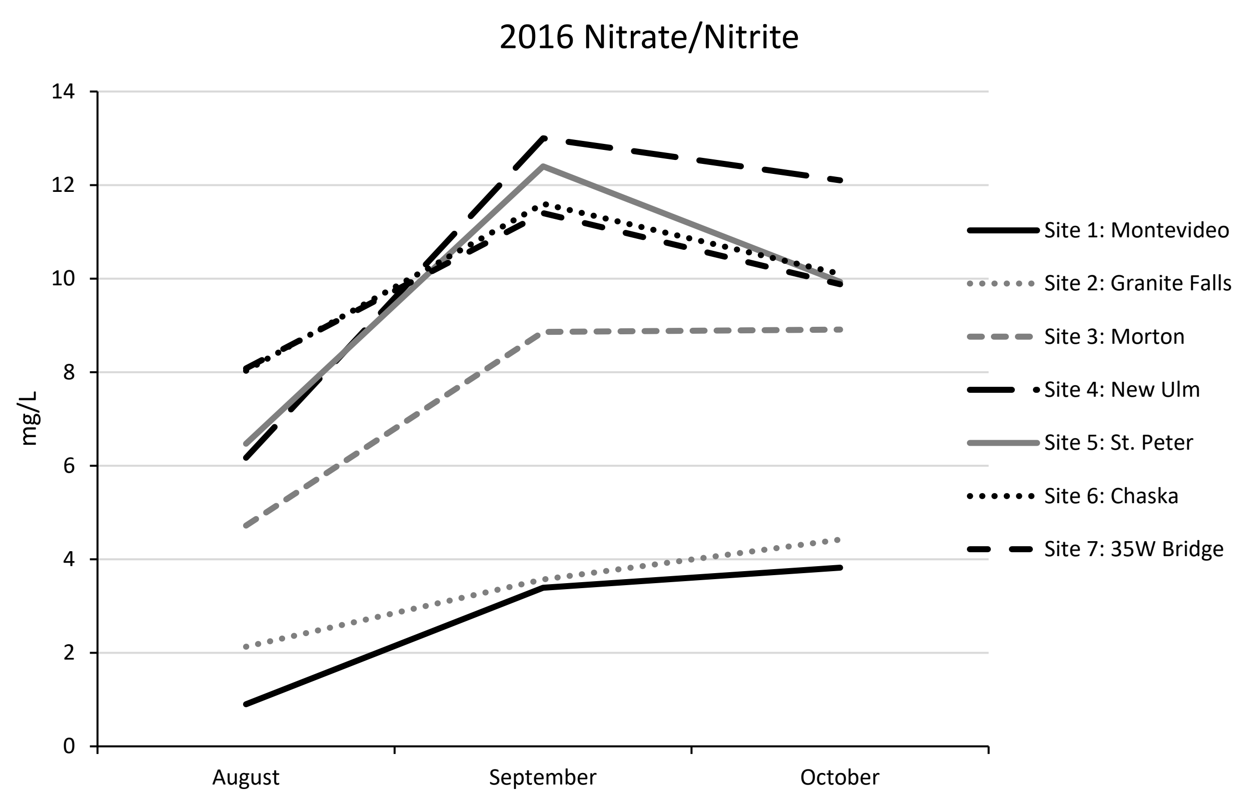


Figure 7. Monthly Nitrate/Nitrite concentrations at seven Minnesota River sample sites during 2016.

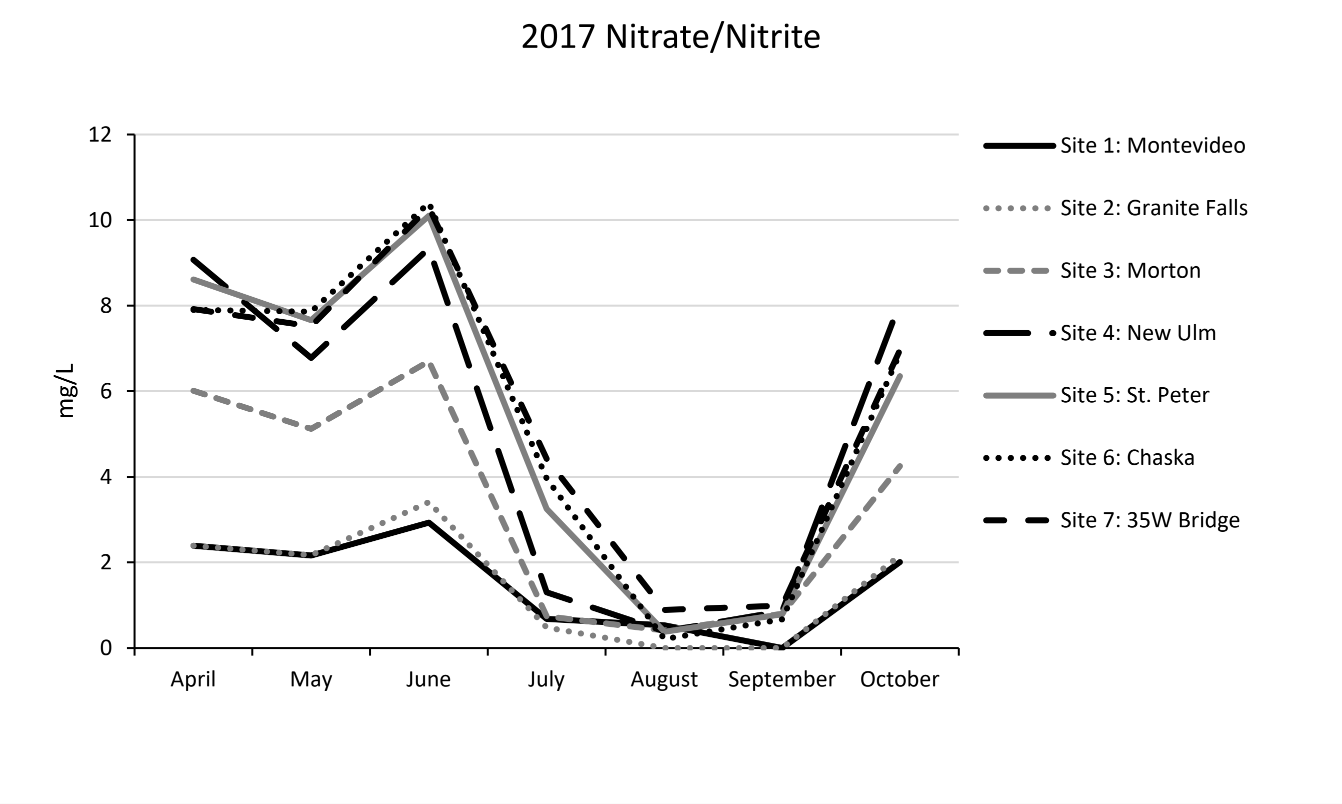


Figure 8. Monthly nitrate/nitrite concentrations at seven Minnesota River sample sites during 2017.

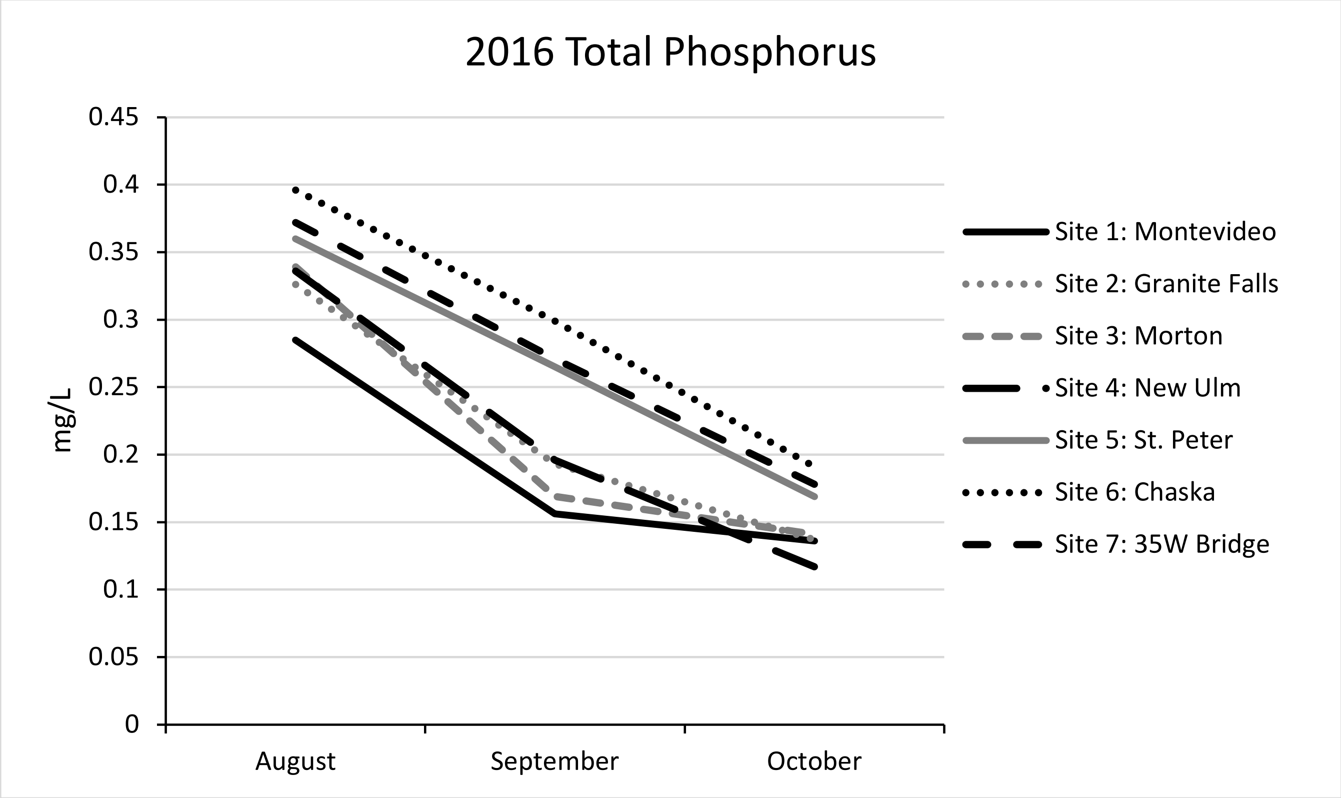


Figure 9. Monthly Total Phosphorous concentrations at seven Minnesota River sample sites during 2016.

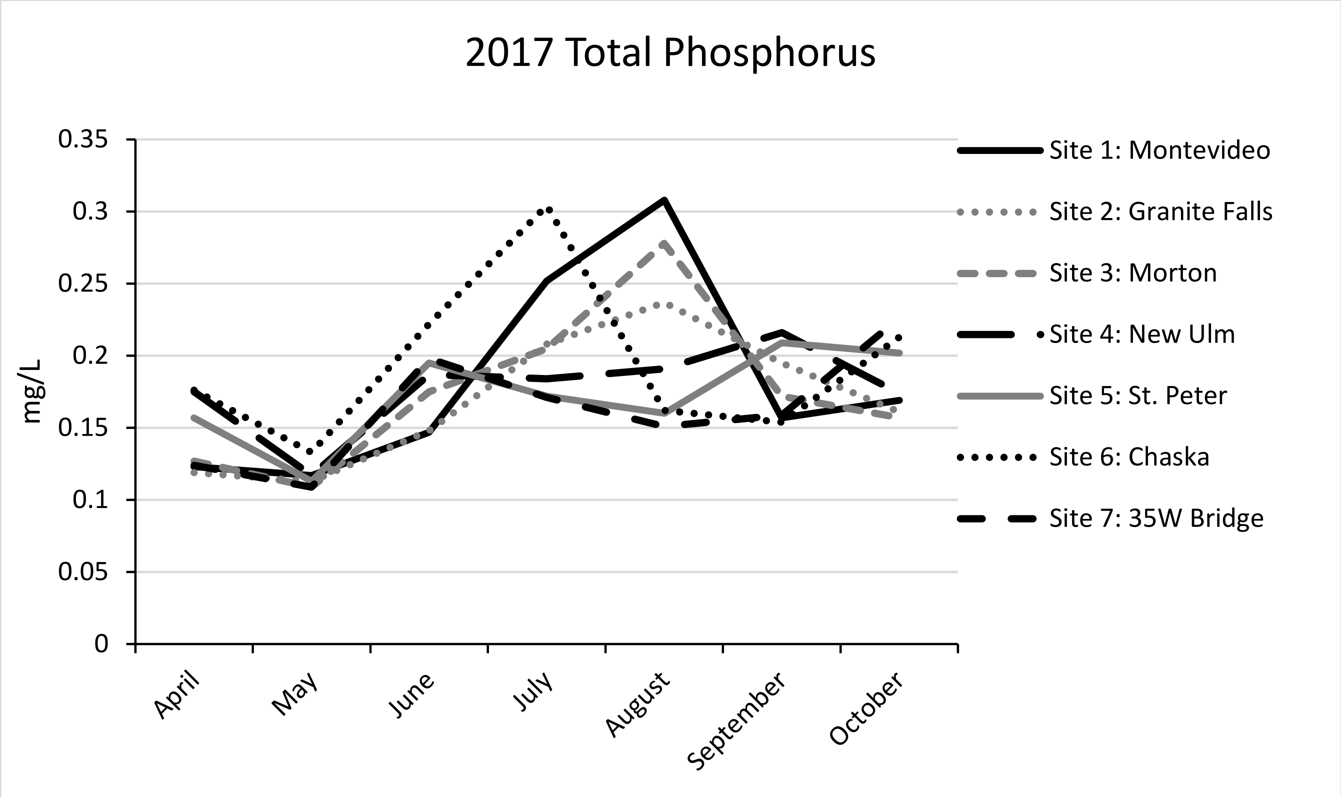


Figure 10. Monthly Total Phosphorous concentrations at seven Minnesota River sample sites during 2017.

Activity Status as of July 16, 2018:
Water chemistry, phytoplankton, and zooplankton samples were collected from study sites during May and June of 2018. Samples will also be collected monthly during July–October of 2018. Immediately following sample collection, water samples are delivered to the Minnesota Department of Agriculture laboratory for water chemistry analyses and zooplankton samples are delivered to Jodie Hirsch at MN DNR Central Office for processing. Phytoplankton and replicate zooplankton samples collected during 2018 will be shipped to BSA environmental. As they are received, data will be compiled and preliminary analyses of 2018 sample collections will be available during winter 2018–2019. All data will be analyzed during winter 2018-2019 and a final report will be completed by spring 2019.

Activity Status as of January 16, 2019:
The final round of water chemistry, phytoplankton, and zooplankton samples were collected from all seven study sites during July, August, September, and October of 2018. Immediately following sample collection, water samples were delivered to the Minnesota Department of Agriculture laboratory for water chemistry analyses and zooplankton samples were delivered to Jodie Hirsch at MN DNR Central Office for processing. All phytoplankton and replicate zooplankton samples collected during 2018 were shipped to BSA environmental for processing. Zooplankton samples were also evaluated for presence of Zebra Mussel veligers. We are currently waiting to receive the remaining data for 2018 samples. Once all data are received, we will finalize data analyses, complete the final activity report, and develop a manuscript that will be submitted to a peer reviewed journal.

Activity highlights

- Establishing baseline understanding of spatial and temporal trends in Minnesota River phytoplankton and zooplankton communities.
- Collected data will be used to identify relationships between abiotic factors, water chemistry, phytoplankton communities, and zooplankton communities.
- Project outcomes provide the ability to identify lower trophic responses resulting from future invasive species, climate change, and land-use changes.

Final Report Summary:
We accomplished all Activity 1 objectives.

Summary—
Phytoplankton and zooplankton communities play important roles in aquatic ecosystems, but are poorly studied in lotic systems such as the Minnesota River. We collected > 100 water chemistry, phytoplankton, and zooplankton samples from seven locations along the Minnesota River during April–October 2016–2018 to establish a baseline understanding of phytoplankton and zooplankton communities, with emphasis on quantifying spatial and temporal trends and identifying relationships between plankton communities and environmental parameters (e.g., water chemistry, discharge). As hypothesized, phytoplankton and zooplankton communities were diverse and significantly differed among both months (i.e., temporally) and sites (i.e., spatially). Blue-green algae and diatoms dominate Minnesota River phytoplankton communities and we observed annual peaks in blue-green algae biovolume during July–October and diatom biovolume during both spring and fall. The presence of dams strongly influenced zooplankton communities with the greatest biomass of crustacean zooplankton at sites downstream of dams while rotifers dominated zooplankton assemblages at sites within the free-flowing reaches. Excluding the influence of dams, the most important factors influencing plankton communities are likely seasonal phenology and temporal variability in river discharge. Water chemistry parameters had insignificant or weak relationships with plankton community dynamics. Invasive species, climate change, and land-use alteration are hypothesized to influence the lower trophic ecology of the

Minnesota River, and because of baseline datasets collected during this study, we now have the ability to quantify and understand future changes resulting from these and other perturbations.

Significant Outcomes—

- Minnesota River phytoplankton biovolume and zooplankton biomass significantly differs among months (temporally) and river kilometers (spatially).
    - Total zooplankton biomass and crustacean zooplankton biomass is greater at upstream sites than downstream sites.
    - We observed peak phytoplankton biovolume during July–October, primarily influenced by abundant blue-green algae.
    - We observed the greatest peaks in rotifer and copepod biomass during May and in daphnid biomass during October.
- Combining months and sites, mean phytoplankton biovolume was 20.4 mm^3 l^{-1}, mean cladoceran biomass was 26.4 µg l^{-1}, mean copepod biomass (excluding nauplii and copepodites) was 17.1 µg l^{-1}, and mean rotifer biomass was 6.1 µg l^{-1}.
- The Minnesota River has diverse plankton communities similar to other large Midwestern rivers.
    - 73 phytoplankton genera, 22 crustacean zooplankton genera, 24 rotifer genera.
    - Blue-green algae are the most abundant phytoplankton, including the *Aphanizomenon* and *Merismopedia* genera.
    - *Keratella spp*. are the most abundant rotifers.
- The occurrence of dams and impoundments has a significant influence on Minnesota River zooplankton communities.
    - Total zooplankton biomass is greatest at sites downstream of dams (mean biomass of 142.6 µg l^{-1} and mean density of 241.7 l^{-1} at river kilometers 424 and 385) where crustacean zooplankton are typically > 80% of the total zooplankton biomass.
    - At sites within the lower free-flowing reach of the Minnesota River (downstream of river kilometer 315), total zooplankton biomass is much lower (mean of 10.8 µg l^{-1} with mean density of 208.5 l^{-1}) and rotifers are typically > 60 % of the biomass.
    - Mean crustacean zooplankton density and biomass is 18.6 individuals l^{-1} and 135.6 µg l^{-1} at the two upstream sites and 0.9 individuals l^{-1} and 5.2 µg l^{-1} at the five downstream sites.
- Overall, spatial variability in plankton communities is strongly influenced by the occurrence of dams, but plankton communities also significantly differ among months which is likely driven by phenology and temporal variability in discharge.
    - Excluding the influence of dams, plankton communities do not significantly differ spatially within the lower free-flowing reach of the Minnesota River.
- Relationships between other abiotic factors (e.g., water temperature, total suspended solids) and plankton communities were generally weak or insignificant.
- Zooplankton communities in the lower-free flowing reach of the Minnesota River are similar to zooplankton communities described from the lower Missouri River, the lower Illinois River, and other turbid prairie rivers.
- Zooplankton communities in the upstream reaches, downstream of dams, are similar to those reported from the Mississippi River above and within Lake Pepin and from the Ohio River.

Resulting Hypotheses—

- Establishment of invasive carps in the Minnesota River will likely shift zooplankton communities towards smaller species within reaches and habitats where crustacean zooplankton are abundant (i.e., rotifers).
    - A shift in zooplankton communities and competitive interactions with invasive carps may lead to declines in abundance and conditions of native planktivores (e.g., Bigmouth Buffalo).
- Increased flows resulting from changes in climate and land use will likely increase durations of reduced main channel phytoplankton biovolume.

- Increased flows are also likely to favor small bodied rotifers rather than large bodied crustacean zooplankton within the main channel of the Minnesota River.
- Natural impoundments may provide an important source of crustacean zooplankton for Minnesota River fishes.
- Plankton production within the Minnesota River floodplain is likely important to the overall dynamics of the Minnesota River ecosystem, providing important forage for higher trophic levels (e.g., fish).
- Natural flow regimes, including natural flood-pulses that connect the main channel with complex floodplain habitats, will facilitate the greatest species diversity and ecosystem health.

See attached report “Spatial and temporal trends of Minnesota River phytoplankton and zooplankton” for thorough analyses, explanation, and discussion. The attached report also includes associated tables, figures, and supplemental figures. Novel datasets collected for this project are also provided as attachments.

ACTIVITY 2: Quantify physical habitat characteristics of the Minnesota River
Description:
Physical habitat characteristics of the Minnesota River have a direct influence on aquatic organisms from phytoplankton to fish. For example, most fish species require specific habitat features (e.g., depth, substrate, current velocity, aquatic macrophytes) for successful spawning. Rivers are a dynamic landscape feature strongly influenced by watershed characteristics, climate, and underlying geology. Establishing baseline habitat data is important for understanding how changes in land use and climate impact the physical features of the Minnesota River. Furthermore, since habitat features greatly influence aquatic organisms and communities, monitoring changes in habitat features will inform how and why aquatic ecosystems respond.

For this project, we will establish at least 12 fixed sites where channel dimensions and physical habitat characteristics will be quantified within the Minnesota River. Specifically, at each fixed site, cross sections will be established where depth profiles and channel dimensions will be measured. Additionally, various physical habitat characteristics (e.g., substrate, woody cover, riparian vegetation, bathymetry, etc.) will be quantified within 1km study reaches. Protocols developed as part of this project activity will be used to monitor physical habitat changes in the Minnesota River over time.

Activity 2 Timeline:

- Winter and spring 2016: Fixed habitat study sites will be identified and habitat survey protocols will be developed.
- Summer and fall 2016, 2017, and 2018: Habitat surveys will be completed at ≥12 fixed sites.
- Winter 2018—Spring 2019: Data will be summarized and the final report for project activity 2 will be completed by July 2019.

Summary Budget Information for Activity 2:		
	ENRTF Budget:	**$ 98,437**
	Amount Spent:	**$ 81,545**
	Balance:	**$ 16,892**

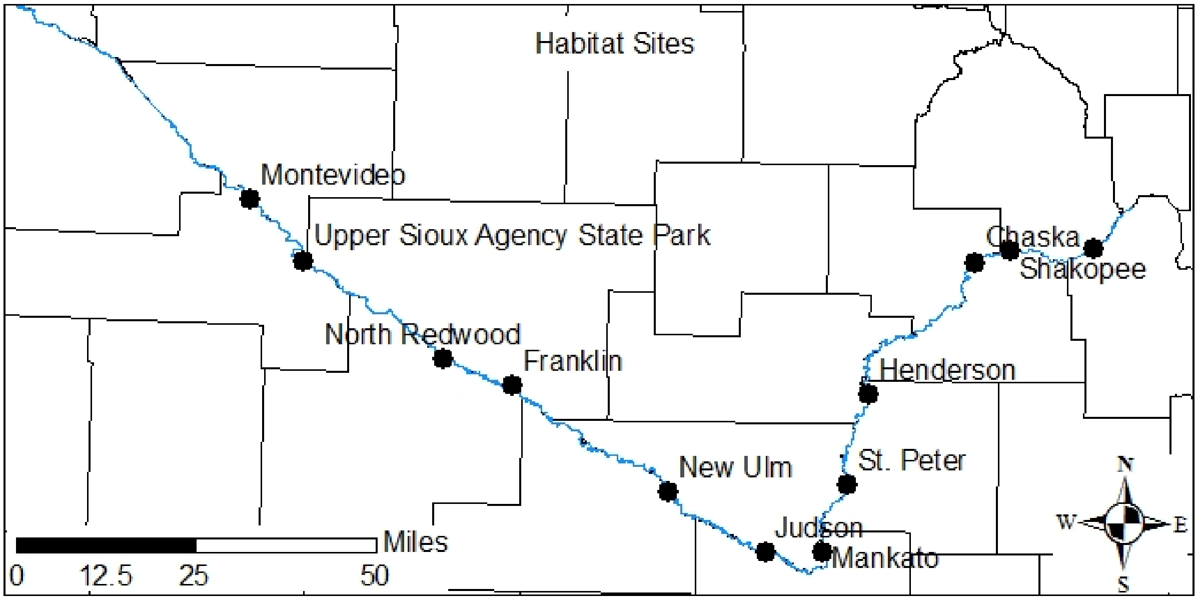
Outcome	**Completion Date**
1. Quantify channel dimensions at ≥12 locations along the Minnesota River	06-30-2019
2. Quantify habitat characteristics for ≥12 1km reaches along the Minnesota River	06-30-2019

Activity Status as of January 16, 2017:
Habitat surveys were not completed during 2016. However, a stream restoration workshop was attended to further refine the skills necessary for conducting robust habitat surveys. Potential study sites have been

identified, and sampling protocols are being developed. Low water conditions are required for conducting habitat surveys and no such conditions occurred during fall 2016.

Activity Status as of July 16, 2017:
We are currently waiting for low water conditions to conduct habitat surveys at 12 sites along the Minnesota River. To date, some reconnaissance of sites has been performed and bathymetric maps have been created for several reaches of the Minnesota River. A minimum of four habitat surveys are planned for summer/fall of 2017 and the remainder of the surveys will be conducted during 2018.

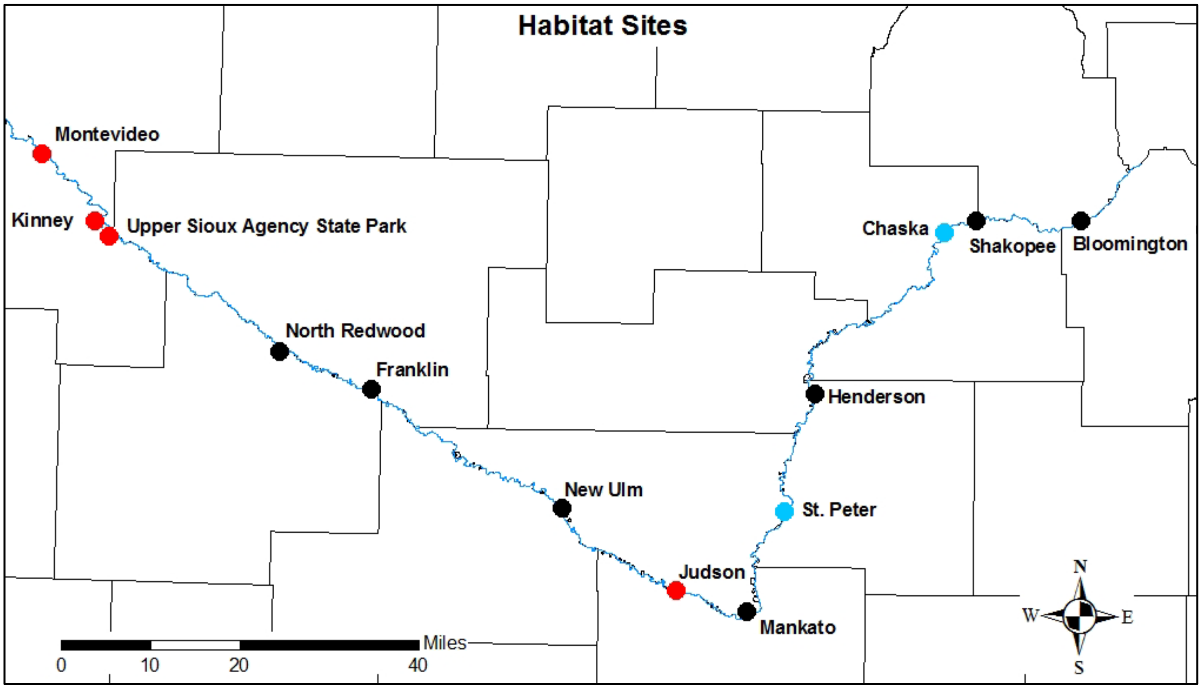
Activity Status as of January 16, 2018:
During 2017, there was a brief period when river conditions were suitable for completing habitat surveys. During that period, we completed habitat surveys at three sites and initiated surveys at three other sites. Specifically, we completed comprehensive habitat surveys at sites near Judson and Montevideo and a basic habitat survey near Upper Sioux Agency State Park (Map 2). Comprehensive surveys included measuring a cross section of the channel at a riffle, measuring the longitudinal profile, creating a bathymetric map, and quantifying the coverage of woody debris present in the site. Basic habitat surveys are similar, but exclude cross sections. We measured channel cross sections with a precision laser level, survey rod, and precise GPS by recording coordinates and elevation of the streambed/bank and water surface at short intervals (0.25-2 m) across the entire river channel. We created longitudinal profiles by measuring the river depths at GPS recorded locations along the thalweg of the river. We created bathymetric maps of habitat survey sites by recording depths along transects with a Humminbird depth finder and Autochart software. Woody debris was quantified within study reaches by recording GPS locations of woody debris and estimating the surface area coverage. We initiated surveys at sites near North Redwood, Franklin, and New Ulm. Habitat surveys will be completed at these sites and six additional sites (St. Peter, Chaska, Mankato, Henderson, Shakopee and Bloomington) during 2018. Although low flow conditions are necessary for completing most components of a habitat survey, bathymetric maps can be created during moderate to moderately high flows. Habitat data will be summarized during the upcoming winter and during fall 2018 thru spring 2019.



Map 2. Locations of habitat survey sites along the Minnesota River.

Activity Status as of July 16, 2018:
We are currently waiting for low water conditions to finish habitat surveys at 9 of 12 sites along the Minnesota River. During the high water periods this spring, we were able to create bathymetric maps for the nine remaining sites. We plan on completing longitudinal profiles and woody debris measurements at seven of nine

remaining sites (North Redwood, Franklin, New Ulm, Mankato, Henderson, Shakopee, and Bloomington) and longitudinal profiles, riffle cross sections, and woody debris measurements at St. Peter and Chaska (Map 3). Additionally, during a brief low water period this spring, we were able to complete a comprehensive habitat survey at a site upstream from the Kinney boat landing near Granite Falls.



Map 3: Locations of habitat survey sites along the Minnesota River. Red dots indicate completed sites, black dots indicate sites that require longitudinal profile and woody debris measurements, and blue dots indicate sites that require a riffle cross section, longitudinal profile, and woody debris measurements.

Activity Status as of January 16, 2019:

Prolonged periods of high water again limited our ability to complete habitat surveys during 2018. Fortunately, surveys are complete at 9 of 12 sites and partially complete at the remaining 3 sites. We anticipate completing the 3 unfished surveys during early spring of 2019. The final report for this project activity is mostly complete, and the data from unfished sites will be added to the final report prior to project completion. The final report for this project activity will serve as an important reference point for Minnesota River physical habitat characteristics (e.g., longitudinal profiles, cross-sections). Below is an example of the data collected from one of the 12 habitat sites.

Preliminary results from the Judson habitat study site near river mile 115.

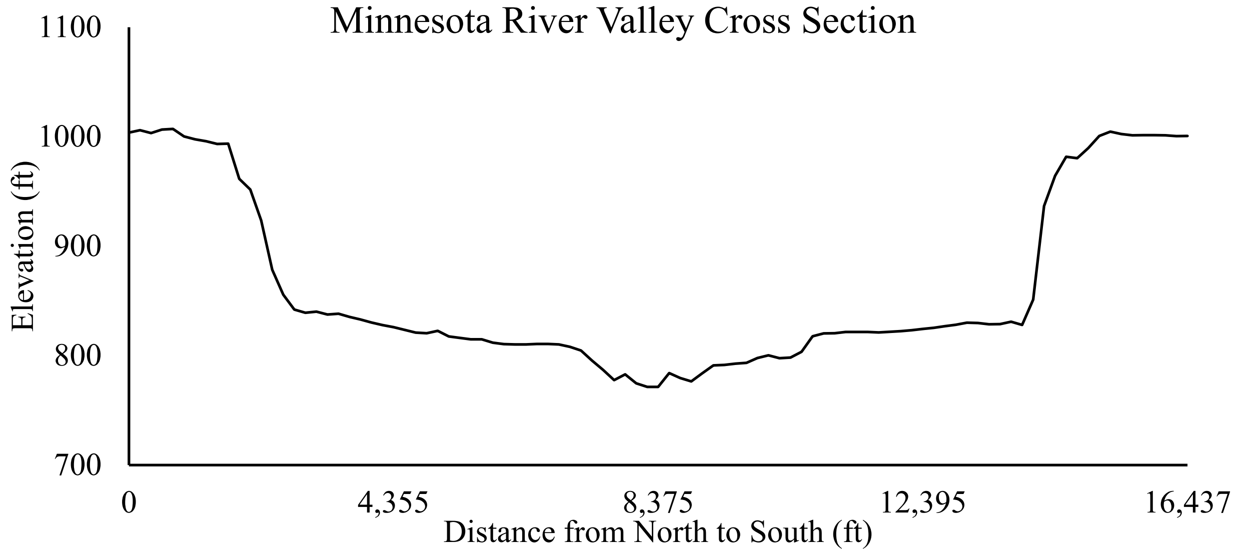


Figure. Elevation cross section of the Minnesota River valley near Judson, MN based on LiDAR data.

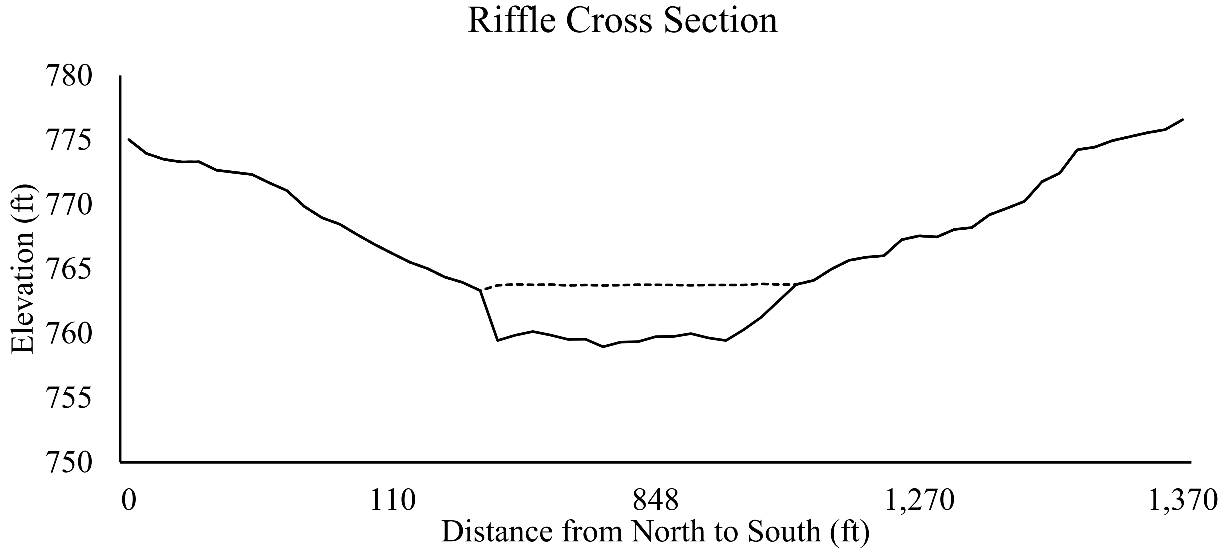


Figure. Surveyed cross section of the Minnesota River at a riffle near Judson, MN.

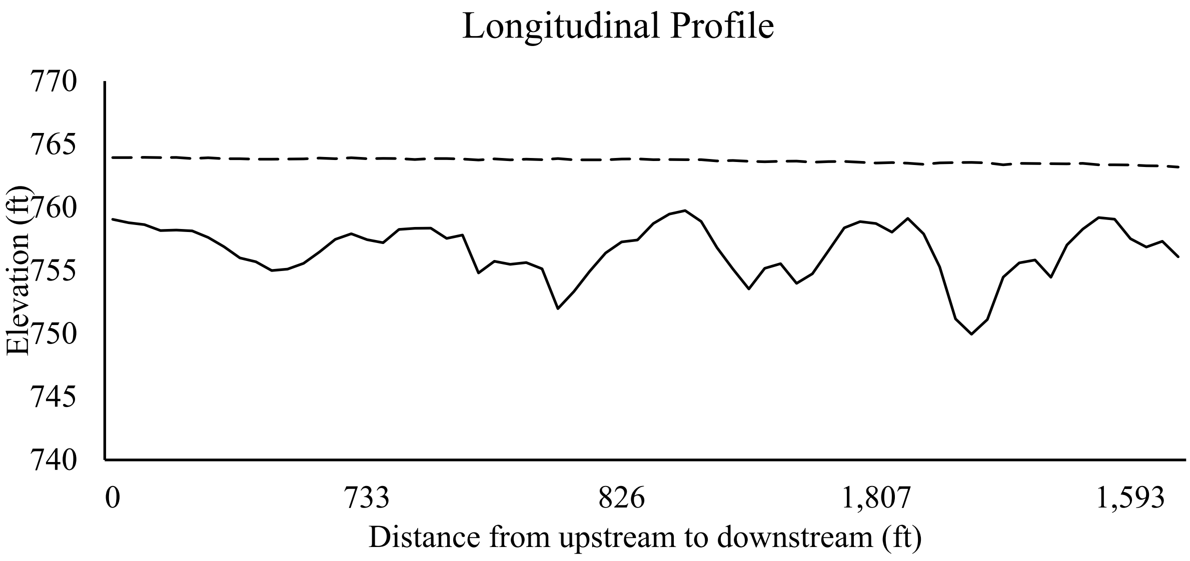


Figure. Longitudinal profile of the Minnesota River thalweg near Judson, MN. The solid line represents the river bed and the dashed line represents the water surface.

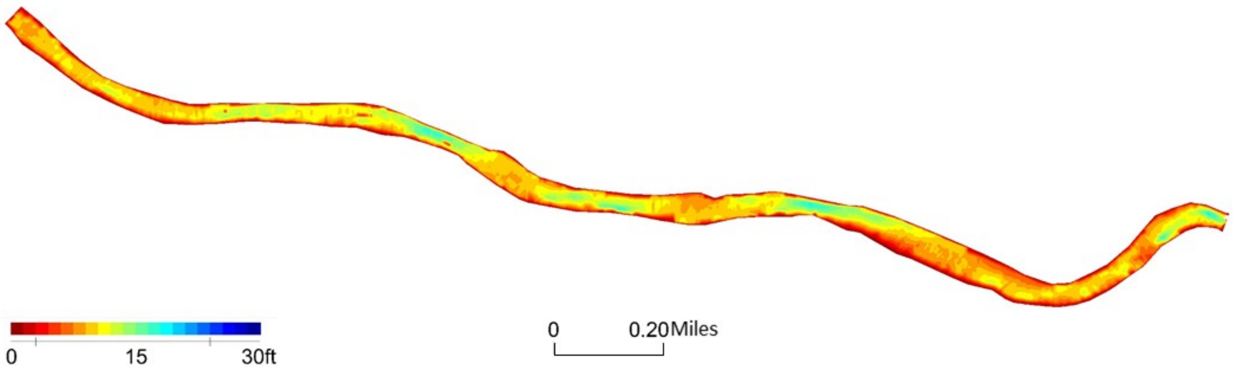


Figure. Bathymetric map of the Minnesota River near Judson, MN.

Table. Land cover types within various distances from the Minnesota River near Judson, MN.

Judson		
Riparian Zone	**Count**	**%**
Agriculture	296	80.43
Forest-cover	30	8.15
Wetlands	36	9.78
Human Disturbance	6	1.63
	368	
500 meter	**Count**	**%**
Agriculture	3244	56.70
Forest-cover	352	6.15
Wetlands	1334	23.32
Human Disturbance	462	8.08
Openwater	329	5.75
	5721	

1000 meter	**Count**	**%**
Agriculture	7913	60.19
Forest-cover	873	6.64
Wetlands	2743	20.87
Human Disturbance	1046	7.96
Openwater	571	4.34
	13146	

5000 meter	**Count**	**%**
Agriculture	99712	73.69
Forest-cover	15449	11.42
Wetlands	9127	6.74
Human Disturbance	7998	5.91
Openwater	3033	2.24
	135319	

Final Report Summary:
We accomplished all project activity objectives. However, extended periods of high-water conditions prevented us from collecting all of the desired data from all 12 habitat sites.

Summary—
Physical habitat has direct and indirect influences on biotic communities of riverine ecosystems. In alluvial systems like the Minnesota River, many factors influence physical habitat and geomorphology including watershed characteristics, underlying geology, climate, flow regime and human induced changes. The complex interactions between these factors often creates a dynamic mosaic of habitats, but some can also lead to homogenization of habitats. The Minnesota River landscape has many anthropogenic alterations (row crop agriculture and artificial drainage systems) and is experiencing changes in climate (increased precipitation and magnitude of single rain events) that impact the physical habitat of the river. The goal of this study is increasing understanding of physical habitat characteristics of the Minnesota River to provide insight into how future anthropogenic changes and climate changes may impact physical habitat and ecosystem health. During August 2016–August 2018, we quantified channel dimensions and other physical habitat characteristics at twelve sites along the Minnesota River. Habitat complexity varied widely among the twelve study sites with channel sinuosity varying 1.05–2.76, mean thalweg depth varying 1.31–6.96 m, and percent of woody debris coverage varying 0.18–2.38%. Land cover types varied at different scales among study sites, but in general, wetlands dominated land cover types at a local scales (e.g., riparian zone) while agriculture dominated land cover type at larger scales (e.g., greater than 500 m zone). Changes in land use and climate will undoubtedly impact physical habitat of the Minnesota River and subsequently the entire ecosystem, but the extent is unknown. The results of this study provide baseline measurements of physical habitat features that will allow for future quantification of changes.

Significant Outcomes—

- We quantified channel dimensions and physical habitat characteristics at twelve 2.0-5.5 km study sites located along the lower 402 km of the Minnesota River.
- Basic habitat surveys at 10 study sites included bathymetric mapping, longitudinal profiles, and woody debris surveys. Comprehensive habitat surveys at 2 study sites also included riffle cross section surveys.
- Average channel sinuosity of study sites was 1.34, varying from 1.05 to 2.76.
- Woody habitat (e.g., log jams, fallen trees) is prevalent in the Minnesota River, with percent of channel surface area covered with woody debris varying from 0.2% to 2.4%.

- Mean thalweg depth of the 12 sites was 3.45 m, varying 1.31–6.96 m.
- Riparian zone land cover is primarily wetlands, while the proportion of agriculture land cover increases at larger scales, accounting for approximately 78% of land in the Minnesota River watershed.
- Sediments in the Minnesota River Basin are highly erodible, consisting mostly of alluvium, till plain, and supraglacial drift complex which results in large amounts of sediment transport and deposition within the Minnesota River.
- Mean annual precipitation and the magnitude of single rain events is increasing throughout the Minnesota River Basin, resulting in increased mean discharge that impacts channel morphology and habitat complexity of the Minnesota River.
- Collection of baseline physical habitat data, coupled with continued monitoring, will provide insight into how the physical features and the Minnesota River ecosystem will respond to continued changes in climate, land use, and conservation efforts.

See attached report “Evaluation of Minnesota River physical habitat features” for thorough analyses, explanation, and discussion. The attached report also includes associated tables, figures, and supplemental materials. Novel datasets collected for this project are also provided as attachments.

ACTIVITY 3: Inventory Minnesota River backwater fish communities
Description:
The floodplain is an important component of the river ecosystem and backwater habitats within the floodplain serve vital ecosystem functions. The Minnesota River floodplain contains hundreds of backwater habitats that provide valuable habitat for fish and other organisms. For fish, these backwaters can serve multiple functions from spawning and nursery habitat, to zooplankton rich foraging areas, and refuge from high-flow conditions. For example, many nest spawning centrarchids (e.g., Bluegill *Lepomis* macrochirus, Black Crappie *Pomoxis nigromaculatus*) utilize the lentic environment of backwaters for spawning habitat. Backwater habitats typically support greater zooplankton densities than main-channel habitats and thus provide important foraging habitat for species such as Bigmouth Buffalo, Gizzard Shad, and Paddlefish. Some Minnesota River fish species such as Bowfin *Amia calva*, Central Mudminnow *Umbra limi*, Largemouth Bass *Micropterus salmoides*, and Weed Shiner *Notropis texanus* are almost exclusively found in backwater habitats.

All backwaters provide some form of habitat for aquatic organisms, but not all backwater habitats are equal. Size, depth, substrate, connectivity, distance from river channel, macrophyte cover, and other physical features influence the species that utilize the habitat. Changes in hydrologic characteristics resulting from climate change and land use practices can greatly influence the functionality of backwater habitats. For example, flood timing, frequency, magnitude, and duration regulate connectivity of backwaters to the river channel and consequently access by fish. Furthermore, sediment deposition can fill in backwaters altering or eliminating their ecosystem function.

Invasive carps are also known to extensively utilize backwater habitats for feeding and as a nursery habitat for juveniles. If invasive carps were to establish in the Minnesota River, they could compete with native fishes for space and food resources found in backwater habitats. Documenting fish communities found in Minnesota River backwaters prior to invasive carp establishment will provide the opportunity to understand how invasive carps impact backwater habitat use by native species if they become established in the Minnesota River.

Despite the importance of Minnesota River backwater habitats, very little information exists about their ecosystem functions or fish communities. For this project activity, we will develop survey protocols for sampling fish communities in backwater habitats and perform extensive fish community assessments in at least 12 Minnesota River backwaters that represent the spatial and physical diversity of backwater habitats found in the Minnesota River floodplain. Fish community assessment gears that will be evaluated and used include but are not limited to gill nets, fyke nets, boat electrofishing, and seines. Evaluated backwaters will represent the diversity of Minnesota River backwaters in regards to size, depth, connectivity, and physical attributes.

Outcomes of this project activity will increase understanding of the ecological function of Minnesota River backwater habitats and utilization of backwater habitats by Minnesota River fishes. Additionally, outcomes of this project activity will provide the DNR and other agencies with protocols for monitoring backwater fish communities and the ability to measure future changes to Minnesota River backwater fish communities. Lastly, outcomes of this activity will help prioritize floodplain habitats for conservation, restoration, and protection efforts.

Activity 3 Timeline:

- Winter and spring 2016: Literature will be reviewed to identify the most appropriate methods for sampling backwater fish communities.
- Winter 2016: Geographic information systems (GIS) and other tools will be used to identify candidate backwaters representative of the spatial and physical diversity of Minnesota River backwaters.
- Winter 2016–2017 and spring 2017: Landowner permission will be obtained for access to backwaters on private property, and reconnaissance of selected backwaters will be performed.
- Summer–fall 2017 and spring–fall 2018: Comprehensive fish community assessments will be performed in at least 12 backwater habitats. Additionally, physical habitat features will be described.
- Winter 2018–2019: Data will be summarized and a final report for project activity 3 will be completed by July 2019.

Summary Budget Information for Activity 3:

ENRTF Budget:	**$ 96,437**
Amount Spent:	**$ 95,190**
Balance:	**$ 1,247**

Outcome	**Completion Date**
1. Develop and evaluate fish community survey protocols for Minnesota River backwater habitats	06-30-2019
2. Characterize fish communities in at least 12 Minnesota River backwaters	06-30-2019

Activity Status as of January 16, 2017:

Aerial imagery was used to identify candidate backwaters. Considerations when selecting backwaters included connection type, size (i.e., area), longitudinal location along the river, past survey history, and accessibility. Field reconnaissance was conducted to evaluate feasibility of accessing several candidate backwaters and river conditions (i.e., water level) necessary for access were identified.

During 2016, four Minnesota River backwaters were surveyed. These backwaters included an oxbow lake near Montevideo, an oxbow lake near Franklin, Mack Lake southwest of Fairfax, and a backwater at the MN River boat ramp near Belle Plaine. A combination of seining, boat electrofishing, gill nets, and fyke nets were used to sample the fish communities. Forty-one species of fish were sampled in these 4 backwaters. Physical characteristics of the backwaters were recorded as well as characteristics of the surrounding land. Most fish were measured, weighed and released. Aging structures (scales and otoliths) from 36 Black Crappie and 28 White Crappie were collected from Mack Lake. Aging structures will be collected from crappies in other backwaters where sample sizes are adequate so that age and growth can be compared among backwaters.

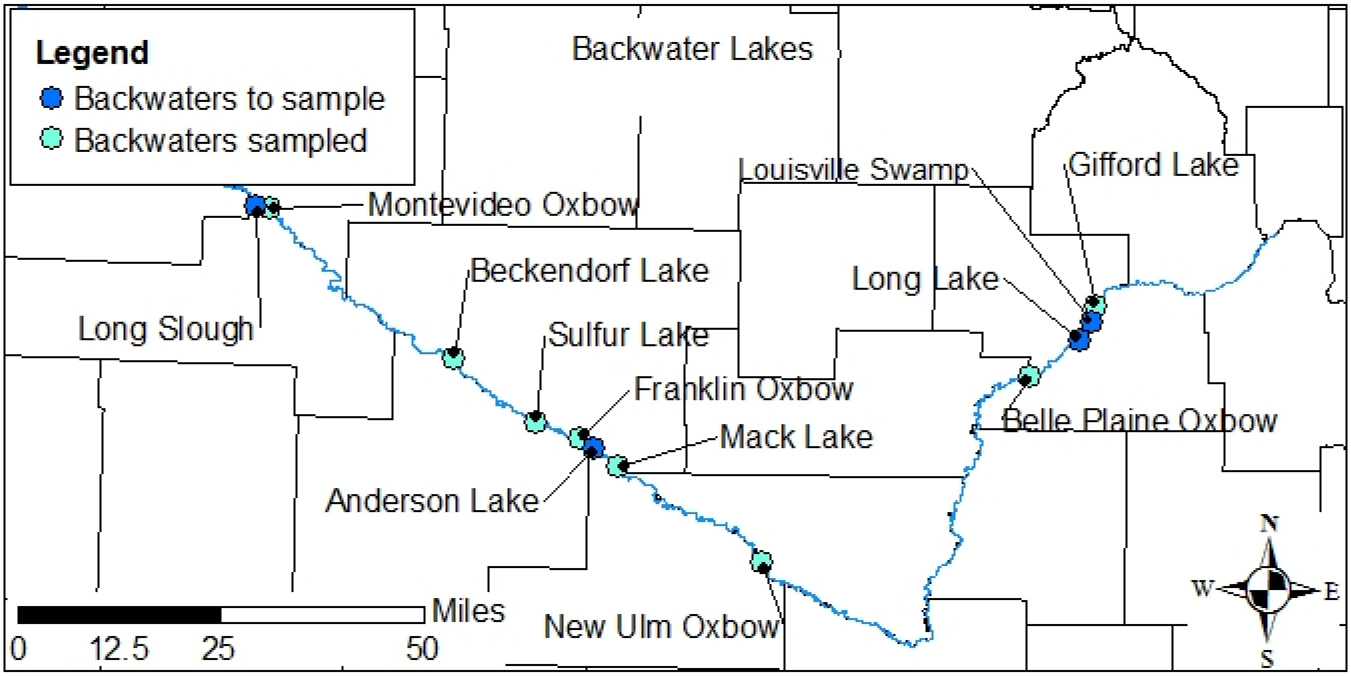
Activity Status as of July 16, 2017:

During spring of 2017, one additional backwater (Gifford Lake near Chaska) was sampled. This assessment included gill nets, trap nets, seines, and boat electrofishing. At least three additional backwater surveys are planned for this summer or early fall. The remaining backwater surveys will be conducted during 2018.

Activity Status as of January 16, 2018:
Three additional backwaters including Sulfur Lake, Beckendorf Lake, and an Oxbow near New Ulm were sampled during summer of 2017 (Map 4). To date, eight of twelve backwater surveys have been completed. The eight surveyed backwaters varied in size from 5 to 100 acres with fish species richness varying from 14 to 30 for a total of 48 unique species (Table 1). During 2018, at least four more backwaters will be surveyed, likely including Long Slough near Montevideo, Anderson Lake near Franklin, Long Lake near Jordan, and Louisville Swamp near Chaska.

Black and White Crappies were aged from Gifford Lake and Mack Lake. For Gifford Lake, White Crappie ranged 190–285 mm in total length and 2–3 years old, while Black Crappie ranged 107–279 mm in total length and 1–6 years old. For Mack Lake, White Crappie ranged 66–256 mm in total length and 0–2 years old, while Black Crappie ranged 95–321 mm in total length and 0–3 years old. We hope catches of Black and White Crappie are sufficient for age and growth analyses in additional backwaters sampled during 2018.

In addition to backwater surveys conducted for this study, past backwater fish surveys by Schmidt and Polomis (2007) and Nickel (2014) will be used to evaluate relationships between backwater characteristics (e.g., size, depth, connectivity) and fish assemblages.



Map 4. Locations of Minnesota River backwater lakes included in this study.

Table 1. List of the 48 fish species sampled in eight Minnesota River backwaters during 2016 and 2017.

Species List			
Bigmouth Buffalo	Common Shiner	Largemouth Bass	Slenderhead Darter
Black Bullhead	Creek Chub	Mooneye	Smallmouth Buffalo
Black Crappie	Emerald Shiner	Northern Pike	Spotfin Shiner
Blackchin Shiner	Fathead Minnow	Orangespotted Sunfish	Spottail Shiner
Bluegill	Flathead Catfish	Pumpkinseed	Tadpole Madtom

Bluntnose Minnow
Bowfin
Brassy Minnow
Brook Stickleback
Central Mudminnow
Channel Catfish
Common Carp
Freshwater Drum
Gizzard Shad
Golden Shiner
Green Sunfish
Highfin Carpsucker
Hybrid Sunfish
Johnny Darter
Quillback
River Carpsucker
Sand Shiner
Sauger
Shorthead Redhorse
Shortnose Gar
Silver Redhorse
Walleye
Weed Shiner
White Bass
White Crappie
White Sucker
Yellow Bullhead
Yellow Perch

Activity Status as of July 16, 2018:

During spring of 2018, two backwaters (Anderson Lake near Franklin and Hwy 14 Oxbow north of Montevideo) were sampled. These assessments included trap nets, seines, and boat electrofishing. At least three additional backwater surveys (Long Slough, Long Lake, and Louisville Swamp) are planned for summer or early fall of 2018.

Activity Status as of January 16, 2019:

During the remainder of the 2018 field season two more backwaters were surveyed (Long Lake and Blue Lake), satisfying our project goal of completing 12 backwater assessments. Although standard backwater assessments included trap nets, seines, gill nets, and boat electrofishing; oftentimes, one or more gear types were infeasible for surveying a given backwater (e.g., too steep sided for seine surveys, inaccessible by electrofishing boat). Overall, a combination of boat electrofishing and shoreline seining were effective at capturing most fish species inhabiting Minnesota River backwaters (see figure below). Brown Bullhead, Bullhead Minnow, and Longnose Gar are the three fish species not captured from backwaters during 2016 or 2017 that were captured from backwaters during 2018. A final report summarizing Minnesota River backwater fish species communities will be completed; adding a wealth of information to the relatively limited knowledge of Minnesota River backwater ecosystems.

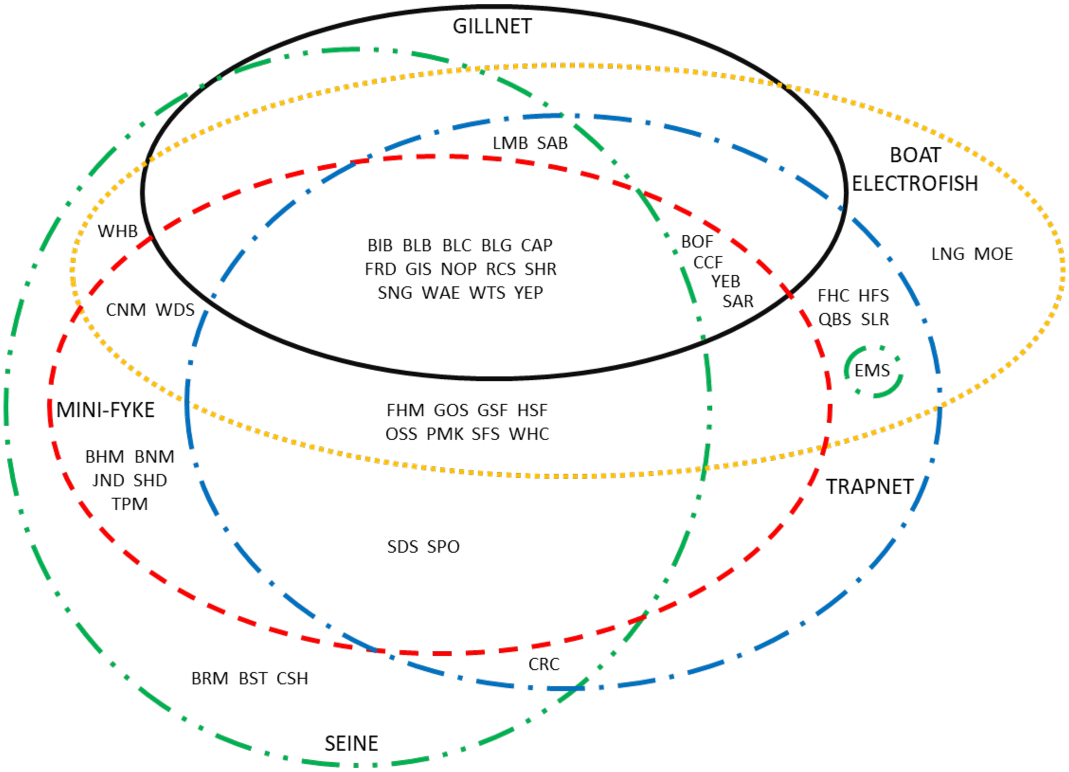


Figure. Venn Diagram depicting the different gears that fish species (standard 3 letter codes) were captured with during Minnesota River backwater assessments.

Final Report Summary:
We completed all project activity objectives by surveying fish assemblages in 12 Minnesota River backwaters.

Summary—
Backwater habitats are a vital component of river ecosystems. Lateral connection between the main channel and backwater habitats allows for crucial ecosystem functions such as the exchange of nutrients, organic matter, and organisms. This exchange has been hypothesized as a primary process structuring riverine species communities that utilize backwater habitats for various purposes (e.g., reproduction, foraging, refuge). The Minnesota River floodplain contains hundreds of perennial and intermittent backwater habitats that provide valuable habitat for fish and other organisms. Despite their importance, very few studies have evaluated their ecosystem function and fish communities. The goals of this study include refining protocols for monitoring backwater fish communities, increasing understanding of fish communities inhabiting Minnesota River backwaters, and collecting baseline data for evaluating future impacts of altered hydrology and habitat or establishment of invasive species. During August 2016–September 2018 we conducted fisheries assessments in 12 backwaters using a suite of sampling gears including boat electrofishing, gill nets (standard and large mesh), fyke nets (19mm, 9.5mm, and 3.2 mm bar mesh), and seines. Surveyed backwaters varied in surface area 2–106 ha, maximum depth 1.2–4.6 m, connectivity low–high, and associated river km 32–433. Fish species richness captured in each backwater varied 14–30 for a total of 51 unique fish species that represented a diversity of feeding habits, spawning behaviors, pollution tolerances, and preferred habitat types. Seines captured the most species (40 of 51) while gill nets captured the fewest species (21 of 51). A combination of seining and boat electrofishing captured 98% of the fish species sampled during this study. Changes in climate and land use and establishment of invasive species will undoubtedly impact Minnesota River backwater ecosystems, but the extent is unknown. The results of this study provide increased understanding of Minnesota River backwater ecosystems and the ability to identify changes attributed to future perturbations.

Significant Outcomes—
- We characterized fish communities in 12 backwaters located along the Minnesota River that represent the diversity of backwater habitats within the floodplain.
- Surveyed backwaters varied in surface area (2–106 hectares), maximum depth (1.2–4.6 m), type (oxbow, wetland, floodplain lake), connectivity with the main channel (low, moderate, high), and associated river kilometer (32–433).
- Fish communities were sampled using a suite of sampling gears including boat electrofishing, gill nets, fyke nets, and seines.
- A total of 51 unique fish species representing 14 families were captured, and species richness varied 14–30 among surveyed backwaters.
- Non-metric multidimensional scaling ordinations (NMDS) revealed that river kilometer and surface area had a significant influence on fish community structure.
- Seining and boat electrofishing were the most effective methods for determining the presence of fish species in backwater habitats. Seines captured 40 of 51 total species while boat electrofishing captured 38 species. Overall, 98% of fish species were captured with a combination of the two gears.
- This study highlights the diversity of Minnesota River backwater habitats and their fish communities.
- Mean annual precipitation and the magnitude of large rainfall events is increasing throughout the Minnesota River Basin resulting in increased mean discharge, more severe flood events, and altered flow regimes. Altered hydrology can impact both the ecological function of backwaters and fish community composition.
- Future impacts caused by the establishment of invasive species are hypothesized. Bighead Carp and Silver Carp will likely utilize backwaters for foraging and nursery habitat if they become established in the

Minnesota River. Invasive carps compete with other planktivorous fishes and can alter zooplankton communities.
- Collection of baseline fish community data along with continued monitoring will provide the ability to identify changes attributed to future perturbations such as altered hydrology, land use changes, or establishment of invasive species.

See attached report "Minnesota River backwater fish communities" for thorough analyses, explanation, and discussion. The attached report also includes associated tables, figures, and supplemental materials. Novel datasets collected for this project are also provided as attachments.

ACTIVITY 4: Evaluate population dynamics, movement, and habitat use of sensitive fish species (i.e., Shovelnose Sturgeon, Paddlefish) in the Minnesota River

Description:

Shovelnose Sturgeon are considered a sensitive large river fish species that have been negatively impacted across their native range by over harvest, habitat degradation, and habitat fragmentation (e.g., dams). Shovelnose sturgeon are also a long-lived species that typically do not reach sexual maturity until after age five and can live more than thirty years. In recent years, shovelnose sturgeon catches have increased during fish community assessments on the Minnesota River providing evidence of an increasing population. As a result, regulations have been changed to allow a catch-and-release angling season. Although the Shovelnose Sturgeon is an important indicator species, very little is known about the Shovelnose Sturgeon population in the Minnesota River.

For this project activity, intensive sampling will occur at four or more study sites on the Minnesota River to capture Shovelnose Sturgeon with a variety of assessment gears (e.g., trammel nets, electrofishing, benthic trawls, hook and line). Captured Shovelnose Sturgeon will be measured for length and weight, implanted with a uniquely coded passive integrated transponder (PIT), and fin clipped. Additionally, up to five fish from each centimeter length group will have a fin ray removed for age estimation. Relative abundance, length frequency, length-at-age, mark-recapture, and age estimation data will be used to estimate growth, recruitment, and mortality of the Minnesota River Shovelnose Sturgeon population in addition to population density or relative abundance.

Acoustic telemetry technology will also be utilized to evaluate seasonal movement patterns and habitat use of Shovelnose Sturgeon in the Minnesota River. Up to ten fish captured from each study site will be surgically implanted with an acoustic transmitter tag (Vemco 69 KHZ acoustic tags). The large-scale movement of these tagged fish will be detected by six acoustic receivers (Vemco VR2W-69KHZ) deployed into the Minnesota River. These acoustic receivers will be an important expansion to an existing array of acoustic receivers deployed throughout the Mississippi River and its major tributaries. The array of acoustic receivers provides the ability to monitor the movement of hundreds of tagged fish throughout the upper Mississippi River basin, representing a diversity of species, including invasive carps. Active tracking equipment (Vemco VR100) will also be used to locate tagged Shovelnose Sturgeon and identify finer-scale seasonal habitat use throughout the duration of this project.

Similar to Shovelnose Sturgeon, very little is known about the Paddlefish population in the Minnesota River as Paddlefish are rarely caught by anglers or fisheries biologists. However, commercial fishermen typically encounter several Paddlefish each year while conducting seining operations in Minnesota River backwaters. During this project, DNR employees will coordinate with commercial fishermen and if Paddlefish are captured they will be surgically implanted with an acoustic transmitter tag. Telemetry data will be used to better understand migration patterns of Minnesota River Paddlefish and determine their tendency to move between the Minnesota River and Mississippi River.

This project will accelerate efforts to better understand rare and sensitive fish species of the Minnesota River. Data collected during this project will provide the foundation for future monitoring of these fish species populations and allow us to track population responses to climate change, land use alteration, and establishment of aquatic invasive species. The array of acoustic receivers deployed during this project will allow tracking of tagged fish well beyond the scope of this project, and can be utilized for future projects to better understand fish movement within the Minnesota River as well as immigration and emigration. Future captures of PIT tagged Shovelnose Sturgeon will also provide continued information about Shovelnose Sturgeon growth and movement within the Minnesota River.

Activity 4 Timeline:

- Winter 2016: Identify intensive study sites and finalize sampling plan for evaluation of Shovelnose Sturgeon population dynamics in the Minnesota River.
- Fall 2016: Deploy 6 acoustic receivers onto Minnesota River bridge pilings to track movement of acoustic tagged fish.
- Spring–Fall of 2016, 2017, 2018: Conduct Shovelnose Sturgeon sampling and tagging
- Continuously:
    - Maintain and upload data from acoustic receivers
    - Coordinate with commercial fishermen for opportunities to tag Paddlefish with acoustic transmitters
    - Actively track acoustic tagged fish to identify seasonal habitat use
- Winter 2018–Spring 2019: Summarized and analyzed data will be compiled for project activity 4 and the final report will be completed by July 2019.

Summary Budget Information for Activity 4:	**Revised Budget:**	**$ 159,428**
	Amount Spent:	**$ 155,131**
	Balance:	**$ 4,297**

Outcome	**Completion Date**
1. Estimate population dynamics (abundance, growth, mortality, recruitment) of Shovelnose Sturgeon in the Minnesota River	06-30-2019
2. Quantify movement patterns and habitat use of tagged Shovelnose Sturgeon in the Minnesota River	06-30-2019
3. If Paddlefish are encountered during this project, quantify movement patterns and habitat use of tagged Minnesota River Paddlefish	06-30-2019

Activity Status as of January 16, 2017:

Study sites were selected where Shovelnose Sturgeon (North Redwood, Judson, Mankato, and Chaska) and Paddlefish (St. Peter) will be targeted with intensive sampling efforts. Additionally, a subsample of Shovelnose Sturgeon or Paddlefish will be surgically implanted with acoustic transmitters at each site. To date, transmitters were surgically implanted in 9 sturgeon near North Redwood, 9 near Judson, 7 near Mankato, and 1 near Chaska. Four Paddlefish captured near St. Peter were implanted with transmitters. Therefore, a total of 30 transmitters were implanted this fall resulting in 10 that still need to be implanted. In addition to implanting transmitters, 62 Shovelnose Sturgeon were PIT tagged and aging structures were collected from 37 Shovelnose Sturgeon.

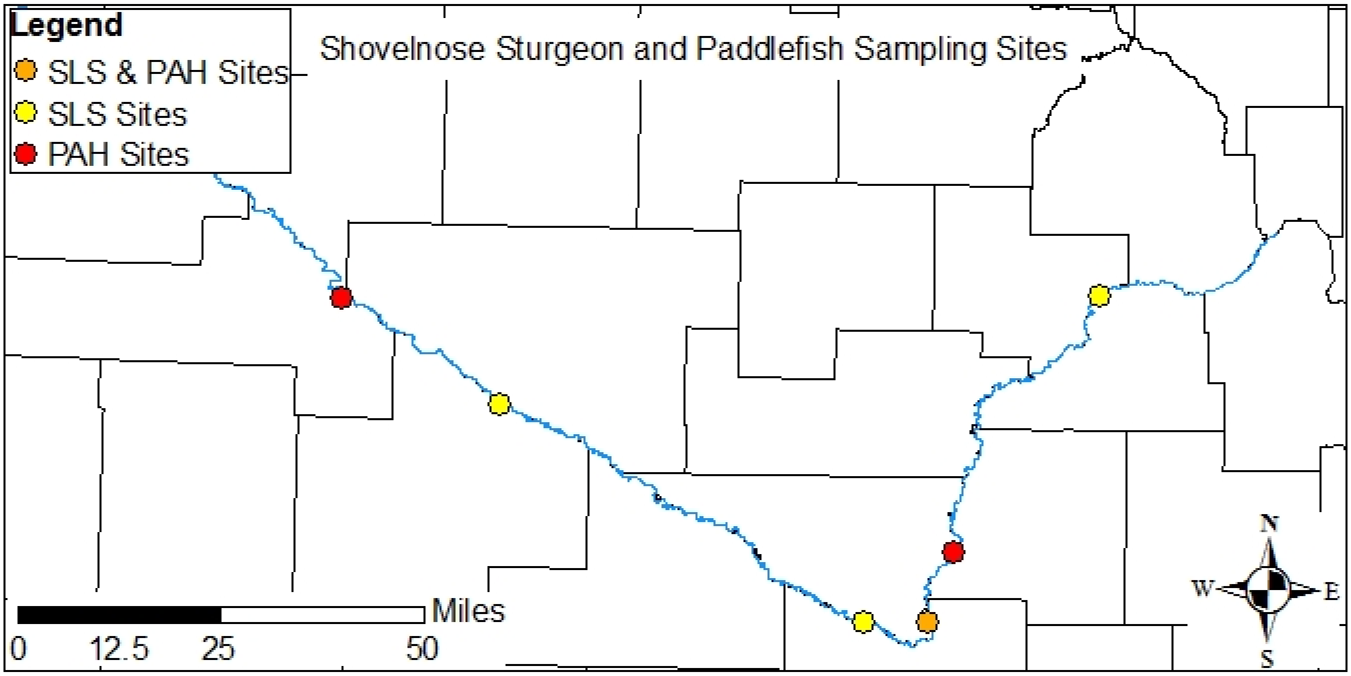
Subsequent tracking efforts detected 28 of 30 fish after initial tagging. Most fish appear to remain close to the site they were caught and tagged at. One exception was a Shovelnose Sturgeon tagged near North Redwood that was later detected on a stationary receiver near New Ulm, approximately 50 river miles downstream. As a result of high water conditions, a complement of gears were required to catch Shovelnose Sturgeon including trammel nets, electrofishing, trotlines, and hook and line sampling. Five additional stationary Vemco VR2 receivers were purchased to install on bridge piers to enhance the already existing array of six VR2 receivers in the Minnesota River. These additional receivers could not be installed this fall due to high water conditions.

Activity Status as of July 16, 2017:
Sampling efforts during spring of 2017 captured 151 Shovelnose Sturgeon across four study reaches and ten of those fish were implanted with acoustic transmitters for a total of 36 tagged Shovelnose Sturgeon. Active tracking surveys were also conducted at each study reach. Ten additional acoustic tags were purchased with external funds for implanting into Paddlefish. Fortunately, 10 Paddlefish were captured at a new study reach near Upper Sioux Agency State Park and seven were implanted with acoustic transmitters. We will continue to sample and tag Shovelnose Sturgeon and Paddlefish for the duration of this project and will use active and passive tracking methods to identify movement patterns and habitat use. Age and growth analyses will be conducted using Shovelnose Sturgeon pectoral fin rays.

Activity Status as of January 16, 2018:
Low water conditions during late summer allowed for installation of three acoustic receivers on bridge piers in the Minnesota River near St. Peter, Judson, and Upper Sioux Agency State Park. Two remaining receivers will be installed during 2018. All receivers (n=9) were uploaded during fall or winter of 2017, and active tracking surveys were completed at each study reach. To date, of the 36 Shovelnose Sturgeon implanted with acoustic transmitters, five fish have been detected outside of the stretch of river they were tagged. Two of the fish made small movements < 10 mile upstream and three fish made large movements of > 50 miles (two upstream and one downstream; Figure 11). Four of the fourteen Paddlefish tagged with acoustic transmitters for this project, as well as three Paddlefish tagged in other rivers (Mississippi River Pools 2 and 3 and the St. Croix River), have made long distance movements. The first Paddlefish tagged for this study travelled over 500 river miles in less than one year, leaving the Minnesota River on multiple occasions (Figure 12).

Additional Shovelnose Sturgeon and Paddlefish sampling was conducted during fall of 2017 to bolster sample sizes. Gillnets were drifted near St. Peter and Mankato catching 51 new paddlefish (45 at St. Peter and 6 at Mankato) for a total of 66 Paddlefish caught during this project (Map 5). Paddlefish are generally captured from current seams between fast currents and adjacent slack waters. Paddlefish captured near Upper Sioux Agency State Park were found feeding in plankton rich water coming from the outlet of a shallow backwater lake. To date, 315 Shovelnose Sturgeon have been captured for this project with only two recaptured fish. Unfortunately, low numbers of recaptured fish limit our ability to estimate abundance, but the relatively large number of fish captured is indicative of a rather abundant population. Future goals are to confirm successful Shovelnose Sturgeon reproduction in the Minnesota River by sampling for juveniles.

The large number of Paddlefish captured during this project provides encouraging evidence that Minnesota's Paddlefish populations are recovering and are more abundant that previously believed. Paddlefish are migratory, exhibiting rather large distance movements among multiple rivers, and should be appropriately managed at a basin-wide scale. Monitoring and managing Paddlefish populations will remain high priority as we hope the status of this state threatened species continues to improve.



Map 5. Shovelnose Sturgeon and Paddlefish sampling locations along the Minnesota River.

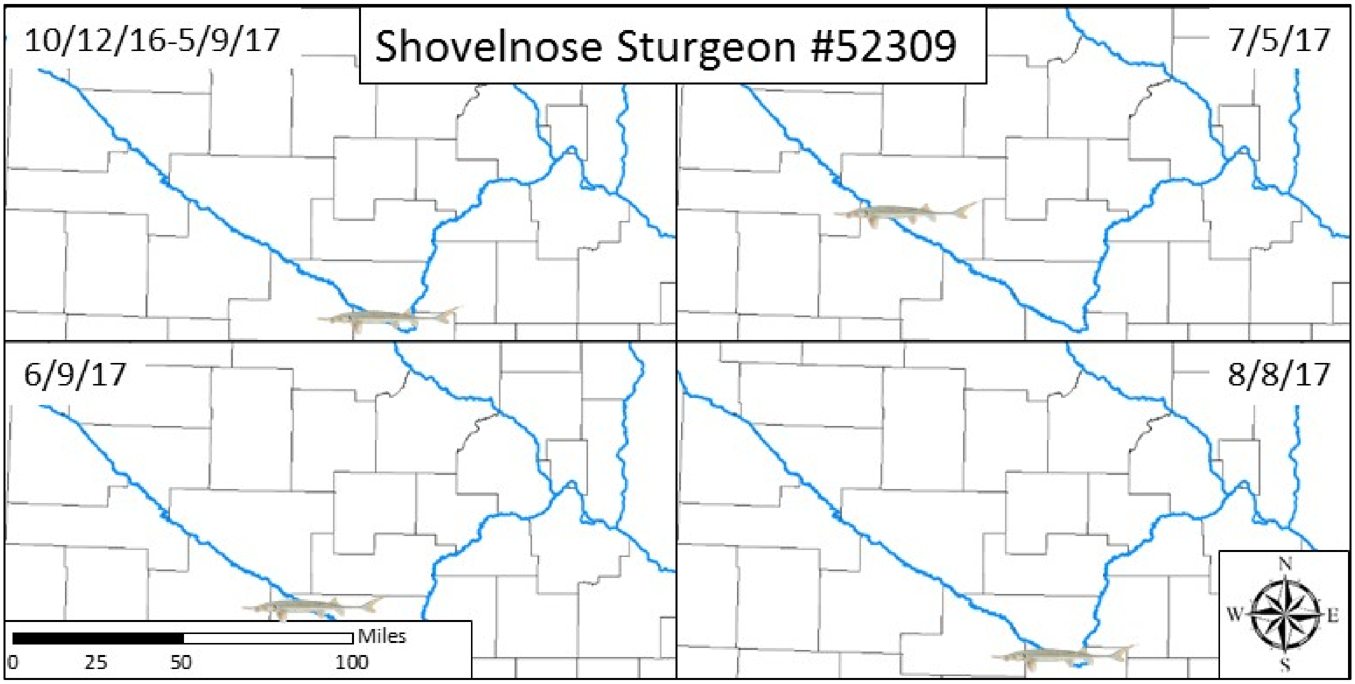


Figure 11. A Shovelnose Sturgeon implanted with acoustic tag number 52309 was initially caught and tagged near Judson, MN on October 12th, 2016 and repeatedly detected at that location until May 9th, 2017. During 2017, this sturgeon passed a stationary receiver near New Ulm, MN on June 6th and a receiver near Vicksburg, MN on July 5th. Then on August 8th this sturgeon passed a stationary receiver near Judson, MN, presumably on its way back to the site where it was tagged.

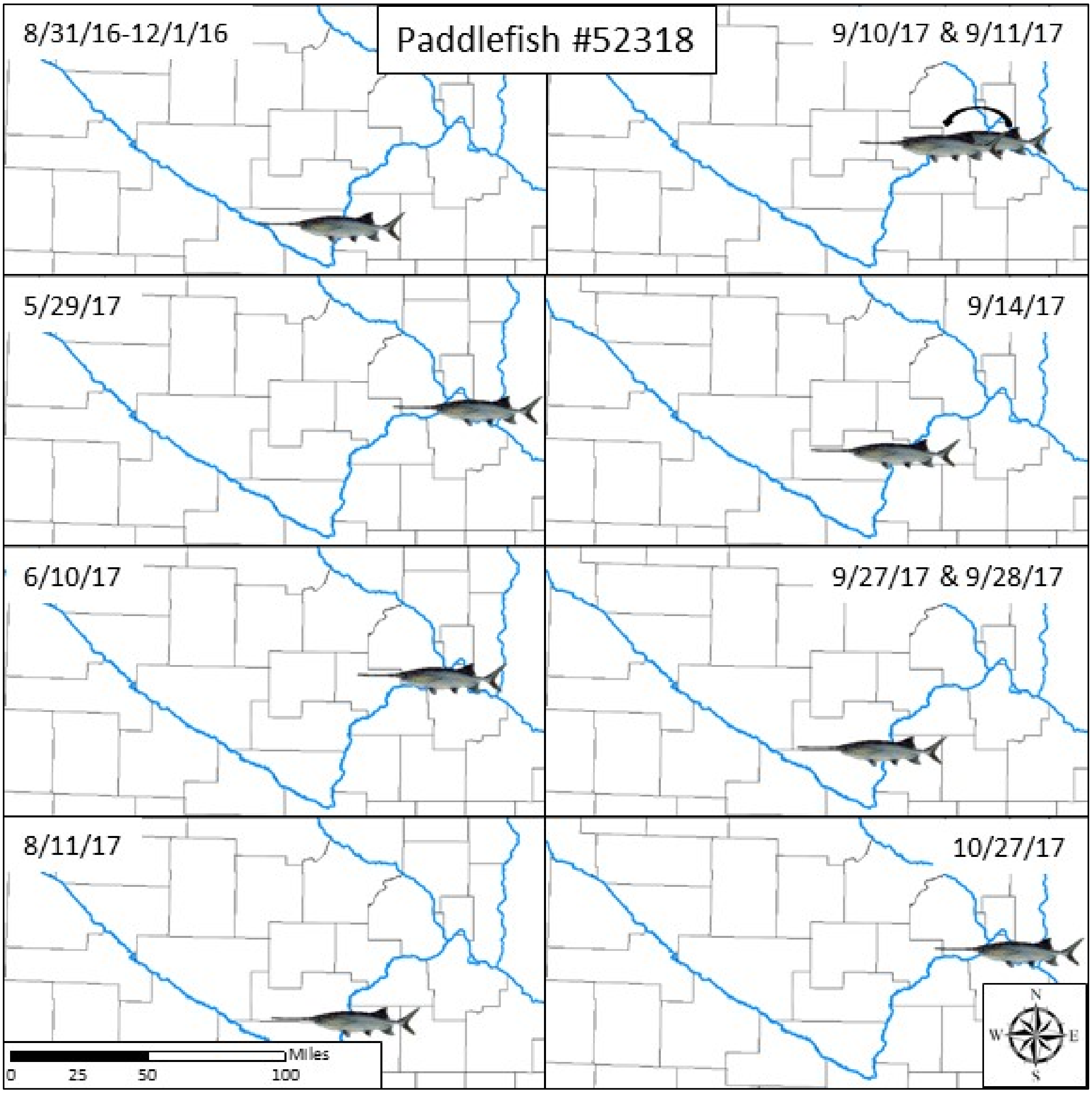


Figure 12. The first Paddlefish captured during this project (acoustic tag number 52318) was caught near St. Peter on August 31st of 2016 and has made several trips past Savage, MN. In less than one year, we have documented over 500 miles of movement from this fish.

Activity Status as of July 16, 2018:

During spring of 2018, we conducted active tracking surveys at all Shovelnose Sturgeon study sites (North Redwood, Judson, Mankato, and Chaska). During these active tracking events we detected seven Shovelnose Sturgeon and one Paddlefish within the study sites where they were originally tagged. Active tracking was also conducted in the stretch of river from below Granite Falls Dam to Upper Sioux Agency State Park (approximately 12 river miles). We detected six of seven Paddlefish that were previously tagged near Upper Sioux Agency State Park during 2017. Most Paddlefish detections were in a deep hole upstream from the Kinney boat ramp (downstream of Granite Falls and Minnesota Falls). We hypothesize that this location might be a staging area for spawning individuals, however no spawning activity was observed. During our most recent tracking event, four of the six Paddlefish were detected in the deep hole near the Kinney Access while one fish moved downstream to another deep hole where it was also detected during the summer of 2017. Along with active tracking, we captured and tagged (PIT and Jaw) six Paddlefish at the Kinney site. Additional congregations of Paddlefish have also been observed near the Kinney boat ramp and Upper Sioux Agency State Park indicating that these areas are heavily used by Paddlefish during the spring.

Due to high water, we have not been able to upload stationary acoustic receivers during 2018. We will upload receivers as soon as water levels allow and install the two remaining receivers. Additional data from receivers in the Mississippi River and St. Croix River indicate that four of the fourteen Paddlefish tagged as part of this study have moved out of the Minnesota River and into other rivers (Mississippi River Pools 2 and 3 and the St. Croix River). Three of the four Paddlefish that left the Minnesota River were tagged at St. Peter, and frequently move between the Minnesota and Mississippi Rivers. The other Paddlefish that left the Minnesota River was tagged at Upper Sioux Agency State Park and was most recently detected near downtown St. Paul. Generally, the fish that have been tagged at Upper Sioux Agency have not made long distance movements and this is the first Paddlefish from that location to move out of the Minnesota River. We will continue to track and sample Shovelnose Sturgeon and Paddlefish throughout the summer and fall of 2018.

Activity Status as of January 16, 2019:
During October and November 2018, Paddlefish gill net assessments were conducted at the St. Peter and Kinney sites and Shovelnose Sturgeon trotline assessments were conducted at the North Redwood, Judson, and Mankato sites. A total of 12 Paddlefish were captured and tagged at the Kinney site (including 2 recaptures), 18 Shovelnose Sturgeon were captured form the North Redwood site (1 recapture), 48 Shovelnose Sturgeon were captured from the Judson site (2 recaptures), and 21 Shovelnose Sturgeon were captured from the Mankato site. Recaptured fish allow for abundance estimates.

Active tracking surveys were conducted at all four Shovelnose Sturgeon sites during fall 2018 while several active Paddlefish tracking surveys were conducted at the St. Peter and Kinney sites throughout 2018. At least one tagged Shovelnose Sturgeon was present in each study reach and we found Paddlefish consistently using the St. Peter and Kinney sites throughout the year. Additionally, each stationary acoustic receiver was uploaded at least once during summer or fall 2018 except the receiver at Henderson. All receivers will be uploaded again during spring of 2019 and additional active tracking surveys will be conducted at Paddlefish sites (most Shovelnose Sturgeon tags will be expired by spring 2019).

The final report will include an exhaustive summary of Paddlefish and Shovelnose Sturgeon population dynamics and movement patterns observed during this study. The bullet points below provide a preview of the study outcomes for Shovelnose Sturgeon as of fall 2018.

Sampling Methods

- Shovelnose Sturgeon were captured with benthic trawls (25; 6%), trammel nets (31; 8%), hook and line (37; 9.5%), boat electrofishing (105; 27%), and trotlines (188; 49%).
- Fall trotlines (water temperature ≤ 50°F) were the most effective sampling method with an average catch rate of 1.3 fish/10 hooks.
- All captured Shovelnose Sturgeon were implanted with a PIT tag and had their left pelvic fin clipped as a secondary external mark.

Acoustic Telemetry

- Thirty-six Shovelnose Sturgeon were implanted with acoustic transmitters, nine at each site.
- Twenty-six were tagged during late-summer or fall 2016, 10 were tagged during spring 2017.

- Active tracking surveys were conducted at study sites 5 to 11 times after fish were tagged.
- Nine VR2W passive acoustic receivers were installed at fixed locations, including sites very near or within study sites at Judson, Mankato, and Chaska.
- Based on detected movements, 25/36 tagged fish were confirmed alive >6 months after tagging.
- Overall, we suspect 30/36 tagged fish survived and retained their tag during the study period.
- Six fish were never detected shortly after being tagged, therefore, these fish were excluded from analyses of movement patterns since their fate is unknown (2 each at North Redwood, Judson, and Chaska)
- Largescale movements (>5 km) were never detected for 17/30 fish.
- Three of 30 fish moved downstream at least 20–142 km (during June, July, or October)
- Ten of 30 fish made large upstream movements of up to >166 km (all during April-June)
- We hypothesize that upstream movements are associated with spawning activity.
- Many tagged fish stayed within or often returned to their initial tagging site.
- After initial tagging, 24/30 fish appeared to stay near their tagging site for at least 6 months, 16 for at least 1 year, and 12 for at least 18 months.
- Twenty-five of 30 fish were detected near their tagging site at least once after the first winter.
- Twenty of 30 fish were detected near their tagging site at least once after 1 year.
- Eight tagged fish exhibited evidence of strong site fidelity by either returning to their tagging site after a confirmed large-scale movement or by being detected within their tagging site throughout the study, but also frequently not detected within the tagging site (indicating frequent excursion away from and back to tagging sites).
- Many fish also exhibited periods of very little movement, for instance, 12/30 fish were suspected to stay within a 1km reaches for over 20 day periods while 5/30 stayed within 1km reaches for over 200 day periods.
- Specifically, fish 52306 tagged at Judson was found repeatedly (8 of 8 trips) within the same general 1km reach of river during a 17 month period before being detected 3km upstream.
- Fish 52322 was detected near the North Redwood site 4 times after tagging (during 9/12/16 to 5/15/18), was then detected 18 km upstream on 5/13/18, and then back in North Redwood on 9/13/18.

Recapture Data

- During the study period, 5 Shovelnose Sturgeon were recaptured within study sites.
- One at North Redwood, 3 at Judson, and 1 at Chaska.
- Unfortunately, catch rates and recapture rates are insufficient for making robust population estimates.
- Very assumptive population density estimates for Shovelnose Sturgeon ≥ 560 mm are 96/km or 35,040 from Granite Falls Dam to Hwy 169 near Shakopee.

Final Report Summary:

We accomplished all project activity objectives including increasing understanding of Paddlefish in the Minnesota River. Estimates of Shovelnose Sturgeon population density were limited by our ability to effectively and reliably capture Shovelnose Sturgeon.

Shovelnose Sturgeon Summary—

Shovelnose Sturgeon *Scaphirhynchus platorynchus* is one of two species of the globally imperiled sturgeon family native to Minnesota. Sturgeons are generally long-lived, slow-growing, and late-maturing resulting in particular sensitivity to habitat alteration and over-harvest. Although perception is Shovelnose Sturgeon are relatively abundant in the Minnesota River, historically collected data are insufficient for monitoring the population. Thus, we sought to establish a baseline understanding of Minnesota Rive Shovelnose Sturgeon population dynamics and evaluate movement patterns. During August 2016–November 2018 we conducted extensive targeted sampling at four Minnesota River sites; capturing 391 Shovelnose Sturgeon varying 282–775 mm fork-length and estimated ages 2–15 years. We found fall trotlines set when water temperatures fell below 10°C as the most effective method for capturing Shovelnose Sturgeon from the Minnesota River, but similar to most evaluated methods, trotlines primarily captured fish > 570 mm fork length. Estimated Von Bertalanffy growth parameters (L_∞ = 669.7 and K = 0.323), annual mortality (A = 0.33), and population density (96 ≥ 560 mm fork length Shovelnose Sturgeon per river km) are relatively similar to estimates reported for other large river populations of Shovelnose Sturgeon, and particularly other populations in the upper Mississippi River basin. Both active and passive telemetry indicated that most Shovelnose Sturgeon surgically implanted with acoustic transmitters exhibited small home ranges of < 20 river km during a two year period, but four fish migrated > 100 river km. Our results provide evidence of an abundant Minnesota River Shovelnose Sturgeon population with typical to fast growth rates, consistent recruitment, and moderate annual adult mortality rates reflective of a healthy population. However, we captured very few young (i.e., < age 5) fish, likely resulting from size bias of sampling methods, but potentially indicating poor recruitment during recent years. The next steps for ensuring sustainability of the Minnesota River Shovelnose Sturgeon population include evaluating recruitment success, identifying critical spawning habits, and continued monitoring of population dynamics.

Shovelnose Sturgeon Significant Outcomes—

- Shovelnose Sturgeon are abundant in the free-flowing reach of the Minnesota River with an estimated population density of approximately 100 adult fish per river kilometer.
- Shovelnose Sturgeon captured during this project varied in fork length 282–775 mm and ages 2–15 years indicating that many year classes are present and recruitment is relatively consistent.
    - However, very few young (< age-5) Shovelnose Sturgeon were captured during this project and zero ≤ age-1 Shovelnose Sturgeon have been captured during the last five years. This is a potentially concerning indication of limited recruitment success during recent years, but more likely a reflection of ineffective sampling methods for capturing small fish.
- Minnesota River Shovelnose Sturgeon growth is similar to growth in other Mississippi River basin populations with fish reaching approximately 600 mm fork length by age 8, maximum observed fork lengths around 800 mm, and maximum age of 15 years.
- Estimated annual survival of age-7 and older Shovelnose Sturgeon is 67%, which is similar to other large river Shovelnose Sturgeon populations.
- Minnesota River Shovelnose Sturgeon are most effectively sampled with fall trotline surveys, but captured fish tend to be ≥ 590 mm fork length.
    - An effective method for sampling young and juvenile Minnesota River Shovelnose Sturgeon has not been identified.
- Most acoustic tagged Shovelnose Sturgeon (17 of 30) exhibited small home ranges (< 5 km), but 7 of 30 exhibited upstream movements > 20 km and up to > 160 km.
- Large upstream movement always occurred during April-June and we hypothesize they are associated with spawning.
- Overall, most acoustic tagged Shovelnose Sturgeon exhibited very little movement, often remaining within a small reach of river for long periods of time, and exhibited site fidelity by often returning to the same reach of river (if they did exhibit any long distance movements).

Shovelnose Sturgeon Remaining Questions—

- Where do Shovelnose Sturgeon spawn within the Minnesota River?
- Do they successfully spawn in a few specific locations or at many locations throughout the river?
- Is successful Shovelnose Sturgeon spawning still frequently occurring, or do low numbers of young Shovelnose Sturgeon captured during this study indicate limited recruitment during recent years?
- Would the Shovelnose Sturgeon population be resilient to harvest mortality?

- Is immigration or emigration important for the Minnesota River Shovelnose Sturgeon population?

Paddlefish Summary—
Minnesota is at the northern periphery of the Paddlefish's *Polyodon spathula* native range, and similar to other regions, habitat alterations (e.g., dams) and commercial fishing likely led to population declines during the early 1900s. By the late 1900's many Paddlefish populations were increasing, but confirmed records from upstream of Mississippi River Navigation Pool 4 remained rare. In fact, prior to 2016, Minnesota Department of Natural Resources fisheries assessments only captured one Paddlefish from the Minnesota River. With a seemingly increasing number of recreational angler and commercial fisher reports of Paddlefish catches during recent years, the goal of this study was to increase understanding of the presence and habitat use of Paddlefish in the Minnesota River. With experimental targeted sampling efforts we captured 85 Paddlefish varying 669–1,098 mm eye-fork length from the Minnesota River during August 2016–October 2018. We captured all Paddlefish from four small reaches of the Minnesota River, two of which appear to have large congregations of Paddlefish nearly year-round. We surgically implanted acoustic transmitters into 14 Paddlefish that exhibited a mean linear home range of 124 river km, but varying widely 0–398 river km. The greatest cumulative movement detected for an individual fish was 1,281 river km during a 2-year period. Four fish tagged during this study emigrated from the Minnesota River while six Paddlefish initially captured in the St. Croix River or Mississippi River immigrated into the Minnesota River. Results from this study provide encouraging evidence of a more abundant population of Paddlefish inhabiting the Minnesota River than previously perceived, and that Paddlefish frequently move between the Minnesota, Mississippi, and St. Croix Rivers. Identifying and protecting important spawning habitats within the upper Mississippi River basin is an important next step for ensuring sustainability of the population.

Paddlefish Significant Outcomes—

- A more significant number of Paddlefish inhabit the Minnesota River than previously perceived and ensuring the persistence and health of this population warrants continued monitoring efforts.
    - DNR staff captured 85 Paddlefish from the Minnesota River compared to one prior to this study.
    - Captured Paddlefish varied 669–1,098 mm in length (eye–fork) indicating presence of multiple year-classes.
- We identified at least four locations where Paddlefish tend to congregate, and suspect many other similar locations exist throughout the 395 rkm free-flowing reach of Minnesota River.
    - Paddlefish congregations are often associated with large slack-water areas.
    - Some congregation areas may be seasonally important because of zooplankton inputs from nearby backwater habitats.
- At least some Paddlefish inhabit the Minnesota River for long periods of time (> 1 year), providing evidence of a persistent Minnesota River population.
- Paddlefish frequently move among the Minnesota River, Mississippi River, and St. Croix River and some fish pass upstream and downstream through lock and dams.
- We summarized movement behaviors of Paddlefish into three categories.
    - One group of **resident** fish that exhibit little movement and occupy a small home range (≤ 50 rkm).
    - Another group of **migratory** Paddlefish that exhibited either one large migration or patterned seasonal migratory movements.
    - The third group of **nomadic** Paddlefish exhibit frequent and seemingly random upstream and downstream movements.
- Some Minnesota River Paddlefish exhibited one-directional migrations > 230 rkm and the most mobile Paddlefish traveled > 1,200 rkm cumulatively during a 2-year period.

- We determined that drifted or stationary hobbled gill nets with 12.7 cm bar mesh are effective for capturing Paddlefish in the Minnesota River but may be size selective for 800–1,000 mm eye–fork length fish.

See attached reports “Paddlefish inhabiting the Minnesota River” and “Minnesota River Shovelnose Sturgeon: population dynamics and movement patterns” for thorough analyses, explanation, and discussion. The attached report also includes associated tables, figures, and supplemental materials. Novel datasets collected for this project are also provided as attachments.

V. DISSEMINATION:

Description:

Project leaders will take advantage of all opportunities to share data and results of this project with other agencies, interested stakeholders, and the general public. At a minimum, one oral presentation will be given each year to provide project updates and preliminary results to relevant scientific audiences at state or regional conferences. Additionally, annual project updates and preliminary results will be disseminated electronically to a diverse audience. After the completion of this project, a final report for each project activity will be published as a DNR report made publicly available and one or more peer-reviewed manuscripts will be published in appropriate scientific journals. All data collected during this project will be freely shared.

Status as of January 16, 2017:

Preliminary findings were presented to the MN DNR southern region fisheries staff at the Region 4 Fisheries Supervisor meeting on 12/15/2016 and 12/16/2016. Tony Sindt and Mike Wolf plan to present a summary of the project and preliminary results at the Minnesota Chapter of the American Fisheries Society meeting during 2017.

Status as of July 16, 2017:

Preliminary results were presented at the Minnesota Chapter of the American Fisheries Society meeting during December 2017. During winter 2017/2018 preliminary analyses will be performed and data will be summarized. We anticipate presenting further preliminary results at a minimum of one scientific meeting this upcoming winter.

Status as of January 16, 2018:

Preliminary results and a description of the project were presented to a group of citizen workgroup members and DNR staff at a MN DNR citizen catfish workgroup meeting during August 2017. During December 2017, a project update was presented at a regional DNR fisheries staff meeting. Multiple presentations are being created to share preliminary project results at the 2018 Minnesota Chapter of the American Fisheries Society meeting.

Status as of July 16, 2018:

During February of 2018 project staff shared preliminary project findings with fisheries professionals at the annual meeting of the Minnesota Chapter of the American Fisheries Society. Mike Wolf gave a presentation titled “Shovelnose Sturgeon and Paddlefish populations and movements in the Minnesota River” while Mike Vaske developed a poster presentation titled “Inventory of Minnesota River backwater fish communities”. Mike Wolf also discussed the project with local anglers at a Hutchinson Area Fisheries Avid Angler meeting. Most recently, Mike Wolf attended a Minnesota River Congress meeting where he discussed the project and preliminary results. We intend on sharing more complete project results at various meetings during the remaining year of the project including internal DNR meetings and the annual Minnesota Chapter of the American Fisheries Society meeting.

Status as of January 16, 2019:

A summary of project activities and outcomes was shared with the MN DNR Catfish Citizen Workgroup during August 2018. Finalized project results will also be presented at the 2019 annual meeting of the Minnesota Chapter of the American Fisheries Society. We currently intend on submitting manuscripts to peer reviewed journals based on outcomes from project activities one and four.

Final Report Summary:
Resulting from this project, we developed five comprehensive reports summarizing and analyzing the novel datasets we collected that provide important comparisons with other aquatic systems and discuss implications for future Minnesota River ecosystem monitoring and management (i.e., Activity 1 Final Report—Spatial and temporal trends of Minnesota River phytoplankton and zooplankton, Activity 2 Final Report—Evaluation of Minnesota River physical habitat features, Activity 3 Final Report—Minnesota River backwater fish communities, Activity 4A Final Report—Minnesota River Shovelnose Sturgeon: population dynamics and movement patterns, Activity 4B Final Report—Paddlefish inhabiting the Minnesota River). Condensed versions of the reports associated with activity one (e.g., plankton dynamics) and activity four (e.g., Shovelnose Sturgeon, Paddlefish) will be submitted for publication in open-access peer reviewed scientific journals (e.g., Journal of Fish and Wildlife Management; Journal of Freshwater Ecology). During the project, we provided project updates and preliminary results to scientific audiences at three annual meetings of the Minnesota Chapter of the American Fisheries Society and to members of the public at Hutchinson Area Avid Angler Meetings, Citizen Catfish Workgroup meetings, and a Minnesota River Congress meeting. Ultimately, we intend on providing data, project reports, and project summaries on the Minnesota River Fisheries page of the Minnesota Department of Natural Resources website (Minnesota River Fisheries Page). We are also seeking appropriate venues to present final project results with interested members of the public and other scientific and conservation entities as one of the most valuable outcomes of this project is the collection of novel datasets on important components of the Minnesota River ecosystem.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	**$ Amount**	**Overview Explanation**
Personnel:	$318,958	NR Fisheries Specialist 100% FTE for ~36 months, NR Fisheries Technician 100% FTE for ~30 months, and Summer Intern 100% FTE for ~8 months
Professional/Technical/Service Contracts:	$38,646	1 contract for water chemistry analyses by the Minnesota Department of Agriculture ($19,152), 1 contract for phytoplankton analyses TBD through competitive bid ($14,631), and 1 contract for zooplankton analyses TBD through competitive bid ($4,863)
Equipment/Tools/Supplies:	$36,917	Plankton and water sampling supplies, habitat survey supplies, fish tags and telemetry equipment, fish sampling equipment, personal protective gear
Capital Expenditures over $5,000:	$6,274	VEMCO VR100 Manual Acoustic Receiver
Travel Expenses in MN:	$29,392	$28,171 for fleet expenses (mileage) and $1,221 for in-state travel expenses (meals and lodging)
Other:	$34,044	Direct and necessary expenses: Human Resources Support, IT Support, Safety Support, Financial Support, Communications Support,

		Planning Support, and Procurement Support necessary to accomplishing funded programs/projects.
TOTAL ENRTF BUDGET:	**$464,231**	

Explanation of Use of Classified Staff: Zero classified staff will be funded by this project. The three positions funded by this project (NR Specialist, NR Technician, and Summer Intern) will be unclassified staff funded specifically for and only for this project. Classified staff, such as the project manager, will provide some in-kind contributions to the project (≈$67,000).

Explanation of Capital Expenditures Greater Than $5,000:
The only capital expenditure greater than $5,000, will be for the purchase of a Vemco VR100 manual acoustic receiver (approximately $6,500). The VR100 receiver will be used for project activity 4 to manually track and identify the location of Shovelnose Sturgeon and Paddlefish implanted with acoustic transmitter tags. This equipment will continue to be used by the DNR to track tagged fish beyond the completion of this project.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 6.16FTEs

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0 FTEs

B. Other Funds:

Source of Funds	**$ Amount Proposed**	**$ Amount Spent**	**Use of Other Funds**
State			
DNR facilities & services (In-kind Support)	$9,000	$9,000	Office space, office overhead, technical & field support
Existing DNR equipment (In-Kind Support)	$14,000	$14,000	Boats, sampling equipment (fyke nets, gill nets, trawls, seines), microscopes, lab supplies, etc. This equipment is already owned and maintained by the DNR, and will continue to be used by the DNR for various other fisheries projects.
DNR staff salary (In-Kind Support)	$67,500	$67,500	Tony Sindt (Project Manager) - 25% FTE for 36 months, Brian Schultz (Project Supervisor) – 5% FTE for 36 months, and Jodie Hirsch (Zooplankton Analyses) – 4% FTE for 36 months
TOTAL OTHER FUNDS:	**$90,500**	**$90,500**	

VII. PROJECT STRATEGY:

A. Project Partners: N/A

B. Project Impact and Long-term Strategy:
Outcomes of this project will be directly or indirectly used to A) enhance fundamental understanding of the Minnesota River ecosystem; B) measure future impacts of land conversion, climate change, aquatic invasive species, and conservation efforts; C) inform monitoring of Minnesota River ecological health; and D) guide future management, restoration, and protection efforts. Although this project is largely focused on gathering foundational data, outcomes from this project may have direct uses for improving the health of the Minnesota

River. For instance, quantifying plankton communities in the Minnesota River will provide information necessary for predicting and quantifying impacts of invasive carps if they become established in the Minnesota River; baseline habitat data can be used to measure the success of future conservation efforts aimed at increasing channel stability and reducing sedimentation; building an understanding of backwater habitat functionality and fish communities can help guide conservation and restoration efforts for maximized floodplain habitat value; and telemetry data may be used to identify important Shovelnose Sturgeon spawning habitats that warrants special protection.

The Minnesota River is an important geological, biological, and recreational resource for all Minnesotan's. Accordingly, the DNR Section of Fisheries has recently dedicated one full-time fisheries specialist to managing Minnesota River fisheries and monitoring long-term biological health. The value and effectiveness of this DNR position will be exponentially increased by the accelerated development of sampling protocols and establishment of baseline ecological datasets resulting from this project. As a result, future DNR sampling efforts can build upon the outcomes of this project, and focus on measuring change and monitoring ecosystem health rather than collecting initial baseline data. Additionally, external funds will be continually sought to increase the DNR's capacity to build upon the outcomes of this project and share data with other entities.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
The type and extent of data collection proposed for this project has never been done by the DNR Section of Fisheries. However, DNR Section of Fisheries has conducted fisheries assessments and other surveys on the Minnesota River which helped inform and develop this project. Past efforts on the Minnesota River include fish population assessments (1959, 1966, 1971, 1985, 1992, 1998, 2004), annual fish index of biotic integrity surveys (2003–2015), creel surveys (1998), and Flathead Catfish assessments (1989–2000, 2008–2009, 2013–present).	1959–Present	Est. $700,000–$1,000,000 from Game and Fish funds
Minnesota River Specialist: Starting in 2014, the DNR Section of Fisheries dedicated one full-time fisheries specialist for inventorying and managing Minnesota River fisheries and with limited monitoring aspects to address long-term biological health. The Minnesota River Specialist is the designated project manager that contributed to the development of this project and will dedicate at least 25% of his time to coordinating and managing this project (in-kind support).	2014–Present	Est. $180,000 from Game and Fish funds
Many past surveys and reports by various agencies and organizations (e.g., Minnesota Pollution Control Agency, Minnesota State University- Mankato, DNR Division of Ecological & Water Resources, University of Minnesota, United State Geological Survey) have contributed to the existing knowledge about the Minnesota River ecosystem and helped inform the development of this project. However, these LGUs have not been able to fund or collect the targeted information listed in this project.	1965–Present	Unknown

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

A. Parcel List: N/A

B. Acquisition/Restoration Information: N/A

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

X. RESEARCH ADDENDUM: N/A

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 16, 2017; July 16, 2017; January 16, 2018; July 16, 2018; and January 16, 2019. A final report and associated products will be submitted between June 30 and August 15, 2019.

ACCELERATING COLLECTION OF BASELINE ECOSYSTEM DATA WILL ALLOW US TO UNDERSTAND HOW THESE FACTORS

IMPACT THESE VITAL ELEMENTS

OF THE MINNESOTA RIVER ECOSYSTEM

Environment and Natural Resources Trust Fund
Final M.L. 2016 Project Budget

Project Title: Enhancing Understanding of Minnesota River Aquatic Ecosystem
Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 03i
Project Manager: Tony Sindt
Organization: Minnesota Department of Natural Resources
M.L. 2016 ENRTF Appropriation: $500,000
Project Length and Completion Date: 3 Years, June 30, 2019
Date of Report: August 12, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Activity 1 Budget 07/06/2018	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	Revised Activity 4 Budget 07/06/2018	Amount Spent	Activity 4 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	**Accelerate collection of baseline Minnesota River lower trophic data**			**Quantify physical habitat characteristics of the Minnesota River**			**Inventory Minnesota River backwater fish communities**			**Evaluate population dynamics, movement, and habitat use of sensitive fish species in the Minnesota River**				
Personnel (Wages and Benefits)	$80,375	$72,649	$7,726	$80,375	$65,290	$15,085	$80,375	$79,998	$377	$102,341	$101,021	$1,320	$343,466	$24,508
NR Fisheries Specialist: $175,000 (70% salary, 30% fringe); 100% FTE for 36 months														
NR Fisheries Technician: $132,000 (70% salary, 30% fringe); 100% FTE for 30 months														
Summer Intern: $14,500 (100% salary); 100% FTE for 8 months														
Professional/Technical/Service Contracts														
Minnesota Department of Agriculture: Water chemistry analyses	$22,000	$19,152	$2,848										$22,000	$2,848
TBD (competitive bid): Phytoplankton analyses	$14,896	$14,631	$265										$14,896	$265
TBD (competitive bid): Zooplankton analyses	$4,864	$4,863	$1										$4,864	$1
Equipment/Tools/Supplies	$5,500	$4,583	$917	$3,000	$1,939	$1,061	$1,000	$1,000	$0	$31,251	$29,395	$1,856	$40,751	$3,834
Plankton and water sampling supplies ($5,500)														
Habitat survey supplies ($3,000)														
Fish tags and telemetry equipment ($29,000)														
Fish sampling equipment ($2,000)														
Personal protective gear ($1,251)														
Capital Expenditures Over $5,000														
Vemco VR100 Manual Acoustic Receiver										$6,274	$6,274	$0	$6,274	$0
Travel expenses in Minnesota														
Fleet transportation	$8,500	$7,905	$595	$5,500	$5,067	$433	$5,500	$5,356	$144	$10,000	$9,843	$157	$29,500	$1,329
In-state travel expenses: meals and lodging for distant and overnight status	$750	$71	$679	$750	$738	$12	$750	$325	$425	$750	$87	$663	$3,000	$1,779
Other														
Direct and necessary expenses: Human Resources Support ($8,963), IT Support ($15,367), Safety Support ($2,113), Financial Support ($6,507), Communications Support ($1,236), Planning Support ($829), and Procurement Support ($235) necessary to accomplishing funded programs/projects.	$8,813	$8,511	$302	$8,812	$8,511	$301	$8,812	$8,511	$301	$8,812	$8,511	$301	$35,249	$1,205
COLUMN TOTAL	**$145,698**	**$132,365**	**$13,333**	**$98,437**	**$81,545**	**$16,892**	**$96,437**	**$95,190**	**$1,247**	**$159,428**	**$155,131**	**$4,297**	**$500,000**	**$35,769**

PROJECT SUMMARY—
ENHANCING UNDERSTANDING OF MINNESOTA RIVER AQUATIC ECOSYSTEM

PROJECT OVERVIEW

Problem—The ecological health of the Minnesota River is continually impacted by:

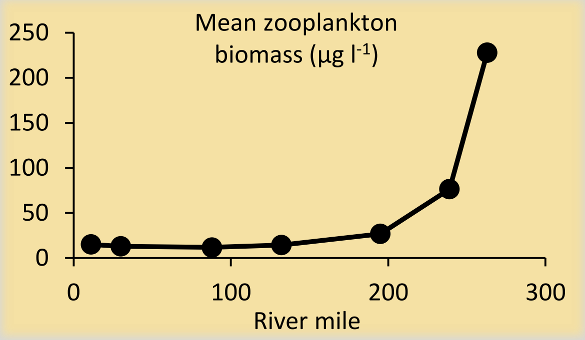
- INVASIVE SPECIES
- CLIMATE CHANGE
- LAND MANAGEMENT
- CONSERVATION EFFORTS

Objective—Accelerate understanding of the Minnesota River ecosystem including:

- PLANKTON COMMUNITIES
- HABITAT FEATURES
- BACKWATER ECOSYSTEMS
- UNIQUE FISH SPECIES

Outcomes

Plankton—Conducted the first comprehensive survey of Minnesota River plankton communities.



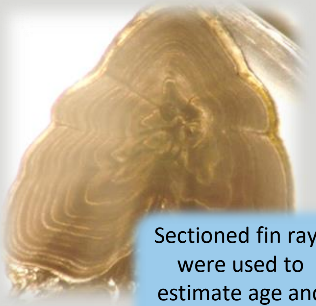
Habitat—Quantified habitat features, including relative elevation of the riverbed at 12 fixed sites.


Bathymetric map of a reach of river near Judson, MN

Backwaters—Highlighted the diversity and importance of backwater habitats; capturing 51 fish species.


©MNDNR C. Iverson

Fish—Unveiled a population of Paddlefish and evaluated population dynamics of Shovelnose Sturgeon.


Sectioned fin rays were used to estimate age and growth of sturgeon

Paddlefish exhibited home ranges of over 200 miles

Project outcomes will be used to quantify future ecosystem changes and inform management strategies that will benefit the ecological health of the Minnesota River.

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund
M.L. 2016, Chp. 186, Sec. 2, Subd. 03ib

July 2019 • Hutchinson.Fisheries@state.mn.us

Inventory of Minnesota River Backwater Fish Communities

Michael Vaske, Michael Wolf, and Anthony Sindt

Minnesota Department of Natural Resources

Introduction

- Floodplains are an important component of large rivers, serving a vital role in ecosystem function.
- Backwater habitats provide critical spawning and rearing habitat, refuge from high-flow conditions, and plankton rich foraging areas for many fish species.
- Despite their importance, relatively little is known about fish communities inhabiting the hundreds of Minnesota River backwater habitats.

Objectives

- Develop protocols for assessing Minnesota River backwater fish communities.
- Characterize fish communities in at least 12 Minnesota River backwaters.
- Compile historical Minnesota River backwater fish community survey data.

Methods

- Identify and assess backwaters representative of the diversity of Minnesota River backwater habitats.
- Assess fish communities with seines, boat electrofishing, gill nets, and fyke nets. Determine sampling effort based on backwater surface area (Table 1).
- Quantify physical habitat characteristics (e.g., size, connectivity, macrophyte cover) of backwaters and surrounding land.
- Utilize Non-metric multidimensional scaling (NMDS) ordinations to identify patterns and relationships among fish communities and habitat characteristics.

Results

- Eight backwater habitats were assessed during 2016 and 2017 (Figure 1).
- Backwaters varied in size from 5 to 100 acres, with fish species richness varying from 14 to 30, for a total of 48 unique species.
- Ordinations indicate that fish communities in the eight assessed backwaters may be influenced (P ≤ 0.2) by river mile and connectivity (Figure 2). For example, Beckendorf lake rarely connects with the main channel, while the Franklin oxbow and New Ulm oxbow (NUox) almost always connect with the main channel.
- Fish communities in Minnesota River backwaters evaluated by Schmidt and Polomis (2007) generally differed from backwaters sampled during this study and were often larger in size and further downstream (Figure 3).

Table 1. Sampling effort based on backwater surface area.

Sampling gear	< 15 acres	15-100 acres	>100 acres
Boat electrofishing	Entire shoreline (10 minute runs)	Four 20 minute runs (or entire shoreline)	Four 20 minute runs
Standard gill net	3	4	6
Large mesh gill net	1	2	2
3/4" fyke net	3	3	4
3/8" fyke net	3	3	4
1/8" fyke net	3	3	4
Seine	4	6	8

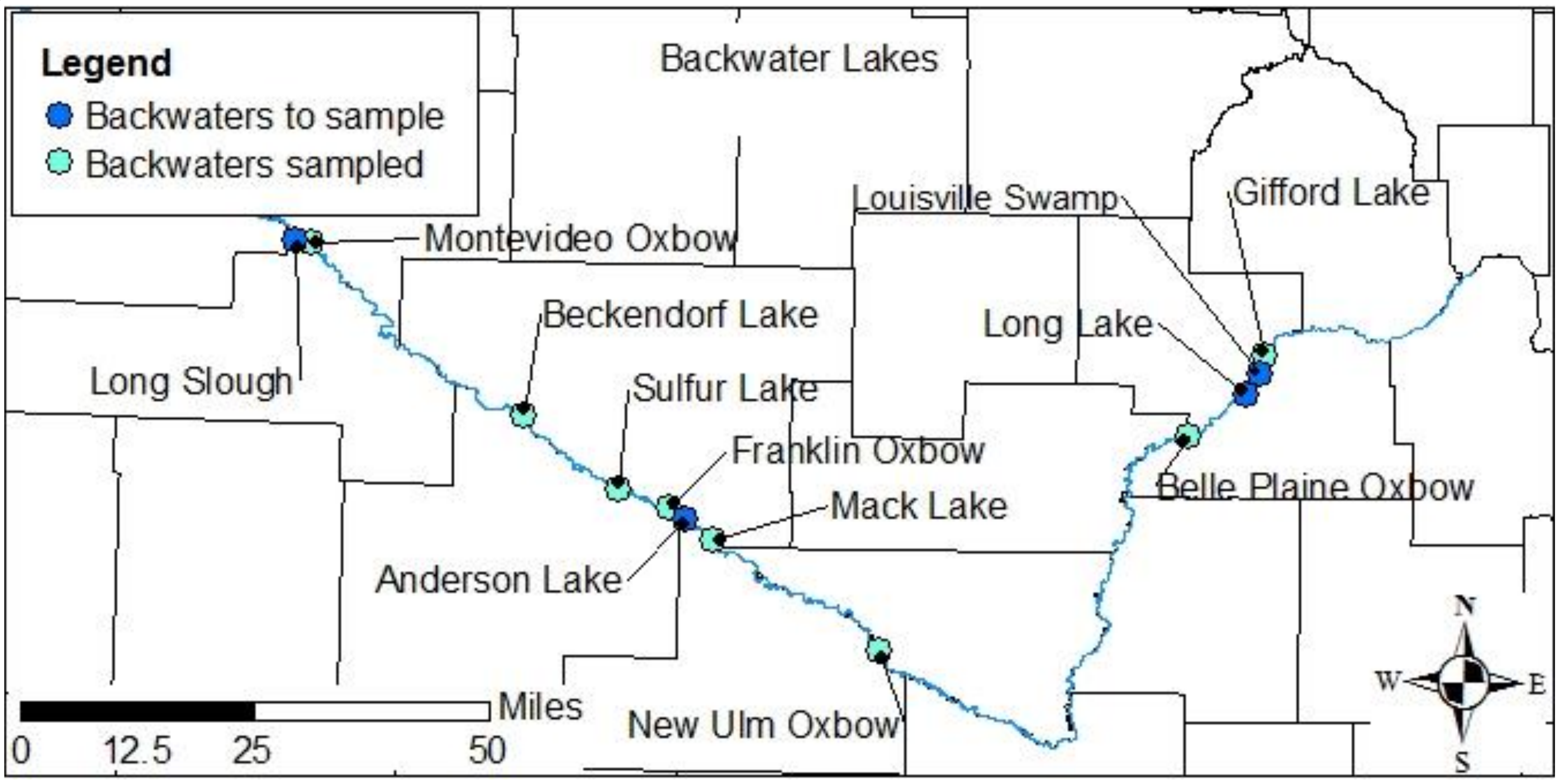


Figure 1. Locations of Minnesota River backwaters identified for this study.

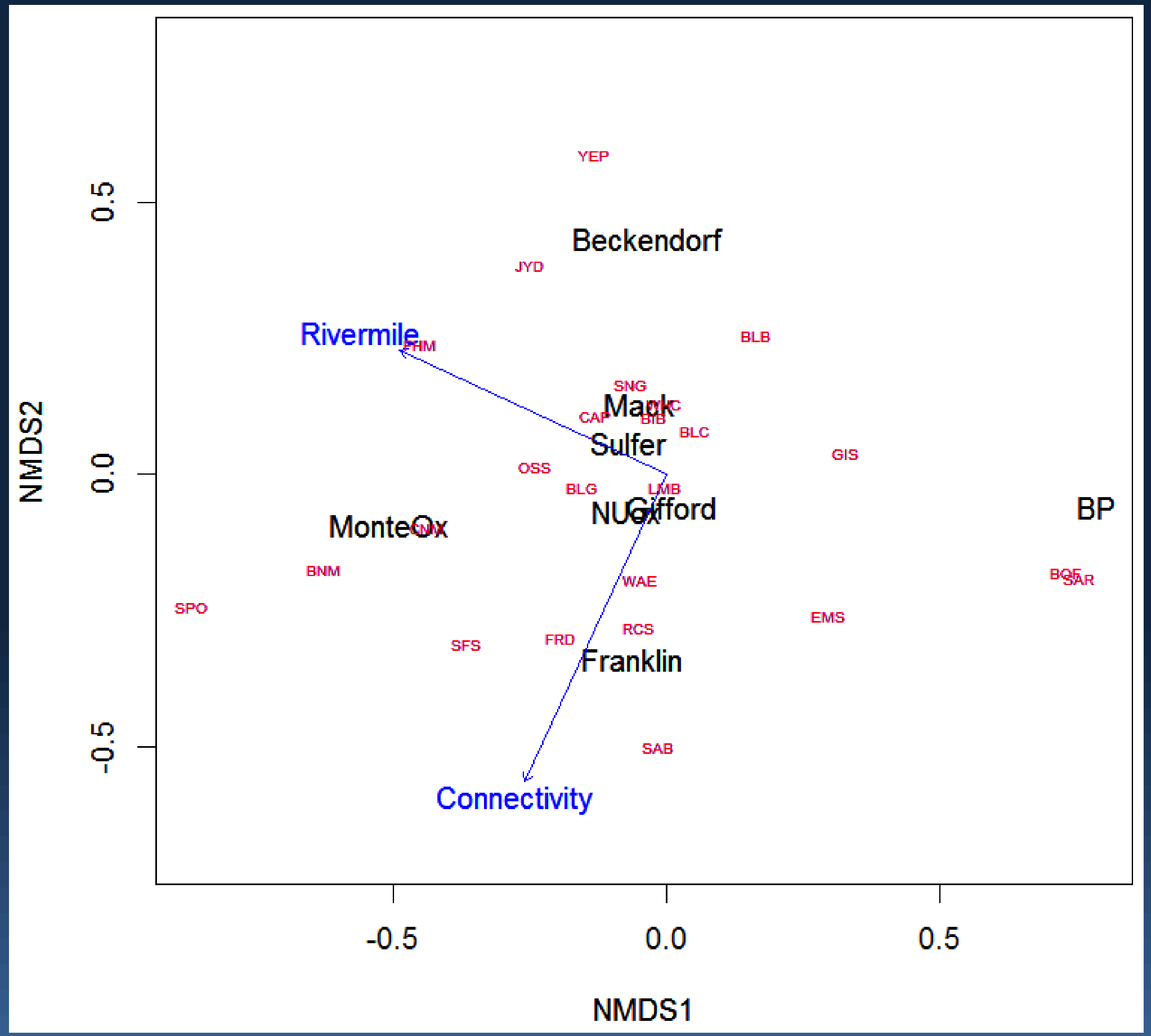


Figure 2. NMDS ordination for eight backwaters included in this study. Backwaters (black) farther away in ordination space are more dissimilar than those that are close to each other. Fish species (red) closest to backwater sites are associated with higher catch rates in those backwaters.

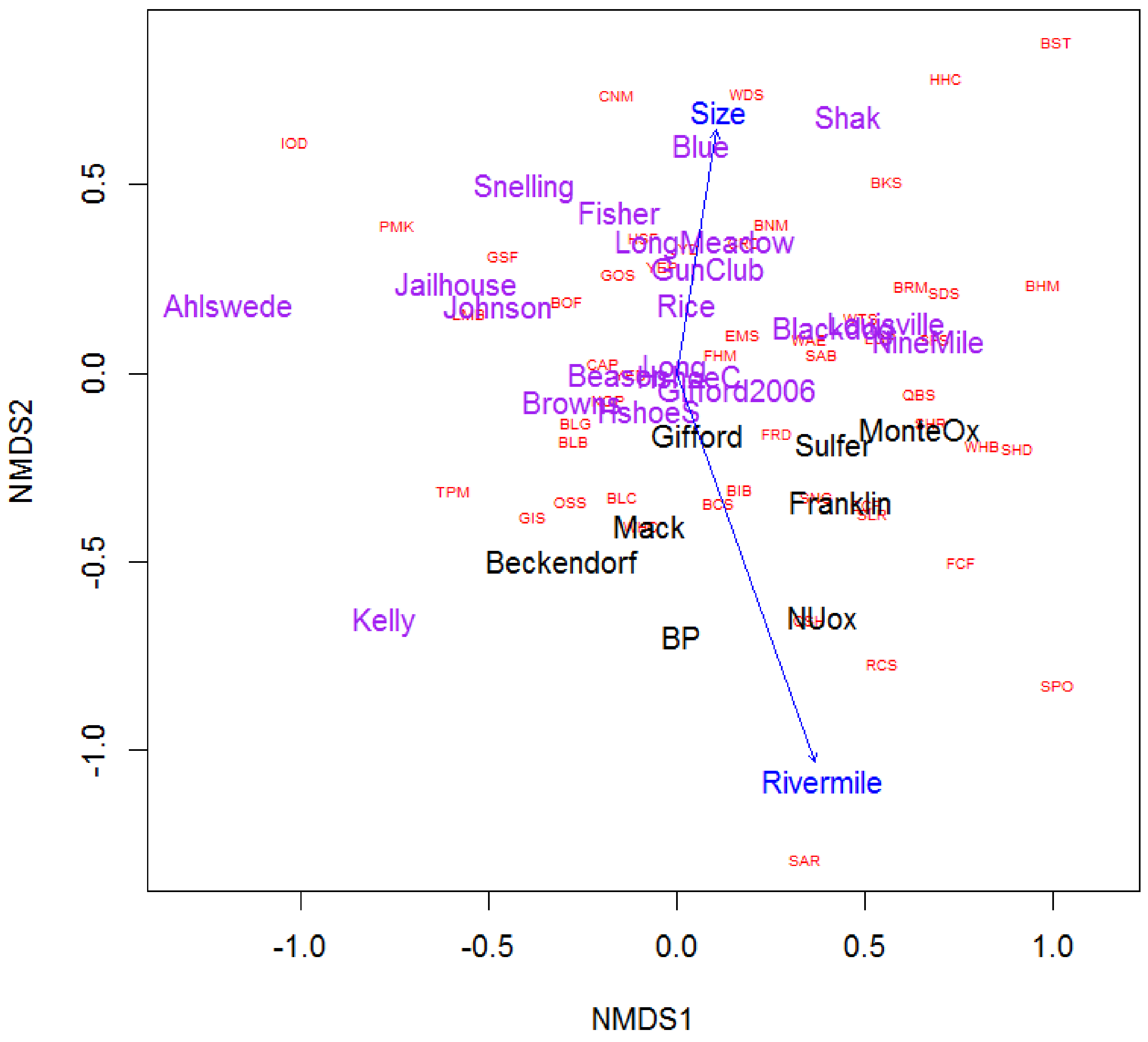


Figure 3. NMDS ordination including eight backwaters sampled during this study (black) and 20 backwaters (purple) evaluated by Schmidt and Polomis (2007).

Conclusions

- Fish communities differ among Minnesota River backwater habitats and are likely influenced by river mile and connectivity with the main channel.
- Although differences exist among fish communities, many fish species are commonly found in backwater habitats throughout the Minnesota River floodplain (e.g., Black Crappie, Bluegill, Common Carp)
- Non-metric multidimensional scaling is a useful method for examining complex relationships among fish communities and habitat characteristics of Minnesota River backwaters.
- Outcomes from this and future studies will increase our understanding of the importance of backwater habitats for fish communities and help identify and prioritize habitats for conservation, restoration, and protection efforts.

References

1. Schmidt, K., and T. Polomis. 2007. Fish Communities of Minnesota River Flood Plain Lakes. MNDNR. Available: files.dnr.state.mn.us/areas/fisheries/westmetro/2006-mnriver-floodplain-survey.pdf (January 2018).

DEPARTMENT OF NATURAL RESOURCES

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

PROJECT SUMMARY—
ENHANCING UNDERSTANDING OF MINNESOTA RIVER AQUATIC ECOSYSTEM

ACTIVITY 3: INVENTORY MINNESOTA RIVER BACKWATER FISH COMMUNITIES

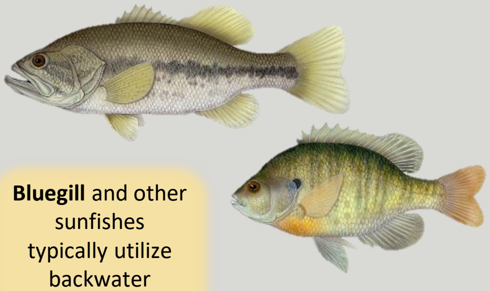
Evaluate fish communities that utilize the diversity of backwater habitats found throughout the Minnesota River floodplain.

Sample methods—

We sampled the diversity of fish species present in backwater habitats using a suite of sampling gears including fyke nets, gill nets, seines, and boat electrofishing. We found the combination of boat electrofishing and seining is most efficient for sampling the greatest number of species from backwaters.

Important functions—

Fish utilize backwater habitats for multiple reasons including spawning, foraging, and refuge from high flows.



Bluegill and other sunfishes typically utilize backwater habitats out of the current to build their nests for spawning

Planktivores such as **Paddlefish** and **Bigmouth Buffalo** utilize plankton rich backwater habitats for feeding

Other species, such as **Bowfin** and **Central Mudminnow**, almost exclusively live in backwater habitats rather than the river channel

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Important outcome—Captured 51 fish species highlighting the importance of backwater habitats for Minnesota River fishes.

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund
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ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

DEPARTMENT OF NATURAL RESOURCES

PROJECT SUMMARY—
ENHANCING UNDERSTANDING OF MINNESOTA RIVER AQUATIC ECOSYSTEM

ACTIVITY 4A: POPULATION DYNAMICS AND MOVEMENT OF SHOVELNOSE STURGEON

Establish an understanding of the Minnesota River Shovelnose Sturgeon population; a species of the globally imperiled sturgeon family.

Shovelnose Sturgeon—

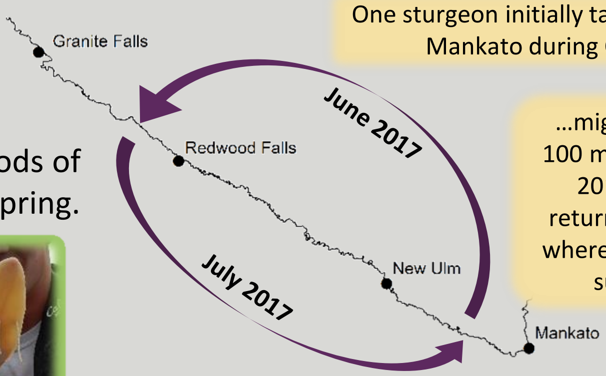
- Smallest of the North American sturgeon species.
- Inhabit many rivers throughout the Mississippi River basin.
- Many sturgeon species have experienced population declines resulting from the construction of dams and over-harvest for their valuable roe (eggs used for caviar).
- Like other sturgeons, Shovelnose Sturgeon are late maturing (after age-5) and spawn infrequently (every 2–3 years).

Evidence of an abundant and healthy population—

Likely more than 150 adult Shovelnose Sturgeon inhabit each mile of the Minnesota River downstream of Granite Falls Dam. Presence of Shovelnose Sturgeon from ages 2 to 15 indicate a self-sustaining and reproducing population.

Acoustic telemetry—

Similar to Paddlefish, many Shovelnose Sturgeon remain within small reaches of river for long periods of time, but others migrate up to 100 miles during spring.

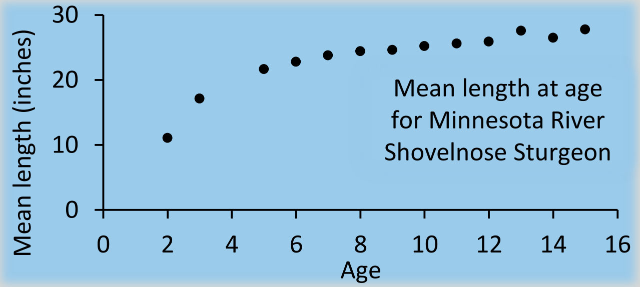


One sturgeon initially tagged upstream of Mankato during Oct. 2016…

…migrated upstream 100 miles during spring 2017 and quickly returned downstream where it remained thru summer 2018

Unique growth pattern—

Shovelnose Sturgeon grow fast during the first several years of life, but unlike other sturgeon species, growth of adults is minimal and few fish reach 30 inches or 6 pounds.



Mean length at age for Minnesota River Shovelnose Sturgeon

Important outcome—Identified a currently healthy population of Minnesota River Shovelnose Sturgeon and provided a baseline for measuring changes resulting from management actions or future perturbations.

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ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

DEPARTMENT OF NATURAL RESOURCES

PROJECT SUMMARY—
ENHANCING UNDERSTANDING OF MINNESOTA RIVER AQUATIC ECOSYSTEM

ACTIVITY 4B: EVALUATE ABUNDANCE AND MOVEMENT OF MINNESOTA RIVER PADDLEFISH

The objective was to better understand use of the Minnesota River by the state threatened Paddlefish, a species recognized for its large paddle-like rostrum and migratory nature.

History—

Paddlefish were historically abundant in Minnesota's large rivers, but populations declined during the early 1900's after the construction of dams, discharge of urban and industrial waste, and over-fishing. The oldest photograph evidence of Paddlefish in the Minnesota River is from 1957. From then until 2016, relatively few Paddlefish were reported in the Minnesota River.

More abundant than perceived—

Targeted sampling efforts during the project captured 81 different Paddlefish from the Minnesota River and identified several reaches of river inhabited by large congregations of likely more than 50 fish.

Acoustic telemetry—

Acoustic telemetry revealed that while some Paddlefish move very little, other Paddlefish are extremely mobile, migrating up to 150 miles and traveling between the Minnesota, St. Croix, and Mississippi Rivers.

The paddle-like rostrum is an electro-sensory organ used for detecting plankton

DNR staff captured Paddlefish by drifting gill nets through "slack-water" habitats of the Minnesota River.

All Paddlefish were measured and tagged so they could be identified if re-captured in the future

invasive carp

Invasive species implications—

If invasive carp become established in the Minnesota River they may compete with Paddlefish for plankton food resources and habitat space.

Important outcome—Unveiled an abundance of Paddlefish inhabiting the Minnesota River and provided insight into habitat use and movement patterns.

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UPDATE (03/2018): ENHANCING UNDERSTANDING OF THE MINNESOTA RIVER ECOSYSTEM (PHASE-I)

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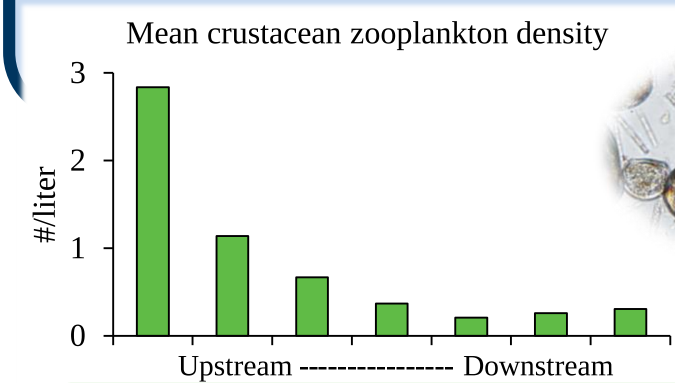
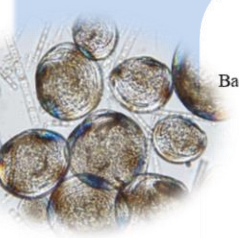
Mike Wolf
MNR Specialist
ENRTF Funded

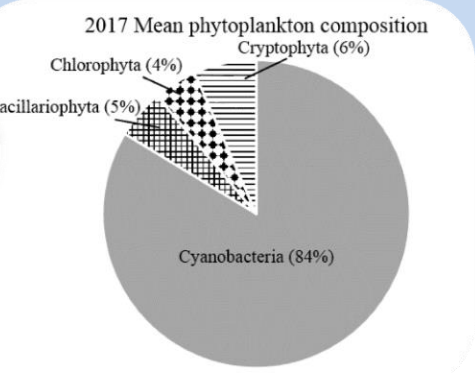
Michael Vaske
MNR Technician
ENRTF Funded

Activity 1: Accelerate collection of baseline Minnesota River lower trophic data

- Collected 227 water quality, phytoplankton, and zooplankton samples.
- Building an understanding of temporal and spatial patterns in Minnesota River phytoplankton and zooplankton communities.
- Documented presence of Zebra Mussel veligers downstream of Granite Falls Dam.

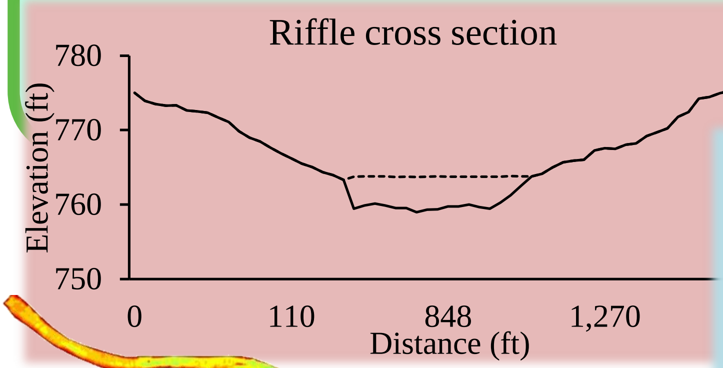

Mean crustacean zooplankton density

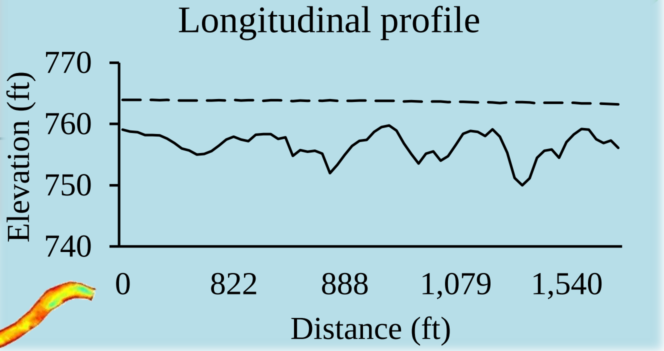

Zebra Mussel veligers

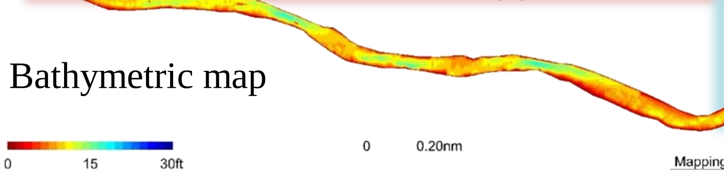

2017 Mean phytoplankton composition

Activity 2: Quantify physical habitat characteristics of the Minnesota River

- Creating bathymetric maps and measuring cross section and longitudinal depth profiles at study sites.
- Quantifying additional physical habitat characteristics at ≥ 12 study sites.


Riffle cross section


Longitudinal profile


Bathymetric map

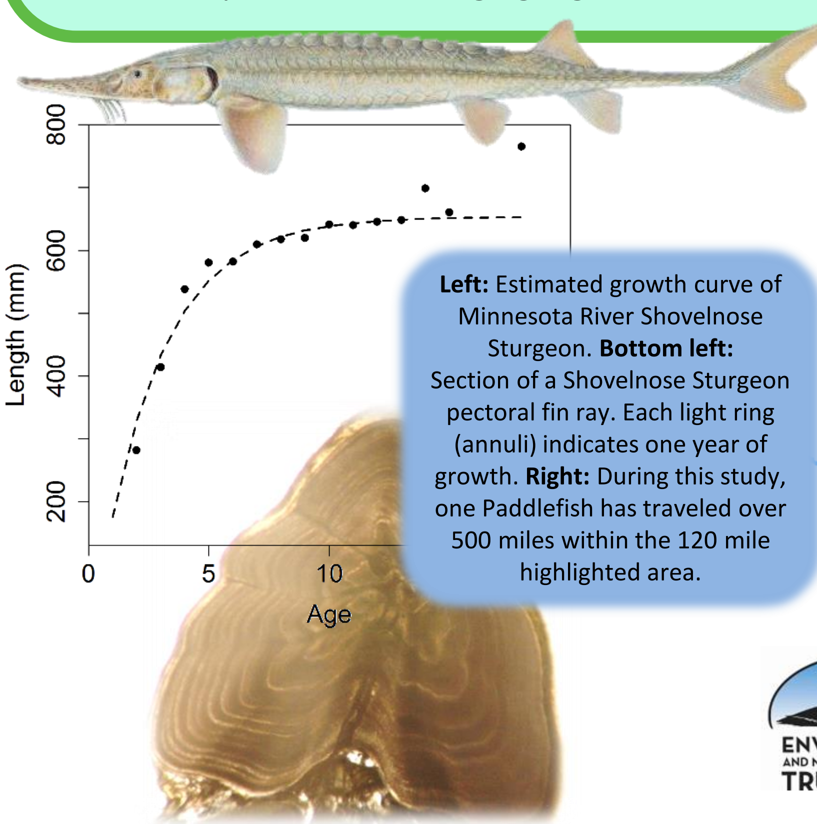
UPDATE (03/2018): ENHANCING UNDERSTANDING OF THE MINNESOTA RIVER ECOSYSTEM (PHASE-I)

Activity 3: Inventory Minnesota River backwater fish communities

- Developed protocols for assessing fish communities in backwater habitats.
- Conducting fish community assessments and compiling historical fish survey data.
- Evaluating relationships between fish communities and habitat characteristics.

Activity 4: Evaluate population dynamics, movement, and habitat use of Paddlefish and Shovelnose Sturgeon in the Minnesota River

- Captured 66 Paddlefish, indicating a more significant population inhabits the Minnesota River than previously known.
- Tracking movements of 36 Shovelnose Sturgeon and 14 Paddlefish tagged with acoustic transmitters.
- Captured and tagged over 300 Shovelnose Sturgeon, and collected fin rays from a subsample for estimating age, growth, and mortality parameters.



Left: Estimated growth curve of Minnesota River Shovelnose Sturgeon. **Bottom left:** Section of a Shovelnose Sturgeon pectoral fin ray. Each light ring (annuli) indicates one year of growth. **Right:** During this study, one Paddlefish has traveled over 500 miles within the 120 mile highlighted area.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

DEPARTMENT OF NATURAL RESOURCES

Introducing an LCCMR funded Minnesota River project and preliminary telemetry discoveries

Tony Sindt; Minnesota River Specialist
&
Mike Wolf; Minnesota River Technician

DEPARTMENT OF
NATURAL RESOURCES

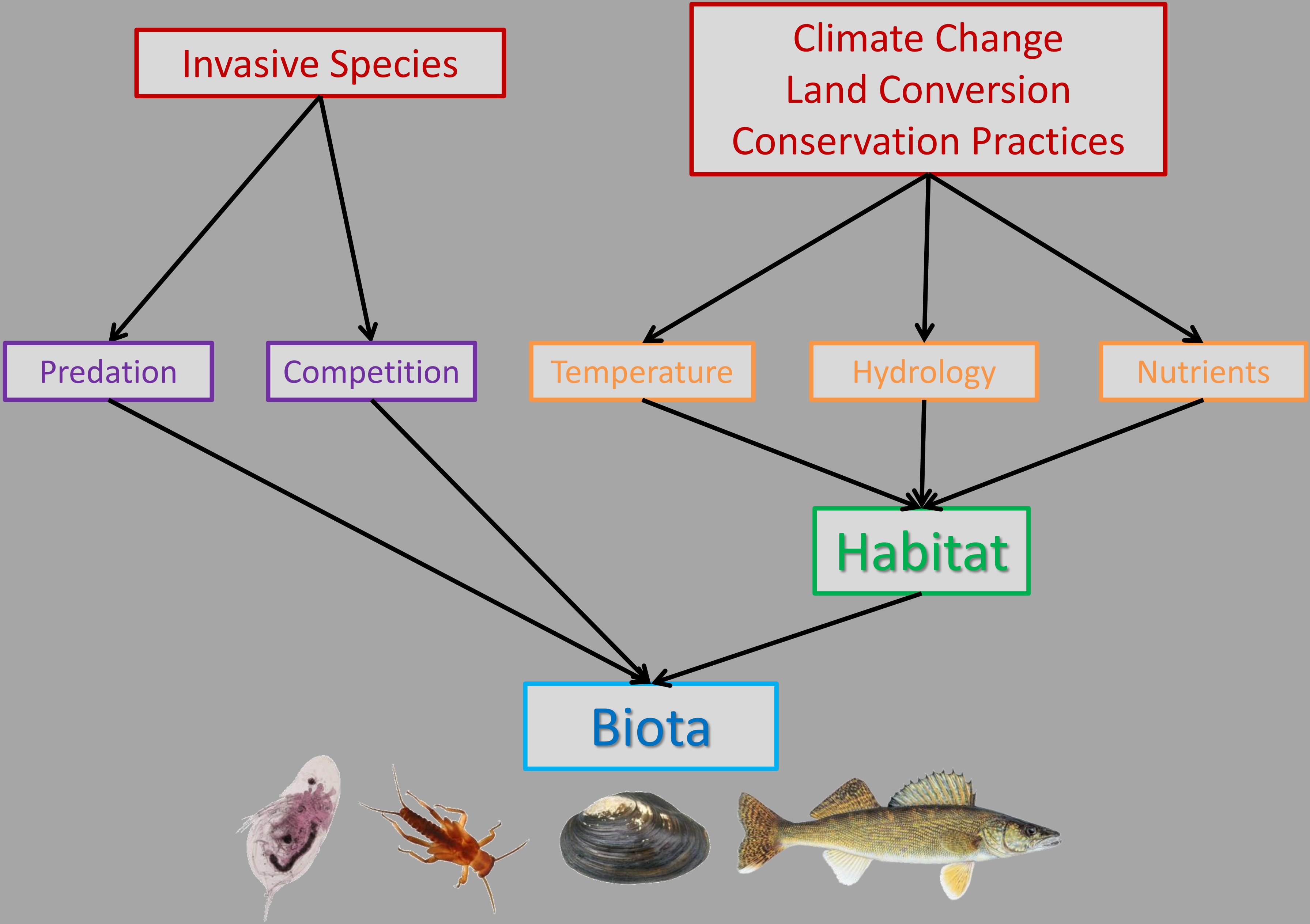
ENVIRONMENT
AND NATURAL RESOURCES
TRUST FUND

LCCMR & ENRTF

Legislative-Citizen Commission on Minnesota Resources: *Committee whose primary function is to make funding recommendations to the Minnesota legislature for special ENRTF projects, and provide oversight for all funded projects.*

Environment and Natural Resources Trust Fund: *Created to provide a long-term, consistent, and stable source of funding for innovative activities directed at protecting and enhancing Minnesota's environment and natural resources for the benefit of current citizens and future generations. Seven cents from every dollar spent on playing the Minnesota lottery is contributed to the trust fund.*

The Minnesota River is being impacted by changing land use, climate, invasive species, and conservation efforts



Invasive Species

Climate Change
Land Conversion
Conservation Practices

Predation

Competition

Temperature

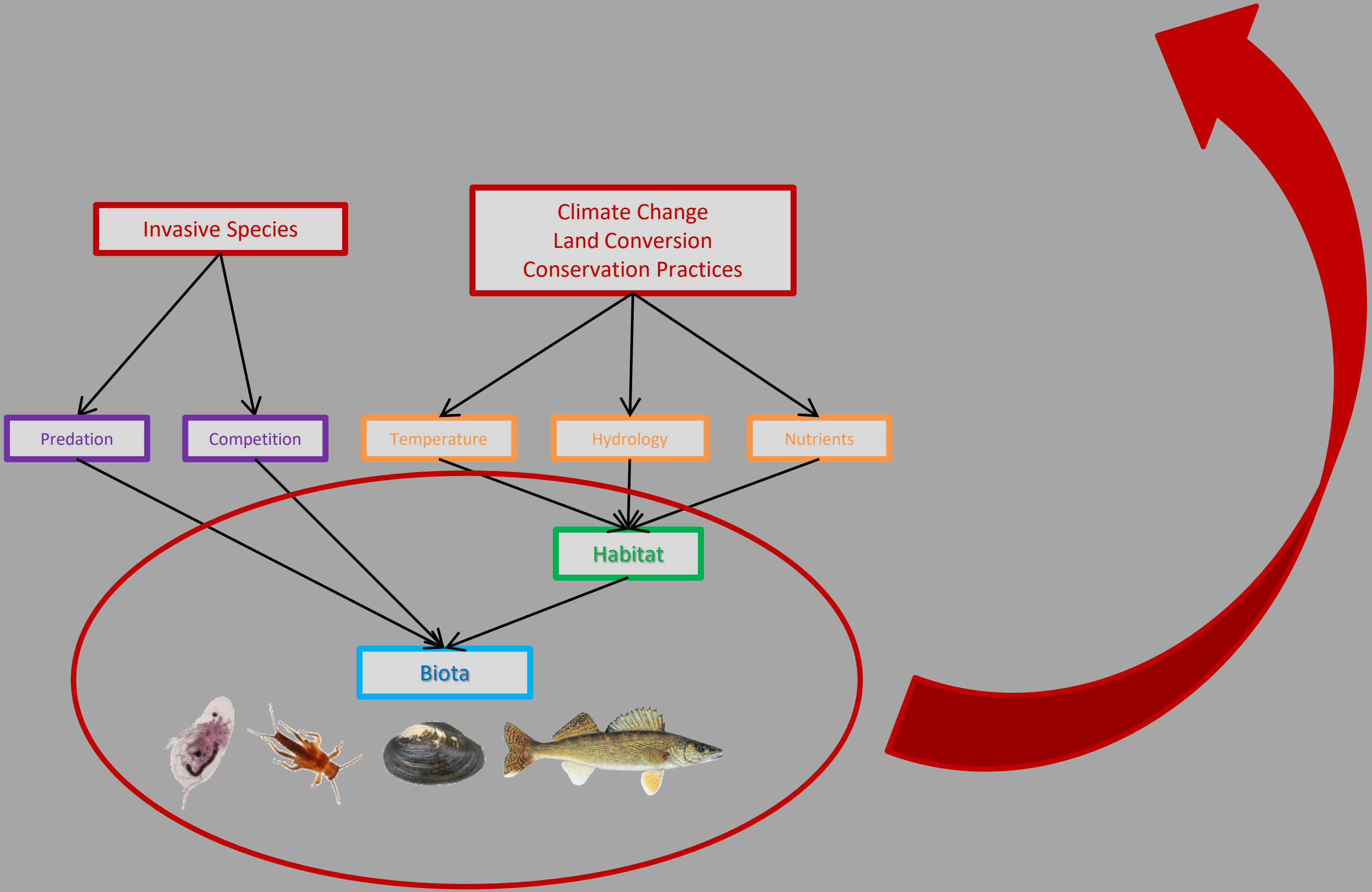
Hydrology

Nutrients

Habitat

Biota

Problem: There are hypothesized and anticipated impacts to the Minnesota River ecosystem (biota and habitat), but we lack the data and understanding to adequately predict and quantify these future impacts



How will


LAND MANAGEMENT


CLIMATE CHANGE


INVASIVE SPECIES


CONSERVATION EFFORTS

IMPACT


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

in the Minnesota River ecosystem?

How will


LAND MANAGEMENT


CLIMATE CHANGE


INVASIVE SPECIES


CONSERVATION EFFORTS

IMPACT


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

in the Minnesota River ecosystem?

We will never know, unless we accelerate efforts to collect baseline data now!

The MNDNR was awarded funds from the ENRTF to address this problem with four specific project activities

PLANKTON

HABITAT

BACKWATER ECOSYSTEMS

FISH

The MNDNR was awarded funds from the ENRTF to address this problem with four specific project activities

PLANKTON

HABITAT

BACKWATER ECOSYSTEMS

FISH

Activity 1: Accelerate collection of baseline Minnesota River lower trophic data

The MNDNR was awarded funds from the ENRTF to address this problem with four specific project activities


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Activity 2: Quantify physical habitat characteristics of the Minnesota River

The MNDNR was awarded funds from the ENRTF to address this problem with four specific project activities


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Activity 3: Inventory Minnesota River backwater fish communities

The MNDNR was awarded funds from the ENRTF to address this problem with four specific project activities

PLANKTON

HABITAT

BACKWATER ECOSYSTEMS

FISH

Activity 4: Evaluate population dynamics, movement, and habitat use of Shovelnose Sturgeon (and Paddlefish) in the Minnesota River

Changes Continue!

- 1 Grass Carp captured Dec. 2015
- 1 Bighead Carp captured Feb. 2016
- Zebra Mussels discovered summer 2016

- New buffer laws

Accomplishments

Activity 1: Accelerate collection of baseline Minnesota River lower trophic data

Collected samples during August, September and October at 7 sites

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Water chemistry analyzed by MN Department of Agriculture

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Zooplankton samples were processed by Jodie Hirsch at MN DNR

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Collected samples during August, September and October at 7 sites

Water chemistry analyzed by MN Department of Agriculture

Zooplankton samples were processed by Jodie Hirsch at MN DNR

Phytoplankton were processed by BSA Environmental Services

Activity 3: Inventory Minnesota River backwater fish communities

Sampled 4 backwaters during fall 2016

BACKWATER ECOSYSTEMS

Activity 3: Inventory Minnesota River backwater fish communities

Sampled 4 backwaters during fall 2016

Aged BLC and WHC from Mack Lake

BACKWATER

ECOSYSTEMS

Activity 3: Inventory Minnesota River backwater fish communities

Sampled 4 backwaters during fall 2016

Aged BLC and WHC from Mack Lake

8 more backwaters to be sampled during 2017-2018

BACKWATER
ECOSYSTEMS

Activity 4: Evaluate population dynamics, movement, and habitat use of Shovelnose Sturgeon (and Paddlefish) in the Minnesota River

Established stationary acoustic receiver array

Activity 4: Evaluate population dynamics, movement, and habitat use of Shovelnose Sturgeon (and Paddlefish) in the Minnesota River

Established stationary acoustic receiver array

Sampled SLS and PAD

Activity 4: Evaluate population dynamics, movement, and habitat use of Shovelnose Sturgeon (and Paddlefish) in the Minnesota River

Established stationary acoustic receiver array

Sampled SLS and PAD

Implanted SLS and PAD with acoustic transmitters

Activity 4: Evaluate population dynamics, movement, and habitat use of Shovelnose Sturgeon (and Paddlefish) in the Minnesota River

Established stationary acoustic receiver array

Sampled SLS and PAD

Implanted SLS and PAD with acoustic transmitters

Manually tracked implanted fish

Acoustic Telemetry

Stationary Receivers

Uploaded each of 6 receivers at least once

Stationary Receivers

Uploaded each of 6 receivers at least once

Pool 2

1 Paddlefish

1 Common Carp

1 White Bass

2 S. Buffalo

5 B. Buffalo

MNR

1 Shovelnose Sturgeon

Stationary Receivers

Uploaded each of 6 receivers at least once

Pool 2

1 Paddlefish

1 Common Carp

1 White Bass

2 S. Buffalo

5 B. Buffalo

MNR

1 Shovelnose Sturgeon

4-1
Big Stone
Ortonville
Swift
Stearns
Sherburne
Isanti
Anoka
Kandiyohi
Meeker
Wright
Hennepin
Ram
St. Pa
Lac qui Parle
Chippewa
Montevideo
Granite Falls
McLeod
Shakopee
Washing
Yellow Medicine
Renville
Dakota
Scott
Belle Plaine
Sibley
Redwood Falls
Lincoln
Lyon
Redwood
Le Sueur
Nicollet
St. Peter
Rice
Good
New Ulm
Brown
Mankato


Pope
Stearns
Isanti
Big Stone
Sherburne
Ortonville
Swift
Anoka
Kandiyohi
Wright
Meeker
Lac qui Parle
Chippewa
Montevideo
Hennepin
Ram
St. Pa
4-2
McLeod
Carver
Granite Falls
Washing
Yellow Medicine
Renville
Dakota
Scott
Sibley
Belle Plaine
Redwood Falls
Lincoln
Lyon
Redwood
Le Sueur
Nicollet
Rice
Good
St. Peter
New Ulm
Brown
Mankato


Pope
Stearns
Isanti
Big Stone
Ortonville
Sherburne
Swift
Anoka
Wright
Kandiyohi
Meeker
Lac qui Parle
Chippewa
Hennepin
Ram
Montevideo
St. Pa
McLeod
Carver
Granite Falls
Yellow Medicine
Renville
Washing
Shakopee
Dakota
4-8
Scott
Sibley
Belle Plaine
Redwood Falls
Lincoln
Lyon
Redwood
Le Sueur
Nicollet
Rice
Good
St. Peter
New Ulm
Brown
Mankato


Stearns
Isanti
Big Stone
Ortonville
Sherburne
Swift
Anoka
Kandiyohi
Wright
Meeker
Lac qui Parle
Chippewa
Hennepin
Montevideo
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Le Sueur
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St. Peter
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Brown

4-14


Stearns
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Sherburne
Ortonville
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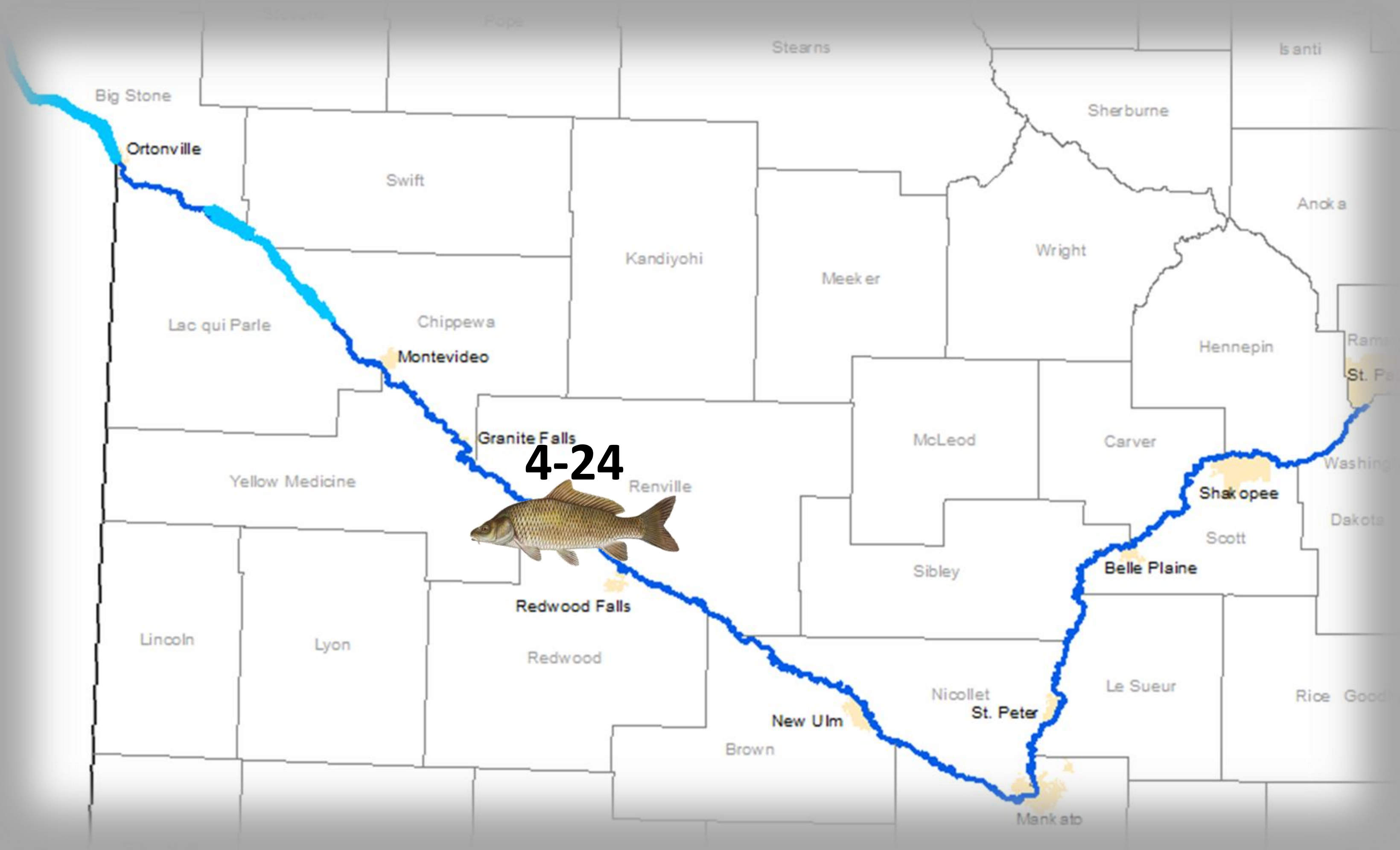
4-17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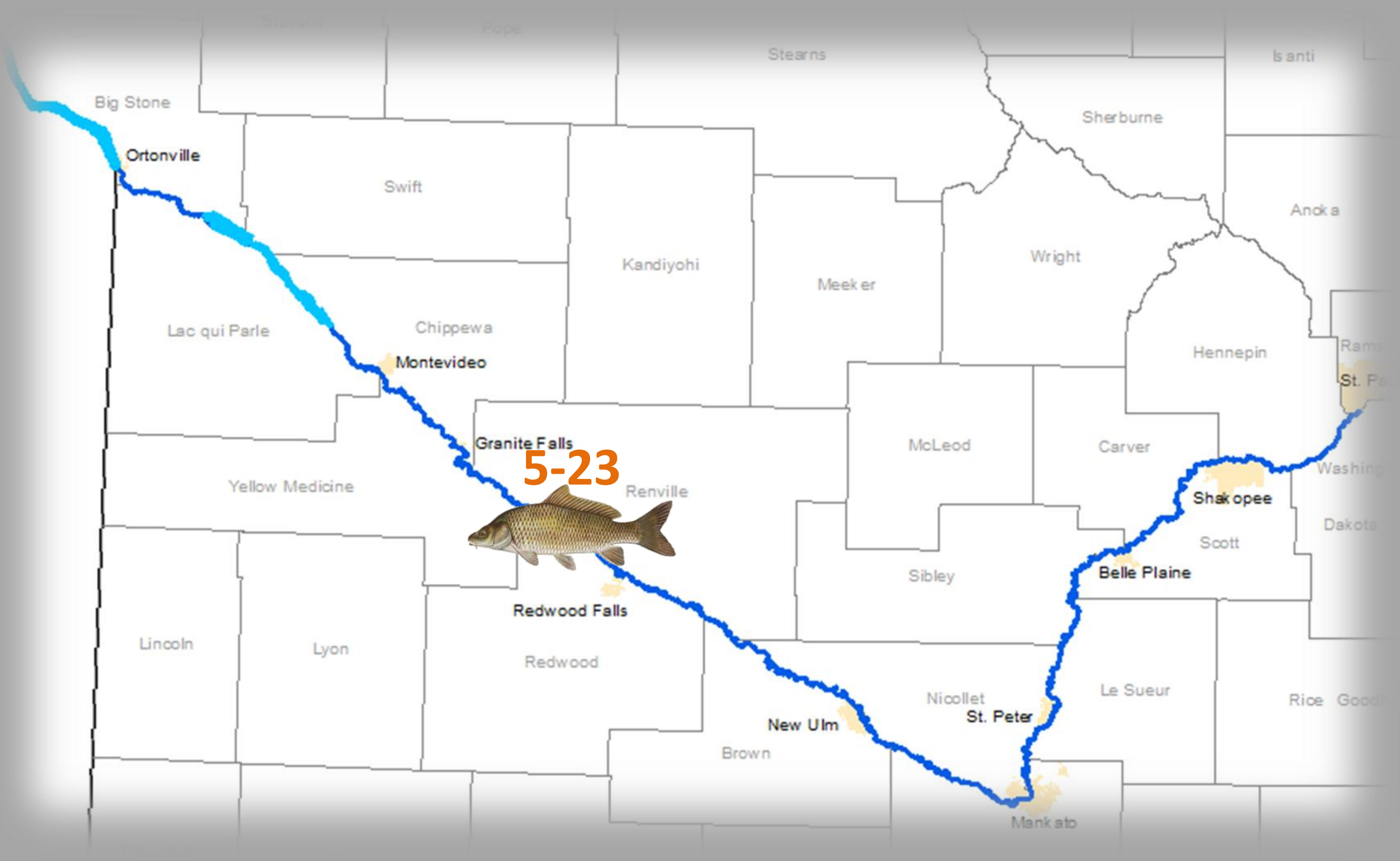
Mankato

4-24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Nicollet
Rice
Good
St. Peter
New Ulm
Brown
Mankato


7-9
Pope
Stearns
Isanti
Big Stone
Ortonville
Swift
Sherburne
Anoka
Kandiyohi
Meeker
Wright
Lac qui Parle
Chippewa
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Nicollet
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New Ulm
7-10
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7-11

Pope
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Big Stone
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Ortonville
Swift
Anoka
Kandiyohi
Wright
Meeker
Chippewa
Lac qui Parle
Montevideo
Hennepin
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Granite Falls
Washing
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Scott
Sibley
Belle Plaine
Redwood Falls
Lincoln
Lyon
Redwood
Nicollet
St. Peter
Le Sueur
Rice
Good
New Ulm
Brown
Mankato

Most recent detection by Joel Stiras VR2


Big Stone
Ortonville
Swift
Stearns
Sherburne
Isanti
Anoka
Kandiyohi
Meeker
Wright
Lac qui Parle
Chippewa
Montevideo
Hennepin
Ramsey
St. Paul
Granite Falls
McLeod
Carver
Washington
Yellow Medicine
Renville
Shakopee
Dakota
Scott
Sibley
Belle Plaine
Redwood Falls
Lincoln
Lyon
Redwood
Le Sueur
Rice
Goodhue
Nicollet
St. Peter
New Ulm
Brown
Mankato

6-12-16


Pope
Stearns
Isanti
Big Stone
Ortonville
Sherburne
Swift
Anoka
Kandiyohi
Wright
Meeker
Lac qui Parle
Chippewa
Montevideo
Hennepin
Ram
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Granite Falls
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Carver
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Redwood Falls
Lincoln
Lyon
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Nicollet
St. Peter
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6-27-16


Stearns
Isanti
Big Stone
Sherburne
Ortonville
Swift
Anoka
Kandiyohi
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Lyon
Redwood
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Nicollet
Rice
Good
St. Peter
New Ulm
Brown
Mankato

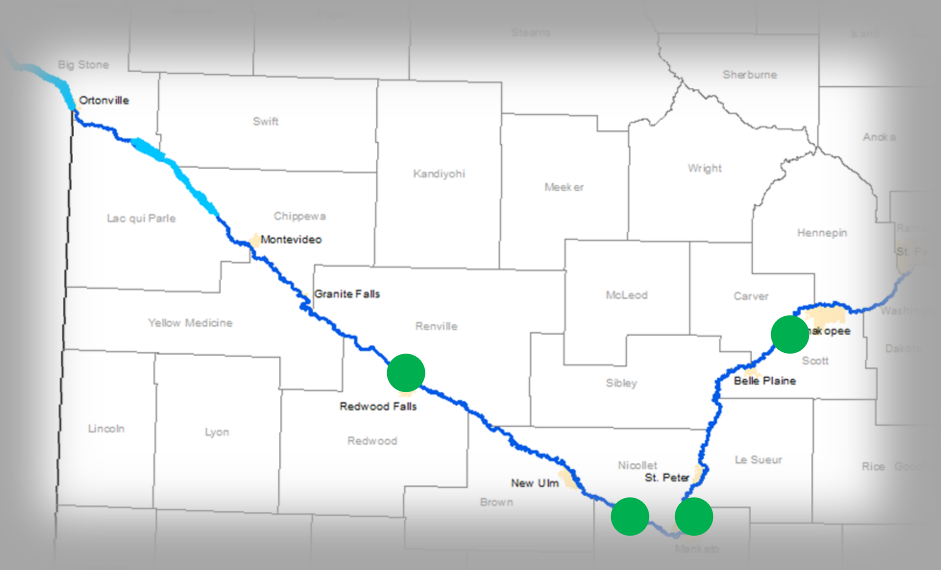
6-30-16

Shovelnose Sturgeon Telemetry

- 26 implanted in Fall 2016 at 4 sites
  - North Redwood (9)
  - Judson (9)
  - Mankato (7)
  - Chaska (1)

- Sites were spaced along 170 river miles

- Actively tracked with a Vemco VR100 during subsequent trips



Judson 9-21

Judson 10-12

Judson 10-19

Judson 10-28

Judson 11-29

North Redwood 8-29-16

North Redwood 8-30-16

North Redwood 9-12-16

North Redwood 10-7-16

54 river miles downstream in 25 days

North Redwood 10-20-16

North Redwood 10-27-16

North Redwood 11-28-16

North Redwood 3-27-17

Paddlefish Telemetry

Implanted 4 Paddlefish at St. Peter during summer 2016

Paddlefish Telemetry

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Tracked during three subsequent trips in the fall

Paddlefish Telemetry

Implanted 4 Paddlefish at St. Peter during summer 2016

Tracked during three subsequent trips in the fall

Fish moved very little and began congregating by the end of October

St. Peter
8-31

St. Peter
9-13

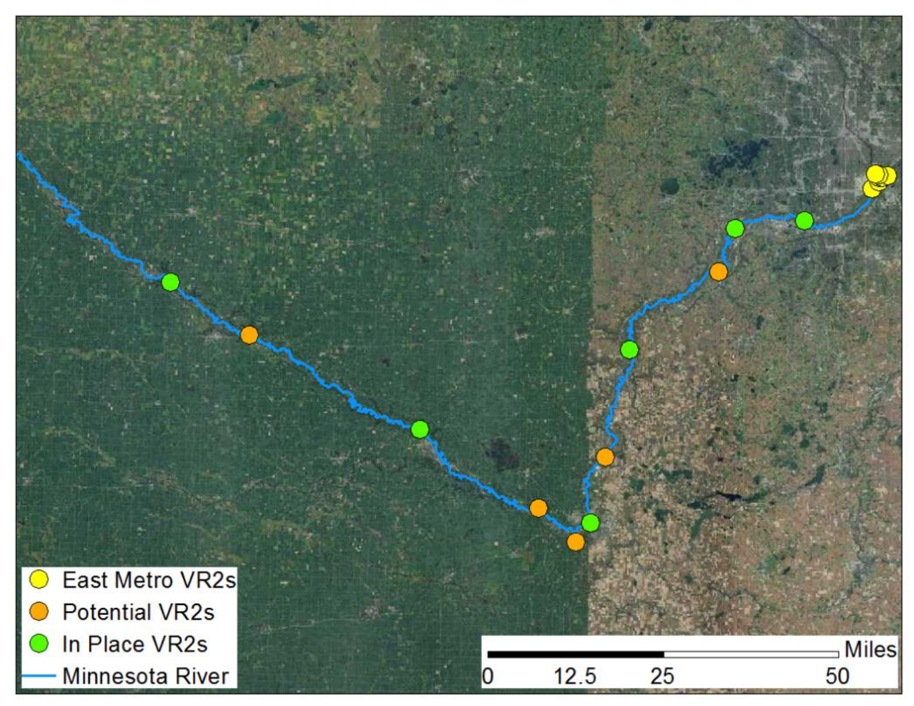
St. Peter
10-28

53215
53216
53217
53218

St. Peter
12-1

53215
53216
53217
53218

Future Directions



- Install five more stationary receivers (orange) during low water conditions
- Continue uploading VR2 data
- Continue active tracking of PAD and SLS
- Implant 10 additional SLS with acoustic transmitters

DEPARTMENT OF NATURAL RESOURCES

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Minnesota River Paddlefish, Sturgeon, Backwaters, Plankton, and More!

Outcomes of a 3-year ENRTF funded project

Tony Sindt
Minnesota River Specialist

DEPARTMENT OF NATURAL RESOURCES

SPORT FISH RESTORATION

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

DEPARTMENT OF NATURAL RESOURCES

Project Staff: Eric Katzenmeyer, Mike Vaske, Mike Wolf, Kayla Stampfle

Jodie Hirsch

Heidi Rantala

Joel Stiras

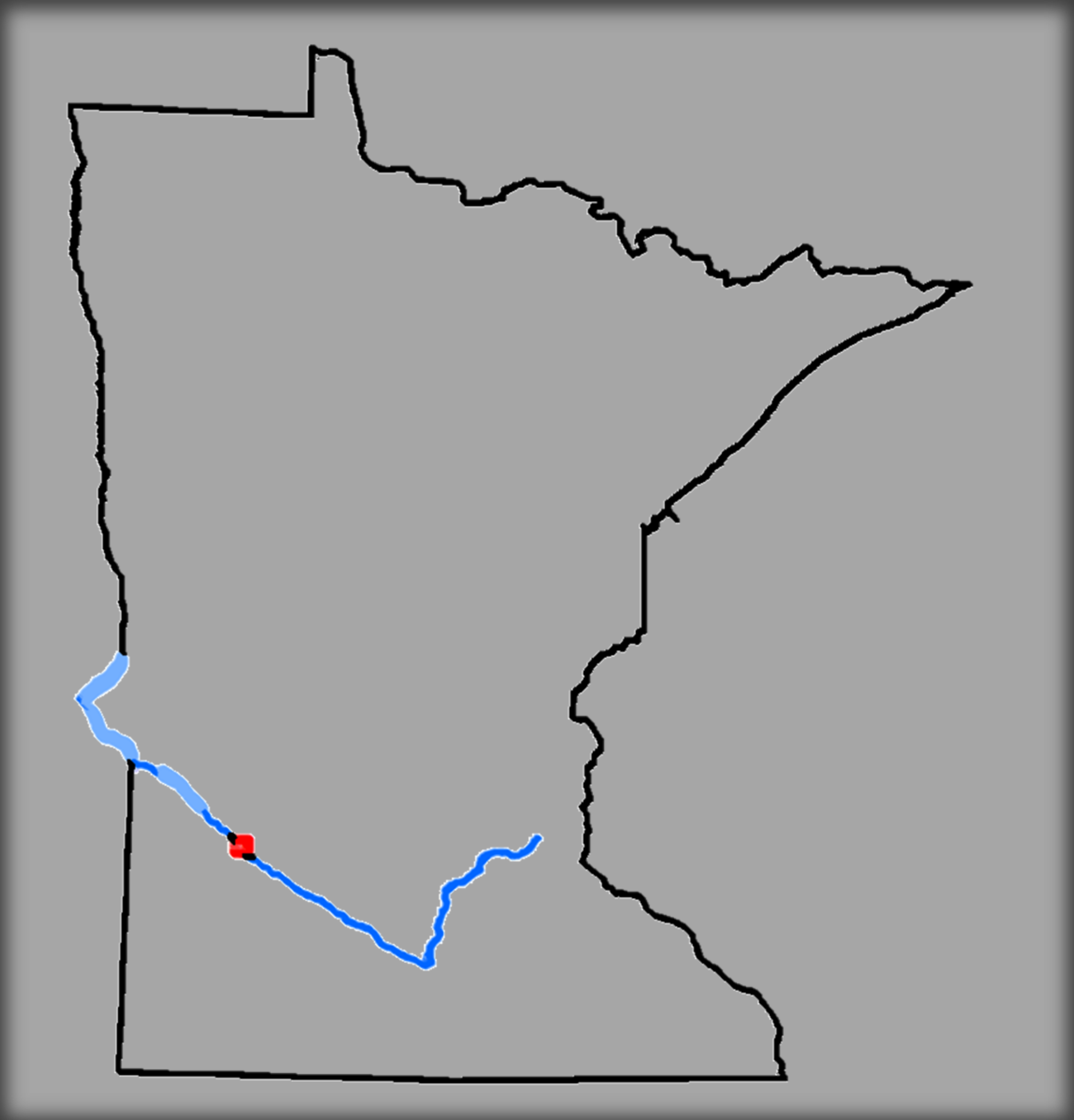
Brian Schultz

AND MANY MORE!

Interns: Garrett Ober, Ben Erb, Melissa Oubre, Sam Peterson

SPORT FISH RESTORATION

Enhance understanding of the Minnesota River ecosystem



Enhance understanding of the Minnesota River ecosystem

Enhance understanding of the Minnesota River ecosystem


LAND MANAGEMENT


CLIMATE CHANGE


INVASIVE SPECIES


CONSERVATION EFFORTS


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Enhance understanding of the Minnesota River ecosystem


LAND MANAGEMENT


CLIMATE CHANGE


INVASIVE SPECIES


CONSERVATION EFFORTS


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Objectives: Establish baseline datasets and enhance understanding

Outline


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Outline

Lower Trophic Ecology:

Evaluate spatial and temporal trends in water chemistry and phytoplankton and zooplankton communities

Outline


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Skip: bathymetry maps & fish community assessments

Outline


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Paddlefish:

presence, abundance, and telemetry

Shovelnose Sturgeon:

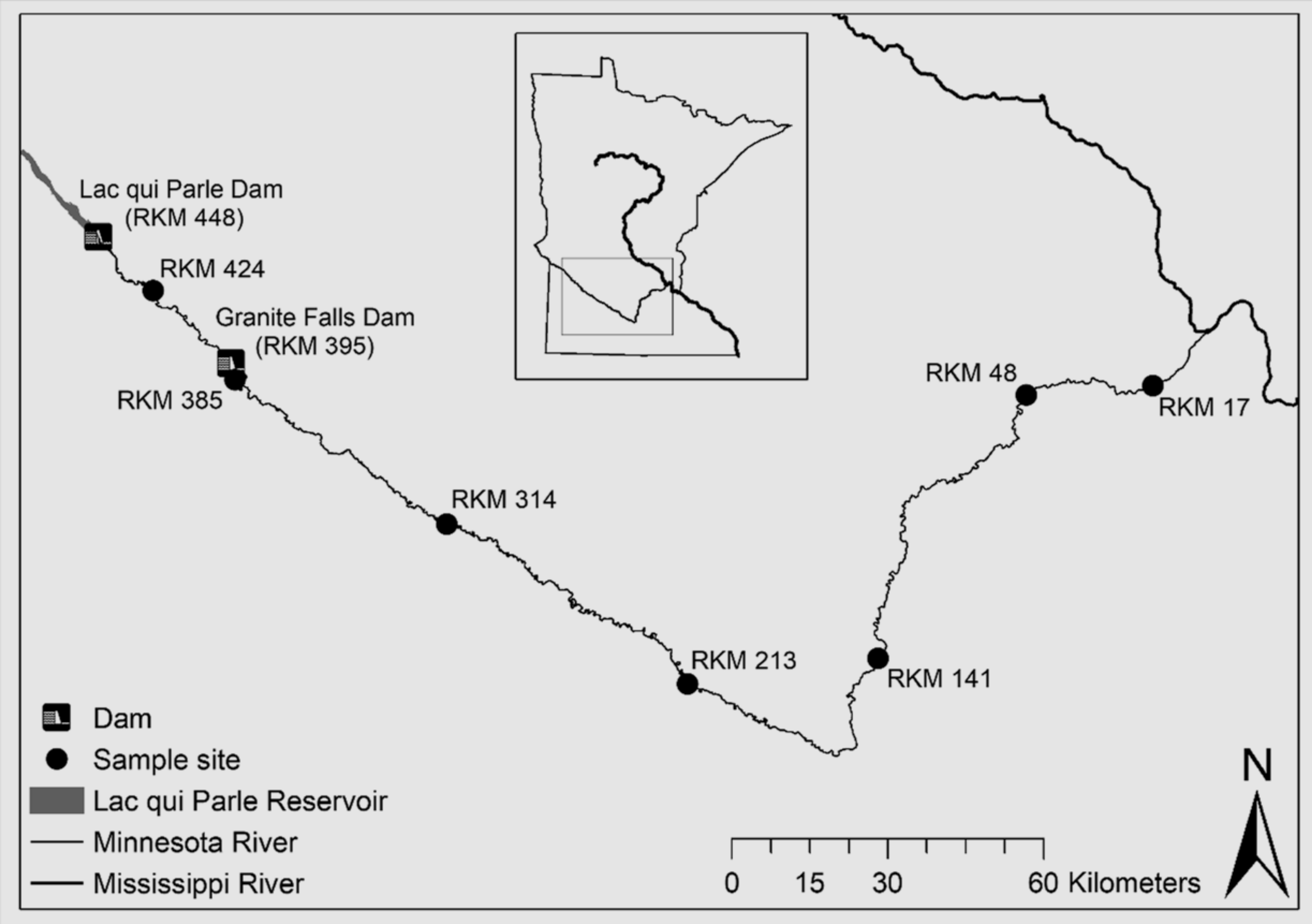
population dynamics and telemetry

Lower Trophic Ecology

PLANKTON

Lower Trophic Ecology

- Water, phytoplankton, and zooplankton samples
- Monthly May–October
- 2016*, 2017, & 2018



Lower Trophic Ecology

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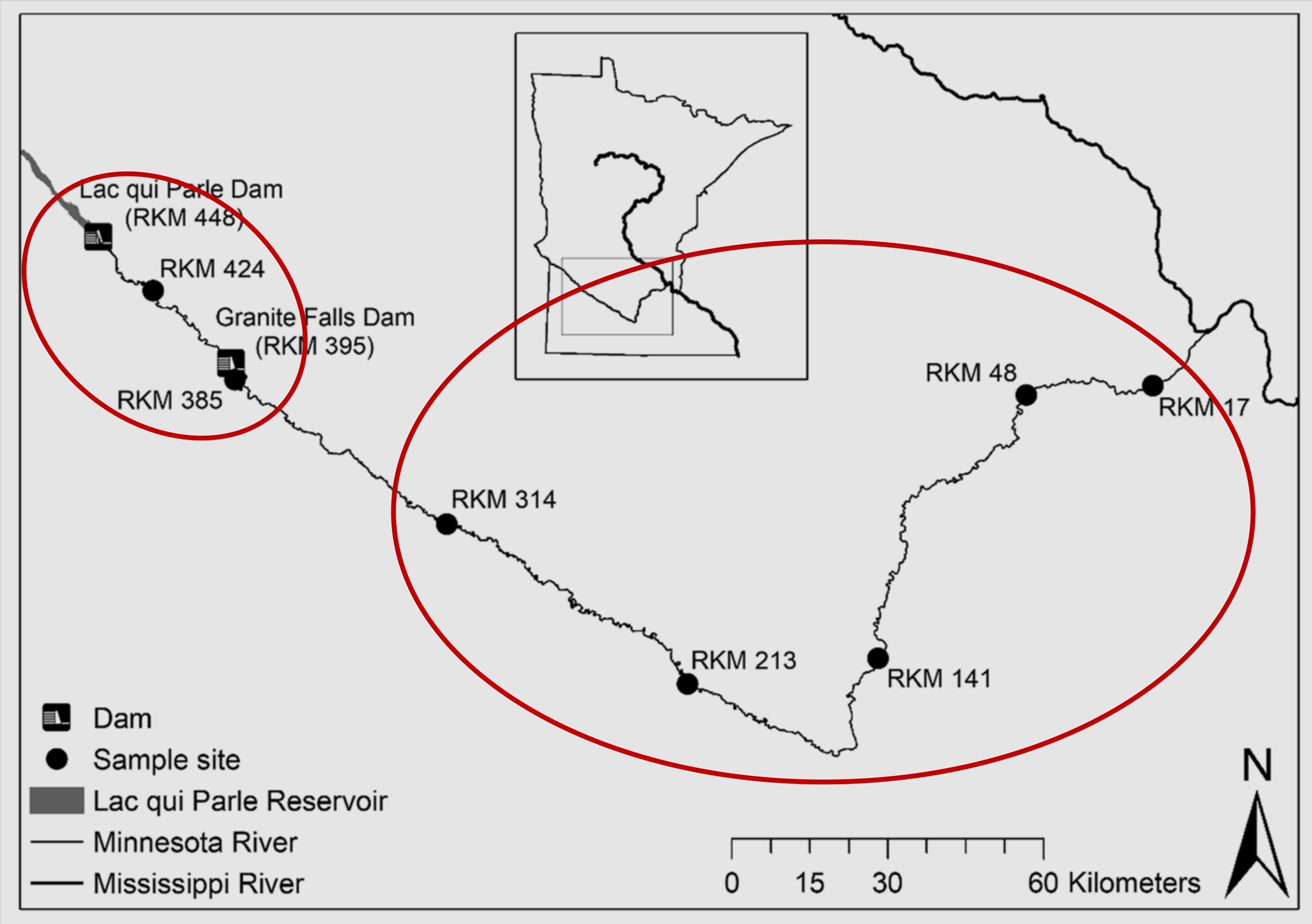
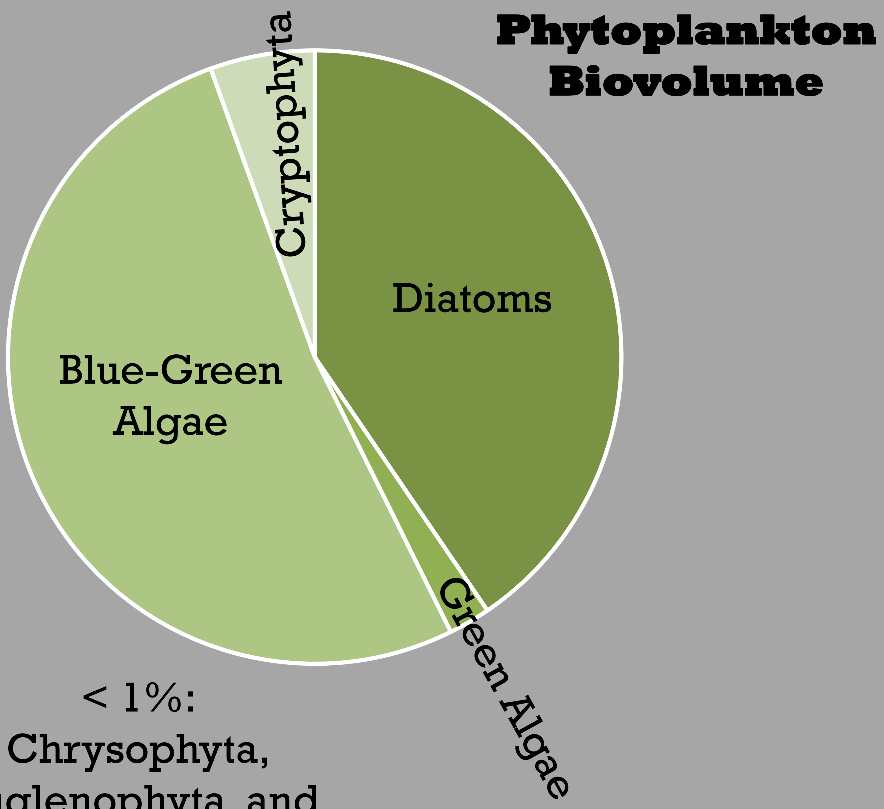


Lower Trophic Ecology

Lower Trophic Ecology

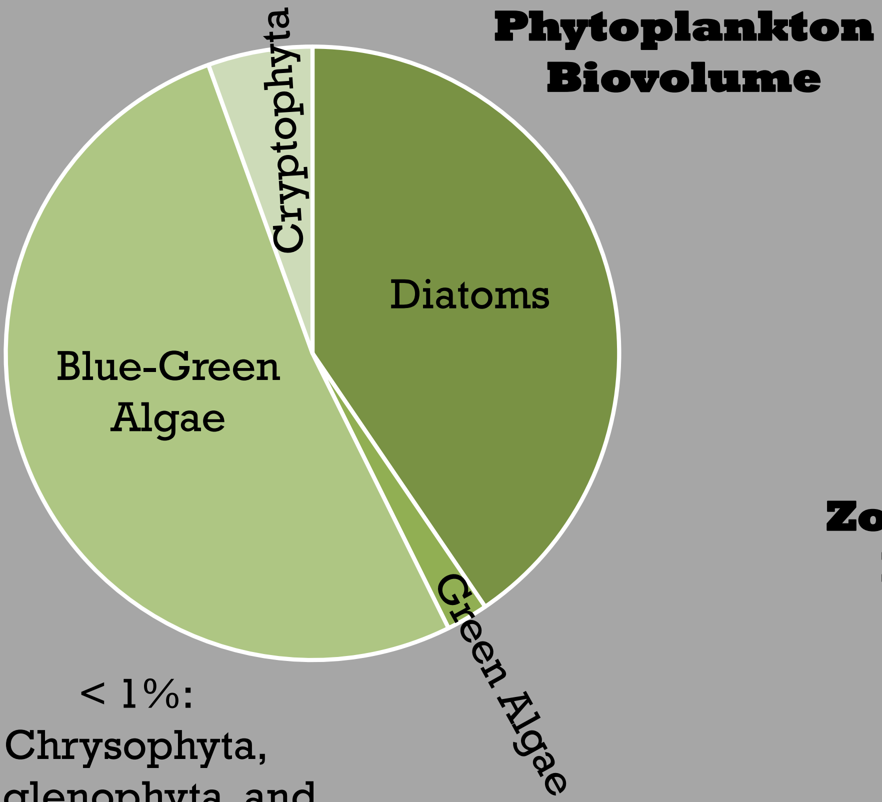
Phytoplankton



< 1%:
Chrysophyta,
Euglenophyta, and
Pyrrophyta

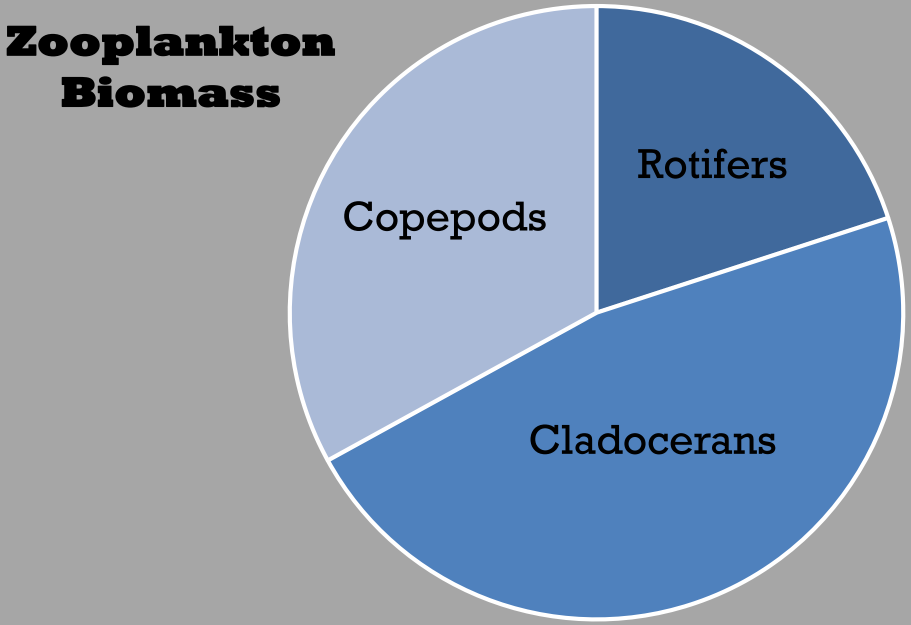
Lower Trophic Ecology

Phytoplankton

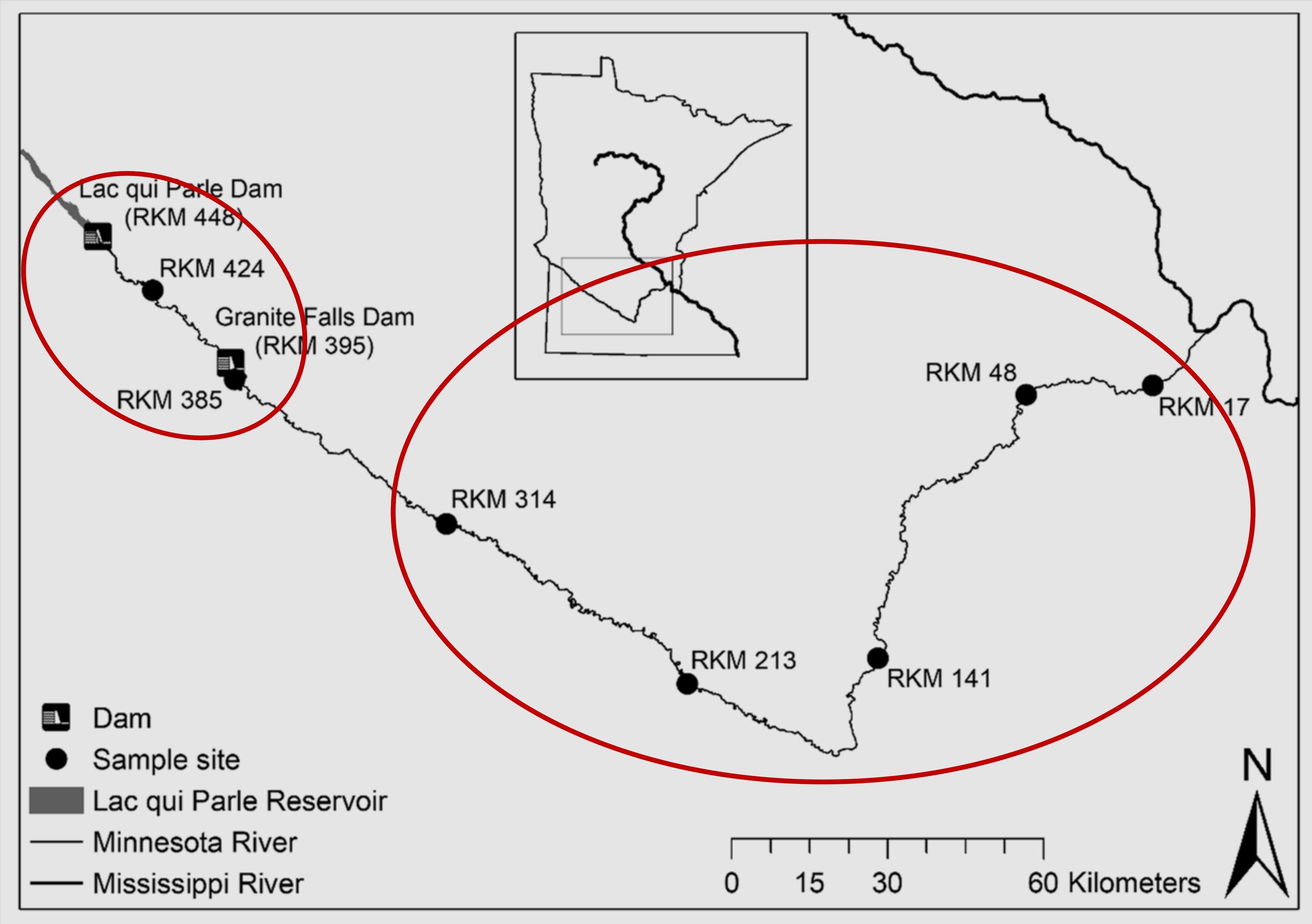


< 1%:
Chrysophyta,
Euglenophyta, and
Pyrrophyta

Zooplankton

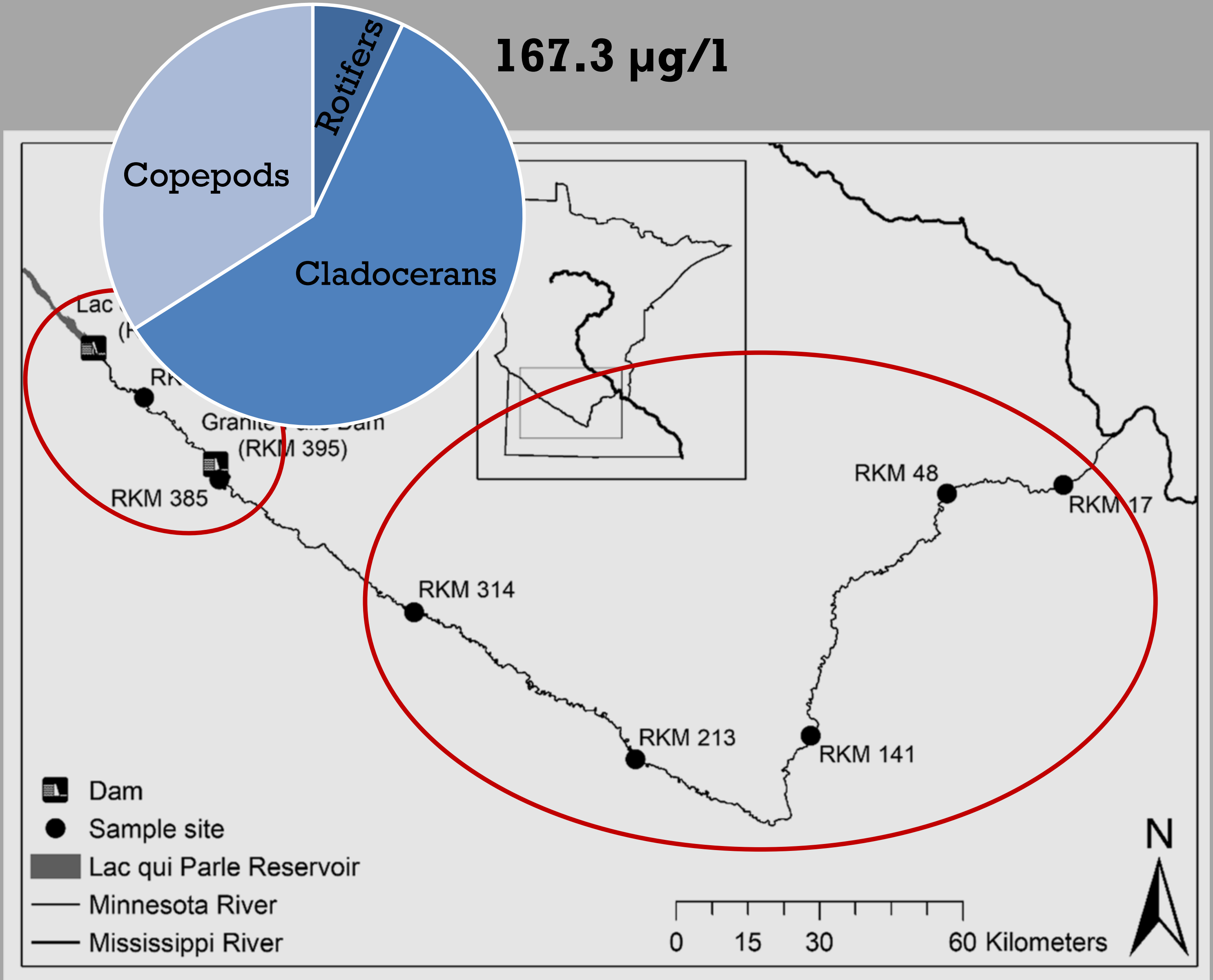


Lower Trophic Ecology

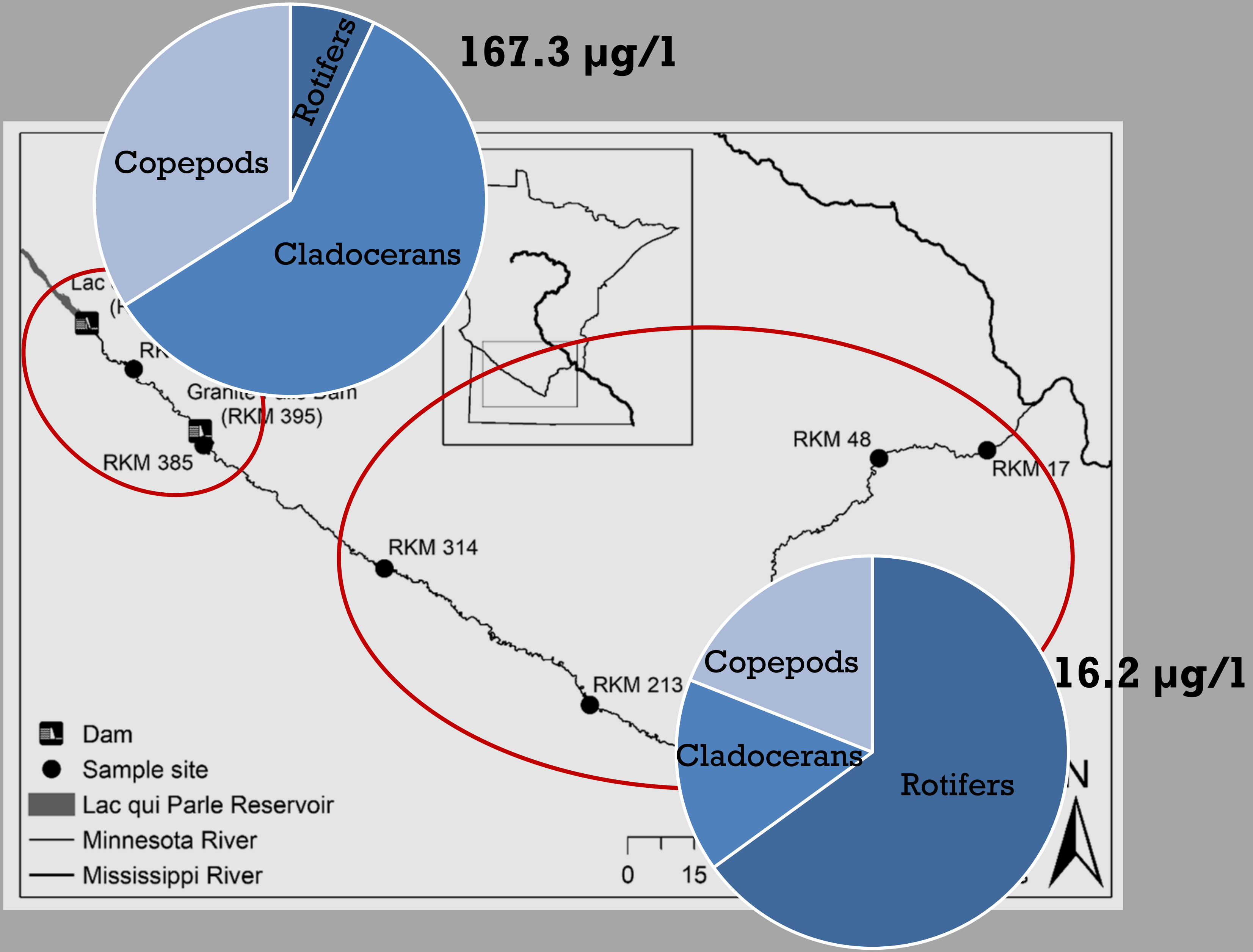


Lower Trophic Ecology

167.3 µg/l



Lower Trophic Ecology



Lower Trophic Ecology - SUMMARY

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Many Abiotic Variables

- Spatial (sites)
- Temporal (year, season, month)
- Water chemistry (e.g., TSS, TKN)
- Site (temp, Secchi, relative discharge)

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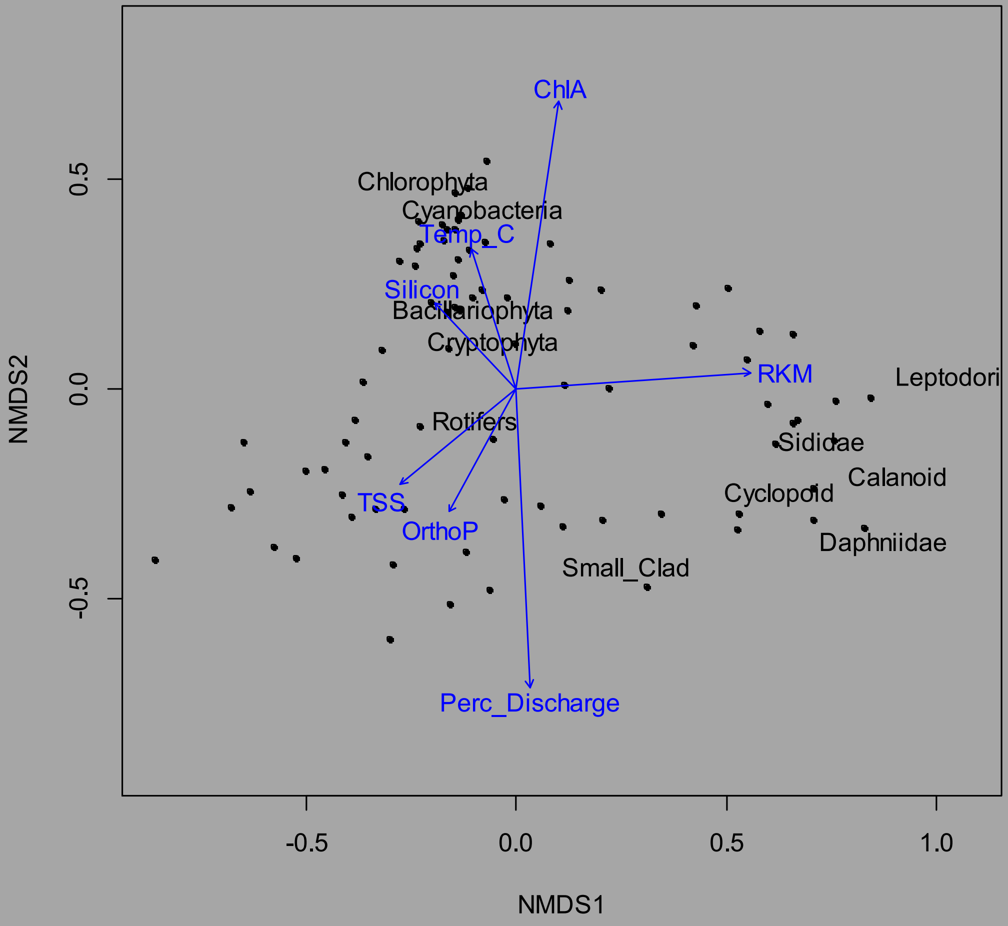
Multivariate Analyses (NMDS)



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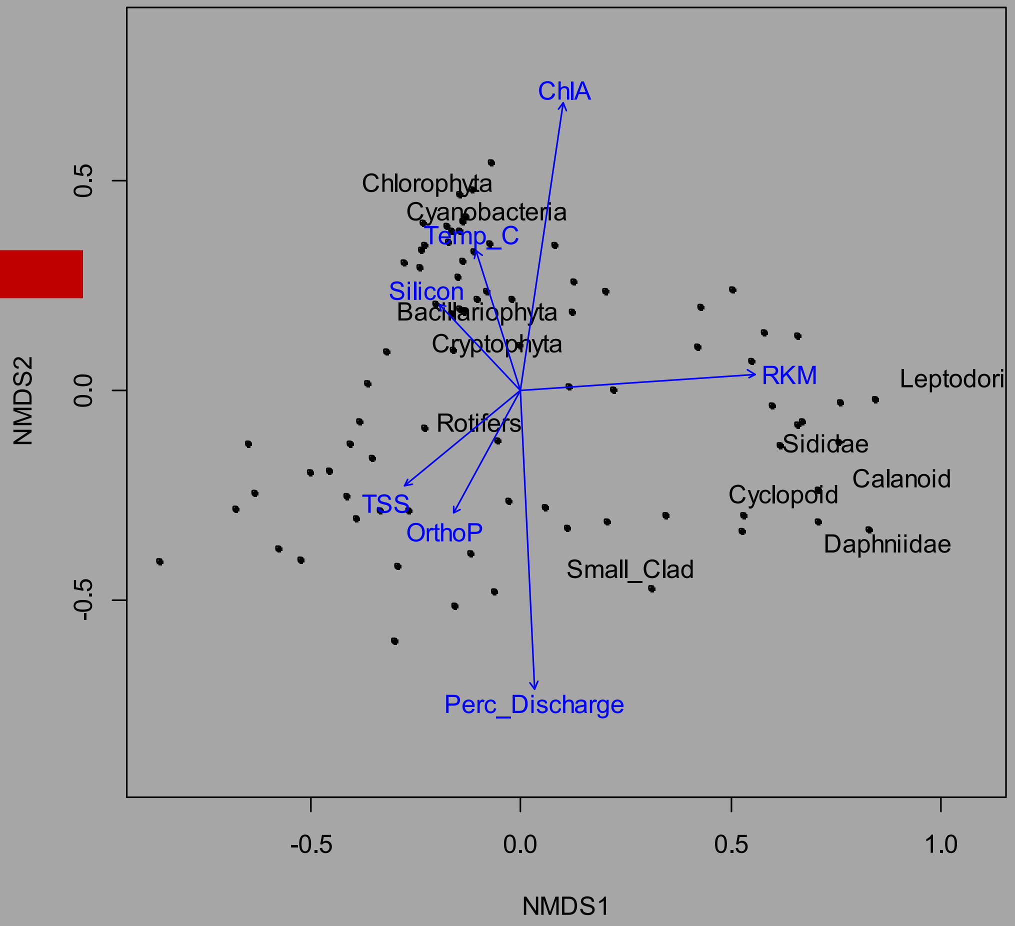
- Impoundments have the greatest influence on **zooplankton**.



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Summary

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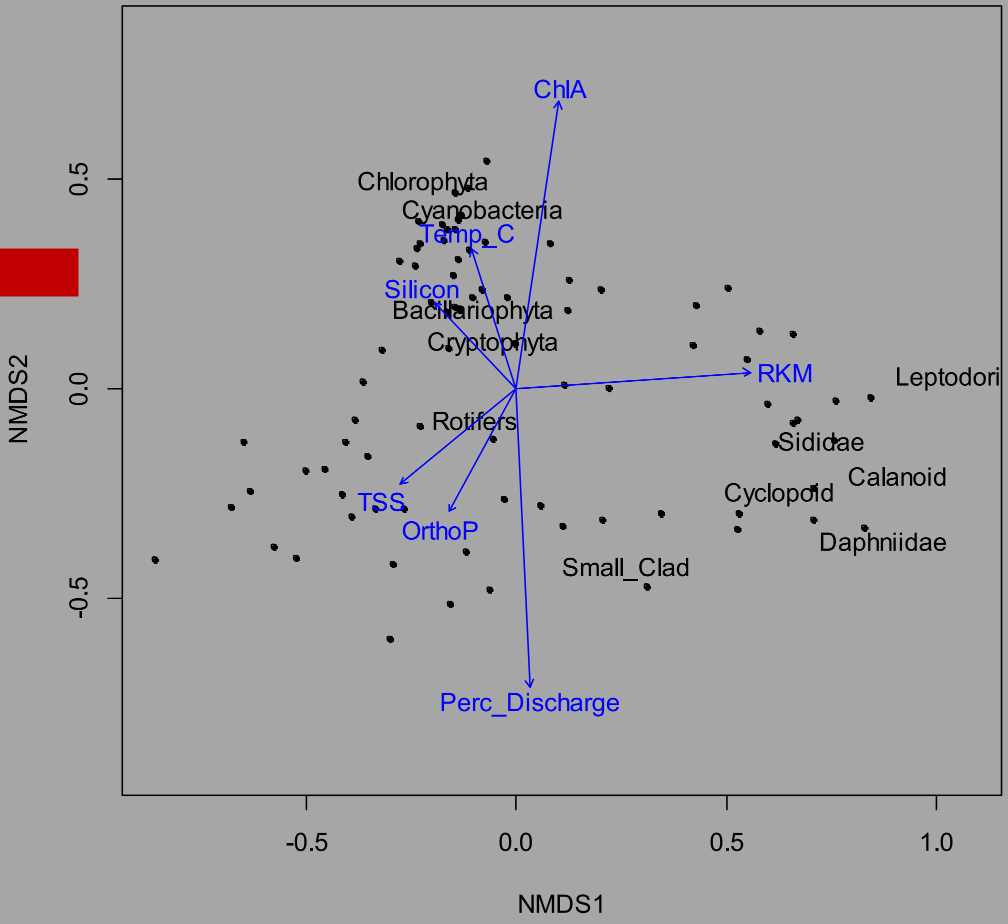
- Excluding that influence, temporal variability (month) is greatest for both **phytoplankton** and **zooplankton**.



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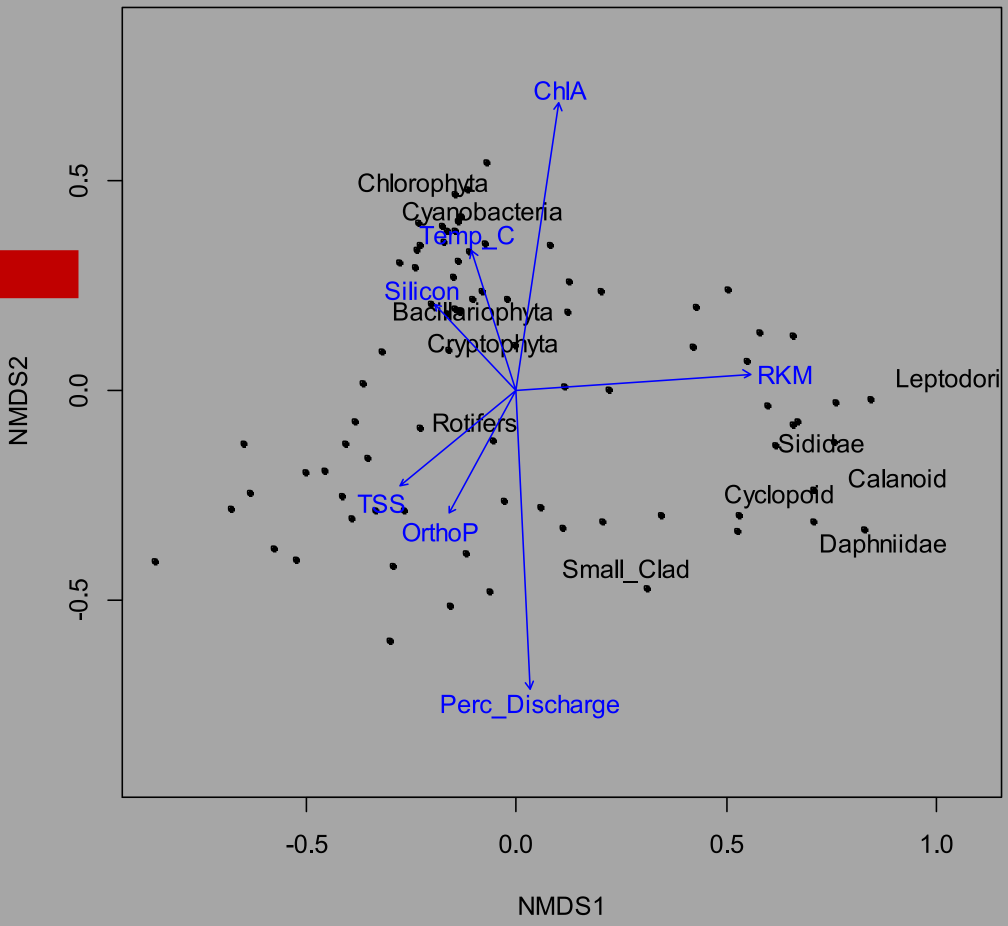
Multivariate Analyses (NMDS)

Summary

- Impoundments have the greatest influence on **zooplankton**.
- Excluding that influence, temporal variability (month) is greatest for both **phytoplankton** and **zooplankton**.
- The greatest influence on temporal variability is **relative discharge**.



Paddlefish

Paddlefish

Oldest photo evidence

Fall 1951 40# 50#

ART Schmidt + Co. Seining Rough Fish Below Pete's Pt.
Gr. Falls MN.

(Paddlefish)

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Only 1 sampled by DNR staff prior to 2016

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Last 20 years:

Increasing incidental catches by anglers and commercial fishermen

Paddlefish

Oldest photo evidence

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Last 20 years:

Increasing incidental catches by anglers and commercial fishermen

Nearest confirmed spawning: Chippewa River > 125 km downstream

Paddlefish

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Primarily with stationary or drifted 5" mesh gill nets

Most PAH were caught from 4 sites

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Paddlefish are certainly more abundant in the Minnesota River than previously perceived

Paddlefish

Telemetry data provides valuable insight into habitat use and movement patterns

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3 Movement Patterns (20 fish):

Paddlefish

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- **Sedentary:** **7 Fish that exhibit small home ranges**

Paddlefish

Telemetry data provides valuable insight into habitat use and movement patterns

3 Movement Patterns (20 fish):

- **Sedentary:** **7 Fish that exhibit small home ranges**
- **Mobile:** **3 Fish that frequently make large movements**

Greatest short-term movement:
> 230 km

Greatest total movement:
> 1,300 km

Paddlefish

Telemetry data provides valuable insight into habitat use and movement patterns

3 Movement Patterns (20 fish):

- **Sedentary:** 7 Fish that exhibit small home ranges
- **Mobile:** 3 Fish that frequently make large movements
- **Forays:** 5 Fish initially tagged in other rivers that made 1 or 2 forays into the MNR (Stiras & Hoxmeier)

Paddlefish

The Big Question:

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Are Paddlefish successfully reproducing within the Minnesota River?

Shovelnose Sturgeon

Shovelnose Sturgeon

Sturgeons are **globally endangered**, but SLS may be among the most resilient spp. due to unique life history characteristics

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2015: removed as state species of conservation need and MN DNR opened a catch-and-release season

Shovelnose Sturgeon

Sturgeons are **globally endangered**, but SLS may be among the most resilient spp. due to unique life history characteristics

2015: removed as state species of conservation need and MN DNR opened a catch-and-release season

Likely more abundant in the Minnesota River than any other MN system. Unfortunately, **very little is know about their population dynamics and movement patterns**

Shovelnose Sturgeon

We captured **391** Shovelnose Sturgeon during 2016–2018 from four study reaches using a variety of sampling gears

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Most Effective Gear:
Fall Trotlines

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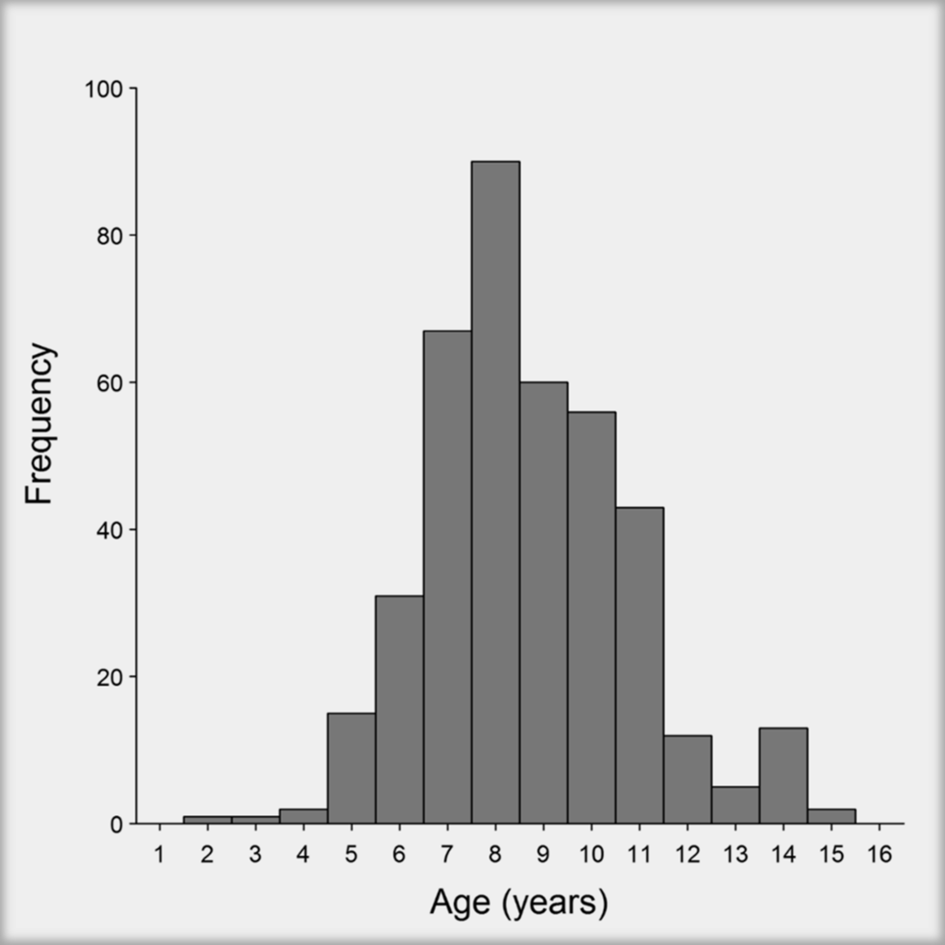

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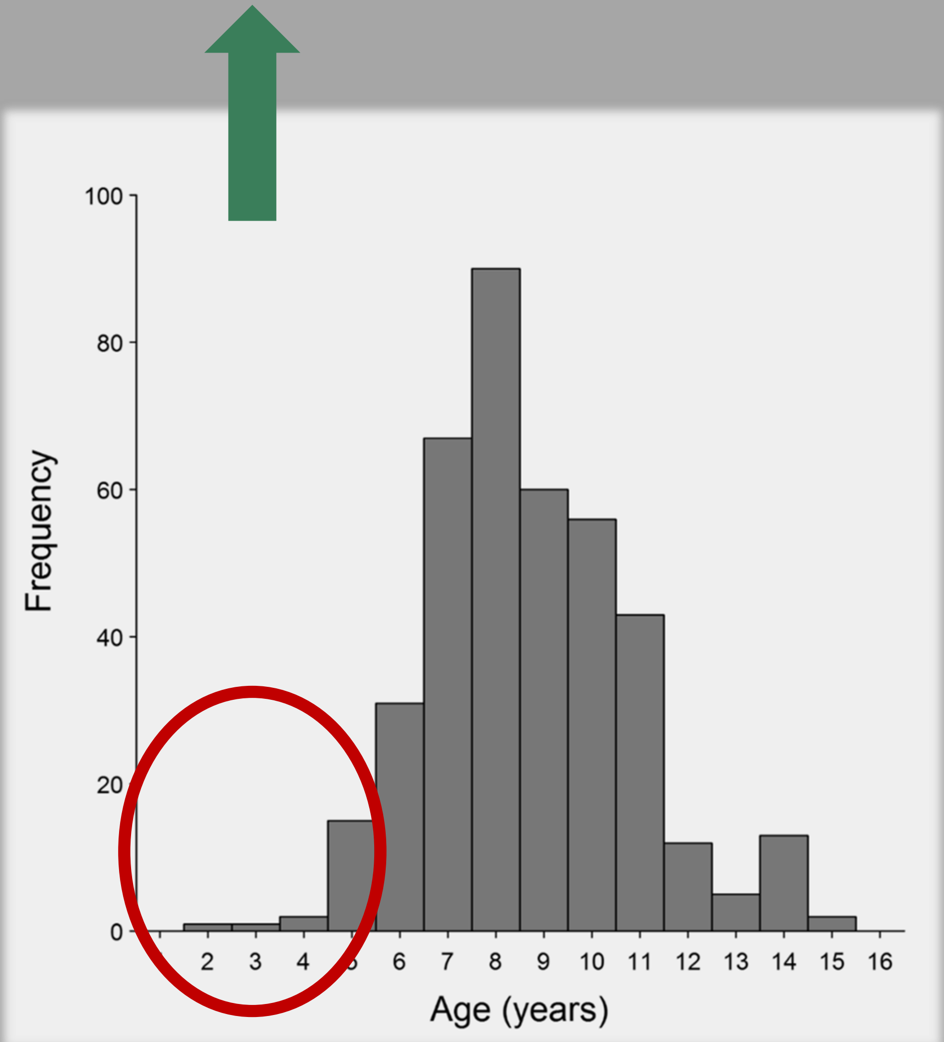
- Consistent recruitment



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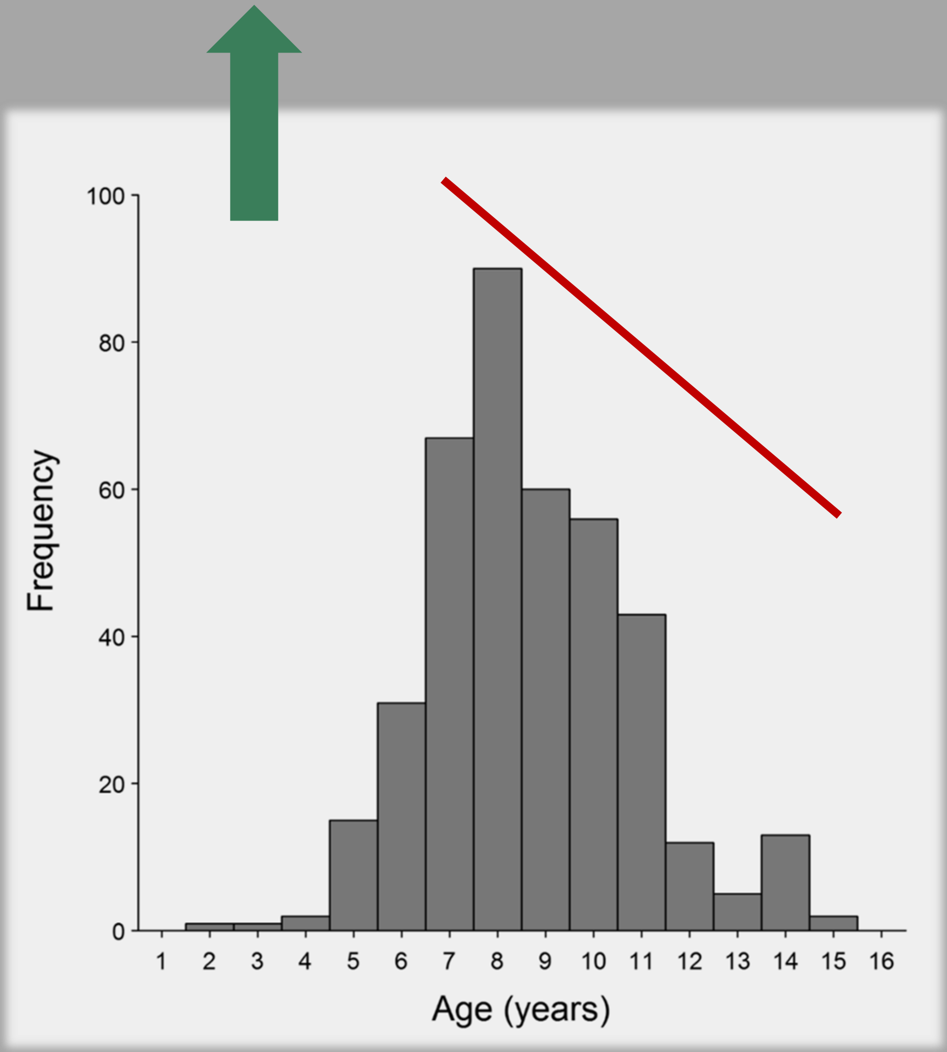

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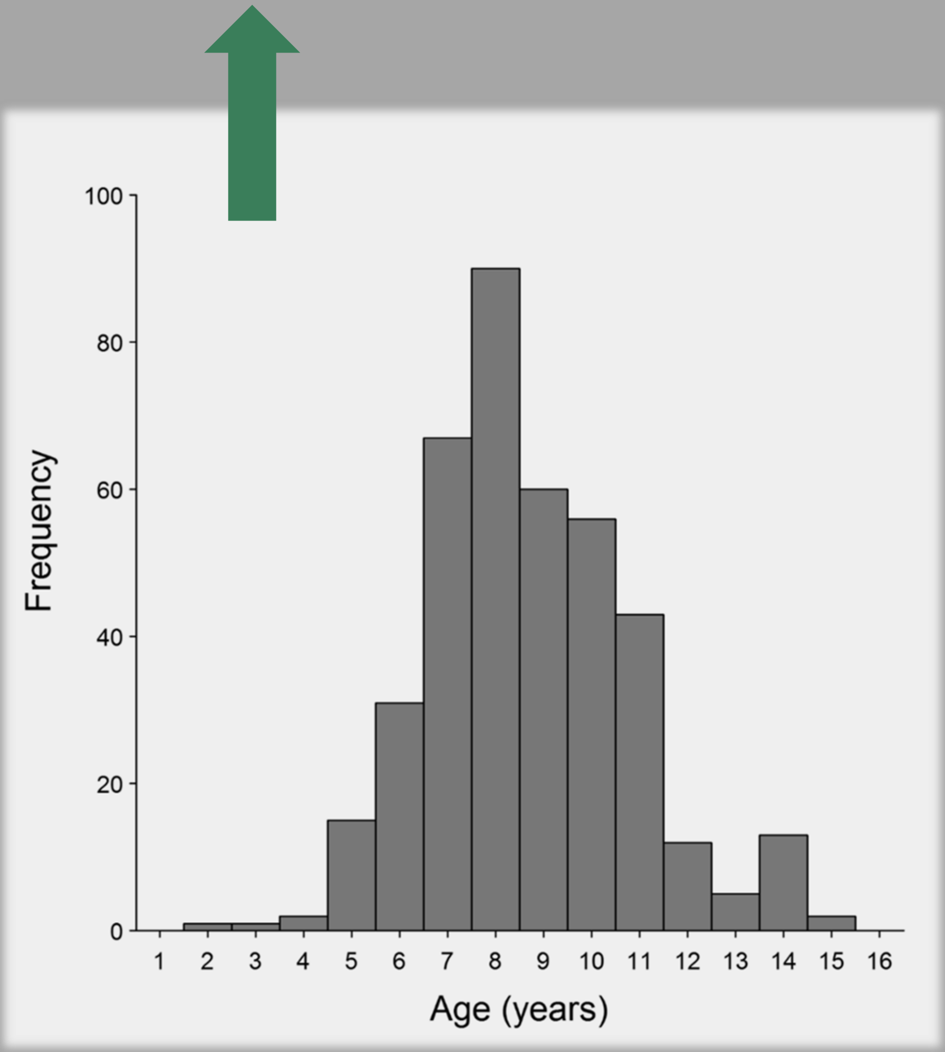
- Consistent recruitment
- Moderate annual mortality (0.33)
- Growth



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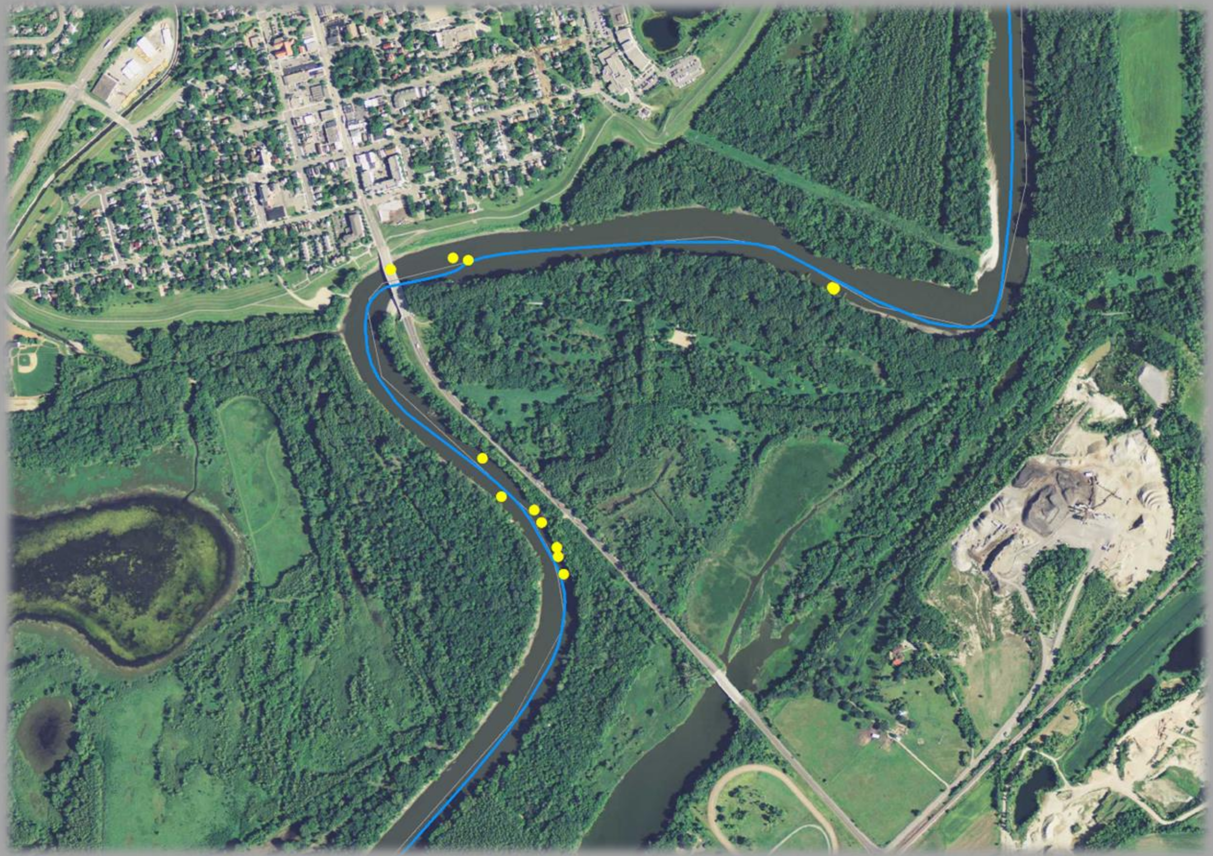

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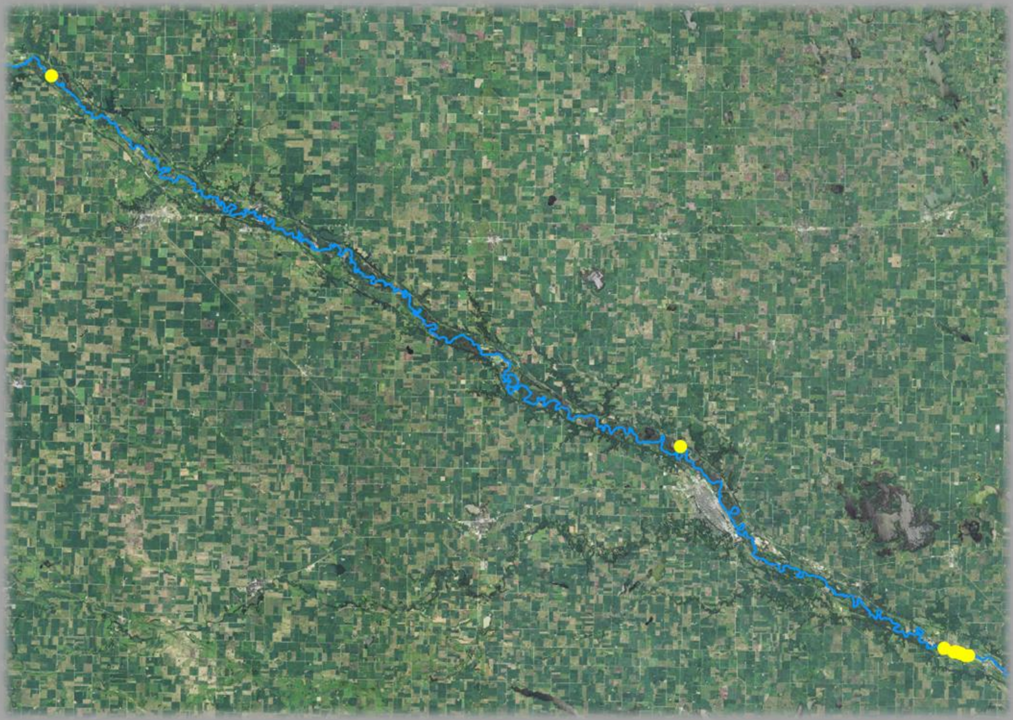

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- Zero emigrated to the Mississippi River


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

Lots of data, more results than presented, if you have any questions please contact me.

Tony Sindt
anthony.sindt@state.mn.us

Fish Art
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ENVIRONMENT
AND NATURAL RESOURCES
TRUST FUND

SPORT FISH RESTORATION

DEPARTMENT OF
NATURAL RESOURCES

Shovelnose Sturgeon and Paddlefish populations and movements in the Minnesota River

Mike Wolf, Mike Vaske and Tony Sindt

DEPARTMENT OF NATURAL RESOURCES

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

LCCMR & ENRTF

Legislative-Citizen Commission on Minnesota Resources: *Committee whose primary function is to make funding recommendations to the Minnesota legislature for special ENRTF projects, and provide oversight for all funded projects.*

Environment and Natural Resources Trust Fund: *Created to provide a long-term, consistent, and stable source of funding for innovative activities directed at protecting and enhancing Minnesota's environment and natural resources for the benefit of current citizens and future generations. Seven cents from every dollar spent on playing the Minnesota lottery is contributed to the trust fund.*

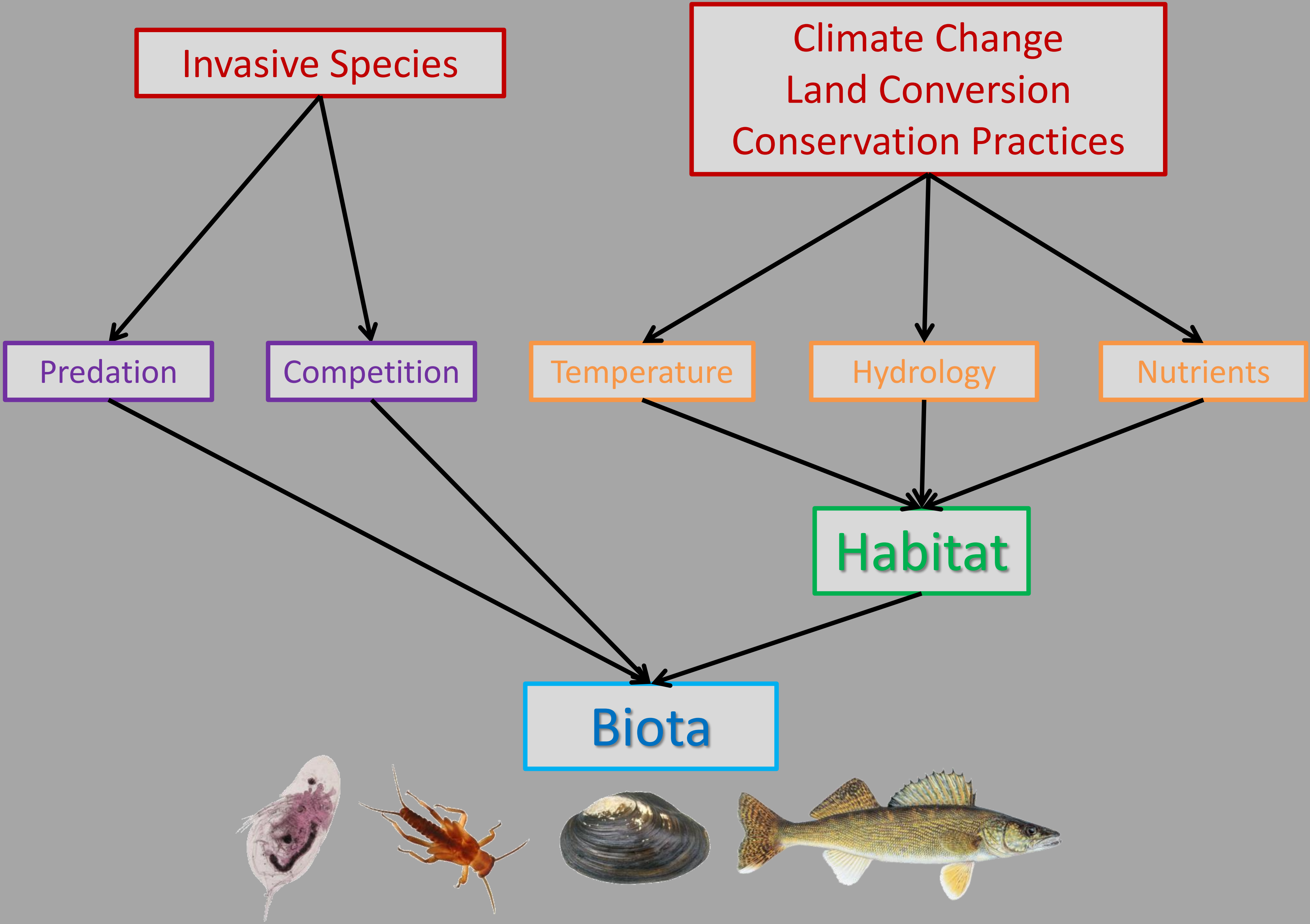
The Minnesota River is being impacted by changing land use, climate, invasive species, and conservation efforts

INVASIVE SPECIES

CLIMATE CHANGE

LAND MANAGEMENT

CONSERVATION EFFORTS



Invasive Species

Climate Change
Land Conversion
Conservation Practices

Predation

Competition

Temperature

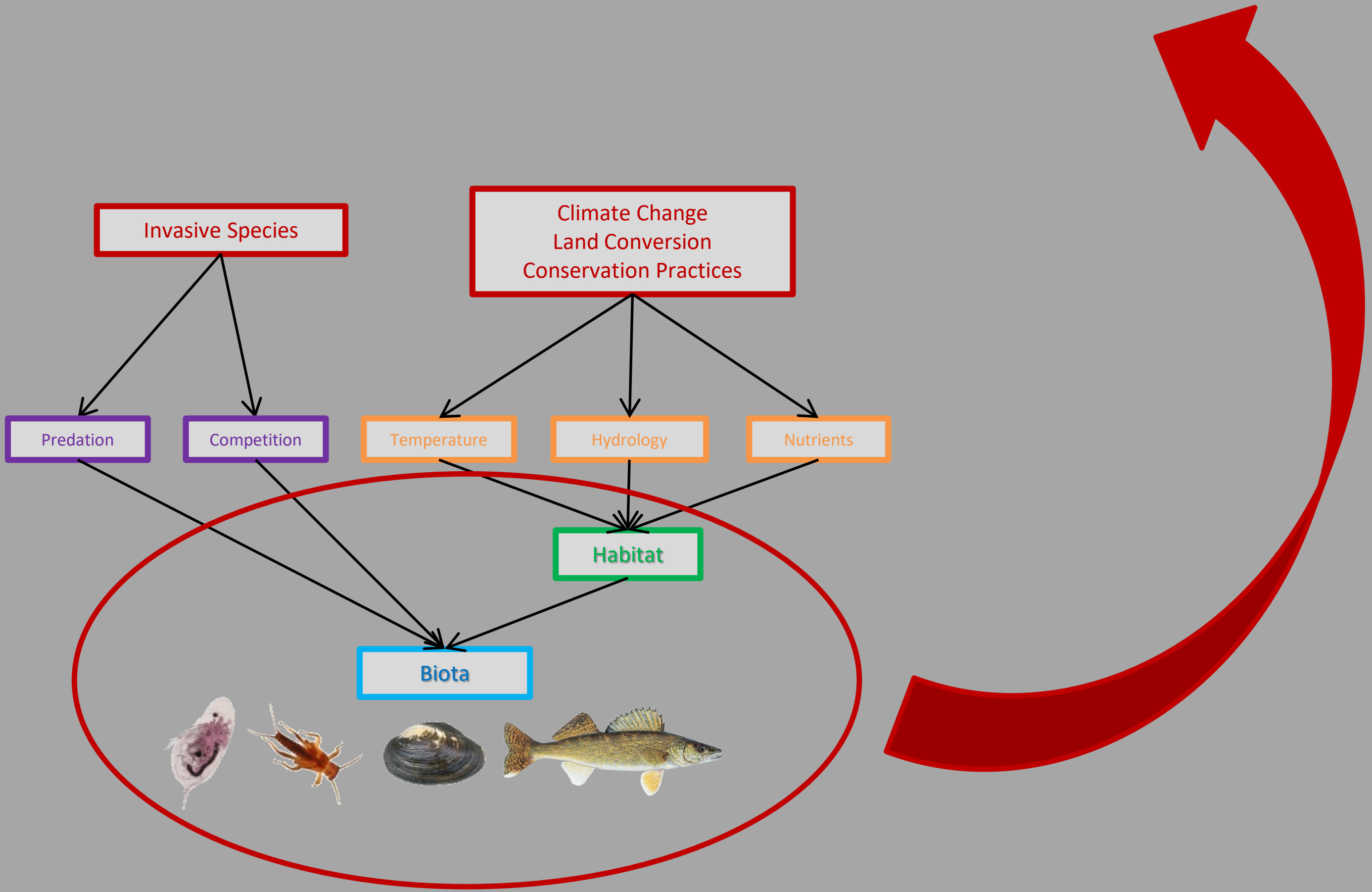
Hydrology

Nutrients

Habitat

Biota

Problem: There are hypothesized and anticipated impacts to the Minnesota River ecosystem (biota and habitat), but we lack the data and understanding to adequately predict and quantify these future impacts



HOW WILL


LAND MANAGEMENT


CLIMATE CHANGE


INVASIVE SPECIES


CONSERVATION EFFORTS

IMPACT


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

IN THE MINNESOTA RIVER ECOSYSTEM?

HOW WILL


LAND MANAGEMENT


CLIMATE CHANGE


INVASIVE SPECIES


CONSERVATION EFFORTS

IMPACT


PLANKTON


HABITAT


BACKWATER ECOSYSTEMS


FISH

IN THE MINNESOTA RIVER ECOSYSTEM?

Evaluate population dynamics, movement, and habitat use of sensitive fish species (Shovelnose Sturgeon and Paddlefish)

Sturgeon and Paddlefish Background

27 unique species with ancient origins

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27 unique species with ancient origins

Targeted for highly valuable black caviar

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27 unique species with ancient origins

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Long lived and late maturing fish

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Long lived and late maturing fish

Declined globally from overharvest and habitat degradation

Sturgeon and Paddlefish Background

27 unique species with ancient origins

Targeted for highly valuable black caviar

Long lived and late maturing fish

Declined globally from overharvest and habitat degradation

Some endangered and all in need of conservation

MN River SLS & PAH Background

Thought to be historically abundant in the MN River

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Declines due to habitat degradation and fragmentation

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Studies that targeted SLS caught relatively few

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Thought to be historically abundant in the MN River

Declines due to habitat degradation and fragmentation

Few studies have targeted PAH or SLS

Studies that targeted SLS caught relatively few

Incidental catches have increased in recent years

Objectives

Evaluate population dynamics and movements of Shovelnose Sturgeon and Paddlefish in the Minnesota River

Project Outline

Establish stationary receiver array

Project Outline

Establish stationary receiver array

Sample Shovelnose Sturgeon and Paddlefish throughout the Minnesota River

Project Outline

Establish stationary receiver array

Sample Shovelnose Sturgeon and Paddlefish throughout the Minnesota River

Surgically implant Sturgeon and Paddlefish

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Actively track tagging sites and maintain receiver array

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Sample Shovelnose Sturgeon and Paddlefish throughout the Minnesota River

Surgically implant Sturgeon and Paddlefish

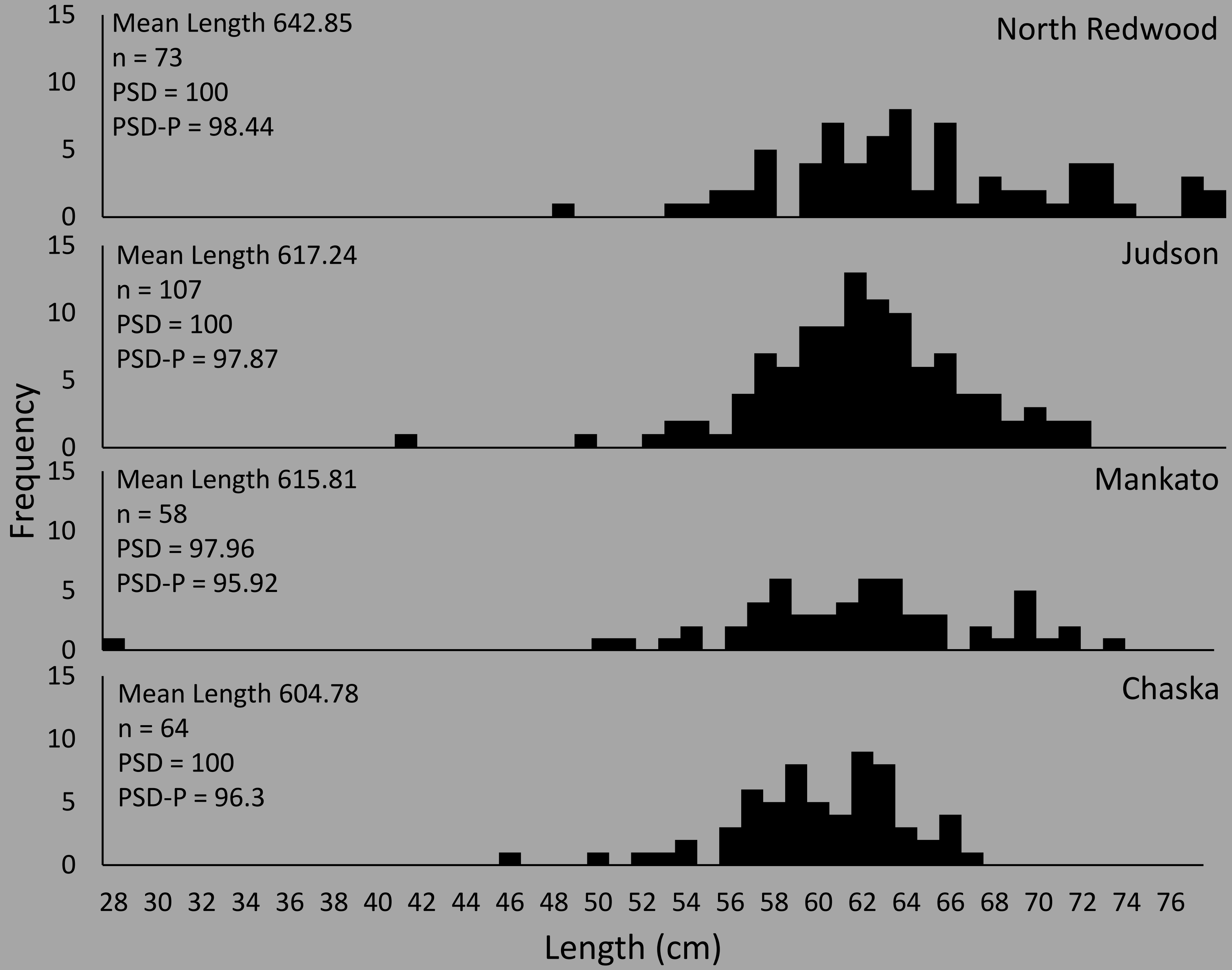
Actively track tagging sites and maintain receiver array

Age Sturgeon and organize data

Sturgeon & Paddlefish Sampling

Site	Shovelnose Sturgeon	Paddlefish
Upper Sioux Agency State Park		10
North Redwood	73	
Judson	107	
Mankato	58	6
St. Peter		50
Chaska	64	

Sturgeon Sampling



North Redwood
Mean Length 642.85
n = 73
PSD = 100
PSD-P = 98.44

Judson
Mean Length 617.24
n = 107
PSD = 100
PSD-P = 97.87

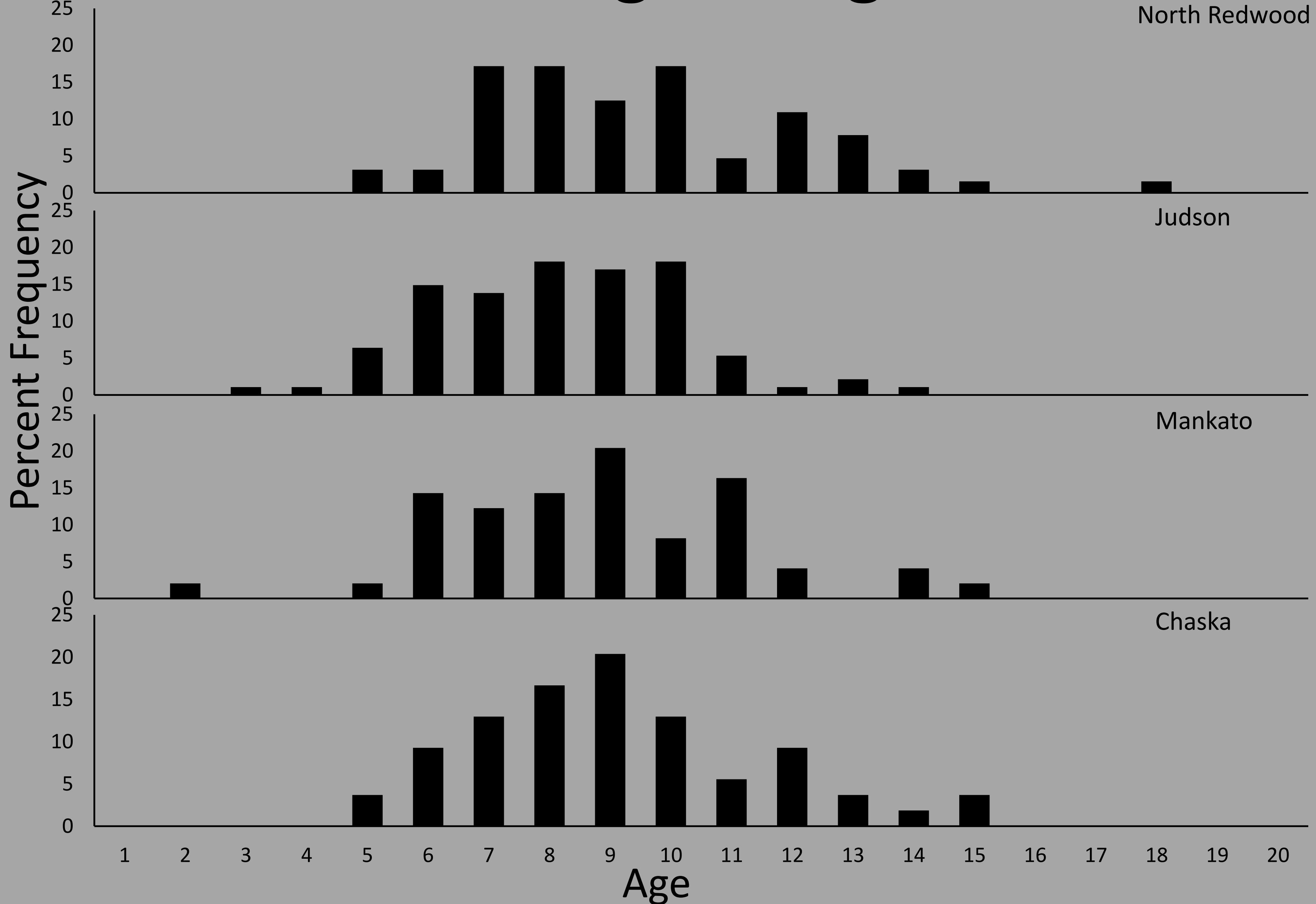
Mankato
Mean Length 615.81
n = 58
PSD = 97.96
PSD-P = 95.92

Chaska
Mean Length 604.78
n = 64
PSD = 100
PSD-P = 96.3

Sturgeon aging

- Difficult to age
- Typically a high degree of disagreement between readers
- We found 87.4% agreement within 1 year and 98.9% agreement within 2 years

Shovelnose Sturgeon Age Structure



Stationary Receivers

Each receiver is uploaded every spring and fall

Stationary Receivers

Each receiver is uploaded every spring and fall

Pool 2

1 Paddlefish

1 White Bass

2 Common Carp

2 Smallmouth Buffalo

6 Bigmouth Buffalo

Pool 3

1 Paddlefish

St Croix

1 Paddlefish

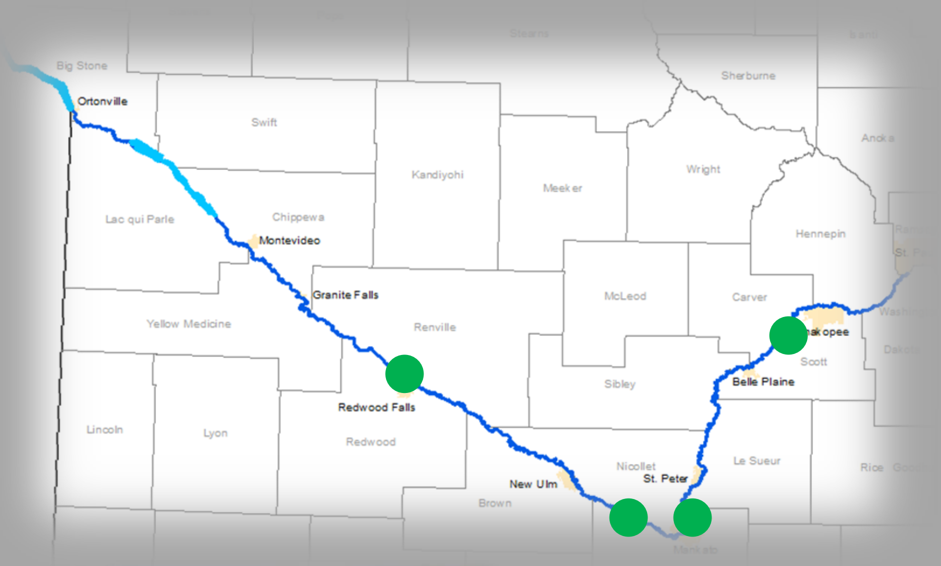
MN River

6 Paddlefish

17 Shovelnose Sturgeon

Shovelnose Sturgeon Telemetry

- 36 implanted in Fall 2016 and Spring 2017 at 4 sites
  - North Redwood
  - Judson
  - Mankato
  - Chaska
- Sites were spaced along 170 river miles
- Tagging sites were monitored by drifting through the area with a Vemco VR100



Shovelnose Sturgeon Telemetry

- Most fish stayed near tagging sites
- 2 made medium scale upstream movements (less than 10 miles)
- 3 made largescale movements (over 50 miles)
  - 2 downstream
  - 1 upstream

Shovelnose Sturgeon Telemetry

- Most fish stayed near tagging sites
- 2 made medium scale upstream movements (less than 10 miles)
- 3 made largescale movements (over 50 miles)
  - 2 downstream
  - 1 upstream

Shovelnose Sturgeon #52309

Tagged 10/12/16 and detected 10/19/16, 10/28/16 and 5/9/17

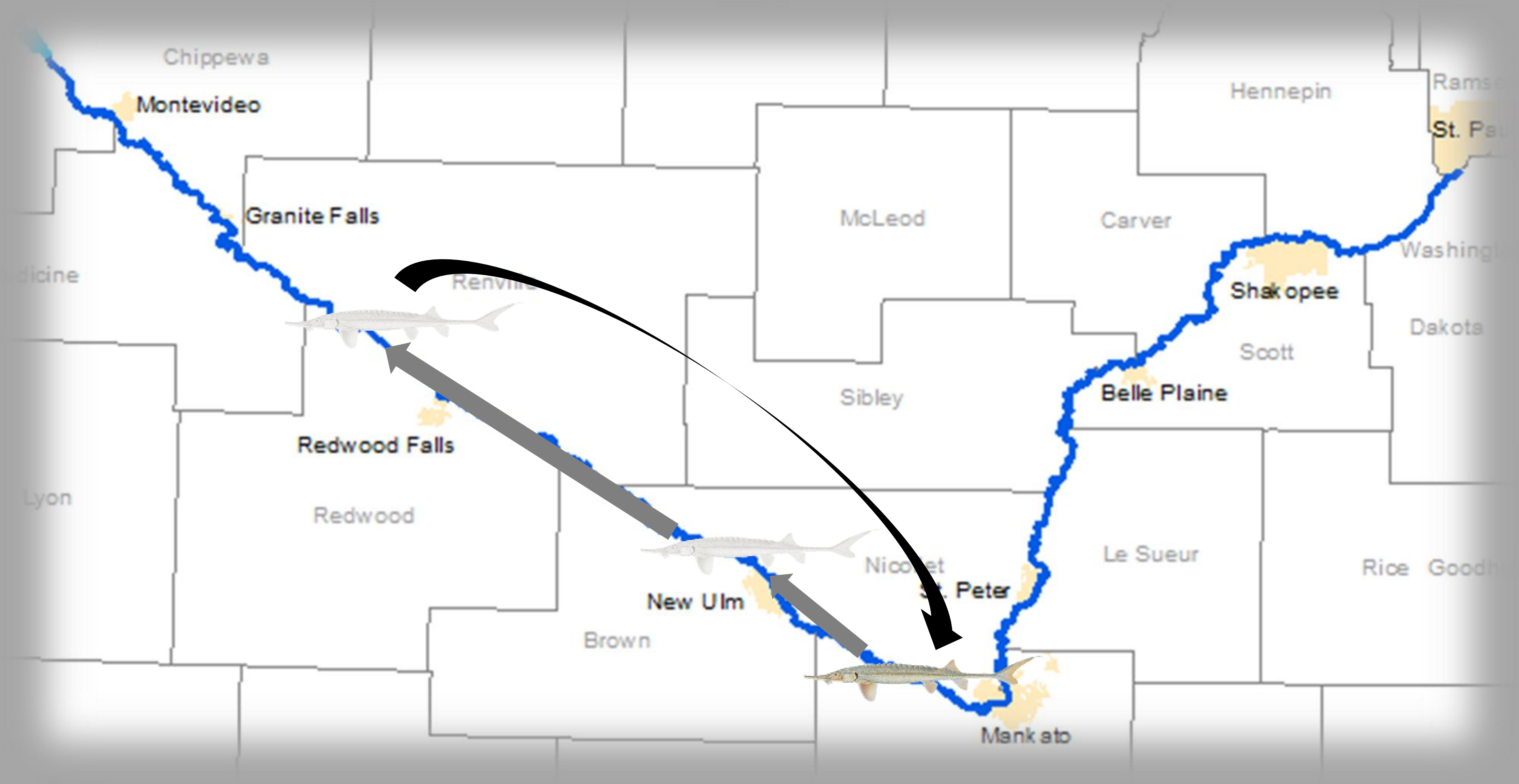
Shovelnose Sturgeon #52309

Detected 6/9/17

Shovelnose Sturgeon #52309

Detected 7/5/17

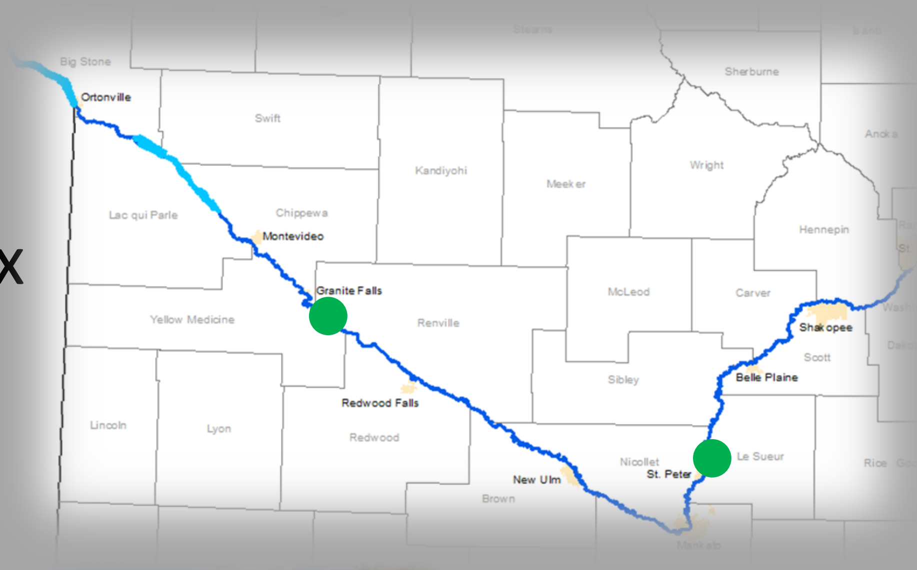
Shovelnose Sturgeon #52309



Detected 8/8/17

Paddlefish Telemetry

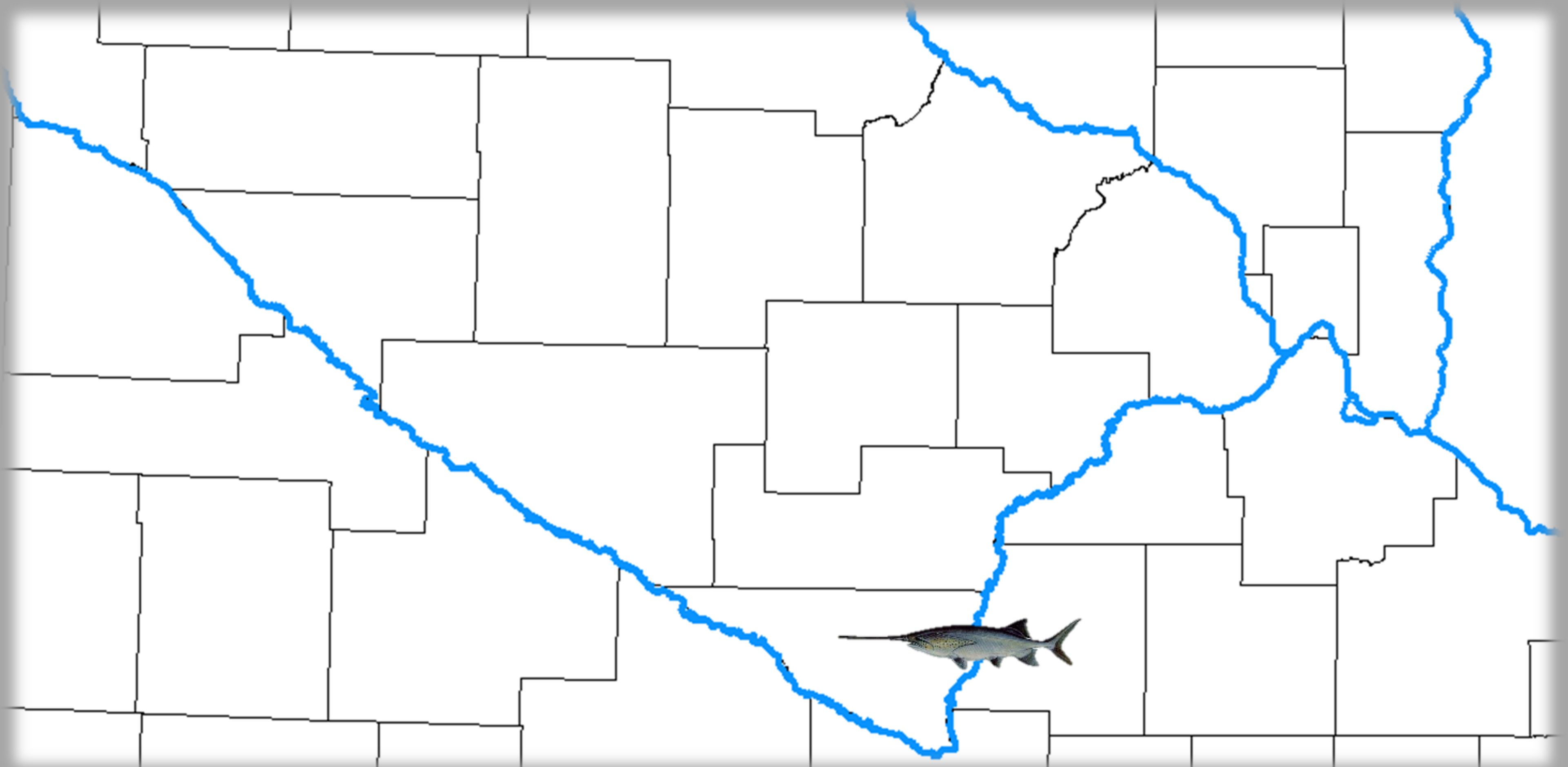
- Initially implanted 4 near St. Peter in August 2016
- Implanted 7 near Upper Sioux Agency State Park in June 2017
- Implanted 3 near St. Peter in September 2017
- Tagging sites were monitored by drifting through the area with a Vemco VR100



Paddlefish Telemetry

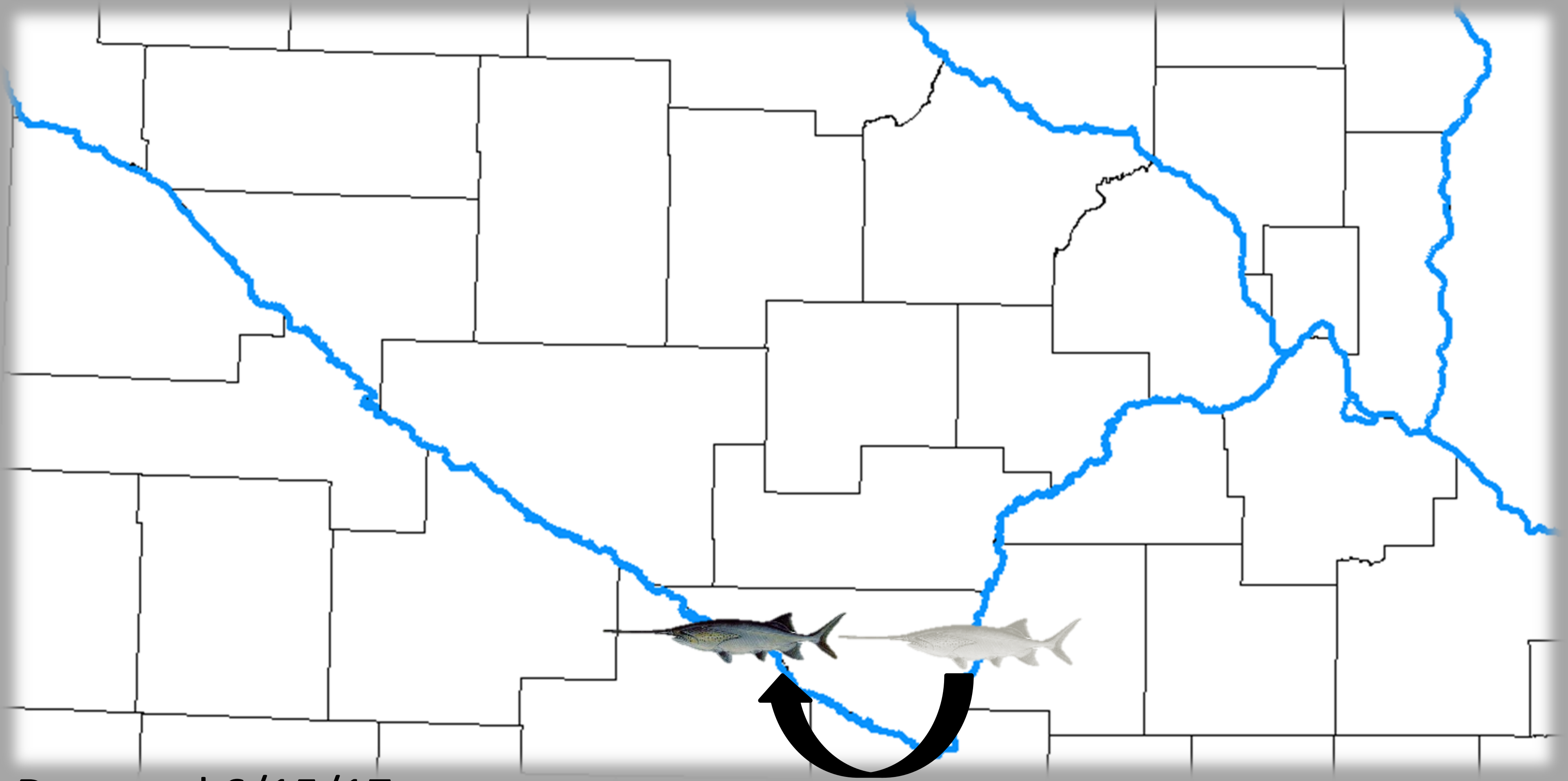
- 6 paddlefish have been documented outside their tagging site
- 5 made largescale movements including
  - 2 paddlefish leaving the Minnesota River
- Movements have been both up and downstream during different times throughout the year
- 3 Paddlefish from other systems have also been detected in the Minnesota River
  - 2 tagged in the Mississippi River (Pools 2 and 3)
  - 1 tagged in the St. Croix River
  - 1 spent over three years in the MN River and was caught near St. Peter this fall

Paddlefish #52315



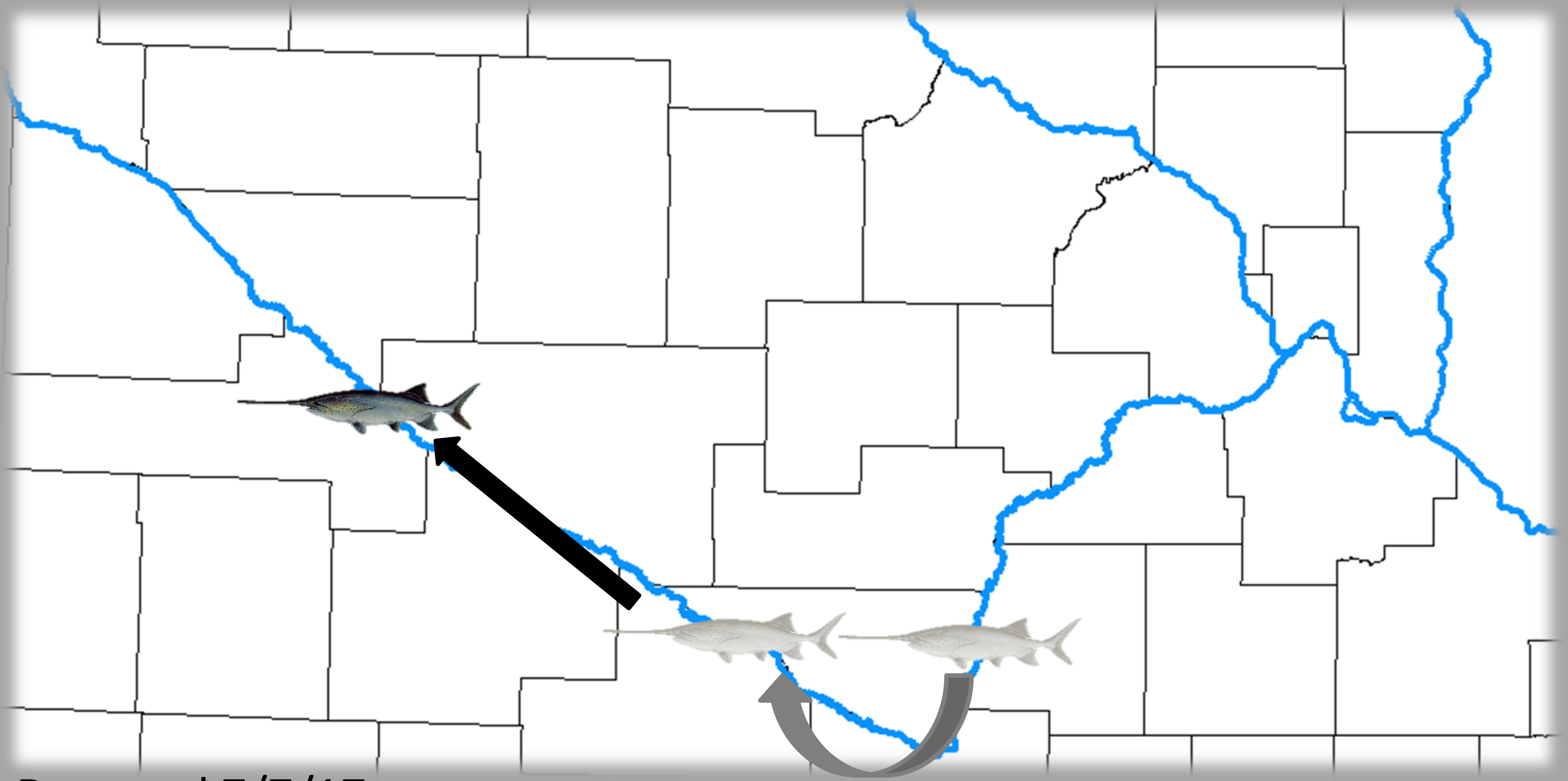
Tagged 9/13/16. Then detected 10/28/16, 12/1/16 and 3/6/17

Paddlefish #52315



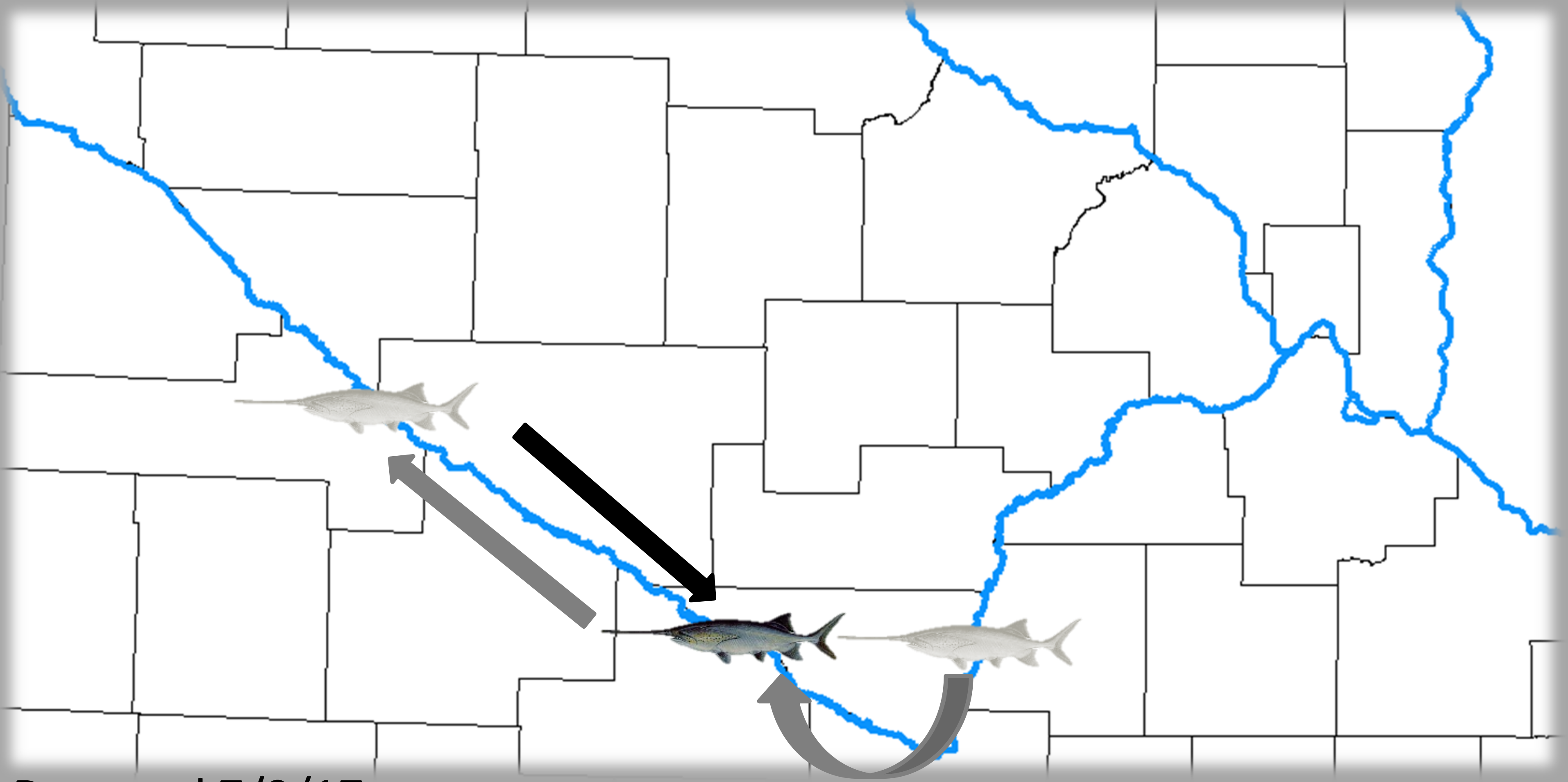
Detected 6/15/17

Paddlefish #52315



Detected 7/7/17

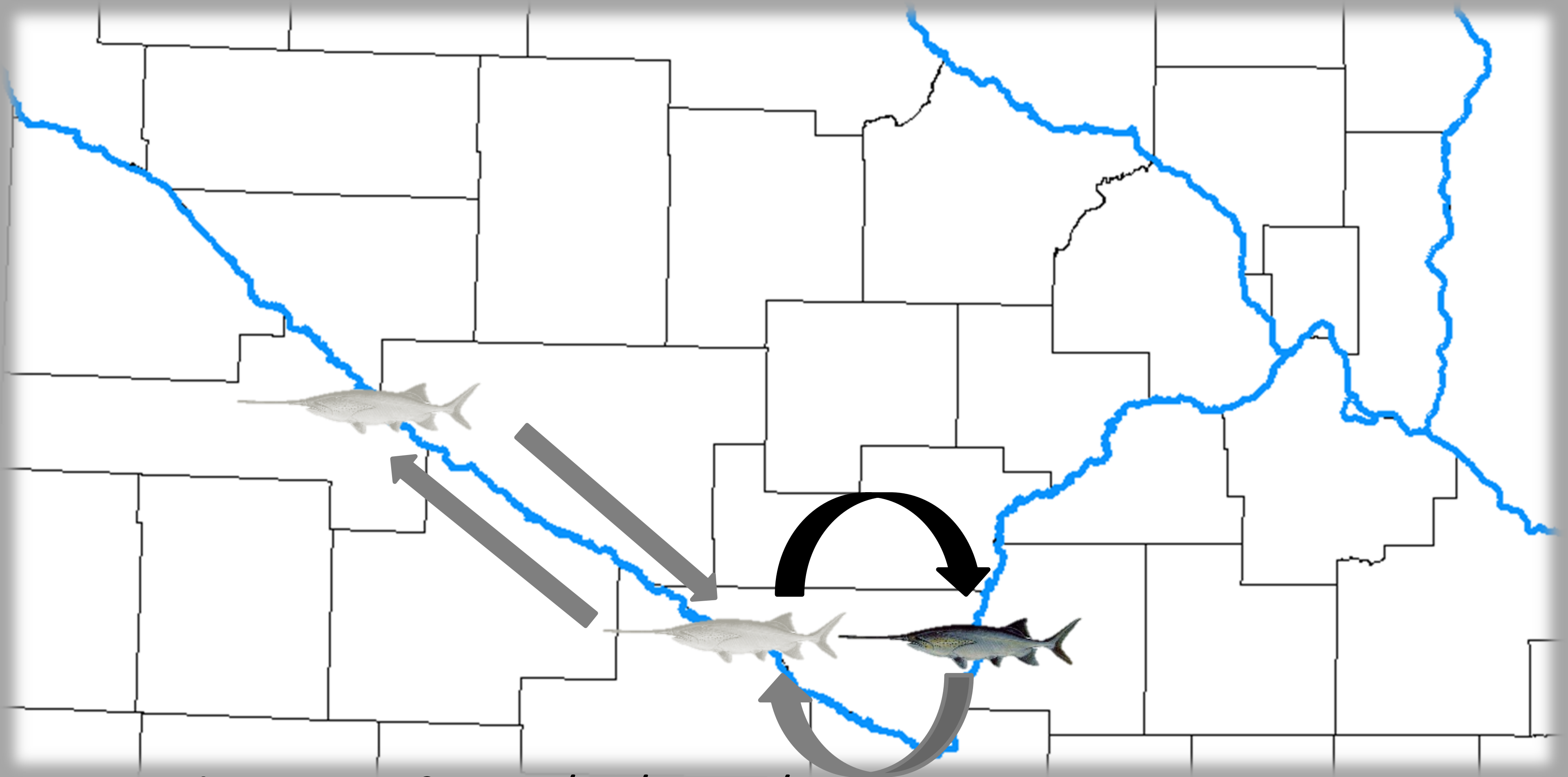
Paddlefish #52315



Detected 7/9/17

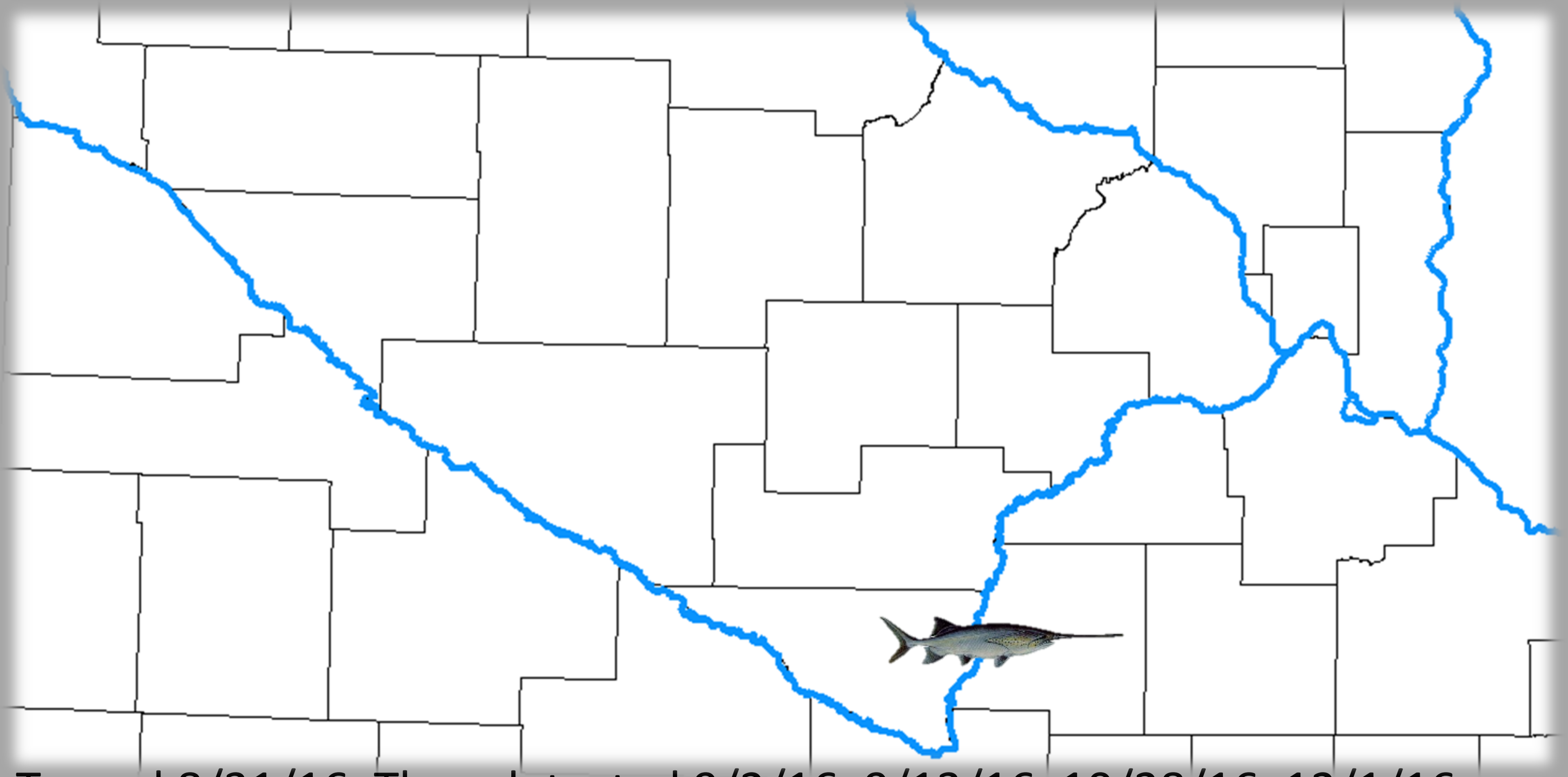
Paddlefish #52315

- Traveled >120 river miles upstream during early summer and returned to original tagging site
- Presumably spent 275 days near St. Peter or 63% of the time since it was tagged



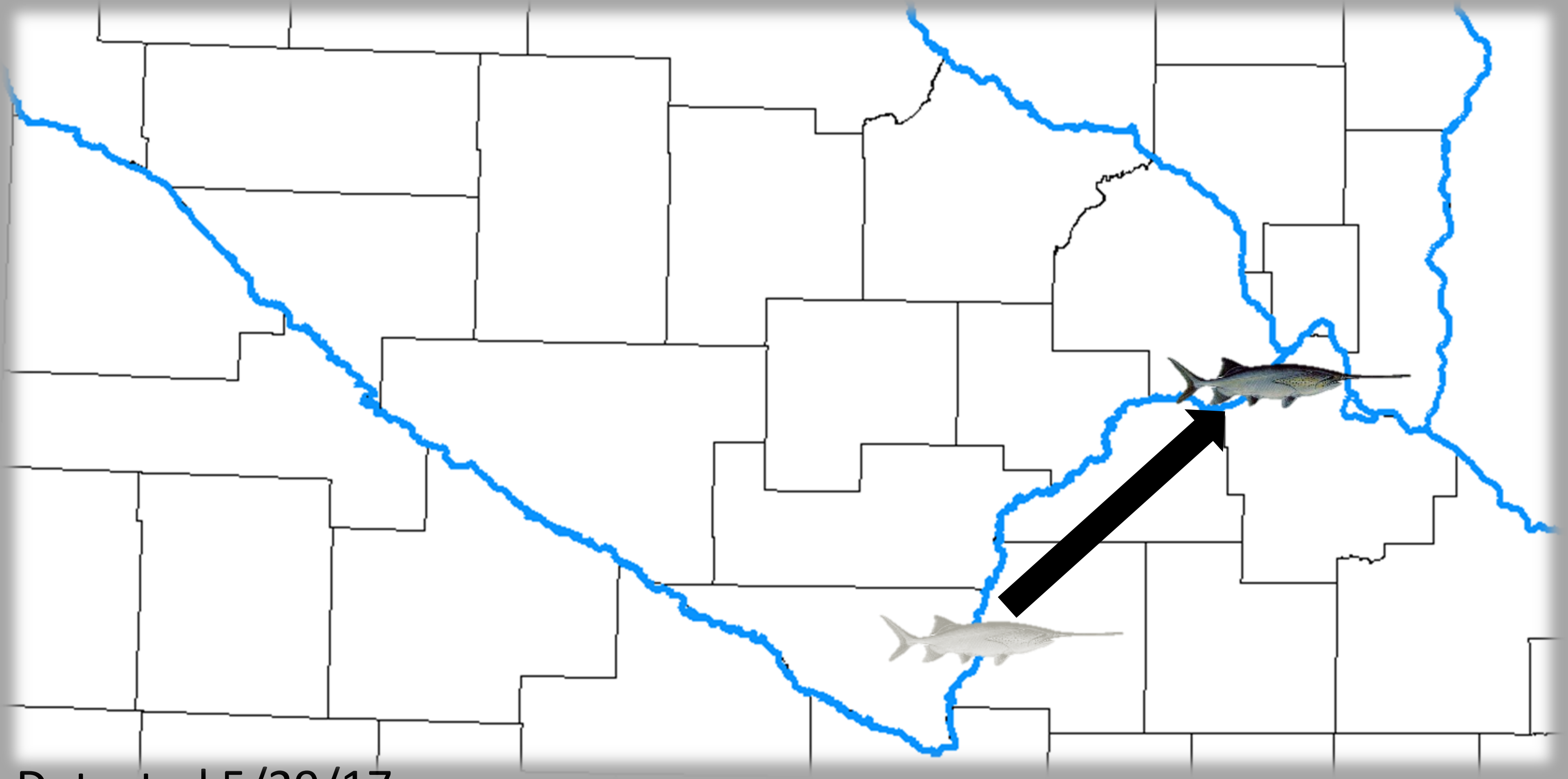
Detected 17 times from 8/11/17-11/20/17

Paddlefish #52318



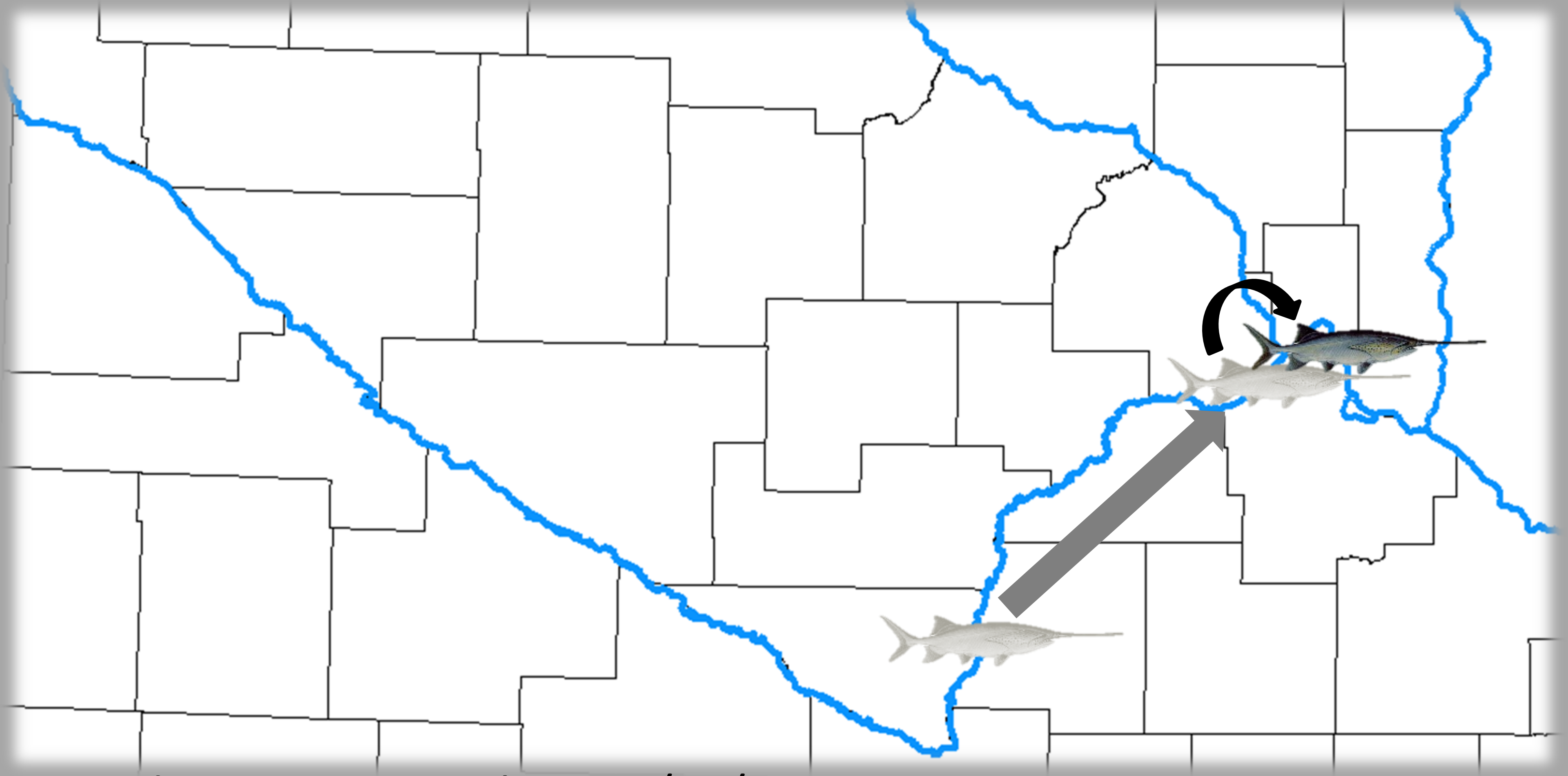
Tagged 8/31/16. Then detected 9/2/16, 9/13/16, 10/28/16, 12/1/16

Paddlefish #52318



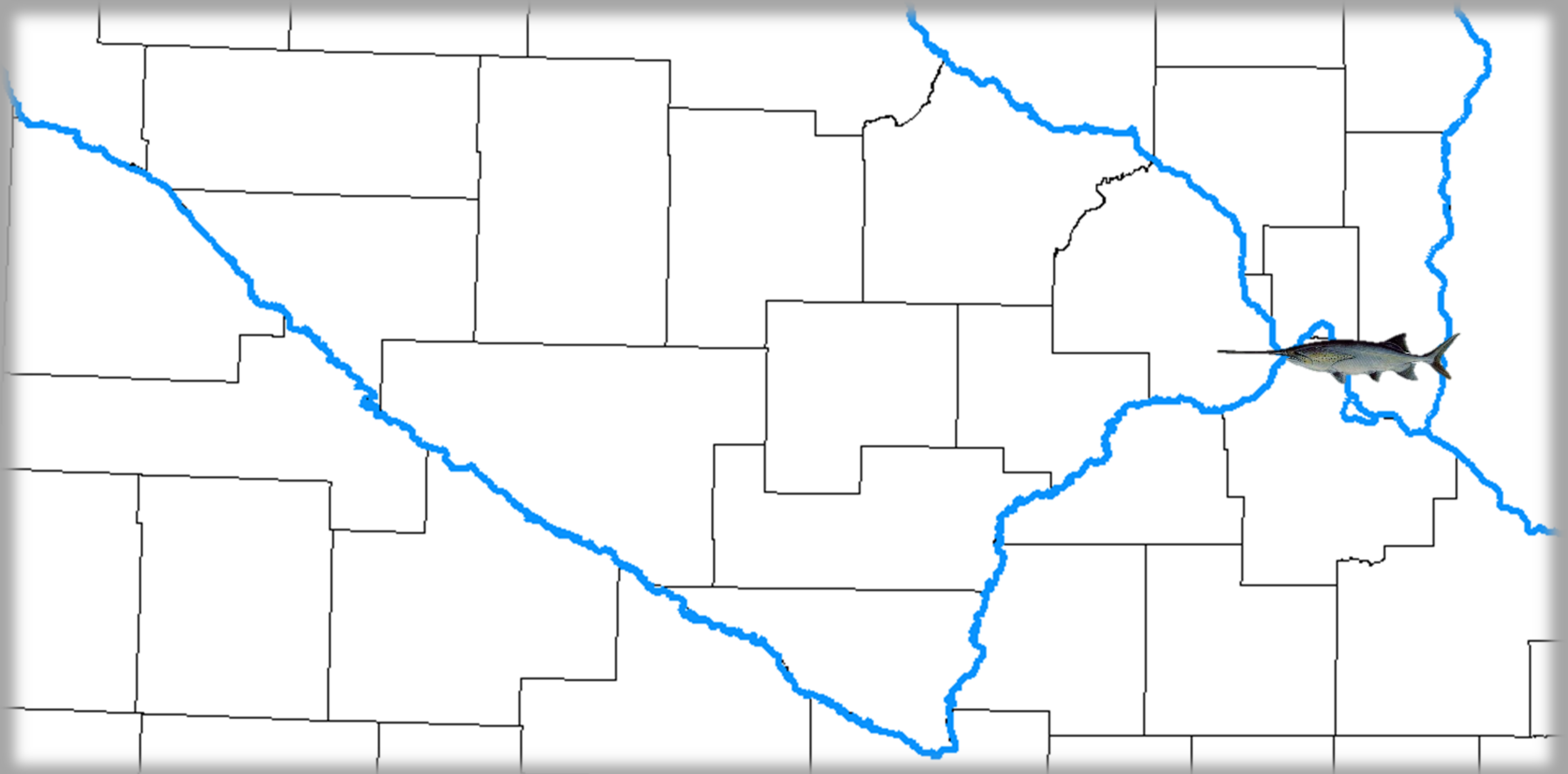
Detected 5/29/17

Paddlefish #52318



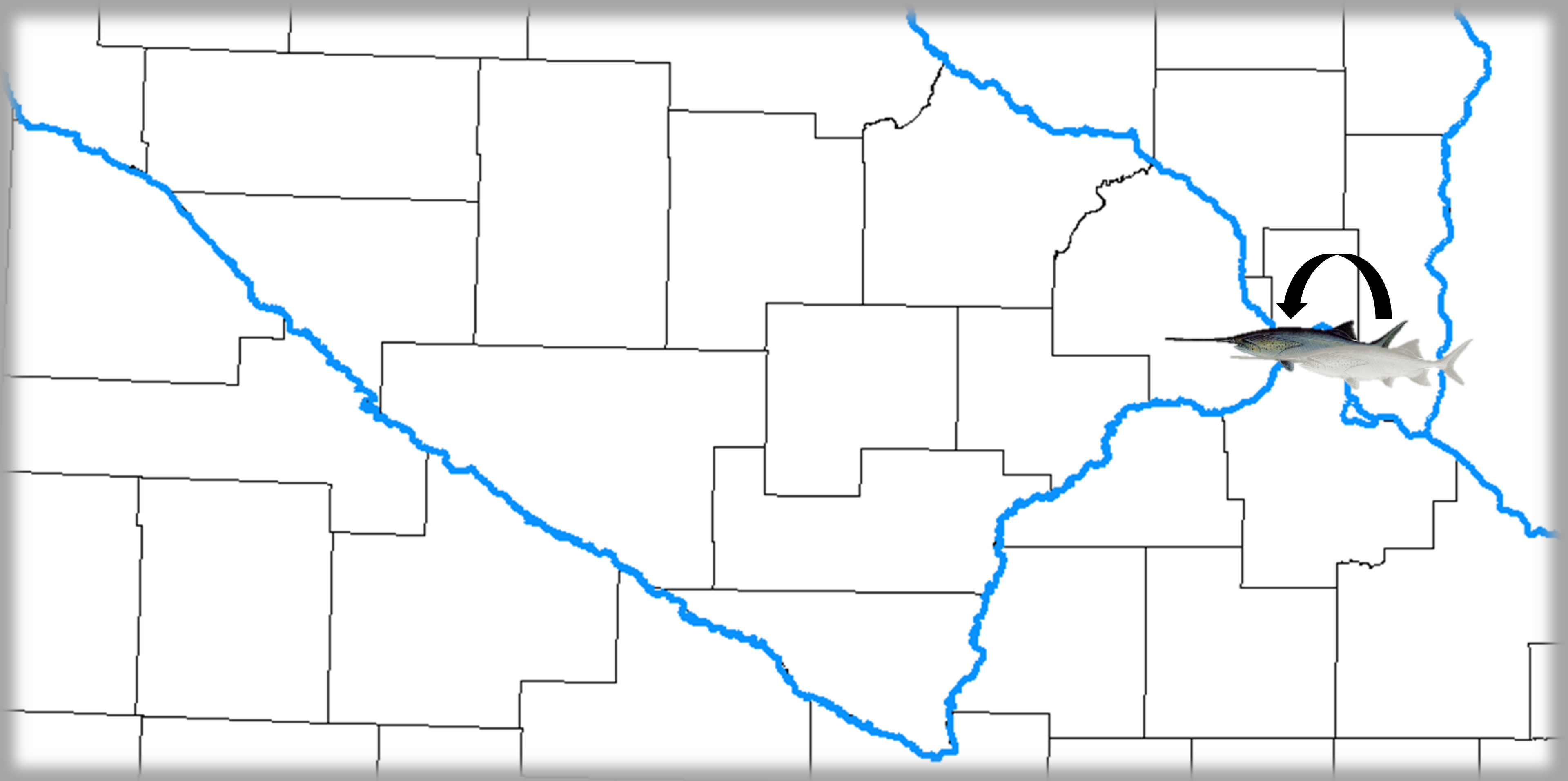
Moved into Pigs Eye Lake on 5/29/17

Paddlefish #52318



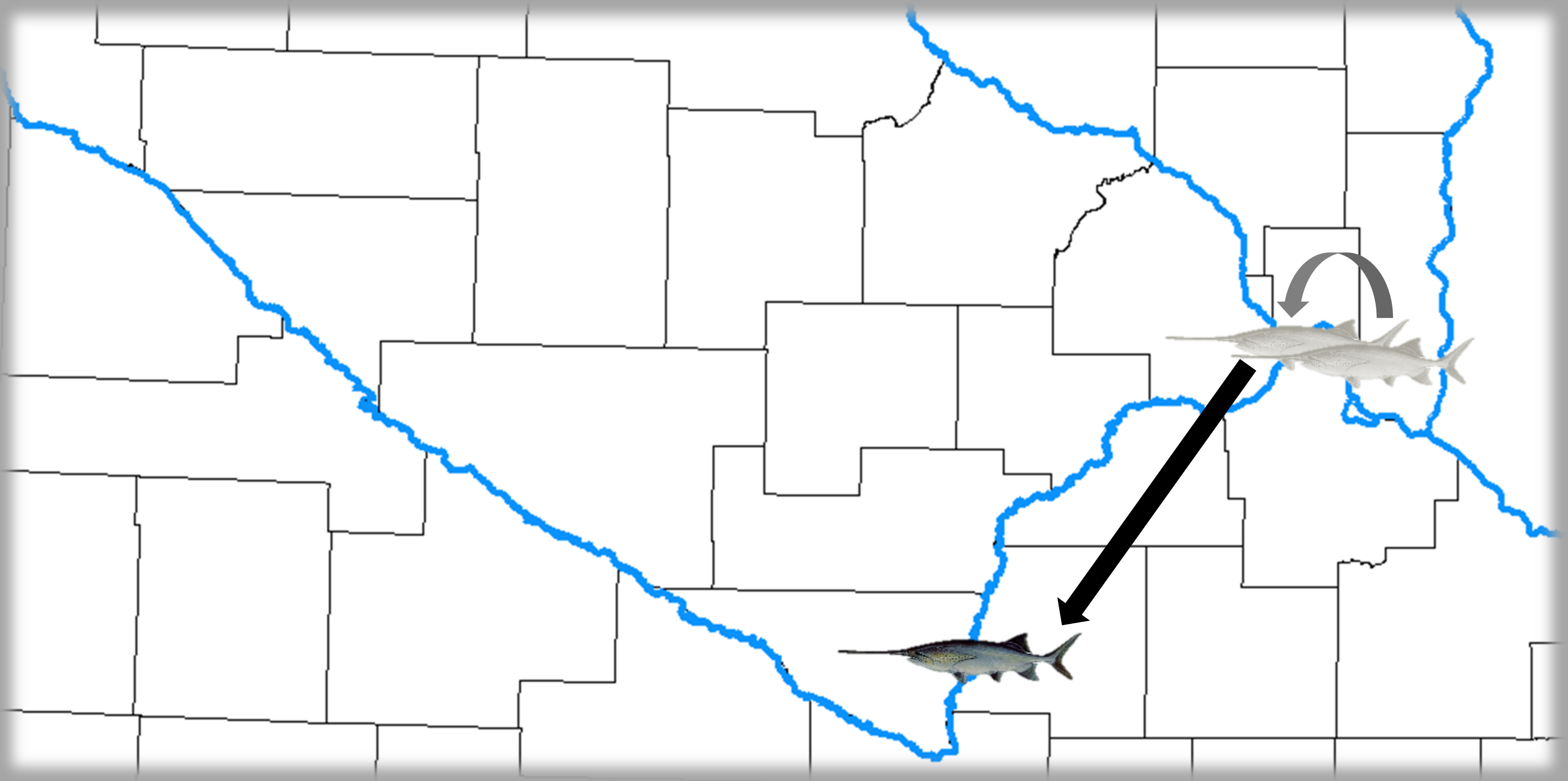
Stayed in Pigs Eye Lake until 6/12/17

Paddlefish #52318



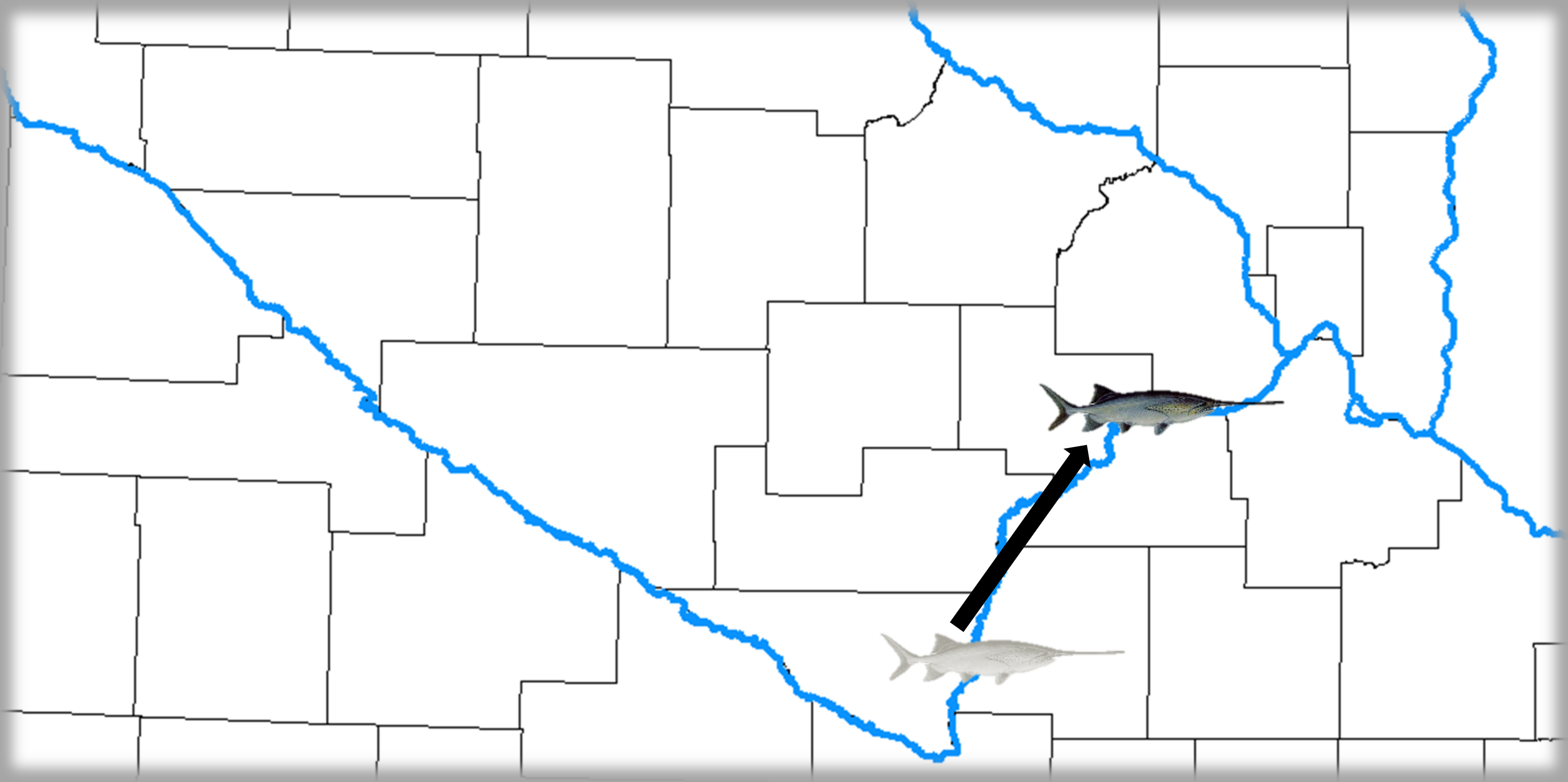
Detected multiple times around the confluence of the MN River and Mississippi River until 6/17/17

Paddlefish #52318



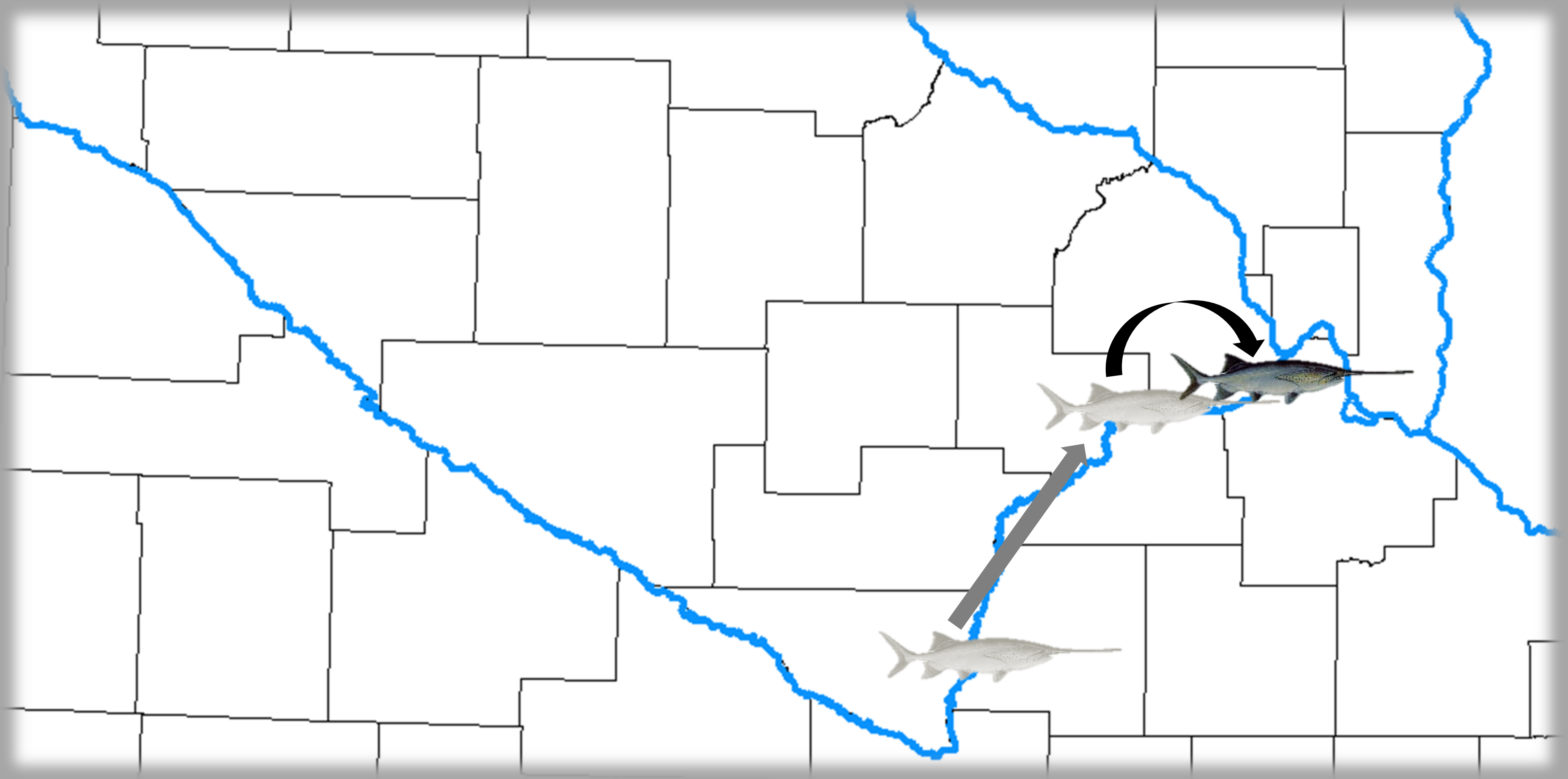
Detected 8/12/17

Paddlefish #52318



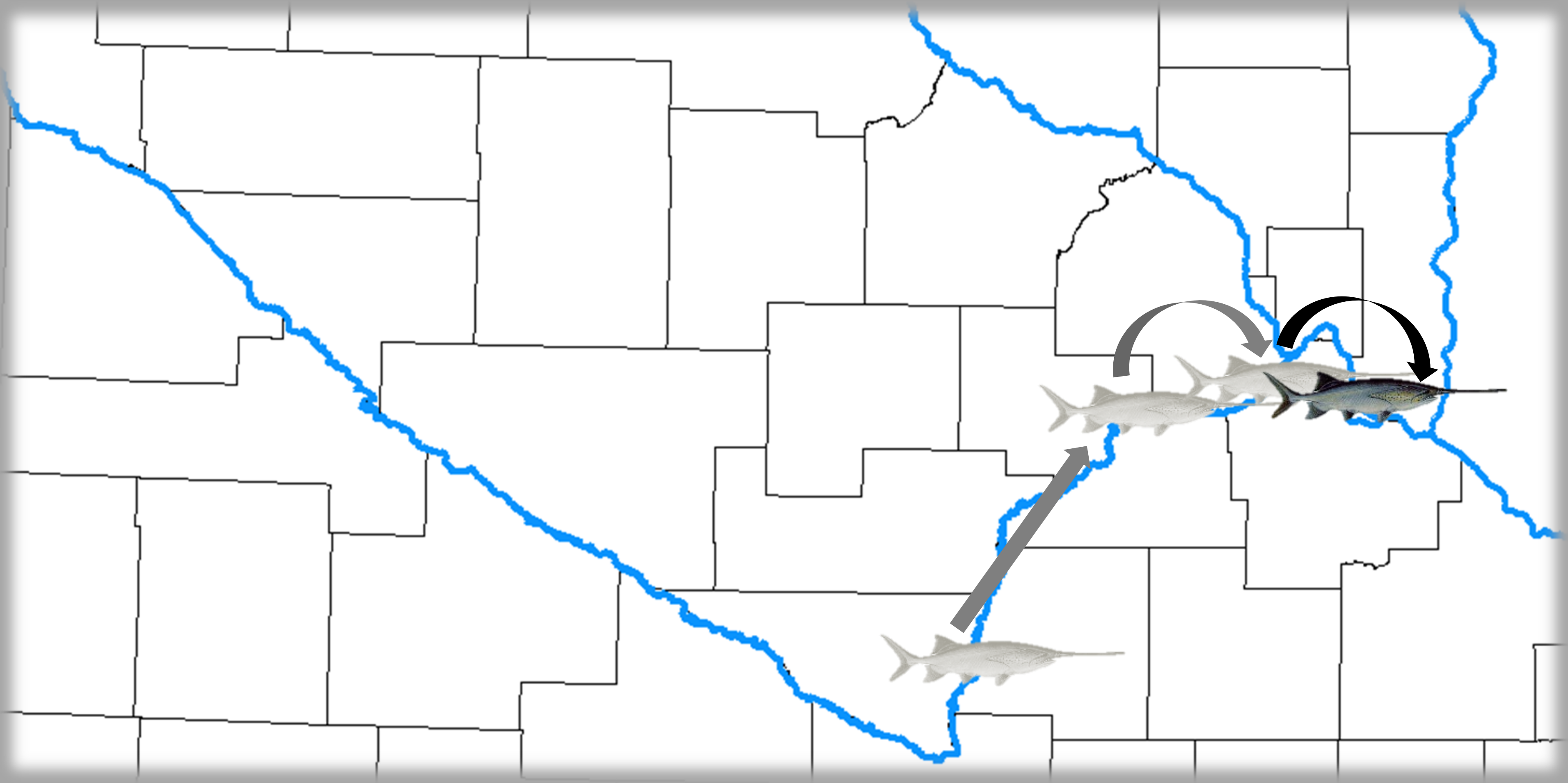
Detected 8/21/17

Paddlefish #52318



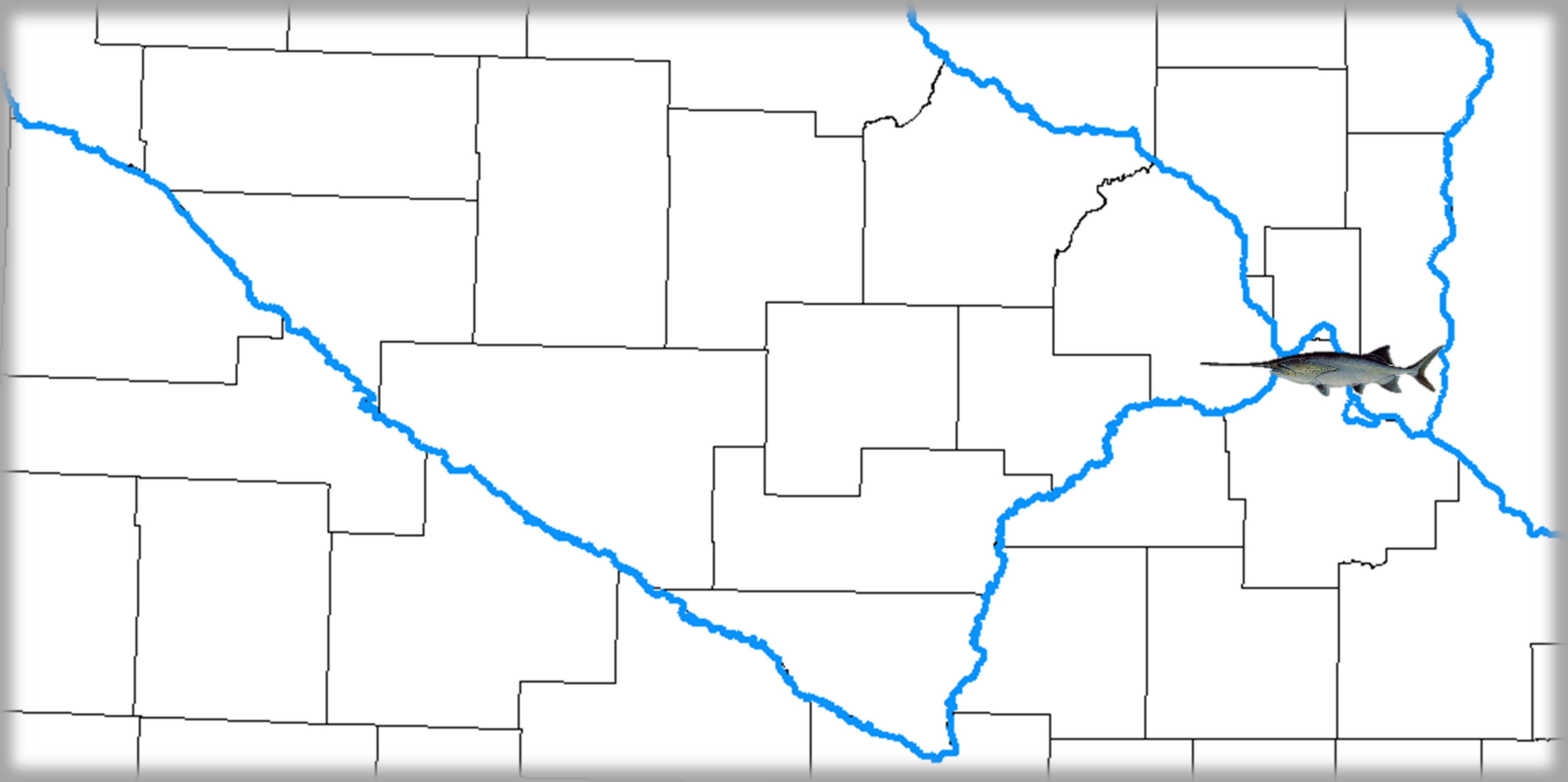
Detected 8/22/17

Paddlefish #52318



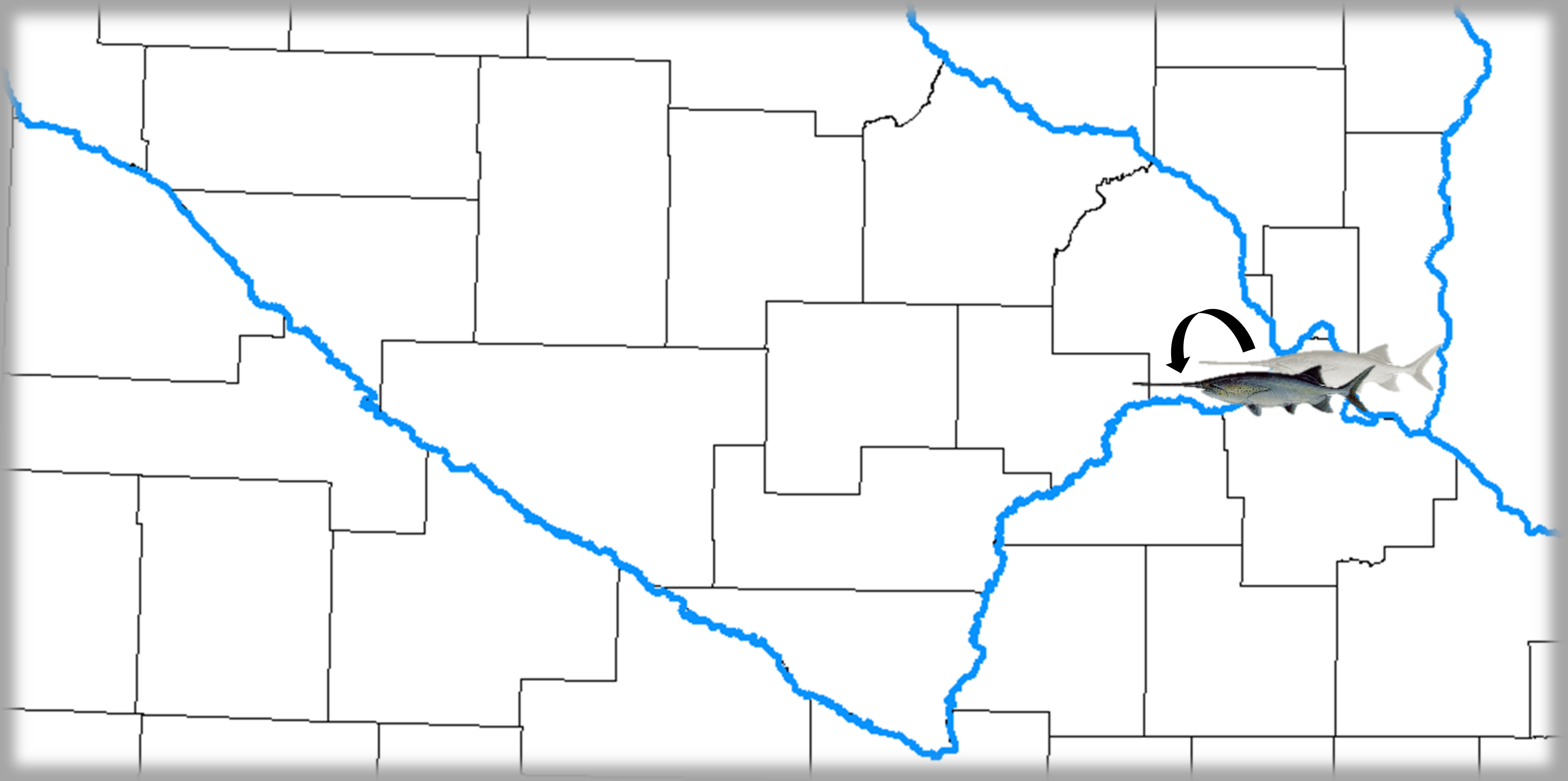
Detected 8/23/17

Paddlefish #52318



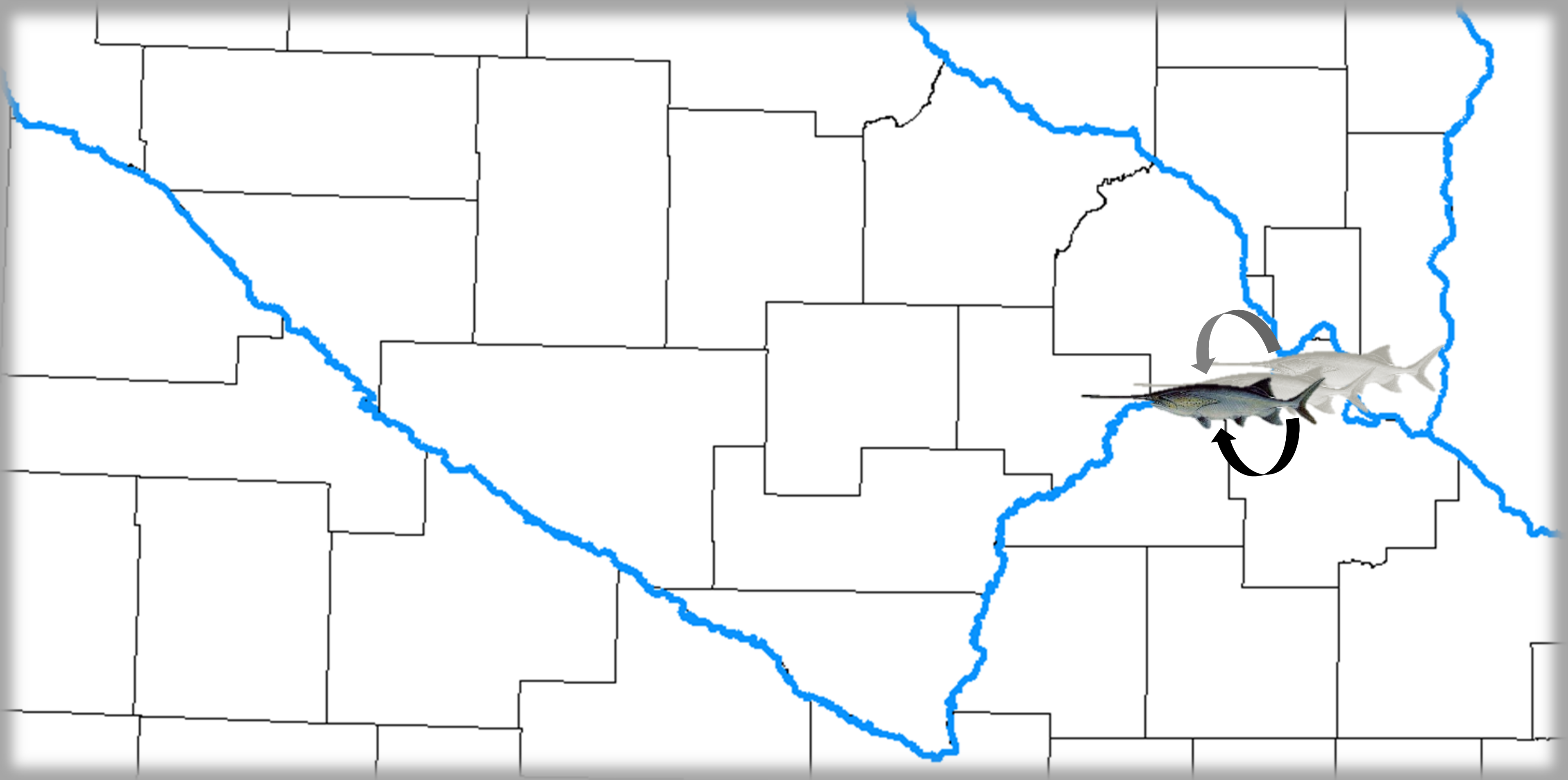
Moved into Pigs Eye lake on 8/26/17 and stayed there until 9/3/17

Paddlefish #52318



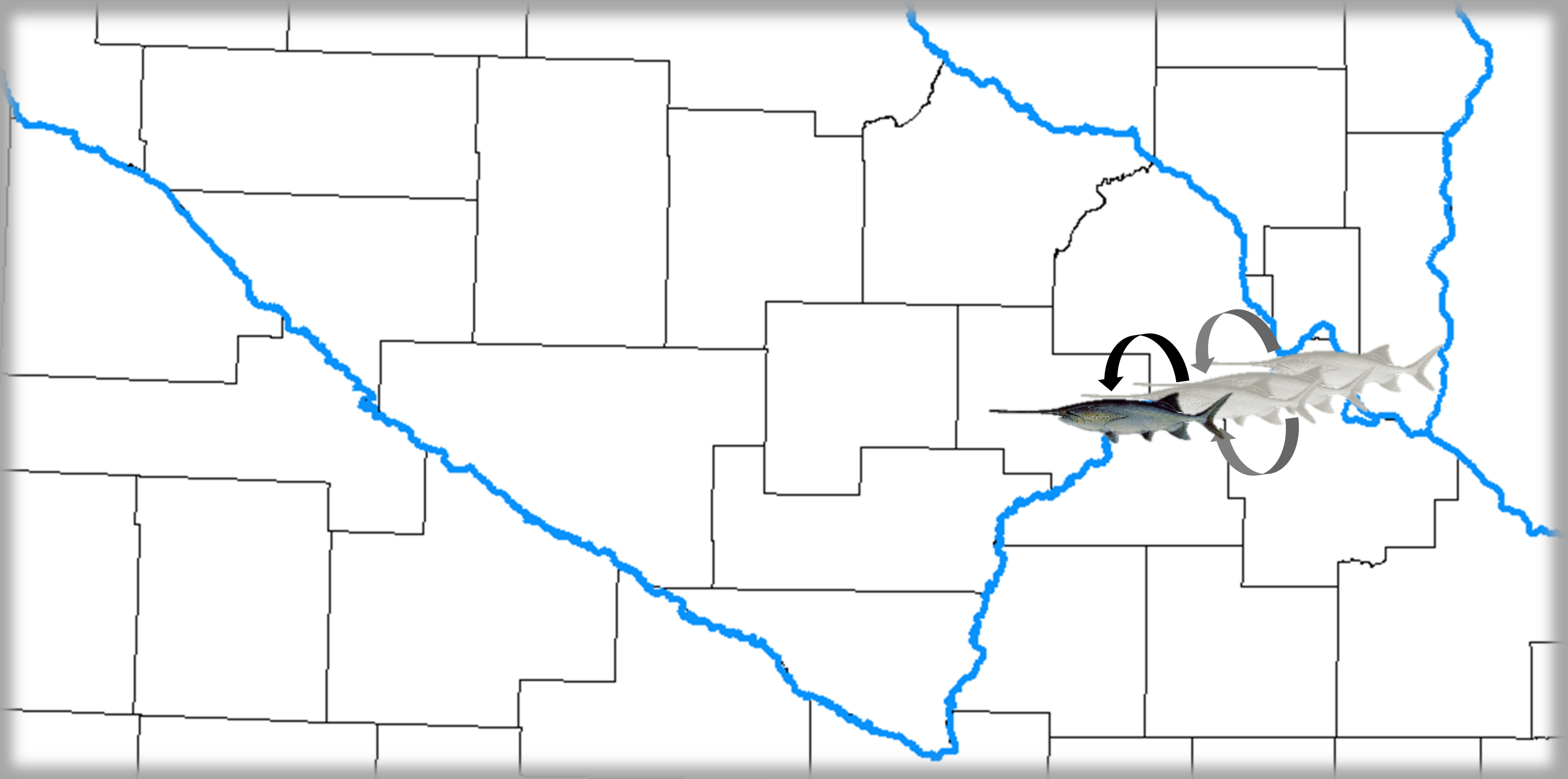
Detected 9/9/17

Paddlefish #52318



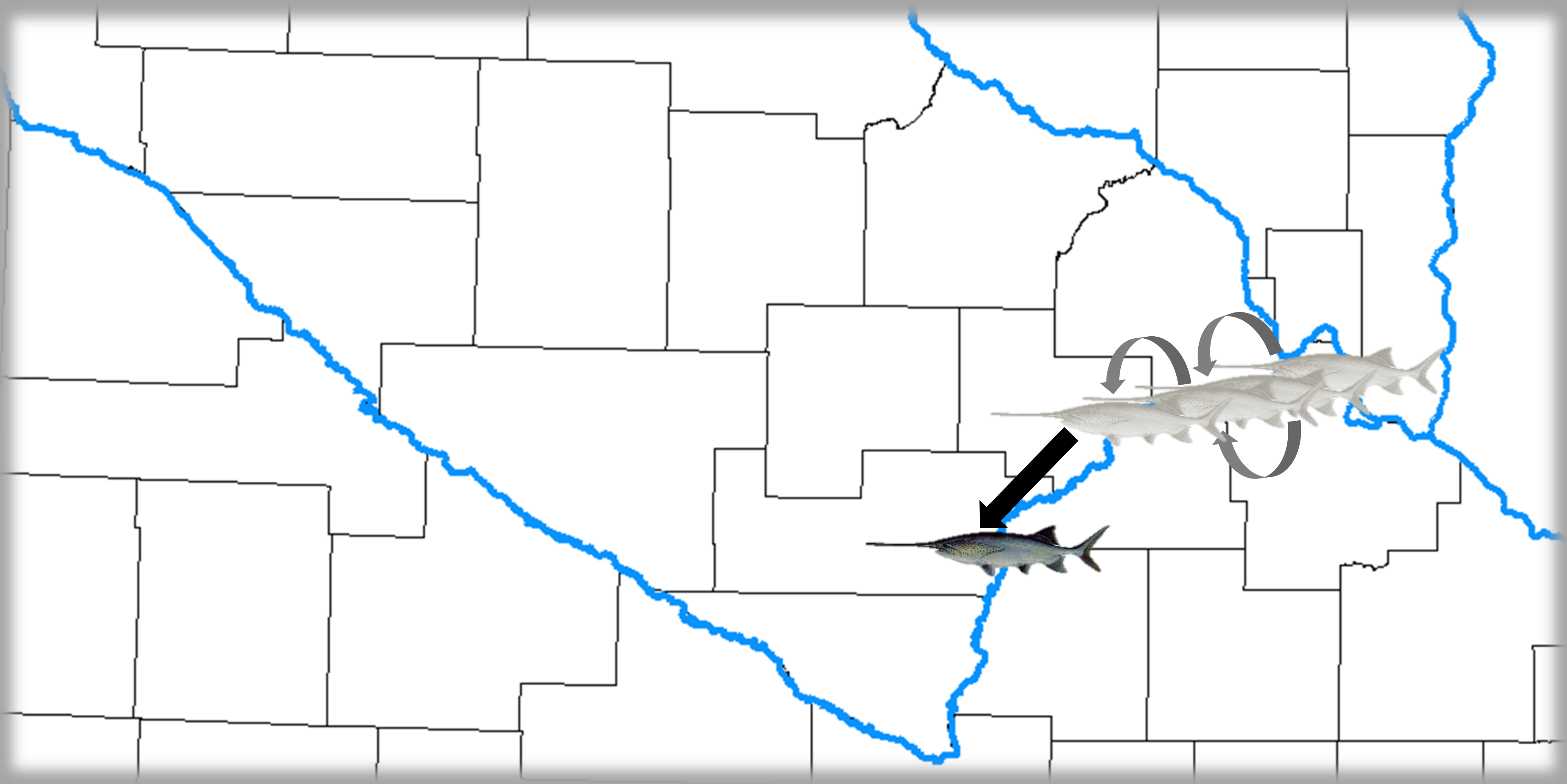
Detected 9/10/17

Paddlefish #52318



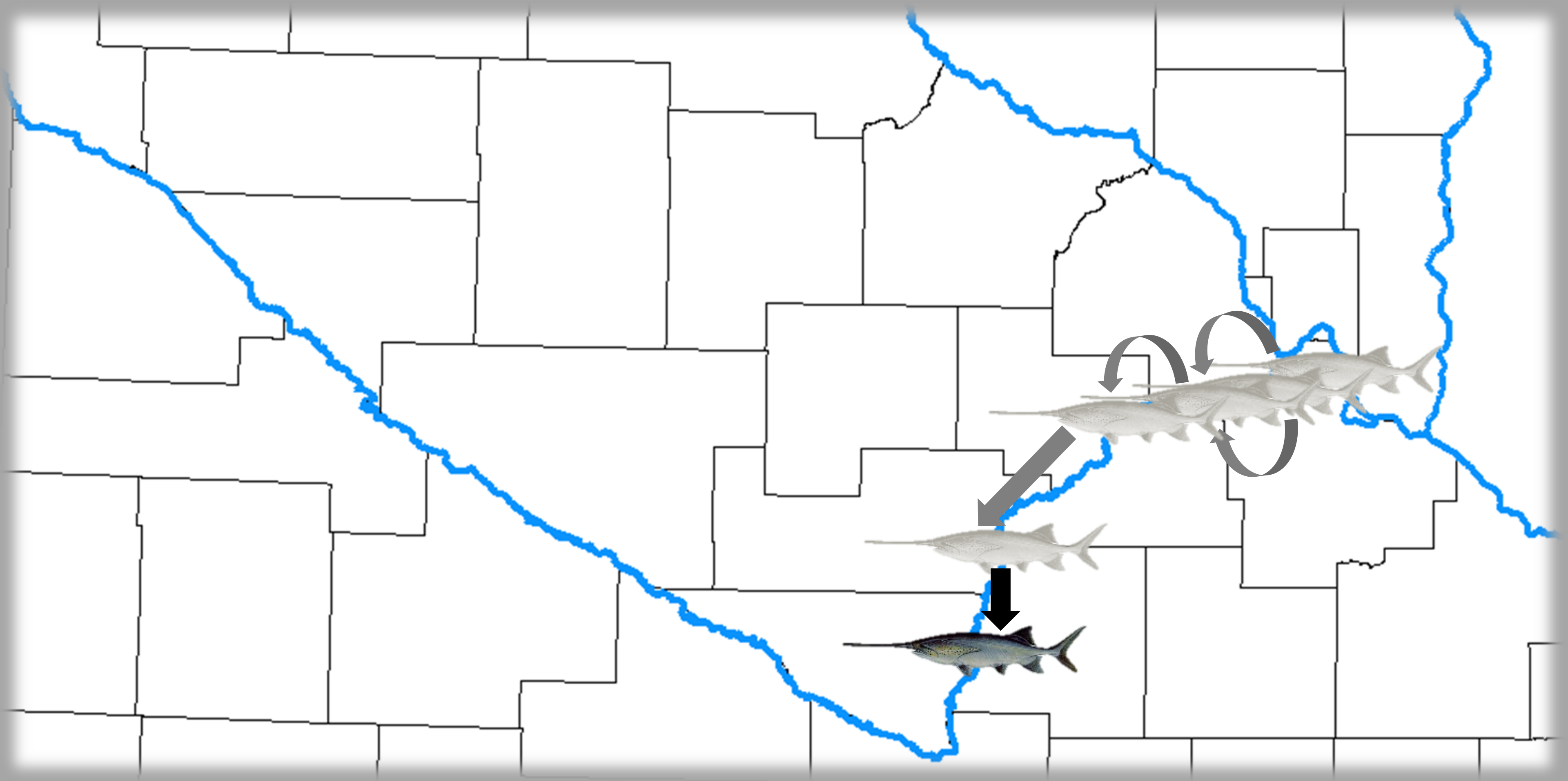
Detected 9/11/17

Paddlefish #52318



Detected 9/14/17

Paddlefish #52318

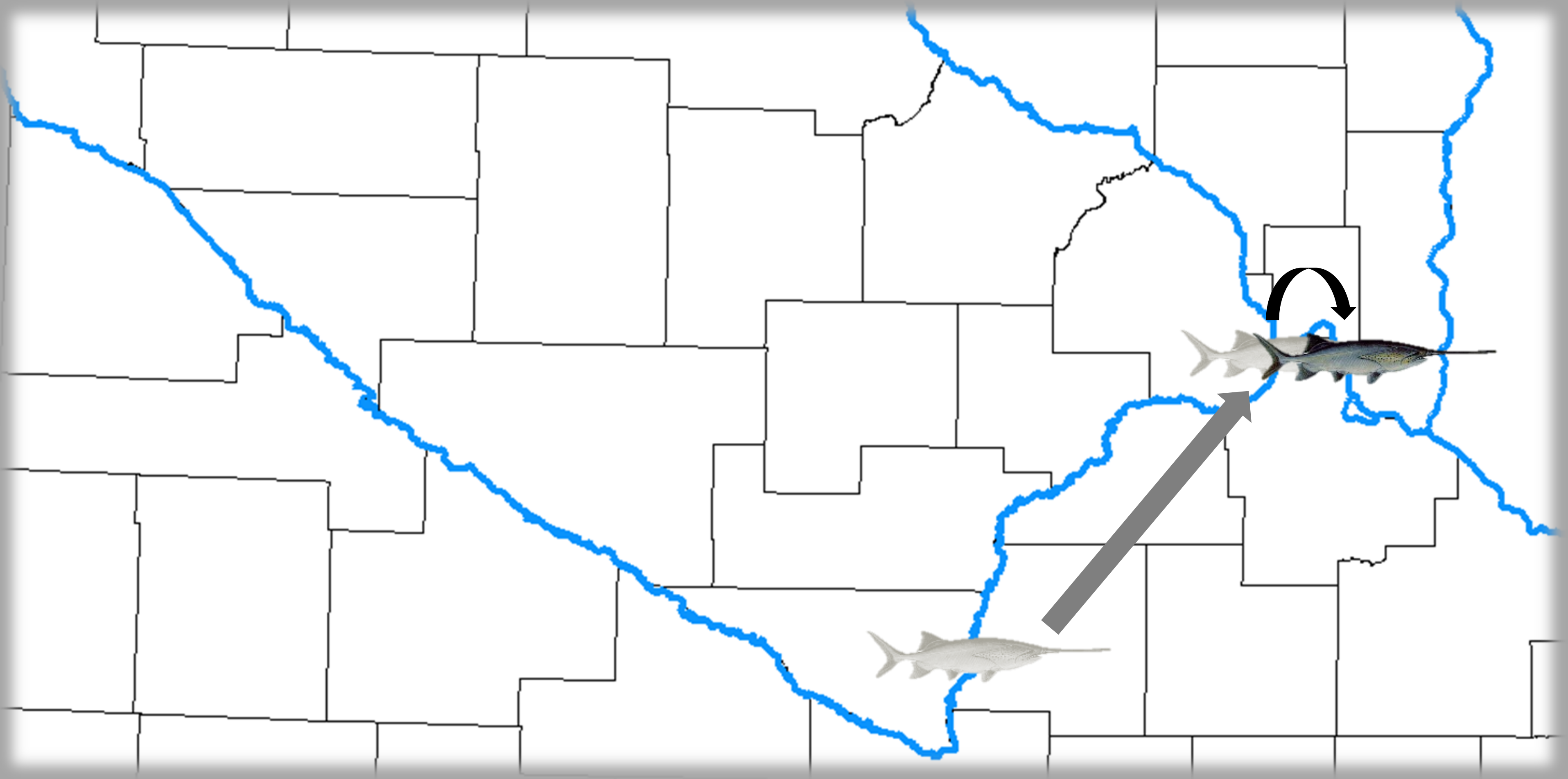


Detected 9/27/17 and 9/28/17

Paddlefish #52318

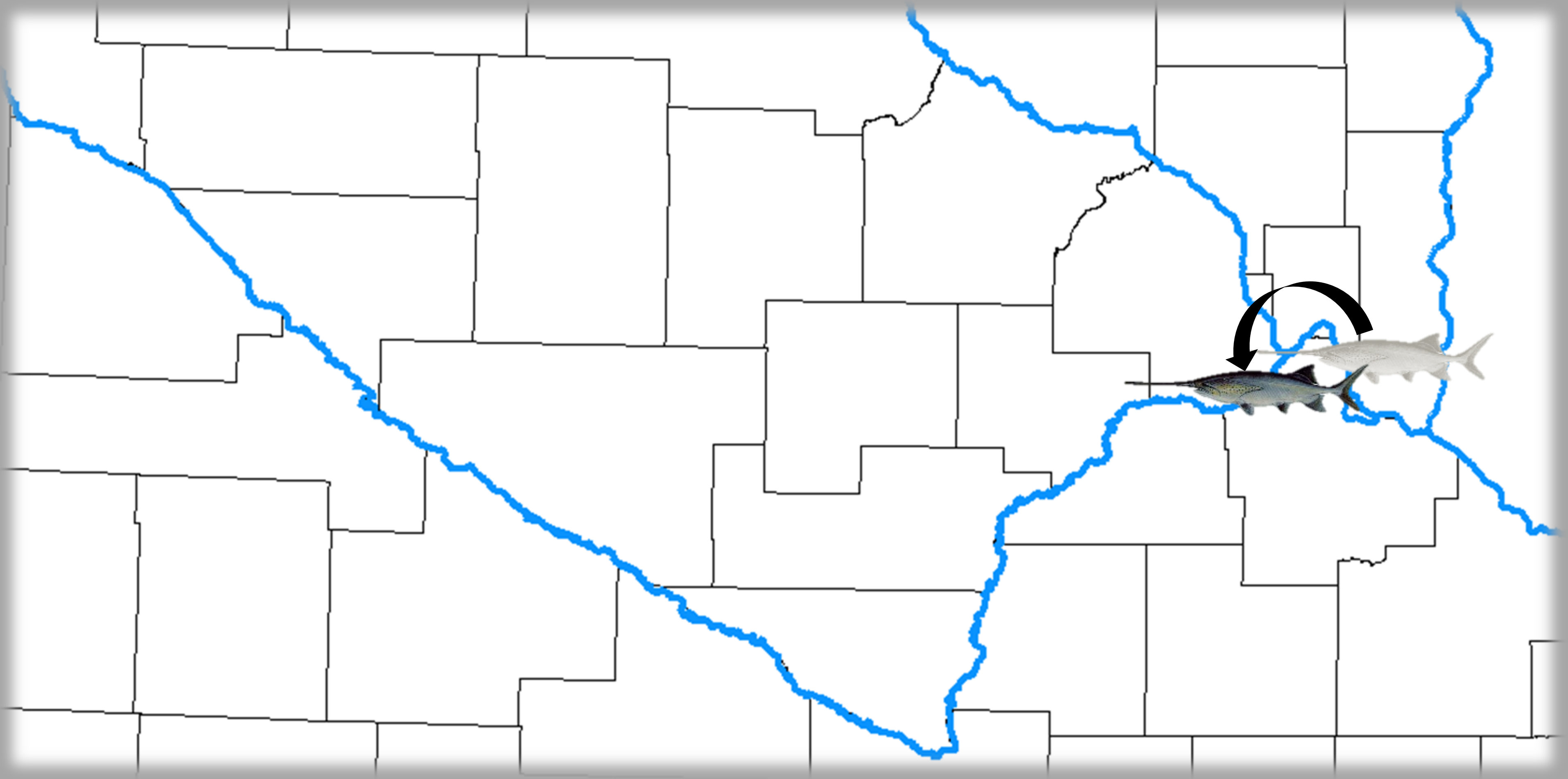
Detected 10/13/17

Paddlefish #52318



Returned to Pigs Eye Lake on 10/14/17 and stayed there until 10/26/17

Paddlefish #52318



Returned to the Minnesota River on 10/27/17

Paddlefish #52318

- Three trips to Pigs Eye Lake and spent almost two weeks each time
  - Each trip is about 100 river miles each way
    - Over 500 river miles since tagging
  - 14, 11 and 12 days for a total of 37 days
- Spent most of its time near St. Peter (~75%)
  - But from May to November of 2017 it spent over half of its recorded time in Pigs Eye Lake (~60%)

Summary

- Paddlefish tagged in our study were bound by three dams
  - Upstream by the Granite Falls dam
  - Downstream by Mississippi River Lock and dam 1 and 2
  - 2 of the 3 PAH to migrate into the MNR passed through the Lock and Dam 2
- St. Peter site could be valuable

Future Directions

- Install final 2 VR2s and continue uploading data
- Continue tracking and sampling
- Attempt to sample small SLS and PAH with Trawling

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ENVIRONMENT
AND NATURAL RESOURCES
TRUST FUND

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RESEARCH ARTICLE

WILEY

Spatial and temporal trends of Minnesota River phytoplankton and zooplankton

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Abstract

Plankton communities have important roles in aquatic ecosystems, but studies of plankton in lotic systems are infrequent. We collected over 100 water, phytoplankton, and zooplankton samples during 2016–2018 to explore spatiotemporal trends in Minnesota River plankton communities and evaluate relationships with physicochemical factors. Phytoplankton and zooplankton community structure exhibited temporal patterns but only the zooplankton community differed spatially. Cyanobacteria (*M* ± *SE*; 11.27 ± 1.43 mm^3/L) and diatoms (8.12 ± 1.08 mm^3/L) dominated phytoplankton biovolume with seasonal peaks in Cyanobacteria occurring during July–September and peaks in diatoms occurring during May, August, and September. All phytoplankton taxa except Cryptophyta exhibited a negative relationship with relative discharge. Crustacean zooplankton biomass was greatest at two upstream sites (146.7 ± 32.6 μg/L) where cladocerans and copepods were likely exported from upstream of dams where water residence time is greater. Within the lower free-flowing reach rotifers dominated the zooplankton community (207.9 ± 40.9 individuals/L and 6.5 ± 1.0 μg/L). Thus, spatial differences in zooplankton community structure were primarily attributed to the influence of dams. Seasonal patterns in zooplankton community structure included peaks in Chydoridae, cyclopoid, immature copepod, and rotifer biomass during May and Bosminidae biomass during October. Excluding the influence of dams on zooplankton, the cumulative effects of month and relative discharge were the most important for explaining variability in plankton community structure. Baseline understanding of plankton community dynamics provides the ability to quantify responses to future perturbations such as climate change and establishment of invasive planktivores.

KEYWORDS

lotic, lower trophic, Minnesota River, plankton

1 | INTRODUCTION

Lower trophic organisms, including phytoplankton and zooplankton, are important components of aquatic ecosystems that link upper trophic levels with basal resources. Phytoplankton is an important source of primary production in the autochthonous lotic food web and zooplankton are primary and secondary consumers that serve as important food for higher trophic levels, including most fish species (Nunn, Tewson, & Cowx, 2012; Thorp & Delong, 2002). Phytoplankton and zooplankton are extensively studied in lentic systems, but understanding of plankton community dynamics in lotic systems is less complete (Lair, 2006; Reynolds, 2000). Yet, a growing number of studies have focused on evaluating factors that influence plankton communities in medium to large rivers (e.g., Burdis & Hoxmeier, 2011;

Descy et al., 2016; Rossetti, Viaroli, & Ferrari, 2009; Salmaso & Braioni, 2008; Thorp & Mantovani, 2005). Influential factors identified include nutrient availability (Basu & Pick, 1996), temperature (Rossetti et al., 2009; Tavernini, Pierobon, & Viaroli, 2011), turbidity (Salmaso & Braioni, 2008; Sluss, Cobbs, & Thorp, 2008; Thorp & Mantovani, 2005), and numerous hydrologic variables (Burdis & Hirsch, 2017; Tavernini et al., 2011; Thorp & Mantovani, 2005). For instance, temporal variability of lotic phytoplankton and zooplankton communities is often associated with seasonal patterns in flow regime, temperature, photoperiod, and nutrient fluxes (Pace, Findlay, & Lints, 1992; Salmaso & Braioni, 2008; Tavernini et al., 2011). An increasing number of studies also demonstrate the importance of biological interactions on lower trophic communities (e.g., bottom-up or top-down trophic interactions; DeBoer, Anderson, & Casper, 2018; Guelda, Kock, Jack, & Bukaveckas, 2005; Thorp & Casper, 2003). Hydrological factors (such as discharge, turbulence, and water residence time), however, have a generally dominant role in structuring lotic plankton communities with phytoplankton and zooplankton biomass increasing with water residence time (Basu & Pick, 1996; Lair, 2006; Pace et al., 1992; Reynolds, 2000; Salmaso & Braioni, 2008; Søballe & Kimmel, 1987).

Lotic ecosystems are complex and ecologists often attempt to describe important riverine features and processes, including longitudinal gradients (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980), the influence of dams (Ward & Stanford, 1983), occurrences of flood-pulses (Bayley, 1995; Junk, Bayley, & Sparks, 1989), hydraulic retention (Schiemer, Keckeis, Reckendorfer, & Winkler, 2001), and trophic cascades (Power, 1990). More recently, the Riverine Ecosystem Synthesis blended many of the existing theories; describing the structure and function of lotic ecosystems with consideration of both the riverscape and floodscape, and suggests that rivers are divided into unique functional zones based on hydrological and geomorphological differences (Thorp, Thoms, & Delong, 2006). Intertwined features and processes of lotic systems influence plankton community dynamics across varying spatial and temporal scales, and consequently spatiotemporal patterns of plankton communities differ among and within systems (e.g., Hardenbicker, Weitere, Ritz, Schöll, & Fischer, 2016). For instance, Varol and Şen (2018) reported a longitudinal trend of increasing phytoplankton biomass from upstream to downstream in the Tigris River, Turkey, whereas Phlips et al. (2000) reported the opposite spatial trend in the St. Johns River, Florida. Rather than longitudinal trends, Abonyi et al. (2014) and Zhao et al. (2017) reported spatial patchiness in plankton communities among river zones with unique environmental conditions. Dams and impoundments can also disrupt spatial patterns and have significant influences on plankton community structure (Havel et al., 2009; Pourriot, Rougier, & Miquelis, 1997; Prygiel & Leitao, 1994). Temporal variability in plankton communities is often influenced by environmental characteristics that exhibit predictable seasonal patterns (e.g., temperature, photoperiod), but these patterns can be disrupted by flood-pulses (Górski, Collier, Duggan, Taylor, & Hamilton, 2013), extreme hydrologic conditions (e.g., droughts; Beaver et al., 2013), or anthropogenic disturbances (Kleinteich, Hilt, Hoppe, & Zarfl, 2020). Most of these influences on spatiotemporal dynamics are attributed to abiotic factors, but biotic interactions can also structure lotic plankton communities, and introduced populations of non-native planktivores have significant impacts on large river plankton communities with cascading impacts on higher trophic levels (Caraco et al., 1997; DeBoer et al., 2018; Pace, Findlay, & Fischer, 1998).

The Minnesota River is an important and complex ecosystem that spans 500 river kilometers (rkm), has a large complex floodplain, and experiences frequent flood-pulses. Similar to other floodplain rivers around the world, the Minnesota River has been altered by the construction of dams and is impacted by agricultural and urban development. In addition, land-use changes, climate change, and invasive species continually affect the Minnesota River ecosystem. For instance, heavy rainfall events are increasingly common and discharge of the Minnesota River has significantly increased over time (Novotny & Stefan, 2007). The threat of invasive bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*) expansion into the Minnesota River is also of particular concern because they may have predatory impacts on plankton communities (Pongruktham, Ochs, & Hoover, 2010) and competitive interactions with native organisms such as paddlefish (*Polyodon spathula*) and freshwater mussels (e.g., Pendleton, Schwinghamer, Solomon, & Casper, 2017). Unfortunately, plankton communities are poorly studied in the Minnesota River, hindering understanding of how lower trophic communities and the Minnesota River ecosystem will respond to ongoing and future changes.

For this study, we explore spatiotemporal patterns of Minnesota River phytoplankton and zooplankton communities, and evaluate the influence of physico-chemical factors on plankton community structure. We hypothesize that both phytoplankton and zooplankton communities will exhibit spatial and temporal patterns in response to differences in abiotic conditions (e.g., turbidity, temperature) among sample sites and months, and that variability in discharge is among the most important drivers of plankton community structure. We also hypothesize that the presence of dams amplifies spatial variability and that variability in discharge and timing of connectivity with floodplain habitats disrupts seasonal patterns and increases temporal variability of plankton community structure. Developing a baseline understanding of Minnesota River plankton community dynamics is important for predicting and understanding ecosystem responses to future perturbations such as climate change and establishment of invasive species.

2 | METHODS

2.1 | Study location

The Minnesota River watershed drains 44,030 km^2 and the Minnesota River flows approximately 520 rkm from Big Stone Lake on the Minnesota–South Dakota border to its confluence with the Mississippi River at St. Paul, MN (Figure 1). The upstream 125-rkm reach of the Minnesota River contains five dams, including the Lac qui Parle Dam at

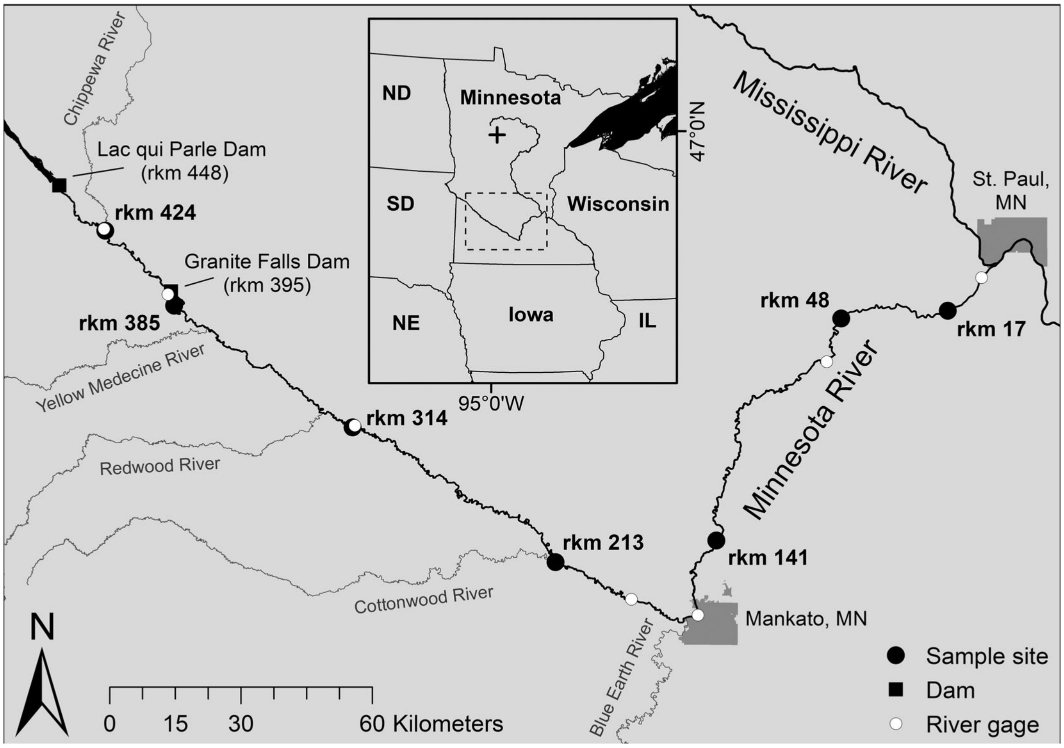

FIGURE 1 Seven Minnesota River sample sites labeled with their corresponding river kilometer (rkm) and the location of nearby river gages. The sample site at rkm 424 is 24-rkm downstream of Lac qui Parle Dam and sample site rkm 385 is 10-rkm downstream of Granite Falls Dam

rkm 448 that controls water levels in a 2,323-ha natural impoundment (Lac qui Parle Reservoir) and the downstream-most dam at rkm 395, which is a 6.4-m tall run-of-the-river hydropower dam in Granite Falls, MN. With the exception of <1 km immediately above Granite Falls Dam, the entire 53-km reach upstream to the next dam at Lac qui Parle is lotic environment. Downstream of the Granite Falls Dam, the Minnesota River is a seventh- through eighth-order (Strahler stream order) floodplain river flowing through the agriculturally dominated prairie region of southern Minnesota. The Minnesota River is a low gradient, productive, and turbid warm water river. For instance, mean discharge, total phosphorus, and total suspended solids were 178.9 m^3/s, 0.25 mg/L, and 127.0 mg/L, respectively, at St. Peter, MN (rkm 142; Minnesota Pollution Control Agency, n.d.) and periodic channel velocity measurements ranged from 0.17 to 2.3 m/s at Mankato, MN (rkm 164; US Geological Survey, n.d.) during 2007–2015.

We evaluated Minnesota River plankton communities by collecting phytoplankton, zooplankton, and water chemistry samples, and measuring physical factors at seven main-channel sample sites distributed along the river at monthly intervals during August–October of 2016, May–October of 2017, and May–October of 2018. The upstream-most site at rkm 424 is 24 rkm downstream of Lac qui Parle Dam and the second-most upstream site at rkm 385 is 10 rkm downstream of Granite Falls Dam (hereafter referred to as "upstream sites"). The remaining five sites are distributed throughout the lower free-flowing reach of the river (hereafter referred to as "downstream sites"). On average, during the 10 years prior to this study (i.e., 2006–2015), mean daily discharge at the downstream-most site was approximately four to five times greater than at the upstream-most site (US Geological Survey, n.d.).

2.2 | Water chemistry samples

During each sample event, we collected two water samples from an anchored boat near the mid-channel of each sample site for water chemistry analyses. We filled a 2-L transparent bottle and a 2-L opaque amber colored bottle with surface water from the upstream side of the boat after rinsing each bottle three times with river water. We immediately stored all water samples in the dark and on ice and then delivered to the Minnesota Department of Agriculture (MDA; St. Paul, MN) Laboratory Services for analyses within 48 hrs.

At the MDA laboratory, staff determined chlorophyll-*a* (Chl-*a*; μg/L) concentrations using Environmental Protection Agency (EPA) Method 445.0 (Arar & Collins, 1997) and total Kjeldahl nitrogen (TKN; mg/L) concentrations using EPA method 351.2 (O'Dell, 1993a). Colorimetry methods determined total phosphorus (TP; mg/L) and dissolved ortho-phosphorus (Ortho-P; mg/L) concentrations (EPA method 365.1; O'Dell, 1993b). Laboratory staff determined nitrate/nitrite (N + N; mg/L) with method SM 4500-NO3F (Eaton, Clesceri, Greenberg, & Franson, 1998). Total suspended solids (TSS; mg/L) and total dissolved solids (TDS; mg/L) were analyzed using SM 2540, parts D and C, respectively (Rice, Baird, Eaton, & Clesceri, 2012). Inductively coupled plasma mass spectrometry determined silica concentrations (Si; mg/L; EPA method 200.8; Creed, Brockhoff, & Martin, 1994).

We also recorded surface water temperature (°C) and measured water transparency (cm) with a 60-cm Secchi tube (S-tube) for each sample site during each sample event. When water temperature or S-tube readings were not measured in the field, we calculated estimates by taking the mean of measured values from the nearest upstream site and nearest downstream site. However, during August 2018 we estimated all water temperatures as 20.0°C. We also obtained hydrograph data associated with each sample event from river gages (US Geological Survey, n.d.) located near (within 0–28 rkm) each sample site.

2.3 | Phytoplankton samples

We collected one integrated water sample from each sample site during each sample event for phytoplankton analyses. First, we rinsed a large container (e.g., 19-L bucket) with river water. Next, we used a 2.5-m long by 7.6-cm diameter clear polyvinyl chloride pipe with a one-way valve (approximate capacity of 12.5 L after accounting for extra volume associated with the valve fitting) to collect an integrated water sample from the surface of the river to approximately 2.5 m depth. We emptied the sample into the large container, and then filled a 250-ml opaque amber bottle with approximately 230 mL of the integrated water sample. We then added 5–10 mL of Lugol's iodine solution for sample preservation and refrigerated.

We shipped phytoplankton samples to BSA Environmental Services, Inc. (BSA; Beachwood, OH) where staff analyzed samples by preparing slides following a standard membrane filtration technique (McNabb, 1960). Phytoplankton enumeration occurred under compound microscopes equipped with epifluorescence with a majority of counting completed at 630× magnification. When possible, BSA enumerated and identified at least 300 units to the lowest practical taxonomic level and estimated abundance of common taxa by random field counts. Staff estimated biovolumes using formulas for solid geometric shapes that most closely match the cell shapes. For each sample, BSA reported estimated densities (cells/L) and biovolumes (μm^3/L) for each identified phytoplankton taxon.

2.4 | Zooplankton samples

We collected zooplankton samples at each sample site during each sample event with similar field methods as Burdis and Hoxmeier (2011). During 2016, we used a 2.5-m long by 7.6-cm diameter clear polyvinyl chloride pipe with a one-way valve (approximate capacity of 12.5 L) to collect two (but only one during August) integrated water samples from the surface of the river to approximately 2.5 m depth. We measured and recorded the volume of each integrated sample to the nearest 0.1 L and filtered the water sample through a 20-μm plankton net. We rinsed contents of the plankton net into a 500-ml bottle and diluted the sample to at least 70% reagent alcohol for preservation. During 2017 and 2018, we used similar methods except we collected three rather than two integrated water samples and filtered samples through a 53-μm rather than 20-μm plankton net to reduce the amount of sediment in samples. We acknowledge that this larger mesh size is less effective for capturing small rotifers (Chick, Levchuk, Medley, & Havel, 2010).

Crustacean zooplankton (i.e., cladocerans and copepods) were enumerated by first adjusting the sample to a known volume, and then transferring 5-ml aliquots into a counting wheel. All zooplankters were identified to the lowest practical taxon (Balcer, Korda, & Dodson, 1984; Haney et al., 2013; Pennak, 1989), counted, and measured under a 25× magnification dissecting microscope with the aid of a computerized image analysis system. Immature copepods were identified as copepodites or nauplii. The entire sample was enumerated if fewer than 30 zooplankters were counted in one 5-ml aliquot. Crustacean zooplankton biomass was estimated using taxa-specific length to weight regression coefficients (Culver, Boucherle, Bean, & Fletcher, 1985; Dumont, Van de Velde, & Dumont, 1975). For rotifer enumeration, samples were adjusted to a known volume and identification was aided by adding a few drops of Biebrich Scarlet/Erosin B stain. A 1-ml aliquot was obtained with a Hensen-Stempel pipette and placed onto a Sedgewick-Rafter cell. Rotifer counts and identification to the lowest practical taxon (Haney et al., 2013; Stemberger, 1979) occurred under a compound microscope at 200× magnification.

We also collected replicate zooplankton samples from sample sites at rkm 385 and rkm 17 for enumeration by BSA. We excluded these replicate samples from further analyses in this manuscript. However, we calculated mean taxon-specific rotifer biomass determined from samples processed by BSA (based on established length–biomass or width–biomass relationships) to estimate biomass of rotifers enumerated in the primary zooplankton samples (Appendix A).

2.5 | Statistical analyses

We performed all statistical analyses with R (R Core Team, 2020) and accepted a 5% probability of false positives ($\alpha = .05$) when testing null hypotheses. We first characterized Minnesota River water chemistry, the phytoplankton community, and the zooplankton community by calculating summary statistics (e.g., *M*, *SE*, quartiles) for all samples pooled. We specifically characterized the phytoplankton community with biovolume (mm^3/L) of the four dominant taxa (Bacillariophyta, Chlorophyta, Cryptophyta, and Cyanobacteria) and the zooplankton community with biomass (μg/L) of five dominant cladoceran families (Bosminidae, Chydoridae, Daphniidae, Leptodoridae, and Sididae), two copepod orders (Cyclopoida and Calanoida), copepodites, copepod nauplii, and rotifers (all taxa combined). We identified correlated physico-chemical variables by calculating Pearson correlation coefficients (using *chart*. Correlation function from the "*PerformanceAnalytics*" package version 1.5.2; Peterson et al., 2018) to prevent multicollinearity issues in multivariate analyses. We increased normality and homoscedasticity of distributions by $\ln(x+1)$ transforming all physico-chemical variables except S-tube reading and water temperature. We considered statistically significant Pearson correlation coefficients ≥0.60 indicative of strong relationships between variables. We then selected the variable hypothesized to have the most direct influence on plankton communities (e.g., selection of TSS rather than S-tube reading) from groups of strongly correlated explanatory variables for inclusion in multivariate analyses.

Discharge is an important environmental driver of plankton dynamics in lotic ecosystems, and is, therefore, an important variable for consideration when evaluating Minnesota River plankton communities. Discharge follows an upstream to downstream gradient, making absolute discharge strongly correlated with river kilometer and comparisons among locations in the river difficult. For example, discharge of 200 m^3/s may cause flood conditions at an upstream site but seasonally low water conditions at a downstream site. For these reasons, we calculated a relativized measure of discharge as a surrogate for hydrologic conditions that allowed for more appropriate comparisons among samples. Specifically, we calculated relative discharge as the percentile value of mean daily discharge for each day, relative to all mean daily discharges during the study period of July 1, 2016–October 16, 2018. We calculated relative discharge for each sample site based on hydrograph data obtained from the nearest river gage (US Geological Survey, n.d.).

We tested the null hypotheses that physico-chemical variables, phytoplankton taxa biovolumes, and zooplankton taxa biomasses do not differ among months (temporally) or exhibit linear relationships with rkm (spatially) by first plotting un-transformed or $\ln(x + 1)$ transformed data as a function of the categorical variable of month (boxplots) and the continuous variable of sample site rkm (scatter-plots). We statistically evaluated the spatial and temporal null hypotheses by conducting one-way Analysis of Variances (ANOVA) and linear regression analyses, respectively, with $\ln(x + 1)$ transformed response variables (except for temperature) to increase normality and homoscedasticity of distributions. We then fit a linear regression line for significant (i.e., $p \le .05$) linear relationships with an adjusted $r^2 \ge .13$. We interpreted adjusted $r^2 < .13$ as small and non-meaningful effects, from 0.13 to 0.26 as medium and moderately meaningful effects, and >0.26 as large and meaningful effects (Cohen, 1988). Following ANOVA tests that indicated significant differences among months, we performed pairwise *t* tests, but did not report all results for brevity. We also tested the null hypothesis of no linear relationship between plankton biovolume or biomass and relative discharge by plotting $\ln(x + 1)$ transformed taxa biovolume or taxa biomass as a function of relative discharge and performing linear regression analyses.

We further evaluated trends in Minnesota River phytoplankton and zooplankton community structure (also referred to as community composition) among months and sample sites by calculating Bray–Curtis dissimilarity matrices with $\ln(x + 1)$ transformed phytoplankton biovolume or zooplankton biomass data. We then conducted permutational multivariate analysis of variance (PERMANOVA; with 999 permutations) on the dissimilarity matrices (using the *adonis* function from the "*vegan*" package; Okansen et al., 2019) to examine individual effects of the categorical temporal variable, month; the categorical spatial variables, reach (i.e., upstream or downstream) and sample site; the continuous spatial variable, rkm; and continuous physico-chemical variables (e.g., relative discharge, water chemistry variables) on phytoplankton and zooplankton community structure. Permutational multivariate analysis of variance is a geometric partitioning of multivariate variation in the space of a chosen dissimilarity measure (Anderson, 2017). The *adonis* function calculates a pseudo-*F* statistic, a *p* value, and an R^2 for each independent variable included in a PERMANOVA. The R^2 is the sum-of-squares for the independent variable divided by the total sum-of-squares and provides a measure of "variability explained". We visually interpreted Bray–Curtis dissimilarity matrices by plotting two-dimensional non-metric multidimensional scaling (NMDS; Clarke, 1993) ordinations (using the *metaMDS* function from the "*vegan*" package) and fit vectors (using the *envfit* function from the "*vegan*" package) depicting the general direction of relationships for significant ($p \le .13$) and meaningful ($R^2 \ge .13$) continuous variables identified with PERMANOVA. On separate NMDS plots, we plotted the 95% confidence interval ellipses (using the *ordiellipse* function from the "*vegan*" package) around the average weighted centroids of statistically significant categorical variables with $R^2 \ge .13$. Additionally, we evaluated patterns in phytoplankton and zooplankton community structure while excluding the influence of dams by conducting the same PERMANOVA analyses with data only collected from the five downstream sample sites. Omitting the two upstream sample sites from these additional analyses allowed for evaluation of spatial trends without the confounding influence of dams that are located upstream of the two upstream sites. Finally, we also used PERMANOVA to evaluate the combined effect of month, relative discharge, and their interaction on phytoplankton and zooplankton community structure.

3 | RESULTS

We collected complete or partial samples from all seven sample sites during August–October of 2016, May–October of 2017, and May–October of 2018; totaling 105 samples. We collected samples from the bank rather than from a boat for five samples that occurred during flood conditions, and consequently, we either failed to collect plankton samples ($n = 2$), collected only phytoplankton samples from the bank ($n = 1$), or collected both phytoplankton and zooplankton samples from the bank ($n = 2$). Discharge generally decreased with river kilometer (Pearson correlation coefficient: $r = -.63$, $p \le .001$) and relative discharge varied widely among sample events (Figure 2). For example, relative discharge varied 0.05–0.94 among sample events at rkm 213 (river gage at rkm 185), exceeding 0.5 for 10 of 15 samples.

We identified several strongly correlated physico-chemical variables and selected Chl-*a*, TP, silica, TDS, temperature, and TSS for inclusion in multivariate analyses (Table 1). The most variable Minnesota River physico-chemical variables included Chl-*a* and TSS with medians (interquartile range, IQR) of 51.2 (70.6) μg/L and 65 (40) mg/L, respectively (Table 2). All retained phyisco-chemical variables significantly differed among months except TSS (Figure 3). Chlorophyll-*a* and temperature exhibited negative relationships with relative discharge and TDS was the only physico-chemical variable that exhibited a significant and meaningful (positive) relationship with rkm (Figure 4).

Phytoplankton identified in samples represented diverse assemblages that included 73 genera from six phytoplankton divisions and Cyanobacteria (Appendix B), but Bacillariophyta (diatoms) and Cyanobacteria (blue-green algae) dominated the biovolume with medians (IQR) of 3.60 (9.8) mm^3/L and 5.69 (14.4) mm^3/L, respectively (Table 2). Cyanobacterial biovolume peaked during July–September while diatom biovolume was generally greatest during May, August, and September (although not significantly different for all pairwise comparisons; Figures 5 and 6). Biovolume of all four phytoplankton taxa had statistically significant negative linear relationships with relative discharge (Figure 6); however, the relationship was not meaningful ($r^2 = .03$) for Cryptophyta. Multivariate analyses indicated the variables month, relative discharge, Chl-*a*, and silica had significant relationships ($p \leq .05$ and $R^2 \geq .13$) with phytoplankton community structure (when all sites were included in analyses; Table 3 and Figure 7). None of the phytoplankton taxa exhibited a significant linear relationship with RKM, and phytoplankton community structure did not significantly differ among sample sites. Non-metric multidimensional scaling plots revealed various relationships including that, phytoplankton communities with greater relative biomass of Chlorophyta and Cyanobacteria were positively associated with Chl-*a* concentration and negatively associated with relative discharge, and that silica concentration was negatively associated with diatoms and Cryptophyta. Analyses (PERMANOVA) indicated the variables that independently had the strongest relationships with phytoplankton community structure included month ($R^2 = .34–.36$), Chl-*a* concentration ($R^2 = .33–.38$), and relative discharge ($R^2 = .24–.33$); regardless of inclusion or exclusion of data from upstream sites influenced by dams. The combination of month, relative discharge, and their interaction explains 57% of the variability in phytoplankton community structure.

Zooplankton identified in samples also represented diverse assemblages that included 7 families and 14 genera of cladocerans, 2 families and 8 genera of copepods, and 14 families and 24 genera of rotifers (Appendixes C and D). Overall, we found median rotifer biomass (3.48 μg/L) exceeded median crustacean zooplankton biomass

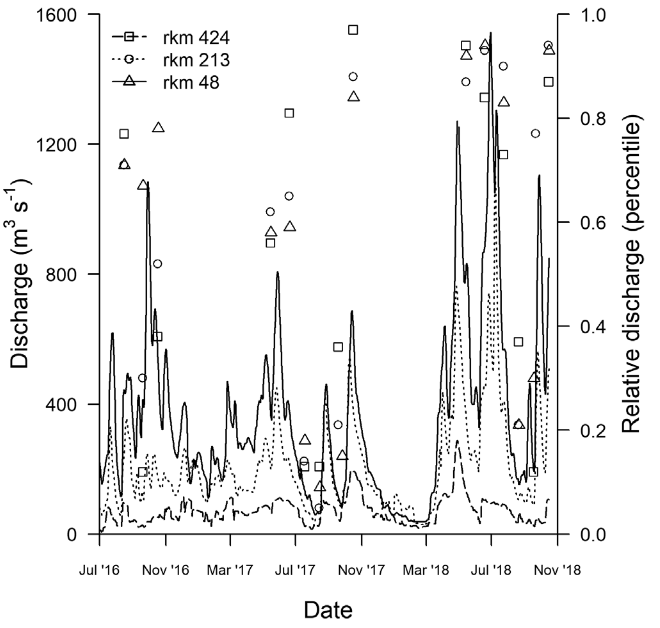

FIGURE 2 Discharge (m^3/s) of the Minnesota River at gaging stations located near three sample sites (rkm 48, rkm 213, rkm 424) during the study period of July, 2016–October, 2018. Symbols indicate the relative discharge (percentile) during each sample events

TABLE 1 Statistically significant ($p \leq .05$) Pearson correlation coefficients for pairwise comparisons of physico-chemical variables measured at seven Minnesota River sites and correlations with river kilometer and relative discharge

	Pearson correlation coefficient									
Variable	**Chl-*a***	**N/N**	**Ortho-P**	**TDS**	**Temp.**	**TKN**	**TP**	**TSS**	**S-tube**	**Silica**
Chl-*a*										
N/N	−0.75									
Ortho-P	−0.40	0.26								
TDS			−0.35							
Temp.	0.48	−0.29		−0.26						
TKN	0.65	−0.72			0.43					
TP			0.64	−0.50	0.25					
TSS	−0.26	0.39	0.33	−0.27			0.64			
S-tube		−0.19	−0.33	0.32	−0.24		−0.61	−0.69		
Silica			0.42				0.46		−0.27	
River kilometer	0.20	−0.47		0.43		0.41		−0.29	0.31	
Relative discharge	−0.74	0.57	0.43		−0.43	−0.54		0.21		

Note: All variables were $\ln(x + 1)$ transformed except temperature, S-tube depth, river kilometer, and relative discharge.
Abbreviations: Chl-*a*, chlorophyll-*a*; N/N, nitrate/nitrite; Ortho-P, dissolved ortho-phosphorus; S-tube, Secchi tube depth; TDS, total dissolved solids; Temp, water temperature; TKN, total Kjeldahl nitrogen; TP, total phosphorus; TSS, total suspended solids.

TABLE 2 Summary statistics for physico-chemical variables, phytoplankton taxa biovolume, and zooplankton taxa biomass across all sample sites and years

Variable or taxa	*n*	Mean	*SE*	Min	Q_1	Median	Q_3	Max
Water chemistry								
S-tube (cm)	105	21.1	0.7	3.6	16.6	20.0	25.0	49.0
Temp (°C)	105	19.0	0.5	5.0	16.0	20.0	22.5	27.1
Ammonia-N (mg/L)	98	0.03	0.00	0.01	0.01	0.01	0.03	0.12
Chl-*a* (μg/L)	105	66.6	4.4	7.8	28.0	51.2	98.6	206.0
N/N (mg/L)	105	4.6	0.3	0.0	1.3	3.9	7.5	13.0
Ortho-P (mg/L)	105	0.060	0.004	0.012	0.029	0.052	0.083	0.157
Silica (mg/L)	105	11.6	0.3	4.2	10.9	12.3	13.6	16.2
TDS (mg/L)	105	659	13	376	560	644	748	992
TKN (mg/L)	105	1.4	0.0	0.2	1.2	1.3	1.6	2.5
TP (mg/L)	105	0.207	0.006	0.105	0.161	0.195	0.234	0.396
TSS (mg/L)	105	82	8	26	50	65	90	758
Phytoplankton biovolume (mm^3/L)								
Bacillariophyta	103	8.12	1.08	0.19	1.53	3.60	11.28	66.44
Chlorophyta	103	0.45	0.06	0.00	0.05	0.20	0.58	3.76
Cryptophyta	103	1.15	0.13	0.02	0.35	0.81	1.43	8.60
Cyanobacteria	103	11.27	1.43	0.00	0.69	5.69	15.05	57.14
Cladoceran biomass (μg/L)								
Family Bosminidae	102	0.10	0.02	0.00	0.00	0.01	0.12	0.70
Family Chydoridae	102	0.08	0.04	0.00	0.00	0.00	0.01	3.43
Family Daphniidae	102	27.33	7.95	0.00	0.00	0.09	4.18	485.81
Family Leptodoridae	102	0.30	0.22	0.00	0.00	0.00	0.00	21.41
Family Sididae	102	0.34	0.12	0.00	0.00	0.00	0.05	8.21
Copepod biomass (μg/L)								
Order Calanoida	102	5.76	1.47	0.00	0.00	0.00	2.51	90.50
Order Cyclopoida	102	11.31	3.11	0.00	0.17	0.77	4.92	191.60
Copepodites	102	1.45	0.34	0.00	0.05	0.25	0.88	24.89
Nauplii	102	0.25	0.06	0.00	0.01	0.05	0.18	3.94
Rotifer biomass (μg/L)								
Rotifers	102	7.07	0.91	1.07	1.96	3.48	6.97	56.10

Abbreviations: Chl-*a*, Chlorophyll-*a*; N/N, nitrate/nitrite; Ortho-P, dissolved ortho-phosphorus; TDS, total dissolved solids; Temp, water temperature; TKN, total Kjeldahl nitrogen; TP, total phosphorus; TSS, total suspended solids; S-tube, Secchi tube depth.

(ranging from 0.00 for several taxa to 0.77 for cyclopoid copepods). However, $M \pm SE$ crustacean zooplankton biomass was greater than mean rotifer biomass with mean crustacean zooplankton biomass ranging from 0.08 ± 0.04 Chydoridae μg/L to 27.33 ± 7.95 Dapniidae μg/L and mean rotifer biomass of 7.07 ± 0.91 μg/L (Table 2). Additional analyses revealed that mean crustacean zooplankton biomass (146.7 ± 32.6 μg/L) was greater than mean rotifer biomass (8.3 ± 2.0 μg/L) at upstream sites (one tailed t test: $t = 4.23$, $df = 29.2$, $p < .001$) but not at downstream sites (one tailed t test: $t = -0.54$, $df = 104.78$, $p = .29$; Table 4). In terms of density rather than biomass, rotifers were more abundant than crustacean zooplankton at both upstream and downstream sites (Table 4).

Zooplankton community structure differed among months with a significant peak in Bosminidae biomass occurring during October (but not greater than during June) and peaks in Chydoridae, cyclopoid copepods, copepodite, nauplii, and rotifer biomass occurring during May (Figure 8). We did not find significant and meaningful linear relationship between rkm and biomass of Bosminidae, Chydoridae, Leptodoridae, nauplii, and rotifers, but identified positive linear relationships for the other taxa groups (particularly for daphnids and adult copepods; Figures 9 and 10). We typically observed the greatest biomass of these taxa at the two upstream sites that are influenced by dams. We also failed to find significant and meaningful linear relationship between relative discharge and biomass for most zooplankton taxa groups (Figures 9 and 10), but identified positive relationships with Bosminidae ($r^2 = .19$) and nauplii ($r^2 = .15$) biomass.

Multivariate analyses indicated that continuous (rkm) and categorical (sample site, reach) variables associated with sample sites ($R^2 = .24$–$.36$) and the categorical variable of month ($R^2 = .18$) had significant relationships with zooplankton community structure

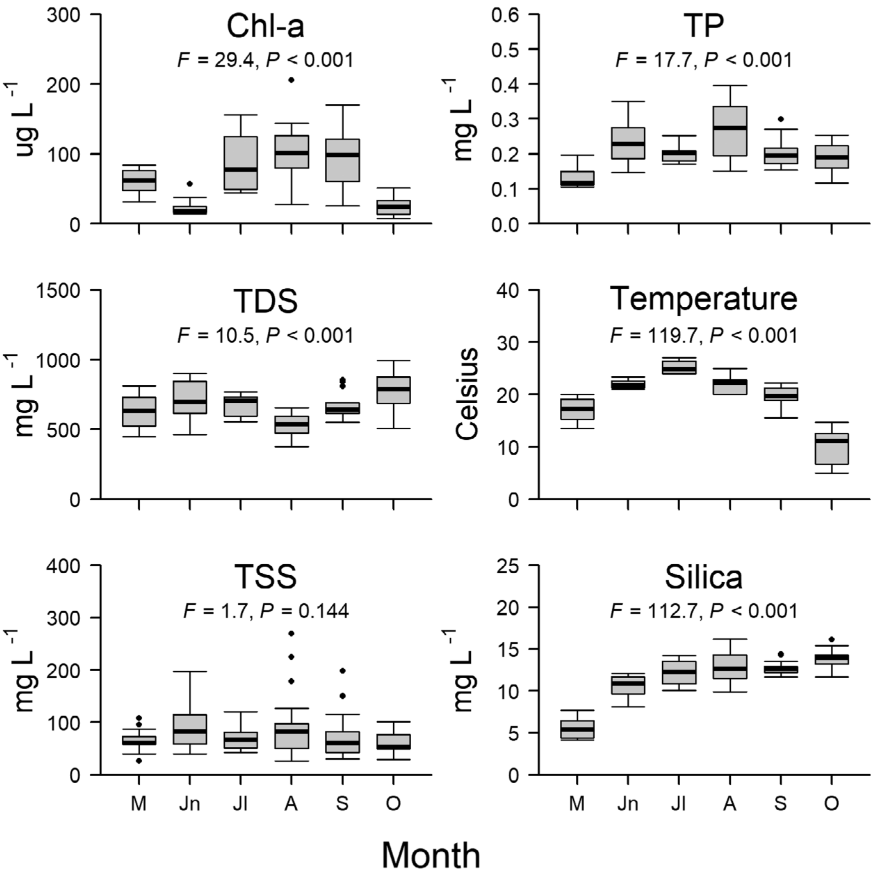

FIGURE 3 Measured Minnesota River physico-chemical variables (Chl-*a*, Chlorophyll-*a*; TP, total phosphorus; TDS, total dissolved solids; Temperature; TSS, total suspended solids; Silica) among months (M, May; Jn, June; Jl, July; A, August; S, September; O, October). Analysis of variance was used to test the null hypothesis of no difference among months using ln($x + 1$) transformed response variables (except for Temperature). Lines within the boxes indicate medians; ends of boxes indicate the 25th and 75th percentiles; ends of the whiskers indicate values up to 1.5× the interquartile ranges; black circles indicate outliers. One extreme outlier (>700 mg/L) for TSS falls outside the bounds of the figure

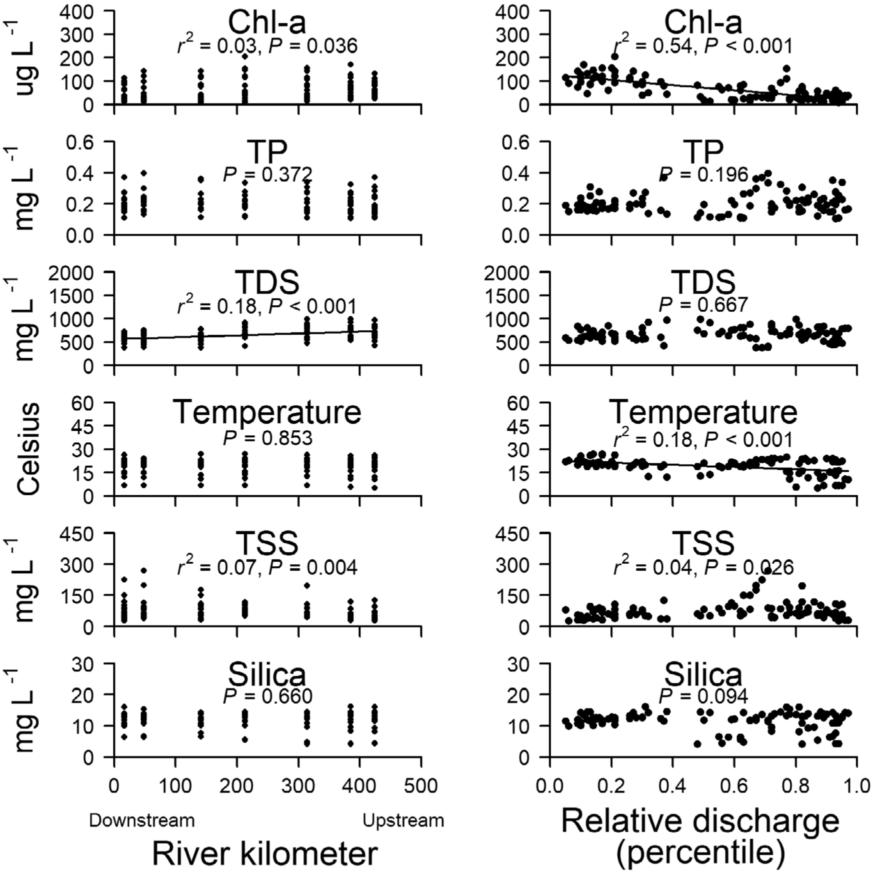

FIGURE 4 Relationships between Minnesota River physico-chemical variables (Chl-*a*, Chlorophyll-*a*; TP, total phosphorus; TDS, total dissolved solids; Temperature; TSS, total suspended solids; Silica) and river kilometer and relative discharge. Linear regression analyses were used to test the null hypothesis of no linear relationship with river kilometer or relative discharge using ln($x + 1$) transformed response variables. Regression lines are provided for statistically significant ($p \leq .05$) and meaningful linear relationships with $r^2 \geq .13$. One extreme outlier (>700 mg/L) for TSS falls outside the bounds of the figure

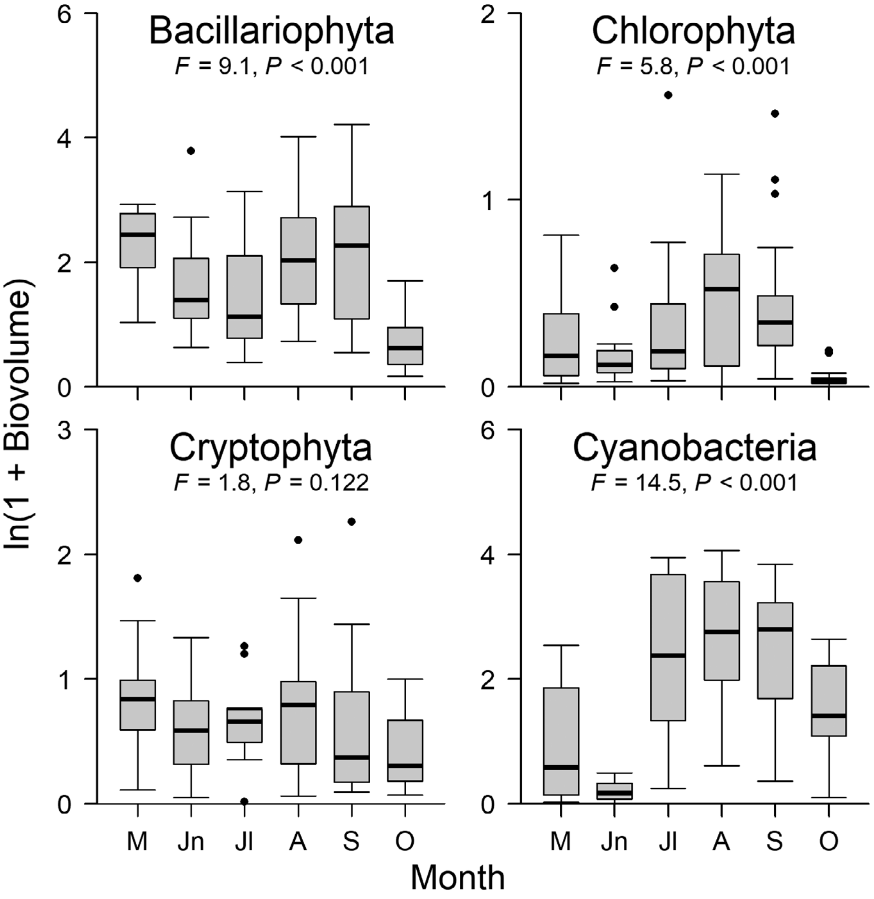

FIGURE 5 Minnesota River Phytoplankton taxa ln($x + 1$) transformed biovolume (mm^3/L) among months (M, May; Jn, June; Jl, July; A, August; S, September; O, October). Analysis of variance was used to test the null hypothesis of no difference among months using ln($x + 1$) transformed response variables. Lines within the boxes indicate medians; ends of boxes indicate the 25th and 75th percentiles; ends of the whiskers indicate values up to 1.5× the interquartile ranges; black circles indicate outliers

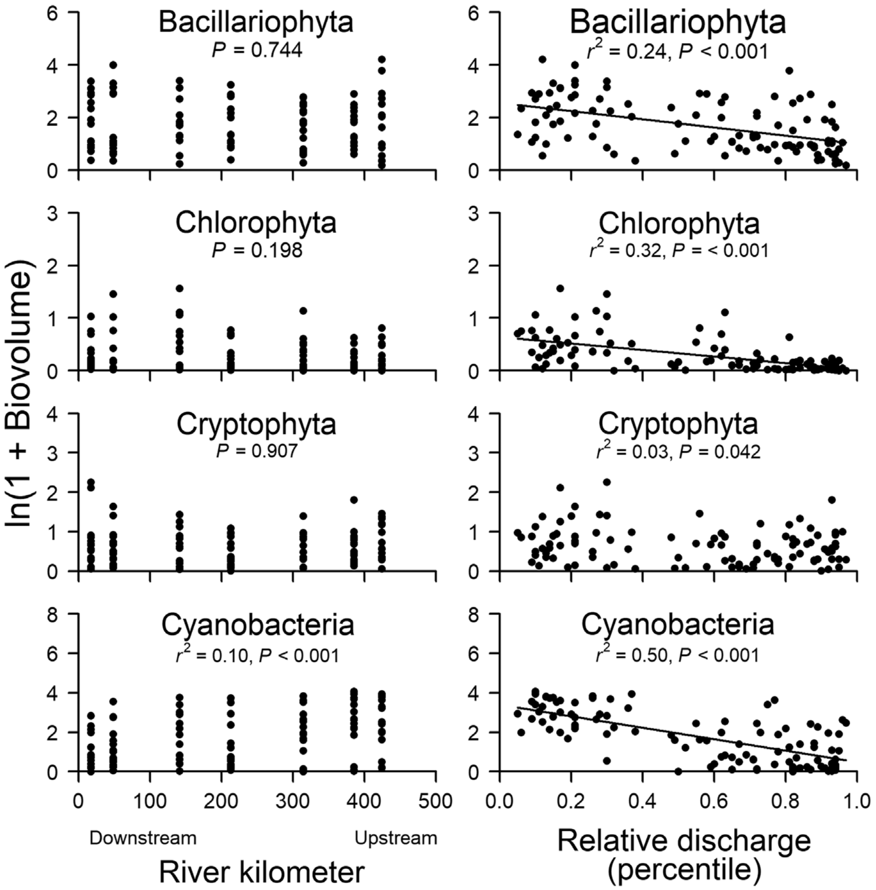

FIGURE 6 Relationships between Minnesota River phytoplankton taxa ln($x + 1$) transformed biovolume (mm^3/L) and river kilometer and relative discharge. Linear regression analyses were used to test the null hypothesis of no linear relationship with river kilometer or relative discharge using ln($x + 1$) transformed response variables. Regression lines are provided for statistically significant ($p \le .05$) and meaningful linear relationships with $r^2 \ge .13$

TABLE 3 Results (pseudo-*F*, R^2, and *p* values) from permutational multivariate analysis of variance using distance matrices (Bray–Curtis) of Minnesota River phytoplankton community samples and fitting individual linear models for spatial, temporal, and physico-chemical variables

	All samples			Excluding upstream sites (RKM 385 and 424)		
Variable	***F***	R^2	***p***	***F***	R^2	***p***
Continuous variables						
River kilometer	5.3	.05	.004	0.7	.01	.572
Relative discharge	31.2	.24	<.001	33.9	.33	<.001
Chl-*a*	48.4	.33	<.001	43.5	.38	<.001
TP	5.4	.05	<.001	7.7	.10	<.001
Silica	15.1	.13	<.001	7.6	.10	<.001
TDS	2.1	.02	.117	0.6	.01	.656
Temperature	7.3	.07	<.001	6.1	.08	.003
TSS	11.3	.10	<.001	9.4	.12	<.001
Categorical variables						
Sample site	1.4	.08	.135	0.7	.04	.714
Month	10.7	.36	<.001	6.9	.34	<.001
Upstream vs. downstream	5.06	.05	.005			
Combined model						
Month +	14.9	.36	<.001	11.1	.34	<.001
Relative discharge +	27.2	.13	<.001	33.3	.21	<.001
Month × relative discharge	3.3	.08	<.001	2.6	.08	.002

Note: Analyses were performed with data from all sample sites and with data excluding the two upstream most sites that are influenced by dams. All biovolume and water chemistry data were $\ln(x + 1)$ transformed.
Abbreviations: Chl-*a*, Chlorophyll-*a*; TP, total phosphorus; TDS, total dissolved solids; TSS, total suspended solids. All biovolume and water chemistry data were $\ln(x + 1)$ transformed.

(Table 5 and Figure 11). Similar to results from linear regression analyses, rkm was positively associated with zooplankton communities that have greater relative biomass of larger-bodied cladocerans and adult copepods and the zooplankton community structure in the upstream reach differed from the downstream reach (PERMANOVA: $R^2 = .28$; $p < .001$). When we excluded data from upstream sites, the strength of relationships with relative discharge and silica become meaningful, the relationship with month is stronger, and the strength of the relationship with rkm ($R^2 = .05$) and sample site ($R^2 = .08$) is weaker and not meaningful. The combination of month, relative discharge, and their interaction only explain 29% of the variability in zooplankton community structure among all seven sample sites, but 49% of variability among the five samples sites within the downstream reach.

4 | DISCUSSION

This study unveiled diverse plankton assemblages within the main channel of the Minnesota River and contributed to an expanding knowledge about spatiotemporal dynamics of lotic plankton communities. Diatoms and Cyanobacteria dominate the Minnesota River phytoplankton community, while rotifers numerically dominate the zooplankton community and typically outnumber crustacean zooplankton by one to three orders of magnitude. Plankton communities in the Minnesota River generally resemble those found in other medium to large rivers (Basu & Pick, 1996; Havel et al., 2009; Thorp & Mantovani, 2005), including downstream in the Mississippi River (Baker & Baker, 1981; Burdis & Hoxmeier, 2011). Results of this study support our hypothesis, revealing that both phytoplankton and zooplankton communities exhibit temporal patterns among years. Differing from expectations, the phytoplankton community did not exhibit longitudinal trends (Basu & Pick, 1997; Hardenbicker et al., 2016; Vannote et al., 1980) or spatial patchiness (Abonyi et al., 2014), but zooplankton communities at the two upstream sites had significantly greater biomass of larger-bodied cladocerans and adult copepods than at downstream sites.

Relatively abundant cladocerans and copepods at the two upstream sites are likely exports from upstream of Granite Falls Dam and Lac Qui Parle Dam where water residence time is greater and zooplankton species with longer generation times are favored (Baranyi, Hein, Holarek, Keckeis, & Schiemer, 2002; Burdis & Hirsch, 2017; Pourriot et al., 1997). Within the lower 300-km free-flowing reach of the Minnesota River, we failed to identify meaningful differences in the zooplankton communities among five sample sites. Thus, we attribute spatial differences in zooplankton communities to the influence of dams rather than longitudinal processes or spatial heterogeneity in other abiotic or biotic conditions. Several other studies document similar influences of dams and reservoirs on downstream lotic zooplankton communities (Akopian, Garnier, & Pourriot, 1999; Burdis & Hoxmeier, 2011; Havel et al., 2009; Pourriot et al., 1997). For instance, Burdis and Hoxmeier (2011) similarly found greater biomass of daphnids and copepods in the Mississippi River downstream of Lake Pepin compared with upstream. Havel et al. (2009) also observed high densities of crustacean zooplankton immediately downstream of Missouri River dams and densities exponentially declined with distance downstream. These findings support our claim that impounded reaches upstream of dams likely serve as a source of crustacean zooplankton for downstream reaches and strongly influence the spatial patterns we observed. In contrast with zooplankton, phytoplankton communities did not exhibit meaningful differences between the upstream and downstream reaches. However, impounded reaches upstream of dams likely provide inoculum that influence downstream phytoplankton communities (Grabowska & Mazur-Marzec, 2011; Prygiel & Leitao, 1994), and those influences may be relatively consistent throughout the entire study reach. Alternatively, phytoplankton exports from upstream of dams may include taxa that are unable to survive the riverine environment long enough to reach our sample sites that are 10 km and further downstream. Future studies should address these questions and advance understanding of the influence of dams and impoundments on lotic plankton communities by sampling plankton from various distances upstream and downstream of dams and within impounded reaches during varying hydrologic conditions.

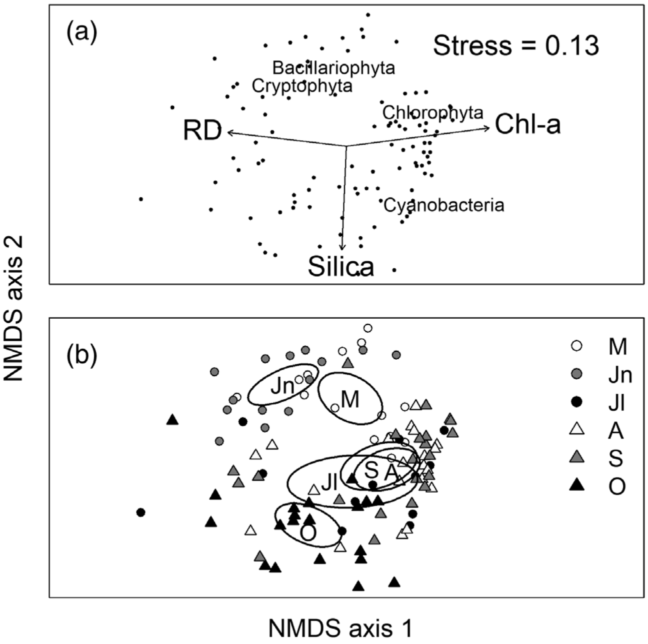

FIGURE 7 Results of NMDS (stress = 0.13, non-metric fit $R^2 = .98$) showing phytoplankton community structure differed with (a) relative discharge (RD), Chlorophyll-*a* concentration (Chl-*a*), and silica concentration and (b) among months (M, May; Jn, June; Jl, July; A, August; S, September; O, October). Significant relationships ($p \le .05$; $R^2 \ge .13$) between phytoplankton community structure and continuous physico-chemical variables determined with permutational multivariate analysis of variance (PERMANOVA) are displayed as vectors depicting the general direction of the relationship. Significant differences (PERMANOVA; $p \le .05$; $R^2 \ge .13$) in phytoplankton community structure among months are displayed with 95% confidence interval ellipses around average weighted centroids

Excluding the influence of dams, relatively spatially homogenous plankton communities observed in the Minnesota River differ from numerous studies that document spatial patterns or patchiness in lotic plankton communities attributed to longitudinal processes or differences in environmental conditions among river reaches (e.g., Abonyi et al., 2014; Basu & Pick, 1997; Hardenbicker et al., 2016; Massicotte, Frenette, Proulx, Pinel-Alloul, & Bertolo, 2014; Varol & Şen, 2018). Many abiotic and biotic attributes (e.g., in-stream habitat complexity, lateral connectivity, fish communities) differ spatially within the Minnesota River at varying scales, but only one of the physico-chemical factors (TDS) evaluated during this study exhibited a meaningful spatial pattern. Similarities in TP (e.g., nutrients), TSS (e.g., turbidity), relative discharge, and water temperature among sample sites likely contributes to the spatial similarities in Minnesota River plankton communities. Zhao et al. (2017) similarly demonstrated spatial homogenization of zooplankton communities in the Ying River system of China associated with homogenization of environmental conditions during high flow events compared with greater heterogeneity among habitats during the dry season. Under certain environmental conditions (e.g., drought) or over a larger spatial scale (e.g., including tributaries) where abiotic factors exhibit greater spatial variability, we would also expect greater spatial variability in plankton communities.

In contrast with spatially homogenous abiotic factors, we found significant temporal variability in Minnesota River physico-chemical attributes that likely influenced temporal patterns in plankton community structure. Both phytoplankton and zooplankton communities exhibited seasonal patterns with differences between spring (May and June), summer (July–September), and fall (October) months. Besides the presumed influence of dams on zooplankton, the variable “month” explained the greatest amount of variability in plankton community

TABLE 4 Minnesota River crustacean zooplankton (cladocerans and copepods, excluding nauplii and copepodites) and rotifer biomass and density in samples collected from five downstream sites and from two upstream sites (influenced by dams) across all study years

		Downstream					Upstream			
Biomass or density	***n***	**Mean**	***SE***	**Min**	**Max**	***n***	**Mean**	***SE***	**Min**	**Max**
Crustacean biomass (μg/L)	72	4.8	1.9	0	118.8	30	142.3	31.9	0.0	695.6
Rotifer biomass (μg/L)	72	6.5	1.0	1.1	36.5	30	8.3	2.0	1.3	56.1
Crustacean density (ind./L)	72	0.8	0.2	0.0	13.3	30	19.4	4.6	0.0	121.3
Rotifer density (ind./L)	72	207.9	40.9	3.5	1,685.3	30	230.8	47.9	13.3	1,197.8

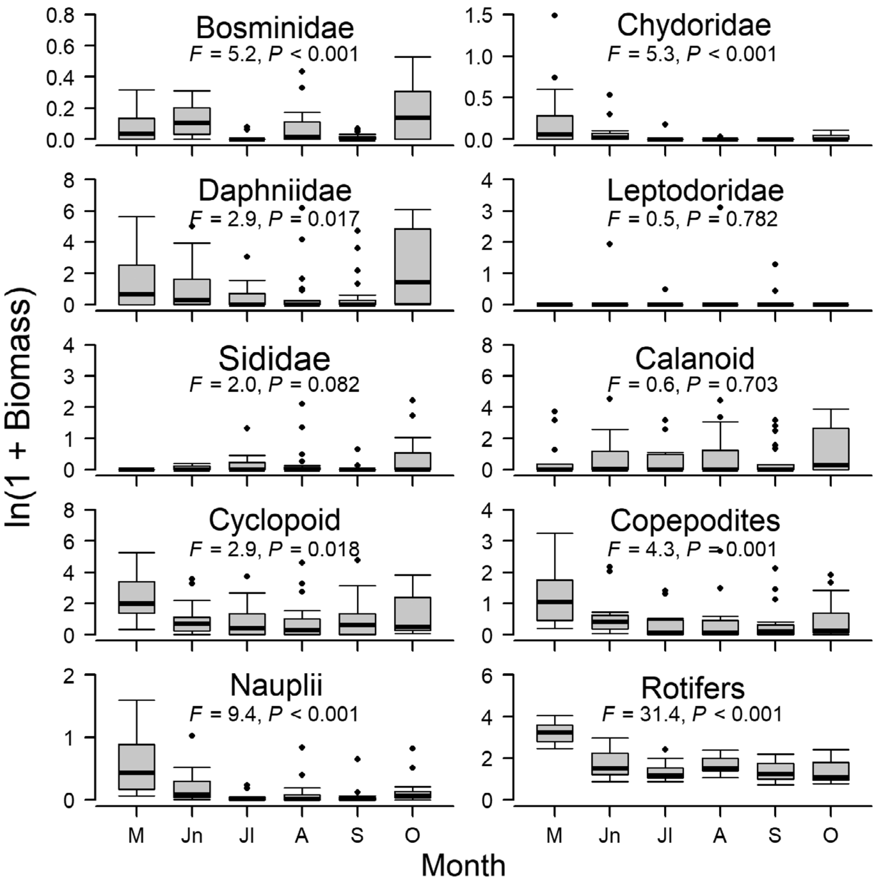

FIGURE 8 Minnesota River zooplankton taxa ln($x + 1$) transformed biomass (μg/L) among months (M, May; Jn, June; Jl, July; A, August; S, September; O, October). Analysis of variance was used to test the null hypothesis of no difference among months using ln($x + 1$) transformed response variables. Lines within the boxes indicate medians; ends of boxes indicate the 25th and 75th percentiles; ends of the whiskers indicate values up to 1.5× the interquartile ranges; black circles indicate outliers

structure. For phytoplankton, we observed seasonal trends similar to those reported downstream in the Mississippi River (Baker & Baker, 1981) with diatoms being dominant during spring, Cyanobacteria dominant during summer, and that other taxa (e.g., green algae, cryptophytes) are present but rarely dominant. Similar seasonal succession of phytoplankton community structure has also been reported for eutrophic Minnesota lakes (Heiskary, Hirsch, & Rantala, 2016), and numerous other studies have documented seasonal succession of phytoplankton communities in lotic systems (e.g., Kleinteich et al., 2020; Peterson & Stevenson, 1989; Salmaso & Braioni, 2008; Tavernini et al., 2011). For zooplankton, community structure differed during May and October compared with other months, and several taxa groups, including rotifers, cyclopoids, copepodites, and nauplii were notably most abundant during May. Other studies have also documented consistent spring or summer peaks in certain zooplankton taxa, especially for rotifers, which are often the most abundant taxa in lotic systems (Lair, 2006). Similar to our findings, Wahl, Goodrich, Nannini, Dettmers, and Soluk (2008) found that rotifer abundance peaked during May in the Illinois River. Pace et al. (1992) and Thorp, Black, Haag, and Wehr (1994) also documented seasonal trends in lotic zooplankton communities, including peaks in rotifer abundance occurring between late spring (June) and mid-summer (July–August). Temperature is often one of the most influential drivers of seasonal patterns, and peaks in rotifers are often associated with seasonal increases in water temperature (Arora & Mehra, 2003; Burdis & Hoxmeier, 2011). Gillooly and Dodson (2000) found that water temperature also influences Daphniidae abundance, with peaks occurring between 15 and 20°C. Accordingly, we typically observed the lowest biomass of Daphniidae in the Minnesota River during summer months when water temperatures exceeded 20°C. Our results did not reveal meaningful relationships between water temperature and plankton community structure, but similarities in temporal patterns among years and among systems indicate that plankton communities exhibit seasonal succession that is influenced by phenological patterns and factors that vary predictably with season (e.g., temperature, photoperiod, nutrient fluxes). However, extreme hydrological and meteorological events (e.g., floods, droughts; Beaver et al., 2013) and anthropogenic disturbances (e.g., draw downs, impoundments) are likely capable of disrupting these seasonal patterns.

The constant downstream transport in lotic systems is a dominant force influencing plankton community dynamics and many studies demonstrate that water residence time has a significant positive relationship with abundance and density of phytoplankton and zooplankton, and can influence species composition (Basu & Pick, 1996; Burdis & Hirsch, 2017; Reckendorfer, Keckeis, Winkler, & Schiemer, 1999; Salmaso & Braioni, 2008; Søballe & Kimmel, 1987). Consistent with that notion, our results revealed strong negative relationships between phytoplankton biovolume and relative discharge, and relative discharge independently explained 24% of variability in phytoplankton community structure. During this study, relative discharge was generally high during May, June, and October, relatively

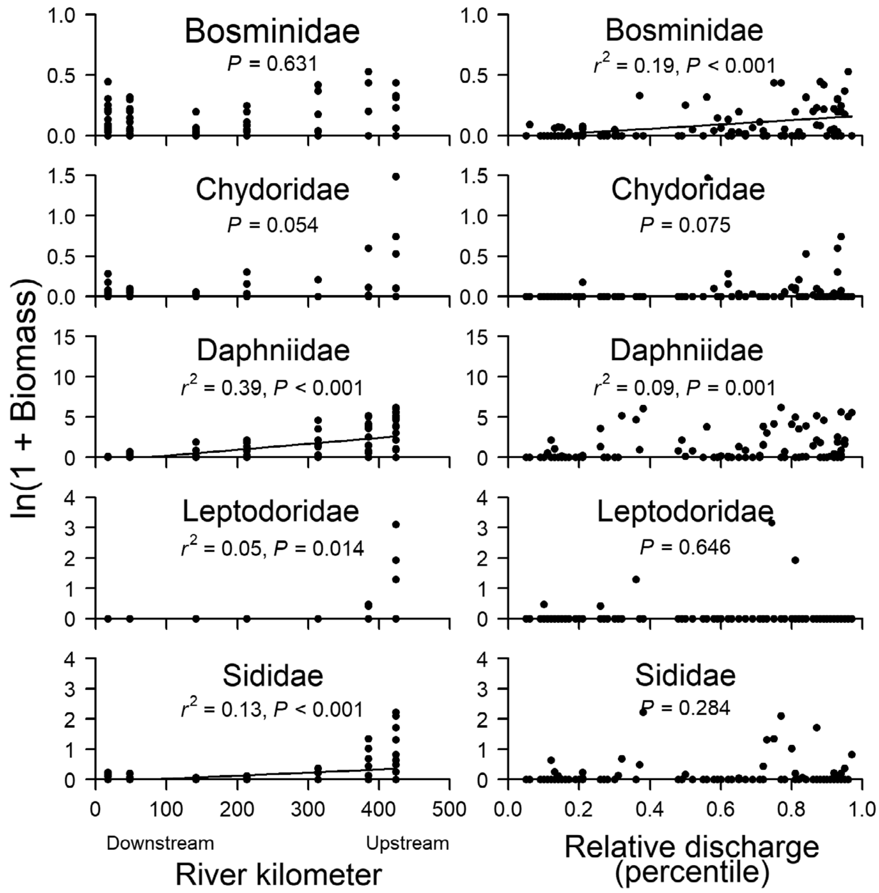

FIGURE 9 Relationships between Minnesota River cladoceran zooplankton taxa $\ln(x + 1)$ transformed biomass (μg/L) and river kilometer and relative discharge. Linear regression analyses were used to test the null hypothesis of no linear relationship with river kilometer or relative discharge using $\ln(x + 1)$ transformed response variables. Regression lines are provided for statistically significant ($p \le .05$) and meaningful linear relationships with $r^2 \ge .13$

low during September, and more variable during July and August among years. Accordingly, phytoplankton biovolume was typically lowest during months with consistently high relative discharge (May, June, and October), especially for green algae and Cyanobacteria. Phytoplankton biovolume presumably decreased with discharge because of increased advective losses and dilution, and because of decreased light availability caused by greater turbulence and river depths (Descy et al., 2016; Reynolds, 2000). Hydrologic factors, such as water residence time, are thought to have an even greater influence on zooplankton communities because of their longer generation times and lesser ability to compensate for advective loss (Basu & Pick, 1996; Pace et al., 1992). Yet, in contrast with other studies (Basu & Pick, 1996; Pace et al., 1992; Rossetti et al., 2009; Sluss & Jack, 2013), we found that relative discharge alone explained a minimal amount of variability in zooplankton community structure and that Bosminidae and nauplii biomass tended to increase with relative discharge. Basu and Pick (1997) similarly found that river discharge was a poor predictor of zooplankton biomass in the Rideau River, Canada, and Burdis and Hoxmeier (2011) found that peaks in zooplankton abundance and biomass in the Mississippi River often occurred during May and June when discharge was greatest. Seasonal peaks in zooplankton biomass are likely influenced by seasonal changes, such as increasing water temperature, and outcomes from this study and others indicate that temporal patterns can have a stronger influence on lotic zooplankton communities than variability in discharge among years. Lotic systems with short water residence times generally favor smaller zooplankton with shorter generation times and taxa that are more tolerant of turbid and turbulent conditions (e.g., rotifers, Bosminidae; Baranyi et al., 2002; Lair, 2006; Pace et al., 1992). The Minnesota River was generally turbid (never exceeding 0.5 m S-tube depth) regardless of relative discharge conditions, which is demonstrated by weak or insignificant relationships between relative discharge and TSS and S-tube depth. Thus, variability within the range of discharge conditions typical of the Minnesota River may have minimal influence on the main channel zooplankton community that is dominated by rotifers and other taxa adapted to turbid riverine environments. Even during periods of low relative discharge sampled during this study, water residence times may not have exceeded thresholds that allow larger-bodied cladocerans to outcompete rotifers and influence significant shifts in zooplankton community structure (Baranyi et al., 2002; Gilbert, 1988).

Although relative discharge independently had a small effect on zooplankton community structure, our analyses revealed that the cumulative effects of month, relative discharge, and their interaction explained 49% of the variability in zooplankton community structure within the downstream reach and 57% of the variability in phytoplankton community structure. These results corroborate the findings of others by demonstrating that seasonal succession and hydrological factors can be interconnected and are both important for regulating lotic plankton communities (Pace et al., 1992; Rossetti et al., 2009;

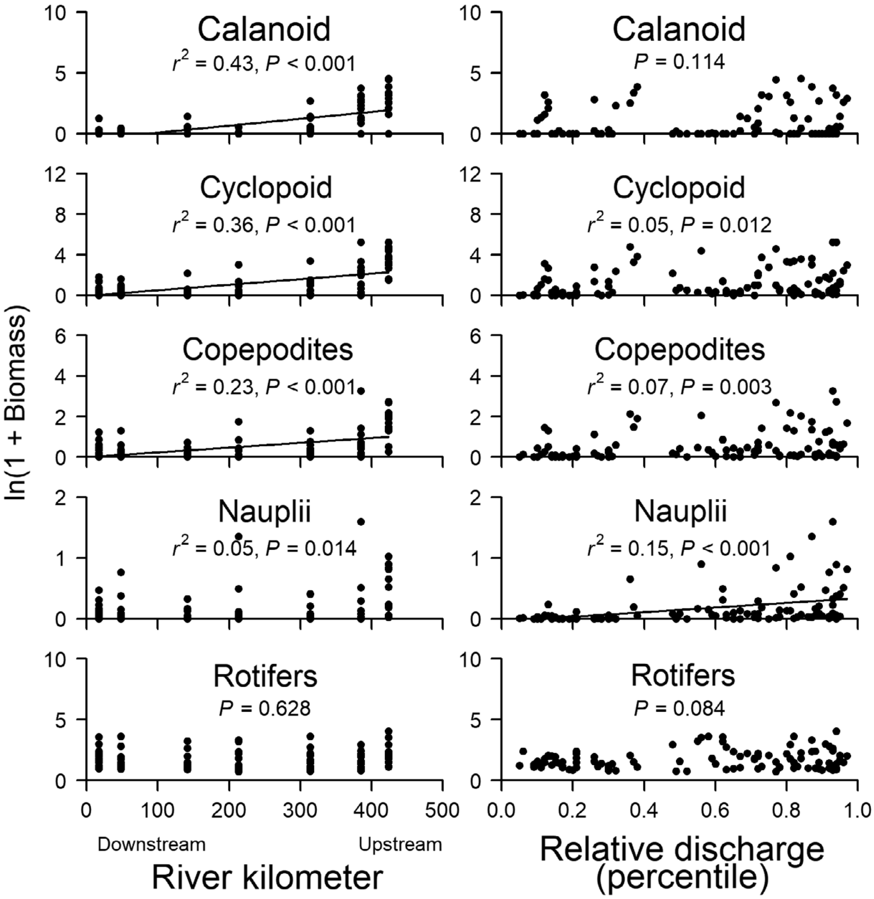

FIGURE 10 Relationships between Minnesota River copepod and rotifer zooplankton ln($x + 1$) transformed biomass (μg/L) and river kilometer and relative discharge. Linear regression analyses were used to test the null hypothesis of no linear relationship with river kilometer or relative discharge using ln($x + 1$) transformed response variables. Regression lines are provided for statistically significant ($p \le .05$) and meaningful linear relationships with $r^2 \ge .13$

Salmaso & Braioni, 2008; Tavernini et al., 2011; Thorp et al., 1994). Relative discharge exhibited seasonal patterns among years in the Minnesota River, making it difficult to decouple the influence of hydrologic conditions and seasonal succession. For instance, seasonal succession is likely a primary factor contributing to differences in phytoplankton and zooplankton community structure between the months of May and October, but it is difficult to evaluate the potential influence of relative discharge during these months because mean relative discharge was relatively high (>0.50) among years. Time of year (month) explained the greatest amount of variability in Minnesota River plankton communities during this study, but hydrologic condition likely influences the temporal trend and may also explain deviations from typical seasonal patterns among years (Burdis & Hirsch, 2017).

With the exception of relative discharge, relationships between physico-chemical variables and plankton community structure were generally weak or indirect. Other studies demonstrate significant relationships between nutrients (i.e., phosphorus, nitrogen), turbidity (e.g., Secchi depth), phytoplankton (frequently represented by Chl-*a* concentration), and zooplankton among systems (e.g., Basu & Pick, 1996; Heiskary & Markus, 2001; Søballe & Kimmel, 1987; Thorp & Mantovani, 2005). However, these relationships are often different or less evident within individual systems (Bukaveckas et al., 2011; Thorp & Mantovani, 2005). For example, when comparing zooplankton densities among seven rivers, Thorp and Mantovani (2005) found that turbidity had a positive relationship with rotifer density and a negative relationship with crustacean zooplankton density. However, Thorp and Mantovani (2005) found opposite relationships when evaluating the zooplankton community within just one of the rivers (Kansas River). Although most physico-chemical variables differed among months in the Minnesota River, the ranges of values observed are smaller than or outside of ranges typically observed among a diversity of systems, and did not explain substantial variability in Minnesota River plankton communities. Silica and Chl-*a* concentrations are the exceptions, but relationships with these parameters are likely a consequence of the phytoplankton community rather than a mechanisms that directly influences plankton communities. Chlorophyll-*a* is a component of phytoplankton that is often measured as a surrogate for phytoplankton biomass (e.g., Basu & Pick, 1996), and we accordingly observed increases in Chl-*a* associated with increases in phytoplankton biovolume, particularly for Chlorophyta and Cyanobacteria. Similarly, silica concentration declines because of uptake by diatoms, and typically increases following diatom blooms (Kleinteich et al., 2020; Tavernini et al., 2011). The Minnesota River is a fertile hypereutrophic system (Dodds, Jones, & Welch, 1998), and similar to many medium to large rivers, we suspect is rarely nutrient-limited (Salmaso & Braioni, 2008; Wehr & Descy, 1998). Basu and Pick (1996) found that among rivers, TP was the most important predictor ($r^2 = .76$) of phytoplankton biomass (measured as Chl-*a*), but mean TP concentrations were below

TABLE 5 Results (pseudo-*F*, R^2, and *p* values) from permutational multivariate analysis of variance using distance matrices (Bray–Curtis) of Minnesota River zooplankton community samples and fitting individual linear models for spatial, temporal, and physico-chemical variables

	All samples			Excluding upstream sites (RKM 385 and 424)		
	F	R^2	***p***	***F***	R^2	***p***
Continuous variables						
River kilometer	30.8	.24	<.001	3.9	.05	.013
Relative discharge	8.3	.08	<.001	9.9	.12	<.001
Chl-*a*	2.7	.03	.054	5.0	.07	.002
TP	4.4	.04	.009	3.1	.04	.038
Silica	10.3	.09	<.001	15.6	.18	<.001
TDS	3.7	.04	.014	2.2	.03	.068
Temperature	5.4	.05	.008	5.8	.08	.003
TSS	4.6	.04	.010	0.3	.00	.868
Categorical variables						
Sample site	8.8	.36	<.001	1.48	.08	.121
Month	4.3	.18	<.001	6.7	.34	<.001
Upstream vs. downstream	39.4	.28	<.001			
Combined model						
Month +	4.6	.18	.001	7.9	.34	.001
Relative discharge +	2.3	.02	.092	5.0	.04	.004
Month × relative discharge	2.3	.09	.010	2.6	.11	.002

Note: Analyses were performed with data from all sample sites and with data excluding the two upstream most sites that are influenced by dams. All biomass and water chemistry data were $\ln(x+1)$ transformed.
Abbreviations: Chl-*a*, Chlorophyll-*a*; TP, total phosphorus; TDS, total dissolved solids; TSS, total suspended solids.

100 μg/L in all but one of the rivers. Total phosphorus concentrations in the Minnesota River varied from 105 to 396 μg/L during this study, likely exceeding concentrations that would limit phytoplankton growth. Water chemistry and nutrient availability have demonstrable influences on plankton communities in other lotic systems (e.g., Arora & Mehra, 2003; Kleinteich et al., 2020; Rossetti et al., 2009; Varol & Şen, 2018), but their influence on Minnesota River plankton communities is minimal at the scale of our analyses (e.g., taxa groups rather than species) and less important than the significant influences associated with seasonal succession, hydrologic condition, and dams.

We evaluated Minnesota River plankton communities in mid-channel habitats, but water retention or storage zones (e.g., habitat complexities, floodplain lakes, side channels, impoundments) within the river channel (Casper & Thorp, 2007; Reckendorfer et al., 1999; Schiemer et al., 2001) and the floodplain (Górski et al., 2013) likely support differing plankton communities that serve important roles in the floodplain river ecosystem (Casper & Thorp, 2007). Nickel (2014) corroborated this hypothesis for the Minnesota River and showed that Minnesota River backwaters generally have greater abundance and diversity of zooplankton than nearby main channel habitats. Most unaltered rivers with natural flow regimes have important connectivity with floodplain habitats (Poff et al., 1997) and these connections allow fish and other biota to utilize the floodplain habitat during flood pulses and for a flush of nutrients and plankton into the main channel as water levels recede. Górski et al. (2013) postulate that heterogeneity and connectivity of floodplain habitats are important for diverse zooplankton assemblages that are important for higher trophic organisms and ecosystem health. Future studies should explore spatial and temporal trends in plankton communities among a diversity of habitat types within the floodplain ecosystem (e.g., nearshore zones, floodplain lakes) to provide a more comprehensive understanding of lotic plankton community dynamics.

This study focused on evaluating abiotic factors, but numerous studies provide evidence that under certain conditions biotic factors significantly influence plankton communities (Akopian et al., 1999; Burdis & Hirsch, 2017; Guelda et al., 2005; Pace et al., 1998; Thorp & Casper, 2003). For instance, Guelda et al. (2005) demonstrated that zooplankton can be biologically limited from the bottom-up by phytoplankton production, and Thorp and Mantovani (2005) suggest that positive relationships between turbidity and rotifer density may be an indirect consequence of reduced competition and predation from other zooplankton and predators (e.g., fish) that are negatively impacted by increased suspended sediments. We did not evaluate biological factors that may influence plankton communities during this study, but we do not suggest dismissing the possibility. We hypothesize that abundant populations of planktivorous fishes such as bigmouth buffalo (*Ictiobus cyprinellus*), gizzard shad (*Dorosoma cepedianum*), paddlefish, and emerald shiner (*Notropis atherinoides*) may influence zooplankton community structure at smaller spatial and

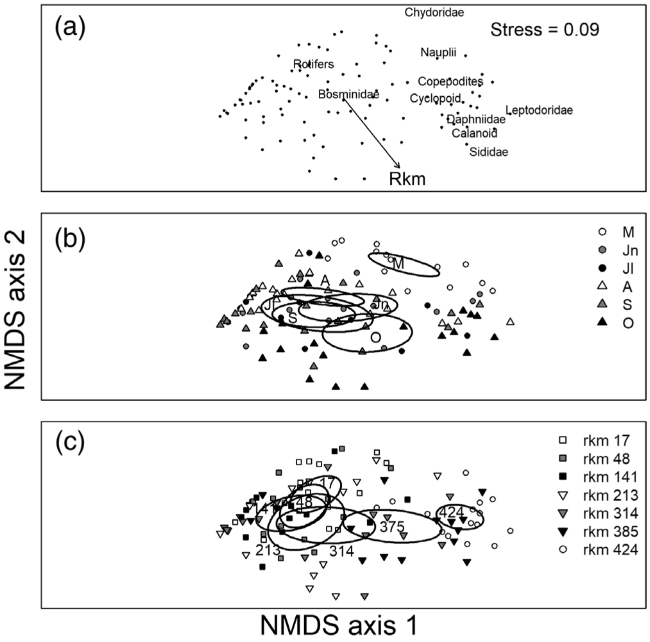

FIGURE 11 Results of NMDS (stress = 0.09, non-metric fit $R^2 = .99$) showing zooplankton community structure differed with (a) river kilometer (Rkm), (b) among months (M, May; Jn, June; Jl, July; A, August; S, September; O, October), and (c) between sample sites. Significant relationships ($p \leq .05$; $R^2 \geq .13$) between zooplankton community structure and continuous physico-chemical and spatial variables determined with permutational multivariate analysis of variance (PERMANOVA) are displayed as vectors depicting the general direction of the relationship. Significant differences (PERMANOVA; $p \leq .05$; $R^2 \geq .13$) in phytoplankton community structure among months and sample sites are displayed with 95% confidence interval ellipses around average weighted centroids

temporal scales (e.g., within backwater habitats, during periods of low flow). For example, Akopian et al. (1999) found that fish predation quickly reduced densities of crustacean zooplankton downstream of dams in the Marne River, France. Establishment of non-native planktivores could also have biological influences on Minnesota River plankton communities with cascading impacts to the entire ecosystem. For example, Sass et al. (2014) found correlated declines in crustacean zooplankton and increases in rotifer zooplankton associated with establishment of invasive carps in the Illinois River, and zebra mussels (*Dreissena polymorpha*) are attributed with greater than 70% declines in phytoplankton and zooplankton biomass in other lotic systems (Caraco et al., 1997; Pace et al., 1998). These aforementioned studies, among numerous others, demonstrate the impact of invasive species on plankton communities, and these impacts can have consequent impacts on higher trophic levels (Pendleton et al., 2017). We recommend that future studies attempt to identify important biological factors that may regulate plankton communities in the Minnesota River (and similar river systems), and determine the impacts of invasive species on plankton communities if they become established.

This was the first spatially and temporally extensive evaluation of phytoplankton and zooplankton communities in the Minnesota River. Our results corroborate others (Burdis & Hirsch, 2017; Pace et al., 1992; Rossetti et al., 2009; Salmaso & Braioni, 2008; Tavernini et al., 2011), demonstrating that seasonal patterns and river discharge are important drivers of phytoplankton and zooplankton community structure in lotic systems. In contrast with other lotic systems, we found that hydrologic conditions had a greater influence on phytoplankton than zooplankton community structure, and that phytoplankton communities did not exhibit significant spatial variability within the 400-km study reach of the Minnesota River. However, similar with findings in other impounded rivers, we found larger-bodied crustacean zooplankton more abundant downstream of dams where they are likely exported from impounded reaches that have greater water residence time (Akopian et al., 1999; Havel et al., 2009; Pourriot et al., 1997). For this study, we explored coarse-scale trends in plankton communities by evaluating broad taxonomic groups, and we hypothesize that trends in community structure are more nuanced and complex at a finer taxonomic resolution. This study provides a baseline understanding of lower trophic communities in a medium-sized river of the Midwestern, USA that will aid in understanding responses of lotic ecosystems associated with a changing climate, landscape, and species assemblage.

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CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, A. Sindt, upon reasonable request.

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APPENDIX: A

MEAN BIOMASS OF ROTIFER TAXA ESTIMATED FROM 20 MINNESOTA RIVER ZOOPLANKTON SAMPLES PROCESSED BY BSA ENVIRONMENTAL INC. (BEACHWOOD, OHIO)

Rotifer taxon	Mean biomass (μg/L)
Anuraeopsis spp.	0.001
Ascomorpha spp.	0.014
Asplanchna spp.	2.426
Bdelloidea order	0.035
Brachionus spp.	0.040
Cephalodella spp.	0.025
Colurella spp.	0.002
Encentrum spp.	0.002
Euchlanis spp.	0.109
Filinia spp.	0.024
Gastropus spp.	0.014
Kelicottia spp.	0.007
Keratella spp.	0.013
Keratella quadrata	0.073
Lecane spp.	0.028
Lepadella spp.	0.011
Mytilina spp.	0.025
Notholca spp.	0.018
Platyias quadricornus	0.040
Ploesoma spp.	0.012
Polyarthra spp.	0.029
Pompholyx spp.	0.012
Synchaeta spp.	0.012
Testudinella spp.	0.014
Trichocerca spp.	0.014
Trichotria spp.	0.014
Unidentified	0.020

APPENDIX: B

LIST OF CYANOBACTERIA, 6 PHYTOPLANKTON DIVISIONS, AND 73 GENERA IDENTIFIED IN WATER SAMPLES COLLECTED FROM SEVEN SITES ALONG THE MINNESOTA RIVER DURING AUGUST–OCTOBER OF 2016 AND MAY–OCTOBER OF 2017 AND 2018

- Bacillariophyta
  - *Achnanthidium*
  - *Amphora*
  - *Asterionella*
  - *Aulacoseira*
  - *Cocconeis*
  - *Craticula*
  - *Cyclotella*
  - *Cymatopleura*
  - *Cymbella*
  - *Diatoma*
  - *Encyonema*
  - *Fragilaria*
  - *Gomphoneis*
  - *Gomphonema*
  - *Gyrosigma*
  - *Hannaea*
  - *Mastogloia*
  - *Melosira*
  - *Meridion*
  - *Navicula*
  - *Nitzschia*
  - *Planothidium*
  - *Rhoicosphenia*
  - *Rhopalodia*
  - *Staurosira*
  - *Staurosirella*
  - *Stephanodiscus*
  - *Surirella*
  - *Synedra*
- Chlorophyta
  - *Ankistrodesmus*
  - *Characium*
  - *Chlamydomonas*
  - *Chlorella*
  - *Closteriopsis*
  - *Closterium*
  - *Coelastrum*
  - *Cosmarium*
  - *Crucigenia*
  - *Dictyosphaerium*
  - *Kirchneriella*
  - *Monoraphidium*
  - *Oocystis*
  - *Pediastrum*
  - *Scenedesmus*
  - *Selenastrum*
  - *Sphaerocystis*
  - *Staurastrum*
  - *Tetraedron*
- Chrysophyta
  - *Dinobryon*
  - *Mallomonas*
  - *Synura*
- Cryptophyta
  - *Cryptomonas*
  - *Rhodomonas*
- Euglenophyta
  - *Euglena*
  - *Phacus*
- Cyanobacteria
  - *Anabaena*
  - *Aphanizomenon*
  - *Aphanocapsa*
  - *Aphanothece*
  - *Chroococcus*
  - *Cylindrospermopsis*
  - *Dolichospermum*
  - *Limnothrix*
  - *Merismopedia*
  - *Microcystis*
  - *Phormidium*
  - *Planktolyngbya*
  - *Pseudanabaena*
  - *Raphidiopsis*
  - *Woronichinia*
- Pyrrophyta
  - *Ceratium*
  - *Glenodinium*

APPENDIX: C

LIST OF CLADOCERAN (7 FAMILIES AND 14 GENERA) AND COPEPOD (2 FAMILIES AND 8 GENERA) ZOOPLANKTON TAXA IDENTIFIED IN SAMPLES COLLECTED FROM THE MINNESOTA RIVER DURING AUGUST -OCTOBER OF 2016 AND MAY -OCTOBER OF 2017 AND 2018

- Order Cladocera
  - Family Bosminidae
    - Genus *Bosmina*
  - Family Chydoridae
    - Genus *Alona*
    - Genus *Chydorus*
    - Genus *Eurycercus*
    - Genus *Oxyurella*
    - Genus *Pleuroxus*
  - Family Daphniidae
    - Genus *Daphnia*
      - *Daphnia ambigua*
      - *Daphnia galeata mendotae*
      - *Daphnia parvula*
      - *Daphnia pulicaria*
      - *Daphnia retrocurva*
    - Genus *Scapholeberis*
    - Genus *Simocephalus*
  - Family Leptodoridae
    - Genus *Leptodora*
  - Family Macrothricidae
  - Family Moinidae
    - Genus *Moina*
  - Family Sididae
    - Genus *Diaphanosoma*
    - Genus *Sida*
- Order Calanoida
  - Family Diaptomidae
    - Genus *Aglaodiaptomus*
    - Genus *Leptodiaptomus*
    - Genus *Skistodiaptomus*
- Order Cyclopoida
  - Family Cyclopidae
    - Genus *Acanthocyclops*
    - Genus *Diacyclops*
    - Genus *Eucyclops*
    - Genus *Mesocyclops*
    - Genus *Tropocyclops*

APPENDIX: D

LIST INCLUDING 3 ORDERS, 14 FAMILIES, AND 24 GENERA OF ROTIFERS IDENTIFIED IN SAMPLES COLLECTED FROM THE MINNESOTA RIVER DURING AUGUST–OCTOBER OF 2016 AND MAY–OCTOBER OF 2017 AND 2018.

- Order Bdelloidea
- Order Flosculariaceae
  - Family Testudinellidae
    - Genus *Pompholyx*
    - Genus *Testudinella*
  - Family Trochosphaeridae
    - Genus *Filinia*
- Order Ploima
  - Family Asplanchnidae
    - Genus *Asplanchna*
  - Family Brachionidae
    - Genus *Anuraeopsis*
    - Genus *Brachionus*
    - Genus *Kelicottia*
    - Genus *Keratella*
    - Genus *Notholca*
    - Genus *Platyias*
  - Family Dicranophoridae
    - Genus *Encentrum*
  - Family Euchlanidae
    - Genus *Euchlanis*
  - Family Gastropodidae
    - Genus *Ascomorpha*
    - Genus *Gastropus*
  - Family Lecanidae
    - Genus *Lecane*
  - Family Lepadellidae
    - Genus *Colurella*
    - Genus *Lepadella*
  - Family Mytiliidae
    - Genus *Mytilina*
  - Family Synchaetidae
    - Genus *Ploesoma*
    - Genus *Polyarthra*
    - Genus *Synchaeta*
  - Family Trichocercidae
    - Genus *Trichocerca*
  - Family Trichotriidae
    - Genus *Tricotria*