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Fish and Macroinvertebrate Response to Restoration and Conservation Efforts

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FISH AND MACROINVERTEBRATE POPULATION RESPONSE TO RESTORATION AND CONSERVATION EFFORTS

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By

Madison Christine Cogar

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ABSTRACT

Fish and macroinvertebrate response to restoration and conservation efforts varies in regards to the size and structure of the system (e.g. headwater streams in WV versus large rivers such as the Mississippi River). This project reviews fish and macroinvertebrate rebound in treated acid mine drainage (AMD) streams in WV as well as macroinvertebrate drift patterns in the Mississippi and Missouri Rivers. AMD is a product of a chemical reaction resulting in an acidic water outflow from mining sites, which may harm aquatic life. As a response, passive AMD treatment systems have been installed. I tested the effectiveness of remediation by sampling water chemistry, macroinvertebrate populations and fish populations. Five streams were sampled both upstream and downstream of where passive treatment systems have been installed, resulting in a control and treated site for each stream. Sampling consisted of water quality grab samples, kick-netting and backpack electrofishing. I found no differences existed in water quality, macroinvertebrates, and fishes between upstream control and downstream treatment locations, suggesting remediation efforts were successful in restoring these stream ecosystems. Macroinvertebrate drift patterns in the Mississippi and Missouri Rivers were reviewed with implications for *Scaphirhynchus* sturgeon conservation. Specifically, sturgeon survival may be influenced by macroinvertebrate availability. I examined macroinvertebrate catch rates longitudinally, laterally, and vertically to assess drift patterns. The average number per day of drifting dominate invertebrate taxa (i.e., Diptera, Ephemeroptera, Plecoptera and Trichoptera) ranged from 6.8 million/d to 36.4 million/d. I found that catch rates of drifting macroinvertebrates differed among reaches, dates, and position in the water column. Furthermore, the interaction of the spatial variables (i.e., depth and reach) coupled with the temporal variable (i.e., date) best describes variability in macroinvertebrate catch rates throughout our study. Efforts to increase macroinvertebrate habitat may provide additional prey resources to *Scaphirhynchus* sturgeon. Thus, the section of river from the Missouri River confluence downstream to the Mosenthein Island complex is unchannelized and may be a good candidate for habitat restoration. Increasing macroinvertebrate abundance and diversity may positively influence *Scaphirhynchus* sturgeon.

KEYWORDS: macroinvertebrates, restoration, conservation, *Scaphirhynchus*, Mississippi River

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Chapter 2

OVERVIEW

This thesis assesses fish and macroinvertebrate population dynamics responses to restoration and conservation efforts. This thesis is split into two chapters that are intended to be published independently. Chapter 1 investigates recolonization of fish and macroinvertebrates in streams in West Virginia where acid mine drainage passive treatment systems have been installed. Chapter 2 examines macroinvertebrate drift patterns in the Middle Mississippi River, the lower portion of the Upper Mississippi River and the lower portion of the Missouri River.

CHAPTER 1: FISH AND MACROINVERTEBRATE REBOUND IN TREATED ACID MINE DRAINAGE STREAMS IN WEST VIRGINIA

Introduction

Ecological disturbance is one of the major forces which molds the environment in terms of development, structure, and function (Attiwill, 1994). Disturbance can influence ecosystems on widespread spatial and temporal scales, resulting in a change to ecosystem structure and resource availability, ultimately influencing population dynamics. Impacts of disturbance can be either beneficial or harmful, and naturally or anthropogenically caused. Disturbances can be beneficial in ecosystems which require disturbance to control growth or induce distribution of seeds. Natural disturbances consist of events such as wildfires, hurricanes and floods, whereas anthropogenic disturbances involve human interference in the environment, such as deforestation, industrialization, or the introduction of invasive species.

Appalachian waters support some of the highest biodiversity levels in the temperate zone of North America (Master *et al*., 1998; Bernhardt *et al*., 2012). For the Appalachian region, mining has been one of the chief anthropogenic impacts to biodiversity. Coal mining has been prevalent in the state of West Virginia since the 1850s and became booming by 1880 (West Virginia Geological and Economic survey, 2017). The state is rich with coal deposits in all but two counties (West Virginia Office of Miners' Health Safety and Training, 2018). It is believed there were 62 individual coal seams, which could be accessed profitably, that could be found within the mountains (West Virginia Office of Miners' Health Safety and Training, 2018). When coal was first mined it was largely used as a fossil fuel for local businesses, and later to heat homes. The industry grew larger as railroads became prominent in the coal fields, making access and transportation easier (National Coal Heritage Area and Coal Heritage Trail).

Mining laws and standards changed rapidly throughout the years as new safety and environmental concerns surfaced. The coal industry had positive impacts (*e.g.*, increase in jobs) as well as negative impacts (*e.g.*, environmental degradation). In the beginning workers dealt with poor labor conditions, and no unionization was allowed at the time. It wasn't until 1883 that the first mine safety laws were passed in West Virginia (West Virginia Office of Miners' Health Safety and Training, 2018). These laws implemented the use of a mine inspector to ensure safety of the employees. By 1890 the state union of United Mine Workers of America was begun in West Virginia, and by 1905 the West Virginia Department of Mines was developed to further protect those working in the mines. Once safety concerns were addressed, attention became drawn to the environmental issues resulting from coal mining. The Clean Water Act of 1977 was passed federally to protect surface waters by regulating the discharge of pollutants into United States waters (United States Environmental Protection Agency, 2019). In 1977 the Surface Mining Control and Reclamation Act (SMCRA) became law. This act controlled the environmental impacts of mining with two programs: one to govern active mines and another to aid in the reclamation of abandoned mine land (Office of Surface Mining Reclamation and Enforcement, 2019). At this time Congress defined one of the purposes of SMCRA as protection of the environment by ensuring coal mining was conducted properly (Zipper, 2000).

Coal mining has caused detrimental environmental impacts in various ways. One of the major issues is water pollution, more specifically acid mine drainage (AMD). Acid mine drainage is the result of a reaction which occurs when sulfide-bearing rocks or minerals are exposed to oxygen and water (Akcil and Koldas, 2006). The production of AMD will occur as a natural reaction, but when coal seams are opened during mining it results in the accelerated oxidization of sulfide minerals to form a highly acidic drainage (Akcil and Koldas, 2006). The production and movement of this highly acidic water greatly impacts stream health and damages aquatic life by degrading water quality, lowering pH, increasing total dissolved solids and more.

In 1988 West Virginia University initiated the beginnings of the National Mine Land Reclamation Center (NMLRC) to assess reclamation problems and implement treatment plans to improve water quality (West Virginia Water Research Institute). The Appalachian region's flora and fauna have been highly impacted by AMD (Haines and Baker, 1986; Schindler, 1988; Welsh and Perry, 1997). One of the ways West Virginia is combatting acid mine drainage is by installing active and passive treatment systems throughout the state. Active treatment operations involve active administration of various chemical agents into a stream, which work to increase pH and ultimately precipitate metals in the system (Johnson and Hallberg, 2005; RoyChowdhury *et al.*, 2015). Passive treatment systems work to treat AMD before it reaches a stream and include constructed wetlands, open limestone channels, settling ponds and more (Johnson and Hallberg, 2005). Advantages to passive treatments include lower costs, less chemical use and long-lasting effects. Passive treatment systems have been constructed throughout the state and have shown the ability to ameliorate acidic water (Gazea *et al.*, 1996; Berghorn and Hunzeker, 2001).

Though water quality improvements have been observed following the installation of these treatments systems, there is little research on the long-term effects of acid mine drainage on benthic macroinvertebrate and fish populations in West Virginia. Thus, the objective of the present study is to quantify differences in water quality, macroinvertebrate assemblages, and fish diversity in control sites (no AMD) versus treatment sites (received passive remediation efforts).

I hypothesized that treatment sites which have received passive remediation efforts will have similar water quality, macroinvertebrate communities and fish diversity relative to control sites which are not impacted by AMD.

Methods

This study area consists of 10 total sites within 5 different streams. All samples were collected during both 2018 and 2019. The streams included in this study are West Run, Lambert Run, Herods Run, Swamp Run, and Smooth Rock Lick Run (Fig. 1). These streams were chosen because they have had passive treatment systems installed to treat AMD entering the water. Streams were sampled upstream of where the treated water enters, as a control, and downstream of where treated AMD water is mixed into the stream. Therefore, each stream contains two sampling sites. The upstream control site is assumed to be unimpacted by AMD whereas the downstream treated site is receiving treated AMD water (Fig. 2).

All streams are located within the Monongahela watershed, and subwatersheds of the Upper Monongahela, West Fork, and Tygart Valley (Fig. 1). This water then flows into the Ohio River drainage and ultimately drains into the Mississippi River Basin (Wohl, 2017). Longitudinal connectivity can have a large impact on trophic organization and biological communities in streams (Wohl, 2017). In order to improve water quality on the large scale, treatment should begin at headwater streams such as those in this study, which comprise 52% of all streams in the world (Downing *et al.*, 2012).

In order to collect current water quality data, grab samples were collected at each site location. For each site and sample period, three different bottles were used for specific analysis purposes. Bottles consisted of one 250 mL acidified with nitric acid and field filtered with 0.45-

micron filter, one 250 mL acidified with nitric acid and unfiltered, and one 500 mL unacidified and unfiltered. Water quality was analyzed by West Virginia University's National Research Center for Coal and Energy analytical lab. The water was then evaluated with an "AMD Suite", testing pH, acidity levels, alkalinity levels, total and dissolved metals. A Yellow Springs Instrument (YSI) water quality meter was also used to record in-stream water quality on site. We recorded water temperature, conductivity, total dissolved solids, dissolved oxygen, and pH at each site.

Kicknetting was used to sample macroinvertebrates, per West Virginia Department of Environmental Protection (WVDEP) protocol to make results comparable with already established indices of biotic integrity (IBIs) (dep.wv.gov). For each site location a set of four kicks were performed throughout the sampling area to incorporate various habitats (e.g, riffle, pool, run) and to collect a sample representative of the entire stretch of stream. A rectangular kick net encompassing a .25 m^2 kick area was used at each of the four locations, totaling 1.0 m^2 total kick area for each site. Once the samples were collected, they were preserved in 70% ethanol and identified to family classification. Fishes were sampled using single-pass backpack electrofishing. For each site a 100 m transect was defined. Once fish were captured, they were identified, measured, weighed, enumerated, and subsequently released. All samples were collected by the West Virginia Water Research Institute and followed associated research compliance protocols. This project was reviewed by Missouri State University's IACUC committee, determining MSU IACUC oversight was not required and provided a waiver.

To analyze multiple water quality parameters simultaneously, lab results for pH, dissolved aluminum, and total iron were standardized. Standardizing scores converts measures taken on differing scales to enable comparisons to be made between multiple influencing parameters. Macroinvertebrates identified to a family classification were used to obtain a multi-metric West Virginia Stream Condition Index (WVSCI) score for each site location. WVSCI scores may range from 0-100 with a score of 0 indicating a highly impaired stream whereas a score of 100 portrays an extremely healthy stream (Table 1). This index is commonly used in West Virginia to evaluate biological conditions of small, wadable streams (dep.wv.gov). Fish species richness was calculated and compared between control and treated sites. Two-sample *t*-tests were used for comparing water quality variables, macroinvertebrates (WVSCI Scores), and fish species richness between control and treatment locations for each stream.

Results

All water quality parameters (pH, dissolved aluminum, total iron) at all sites did not differ between control and treatment locations (all *t*-test results $p>0.05$, Fig. 3). The WVSCI scores for all sites ranged 24.95 – 82.45 (poor to very good, Table 1, Fig. 4). Control and treated sites were not different in terms of the associated WVSCI scores (all *t*-test results $p>0.05$). A total of 13 species were caught at all sites: creek chub, blacknose dace, stoneroller, white sucker, green sunfish, smallmouth bass, rosyface shiner, bluntnose minnow, longnose dace, spotfin shiner, river chub, brook trout and golden redhorse. Species richness of fish did not differ between control and treated sites among all streams sampled (all *t*-tests results $p>0.05$, Fig. 5).

Discussion

This evidence suggests overall the remediation efforts are proving to be successful because of the similarities made between the control and treated sites. The AMD water which has been treated is functionally resembling the control site, which is unimpacted by AMD. One site, Herods Run, reported a relatively low pH; however, the values between the control and treated sites for Herods Run are nearly identical, indicating AMD may be entering further upstream or there is another source causing acidification. Aluminum and iron levels stayed consistent between control and treated sites.

The WVSCI scores between control and treated sites did not differ, but overall scores were low. A stream with a score over 68 is considered unimpaired, and only 3 of our 10 sites scored greater than 68. The majority of the sites are still showing only "fair" biological health (Table 1). This is likely because an overwhelming majority of the macroinvertebrate families collected consisted of pollution tolerant organisms. This result indicates that other factors may be impacting the health of the stream, such as agriculture inputs and increased sedimentation, but further data collection and analyses would be needed to aid in finding the main causes of the poor health of these streams.

The abundance and diversity of fish collected was low. Most of these streams were dominated by creek chubs, but some less pollution tolerant species (brook trout and river chub) were also caught in treatment and control sites. There could be various causes for low fish catch. One potential explanation for low abundance in both control and treatment locations may be the increased turbidity, based on personal observation, due to soil erosion from agricultural runoff or prior anthropogenic disturbances (Parsons, 1968).

The ultimate goal of this study was to determine if passive remediation projects are efficiently able to improve water quality, increase benthic macroinvertebrate diversification, and eventually support a sustainable fishery. Based on these two years of data, we suggest water quality, diversity of macroinvertebrates, and fish populations are similar between control and treated sites, indicating success of AMD treatment. Passive treatment systems have been successful in remediating these West Virginia streams and could be implemented in other areas impacted by AMD. Future efforts should acquire water quality, macroinvertebrate, and fish data before the treatment installations are put in place to measure long term water quality, macroinvertebrate WVSCI scores, or fish population changes.

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Table 1. West Virginia Stream Condition Index (WVSCI) scores related to stream health

Stream Health	WVSCI Score
Very Good	78.1 – 100
Good	68.1 – 78.0
Gray Zone	60.6 – 68.0
Fair	45.1 – 60.5
Poor	22.1 – 45.0
Very Poor	0.0 – 22.0

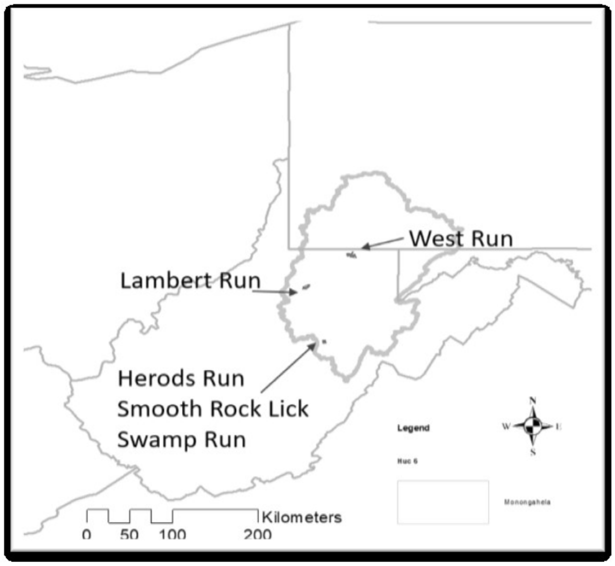

Figure 1. Map showing the locations of the sampling sites, located in the Monongahela watershed

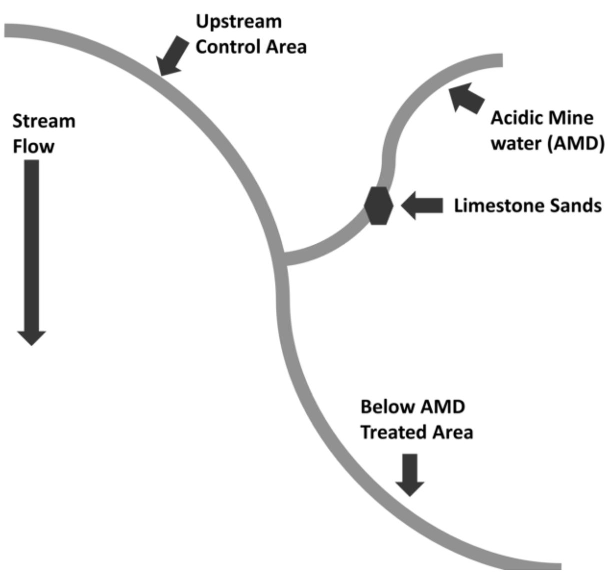

Figure 2. Graphic depicting sampling sites in each stream. I sampled at "upstream control area" and "below AMD treated area" in each stream in 2018 and 2019

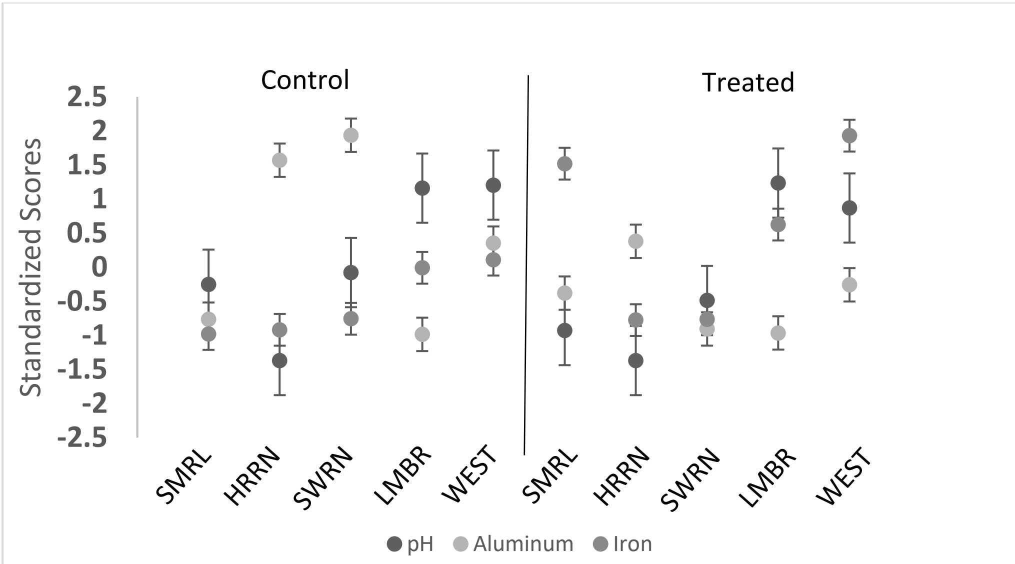

Figure 3. Standardized scores for water quality variables pH, dissolved aluminum, and total iron from 2018 and 2019 in control versus treated sites. Abbreviations on the x-axis are as follows: Smooth Rock Lick Run (SMRL), Herods Run (HRRN), Swamp Run (SWRN), Lambert Run (LMBR), and West Run (WEST)

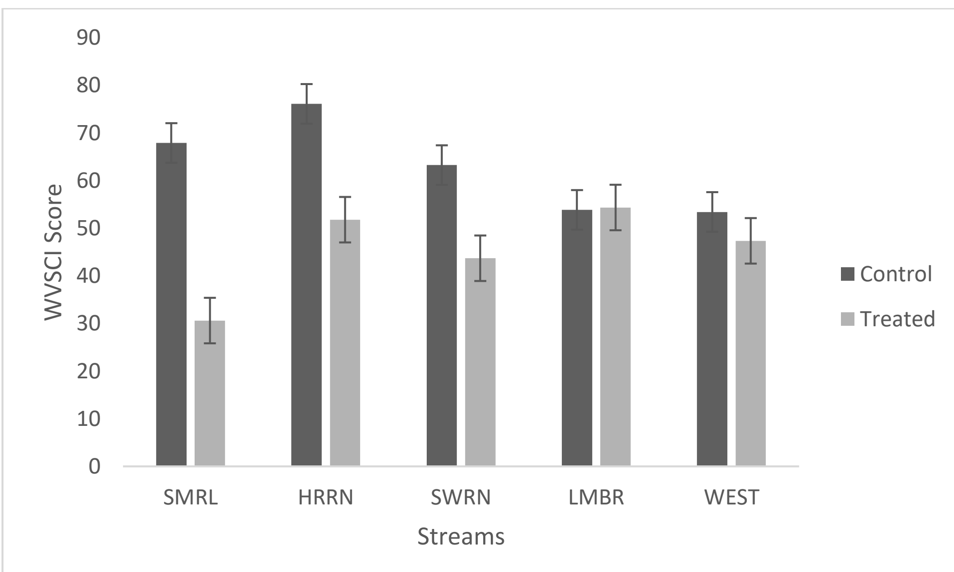

Figure 4. Mean (+SE) of control versus treatment West Virginia Stream Condition Index (WVSCI) scores for all sites. The abbreviations on the x-axis are as follows: Smooth Rock Lick Run (SMRL), Herods Run (HRRN), Swamp Run (SWRN), Lambert Run (LMBR), and West Run (WEST)

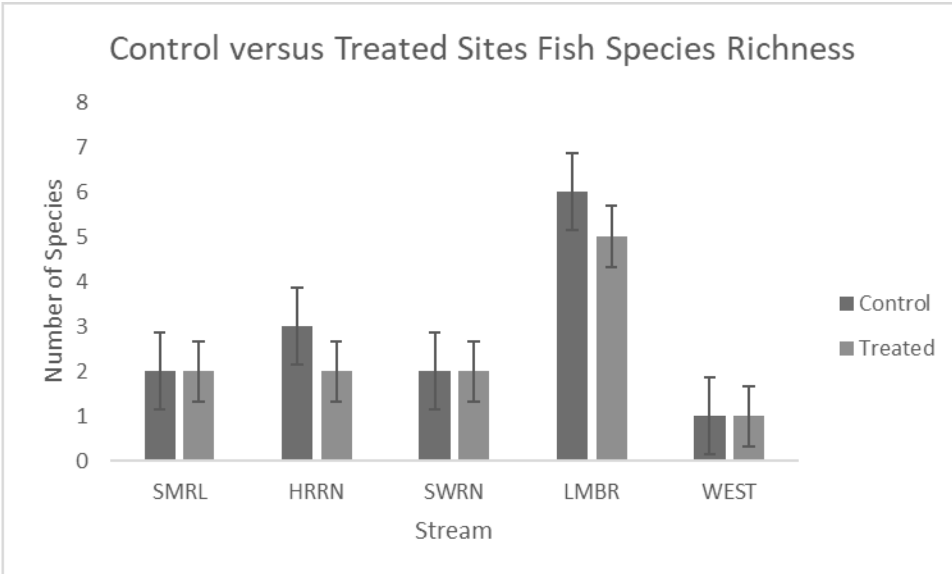

Figure 5. Fish species richness in control versus treated sites in 2018 and 2019. The abbreviations on the x-axis are as follows: Smooth Rock Lick Run (SMRL), Herods Run (HRRN), Swamp Run (SWRN), Lambert Run (LMBR), and West Run (WEST)

CHAPTER 2: MACROINVERTEBRATE DRIFT PATTERNS IN THE MISSISSIPPI AND MISSOURI RIVERS: IMPLICATIONS FOR *SCAPHIRHYNCHUS* STURGEON CONSERVATION EFFORTS

Introduction

Aquatic ecosystems largely depend on energy received from two sources, autochthonous and allochthonous inputs. Autochthonous energy is derived from aquatic plants within the system, while other systems gain energy from allochthonous inputs from terrestrial sources (Allan & Castillo, 2008). Allochthonous inputs come in the form of plant and animal detritus, large woody debris or any other terrestrial organic matter and the associated nutrients. Autochthonous energy is provided from the photosynthesis of aquatic vegetation, algae, and phytoplankton. Many aquatic systems cannot depend solely on autochthonous inputs fueling production. Allochthonous based systems require coarse particulate organic matter (CPOM) from the surrounding riparian zone (Lamberti et al., 2017). Once CPOM enters a system, macroinvertebrates (e.g., shredders) process detrital inputs into smaller particles (Covich et al., 1999). These smaller particles (i.e., fine particulate organic matter, FPOM) are exported downstream and consumed by other macroinvertebrate feeding groups (e.g., filterers). Macroinvertebrates feeding on and accelerating the decomposition of detritus makes them a key component in energy flow in food webs. The rates at which this particulate organic matter is converted to secondary production (i.e., invertebrate biomass via growth) can provide insight into overall structure and function of aquatic systems.

Aquatic macroinvertebrates encompass a wide range of taxa that occupy various habitats and environmental conditions (Miller, 2011). Due to their varying pollution tolerances across taxa and lack of mobility compared to higher trophic levels (e.g., fishes), macroinvertebrates display diverse responses to different environmental stressors and disturbances (e.g., pollution or habitat alteration). These characteristics make aquatic macroinvertebrates useful as bioindicators. Further, macroinvertebrates are also essential in nutrient cycling because of the diversity of feeding habits which are essential to the efficient exploitation of CPOM and FPOM and subsequent conversion to higher trophic biomass. Macroinvertebrates are important prey for larval, juvenile and adult fishes and represent the most prevalent and widespread food source for fish in lotic systems (Townsend, 1996). In the Mississippi River macroinvertebrates are an essential food source for many fishes, particularly in the reaches not influenced by dams where allochthonous energy inputs may play a key role in structuring the food web (Sobotka & Phelps, 2016).

Human impacts are varied along the Mississippi River (Chen & Simons, 1986; Ickes et al., 2005; Schramm et al., 2016). Ultimately, the Mississippi River has been modified to support human development (e.g., navigation and flood control). Much of the Upper Mississippi River (i.e., upstream from Mel Price Lock and Dam near St. Louis to Lake Itasca near Minneapolis) is impounded by a series of locks and dams (Chen & Simons, 1986). While lower reaches, from the Missouri River confluence to the Gulf of Mexico, is free flowing. The Middle Mississippi River (i.e., from Missouri River confluence to the Ohio River confluence in Cairo, IL) is free flowing and heavily channelized. Various channel training structures (e.g., dikes) have been constructed to maintain a 2.7 m (9 ft) navigational channel (Chen & Simons, 1986; Barko et al., 2004; Phelps et al., 2010). Additionally, much of the Middle Mississippi River floodplain is behind levees (Chen & Simons, 1986; Theiling, 1995; Ickes et al., 2005). Ultimately, these river modifications have negatively influenced aquatic organisms and their habitats. The majority of the Middle

Mississippi River has been channelized through the years while simultaneously being cut off from the floodplain (Phelps, et al. 2014). These major changes have drastically altered flows, stage heights, temperatures and access to off-channel habitats (Chen & Simons, 1986; Raymond et al., 2008; DuBowy, 2013). Several studies have demonstrated that these anthropogenic disturbances have led to reductions in survival or persistence of macroinvertebrate and riverine fish populations (Kennedy & Turner, 2011; Phelps et al., 2014; Love et al., 2016). Simply, ecological disturbance has influenced and will continue to shape the structure and function of the Middle Mississippi River (Chen & Simons, 1986). Being primarily a heterotrophic system, the Middle Mississippi River relies heavily on allochthonous energy inputs for their nutrients, which macroinvertebrates can process and convert to biomass. As noted above, macroinvertebrates are an important source of food for a multitude of larval, juvenile and adult fishes. This is especially true in the Middle Mississippi River for those fishes that are threatened and endangered.

The genus Scaphirhynchus consists of two sympatric sturgeon species: the pallid sturgeon *Scaphirhynchus albus* and the shovelnose sturgeon *Scaphirhynchus platorynchus*. Both of these fish populations have been greatly threatened by anthropogenic changes to the Mississippi and Missouri rivers, over-harvest, and habitat loss (Sechler et al., 2011; Johnson et al., 2014; Phelps et al., 2010, 2016; Steffensen et al., 2016). Ultimately, these human induced perturbations have led to the decline of sturgeon populations both directly and by influencing spawning and recruitment success (Wildhaber et al., 2007; Tripp et al., 2009). The Pallid Sturgeon, federally listed as endangered throughout its range in 1990, is endemic to the Missouri River and middle/lower Mississippi River (Phelps et al., 2010). The Shovelnose Sturgeon is relatively more abundant and widely distributed; however, it also became listed as threatened where ranges of the two species overlap under the Similarity of Appearances provision under the

Endangered Species Act (Phelps et al., 2010; Boley & Heist, 2011). These two benthic-dwelling species are similar phenotypically, have overlapping geographic ranges, long life spans and slow maturation (Phelps et al., 2016). The shovelnose sturgeon tends to be smaller in size and have a shorter lifespan than pallid sturgeon (Tranah et al., 2014). Macroinvertebrates are an important prey species for both shovelnose sturgeon and pallid sturgeon.

Shovelnose sturgeon and pallid sturgeon survival and growth may be influenced by macroinvertebrate prey availability. Larval and adult sturgeon feed on Diptera, Ephemeroptera, and Trichoptera (Wanner et al., 2006, Hoover et al., 2007, Seibert et al., 2011; Sechler et al., 2012, Tobias, 2014). Braaten et al. (2012) further determined that young of year pallid sturgeon diets consisted primarily of Diptera larvae and pupae and Ephemeroptera nymphs. Diptera and Ephemeroptera can comprise up to 75% of pallid sturgeon diets (Grohs, 2008; Spindler et al., 2012). However, channelization may reduce invertebrate densities by up to 50% (Kennedy & Turner, 2011).

Despite the relative importance of invertebrate availability to both sturgeon species, we are unaware of any other studies that have quantified macroinvertebrate drift in the mainstem Middle Mississippi River and the adjacent rivers (i.e., Missouri River ad Upper Mississippi River) that may be contributing invertebrates to the MMR. Therefore, the overall objective of our study was to quantify drifting macroinvertebrates in the Middle Mississippi River and the adjacent rivers. More specifically, I sought to understand the importance of relative lateral position (e.g., right descending bank, thalweg, left descending bank), reach (e.g., Missouri River, Middle Mississippi River), date, and depth (i.e., surface, middle, bottom) relative to drifting macroinvertebrate density. Understanding important spatiotemporal patterns related to drifting invertebrates could provide insight to understand the prey needs of our threatened and endangered sturgeon in the Mississippi and Missouri rivers.

Methods

Macroinvertebrate drift net samples were collected on the Middle Mississippi River, the lower portion of the Upper Mississippi River and the lower Missouri River (Figure 1). Sampling was conducted from April 15-June 14 during 2018. Included were a total of 31 sampling sites within 9 reaches on the Middle Mississippi River, the lower portion of the Upper Mississippi River and the lower Missouri River. The nine river reaches (Figure 1) were the Missouri River (MOR), Upper Mississippi River (UMR), Middle Mississippi River (MMR), Above Chain of Rocks (Above Chain), Below Chain of Rocks (Below Chain), Main Channel Upstreams (MC Up), Main Channel Downstream (MC Down), Side Channel Upstream (SC Up), and Side Channel Downstream (SC Down). Dependent on river width, each of these reaches were then divided into three or four equidistant locations on a transect spanning the width of the river, in order to achieve bank to bank coverage and ultimately to help us understand the lateral macroinvertebrate drift patterns. Each location along the transect was sampled at the surface, middle and bottom of the water column (Figure 1).

Drift nets were chosen as the sampling gear to collect free-flowing drift material (i.e., macroinvertebrates and fishes). We employed a rectangular frame (0.75 m width, 0.5 m height) net with a 3 m long tapered cod end net (0.07 m cod end width, 0.08 m height) with a mesh size of 1000 µm (Braaten et al., 2010). A flowmeter was attached to the middle of the frame to estimate volume of water being filtered in each sample. Lastly, a 45.4 kg sounding weight was attached in order to hold the net in the correct water column position (e.g., surface, middle and bottom). A Garmin® Panoptix Live Scope™ sonar (Garmin.com) was utilized to visually verify that the net deployed properly. Each sample was acquired by concurrently deploying two nets, one on each side of the boat (port and starboard) for two to five minutes (depending on debris load). This approach was intended to maximize sampling efficiency while reducing the amount of detritus collected. Sites were sampled in order from downstream to upstream to avoid disrupting downstream capture sites. Samples were collected, rinsed and preserved in 95% ethanol. Samples were processed in the lab and all macroinvertebrates were separated, identified to order and enumerated.

I examined the number of Diptera, Ephemeroptera, Plecoptera and Trichoptera drifting each day in each reach. The cross-sectional area of each river reach was calculated by multiplying the width of the river by the average water depth. This information was used to determine the average number of Diptera, Ephemeroptera, Plecoptera and Trichoptera drifting through a cross section of the river in one 24 h period at each of our study reaches. I generated 95% confidence intervals for these data, but no statistical inferences were made because of the novelty of our calculations. However, one-way analysis of variance (ANOVA) was used to determine whether differences existed in biologically important factors (reach, location, date, and water column) that influence drifting macroinvertebrates. All post hoc comparisons were made using Tukey's HSD. I then created several a priori models using an information theoretic approach (Burnham & Anderson, 2002) to determine whether a single variable or a combination of variables were most influential in determining CPUE of drifting macroinvertebrates. Similar to the methods described by Phelps et al. (2008, 2010) we compared various single-variable models (i.e., model 1 reach; model 2 date, model 3 water column), an interactive spatial model (model 4 reach*water column), and an interactive global model (model 5 reach*date*water column) (Table 1). Akaike's information criterion (AIC) was used to decide which model best described the interactions influencing drifting macroinvertebrate catch rates.

Results

Overall, 362,000 m^3 of Missouri River and Mississippi River water was filtered during sampling events. We were successful in capturing macroinvertebrates throughout the water column in the lower Missouri River, lower portion of the Upper Mississippi River, and the Middle Mississippi River. Furthermore, macroinvertebrates were collected on all dates and at all 31 sampling sites. A total of 3,414 samples were collected from April 15 to June 14 in 2018. Overall, 72,216 macroinvertebrates were captured in the drift. Of all macroinvertebrates caught, 99% were in the orders Diptera, Ephemeroptera, Plecoptera and Trichoptera. We collected 6,742 Diptera, 9,560 Ephemeroptera, 1,334 Plecoptera and 53,275 Trichoptera. Trichoptera comprised 75% of the total macroinvertebrate drift sampled Diptera (9%), Ephemeroptera (13%) and Plecoptera (2%), comprised a much smaller portion. Because Trichoptera constituted an overwhelming majority by number and mass, all subsequent analyses will be based on the combined dominant macroinvertebrate assemblage (i.e., Diptera, Ephemeroptera, Plecoptera and Trichoptera) collected, all of which are important prey species for Scaphirhynchus sturgeon growth and survival. The average number per day of drifting dominate invertebrate taxa (i.e., Diptera, Ephemeroptera, Plecoptera and Trichoptera) ranged from 6.8 million/d to 36.4 million/d (Figure 2).

Macroinvertebrate catch rates did not differ laterally across the river ($F_{3,3410}$=2.09; P=0.0998, Figure 3) and were therefore omitted from further analysis. I found that catch rates of drifting macroinvertebrates differed among reaches ($F_{8,3405}$=4.99; P<0.0001). Specifically, catch rates were generally higher in UMR, MMR, Above Chain and MC Down reaches relative to the MOR and Below Chain reaches (Figure 4). Macroinvertebrate catch rates did vary across dates ($F_{17,3396}$=49.68; P<0.0001). Catch rates were bimodal with respect to date, highest catch rates occurred from May 1st through May 10th and June 11th and 12th (Figure 5). Lastly, macroinvertebrate catch rates varied ($F_{2,3411}$=92.68; P<0.0001) with position in the water column (surface, middle and bottom). Specifically, macroinvertebrate catch rates were highest in the bottom and lowest at the surface (Figure 6).

Of the 5 a priori models that I developed, the best single variable model to explain variation in macroinvertebrate catch rates was date while the reach single variable model performed the worst (Table 1). That being said, all single variable models and the spatial interactive model performed poorly relative to the interactive global model. This suggests that macroinvertebrate catch rates are not structured by a single environmental variable or a spatial model; rather, the synergistic nature of the global model best fits our data. Specifically, the interaction of the spatial variables (i.e., depth and reach) coupled with the temporal variable (i.e., date) best describes variability in macroinvertebrate catch rates throughout our study area (Figure 7).

Discussion

Aquatic macroinvertebrates represent an important prey type for large river fishes and in particular, their juvenile stages (Wallace & Webster, 1996; Hoover et al., 2007; Howe et al., 2014; Worischka et al., 2015). As such, prey availability is an important factor influencing riverine fish population dynamics (i.e., recruitment, growth and mortality). Changes in these rates can negatively influence fish populations (Phelps et al., 2010). In the Middle Mississippi

River, *Scaphirhynchus* sturgeon have experienced increased mortality and decreased recruitment (Birstein, 1993; Boreman, 1997; Keenlyne, 1997; Colombo et al., 2007; Tripp et al., 2009; Phelps & Tripp, 2011; Phelps et al., 2013). These factors have been attributed as leading causes for *Scaphirhynchus* sturgeon declines in the Middle Mississippi River (Quist et al., 2002; Tripp et al., 2009; Steffensen et al., 2016). Given the importance of macroinvertebrates to *Scaphirhynchus* sturgeon at all life stages, understanding the macroinvertebrate drift dynamics may be important for *Scaphirhynchus* sturgeon recovery. Sufficient prey availability can increase *Scaphirhynchus* sturgeon survival, particularly at the most vulnerable stages (i.e., larval) (Braaten et al., 2007; Spindler et al., 2012). Previous studies have demonstrated that our study reaches may provide sufficient habitat for spawning and rearing *Scaphirhynchus* sturgeon (Dryer & Sandcol, 1993; Hurley et al., 2004; Tripp et al., 2008, Koch et al., 2011; Sechler et al., 2013). Furthermore, our study suggests that commonly consumed prey items exist in our study reaches. Specifically, the average number of drifting macroinvertebrates per day presented in this study, ranging from 6.8 million/d to 36.4 million/d for those commonly consumed invertebrate taxa. However, true macroinvertebrate density is likely much higher given diel periodicities were not considered (Tanaka, 1960; Waters, 1962, 1972; Müller, 1963; Elliot, 1970, Mendoza et al., 2018).

The Middle Mississippi River is a novel habitat influenced by the Missouri River and the Upper Mississippi River. Further, the section of river from the Missouri River confluence to the Mosenthein Island complex is navigation free. As such, the 9-mile stretch is relatively unchannelized and potentially a good candidate for habitat restoration. Studies have demonstrated greater macroinvertebrate diversity in unchannelized rivers (Friberg et al., 1994; Nakano & Nakamura, 2006, 2007; Kennedy & Turner, 2011). Increasing macroinvertebrate abundance and diversity may positively influence *Scaphirhynchus* sturgeon (other fishes as well) growth and survival. Our results indicated that a wide range of macroinvertebrate taxa are drifting through the Middle Mississippi River.

Our results suggest that the interplay of spatial (i.e., reach and water column) and temporal (i.e., date) best explains macroinvertebrate CPUE variation. The synergistic relationship of these variables and other abiotic and biotic factors are likely influencing our results. Our results highlight the interconnectedness of these various factors that explain macroinvertebrate drift densities and patterns. Further, our study suggests macroinvertebrate drift patterns are not static and influenced by various spatiotemporal factors that require additional study. Overall, I observed that macroinvertebrate drift is highly variable and efforts to increase macroinvertebrate abundance likely cannot be achieved without ecosystem wide restoration (i.e., restoring natural river functional processes).

Our study area represents one of the most natural river formations on the Middle Mississippi River. This section unencumbered by navigation, provides suitable spawning and rearing habitat for fishes, especially *Scaphirhynchus* sturgeon (Tripp et al., 2009; Phelps et al., 2012). Additionally, this section receives inputs from the Upper Mississippi River and the Missouri River. These inputs (e.g., allochthonous energy [detritus] and macroinvertebrates) are likely drifting through the Middle Mississippi River and provide various ecological benefits (Eckblad et al., 1984; Tank et al., 2010). As such, improving habitat (e.g., more off-channel habitat) in this reach can promote macroinvertebrate survival for immigrant individuals coming from upstream (Missouri River and Upper Mississippi River) and those produced in the Middle Mississippi River. Ultimately, protecting these habitats will benefit macroinvertebrates and subsequently *Scaphirhynchus* sturgeon and all other fishes throughout the Mississippi and Missouri Rivers (Wallace & Webster, 1996).

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Table 1. Akaike's information criterion analyses of macroinvertebrate catch rates in the middle Mississippi River from April 15th to June 14th in 2018, and the associated biologically important models (ΔAIC = AIC for the given model – minimum AIC, where minimum AIC is the smallest observed AIC value among the models; W_i = probability that model i is the best model among the set of possible models). Models are presented in the order of relative support. Models with a multiplication symbol signify interactive effects among or between variables.

Model	**AIC**	**ΔAIC**	$\mathbf{W_i}$
Reach x Date x Water Column	5211.8	0	1
Date	6055.5	843.7	6.2E-184
Reach x Water Column	6549.5	1337.7	3.3E-291
Water Column	6570.6	1358.8	8.7E-296
Reach	6737.8	1526	0

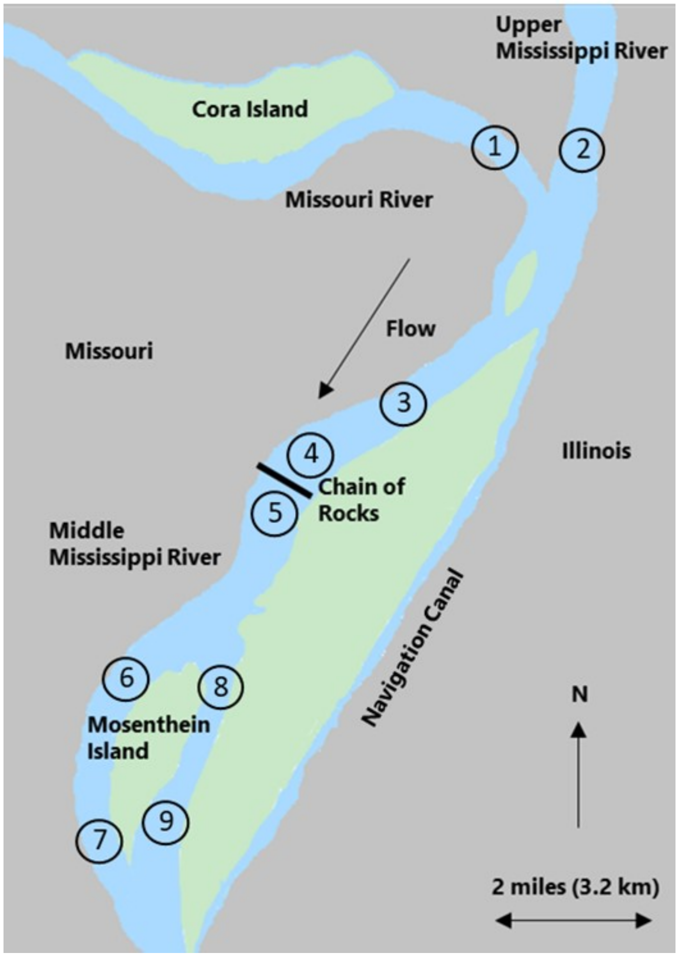

Figure 1. – Study reaches from the Missouri River confluence to below Mosenthein Island complex. Reaches are listed with corresponding numbers; (1) Missouri River, (2) Upper Mississippi River below Mel Price Lock and Dam, (3) below the Missouri River confluence, (4) above the Chain of Rock complex, (5) below the Chain of Rock complex, (6) main channel on upper end of Mosenthein Island complex, (7) main channel on the lower end of Mosenthein Island complex, (8) side channel on upper Mosenthein Island Complex, and (9) side channel on the lower end of the Mosenthein Island complex. Reaches 1-5 contained four sampling sites (i.e., bank to bank coverage) and reaches 6-9 contained three sampling sites. Surface, middle and bottom sets were conducted at all sites.

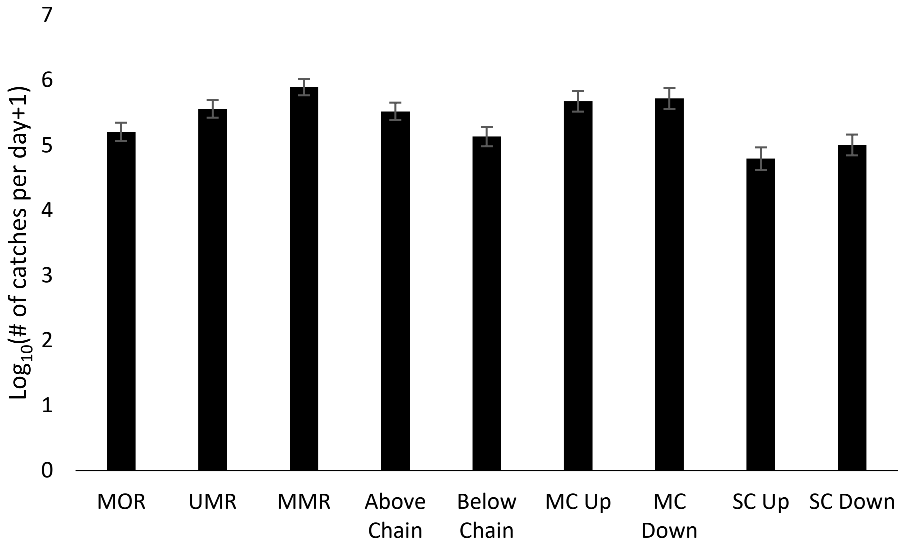

Figure 2. Mean (+SE) number of Diptera, Ephemeroptera, Plecoptera and Trichoptera per 24 h period in each reach from April 15th to June 14th in 2018 (MOR = Missouri River; UMR = Upper Mississippi River; MMR = Middle Mississippi River; Above Chain = Above chain of rocks; Below Chain = Below chain of rocks; MC Up = Main Channel Upstream; MC Down = Main Channel Downstream; SC Up = Side Channel Upstream; SC Down = Side Channel Downstream).

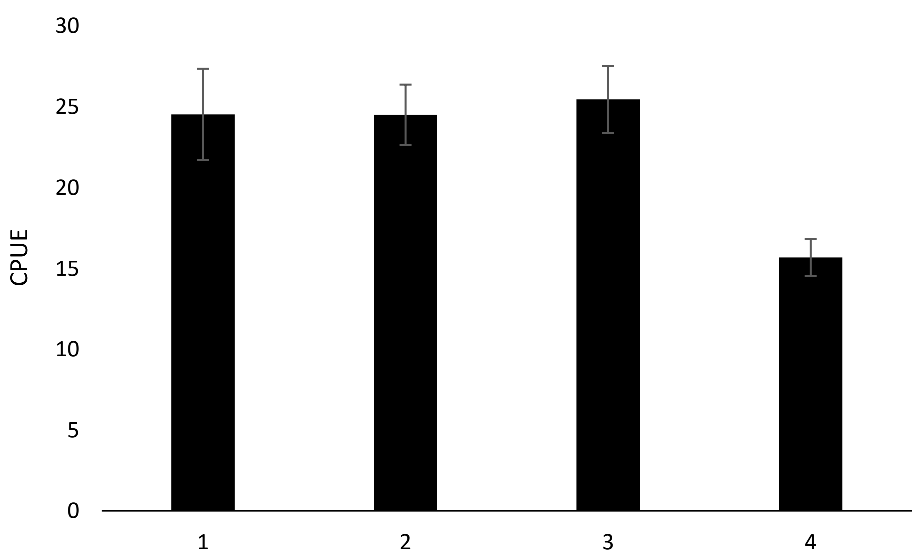

Figure 3. Mean (+SE) catch per unit effort (CPUE; Number/100m^3) for Diptera, Ephemeroptera, Plecoptera and Trichoptera from April 15th to June 14th in 2018 laterally across the river (1 = Right descending bank; 2 = thalweg; 3 = thalweg; 4 = Left descending bank).

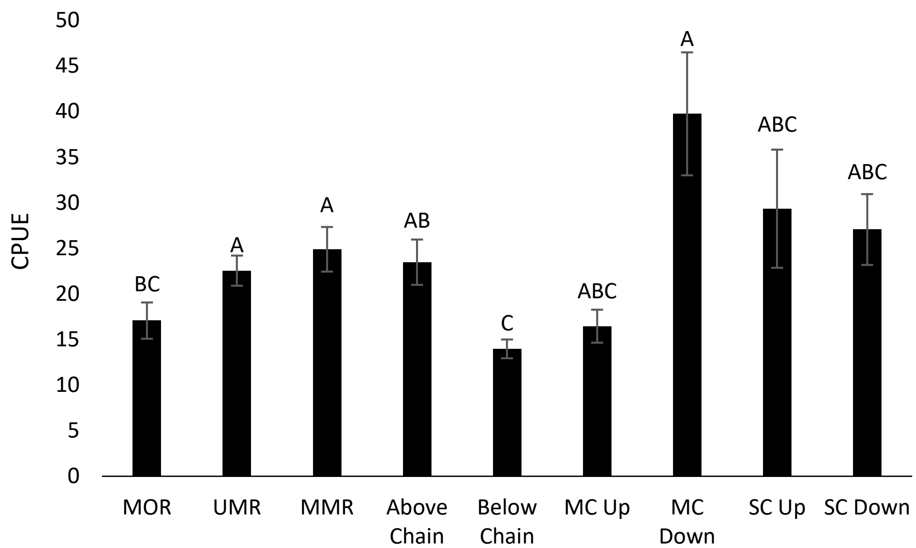

Figure 4. Mean (+SE) catch per unit effort (CPUE; Number/100m^3) for Diptera, Ephemeroptera, Plecoptera and Trichoptera in each reach from April 15th to June 14th (MOR = Missouri River; UMR = Upper Mississippi River; MMR = Middle Mississippi River; Above Chain = Above chain of rocks; Below Chain = Below chain of rocks; MC Up = Main Channel Upstream; MC Down = Main Channel Downstream; SC Up = Side Channel Upstream; SC Down = Side Channel Downstream). Means with common letters are not significantly different (P > 0.0001).

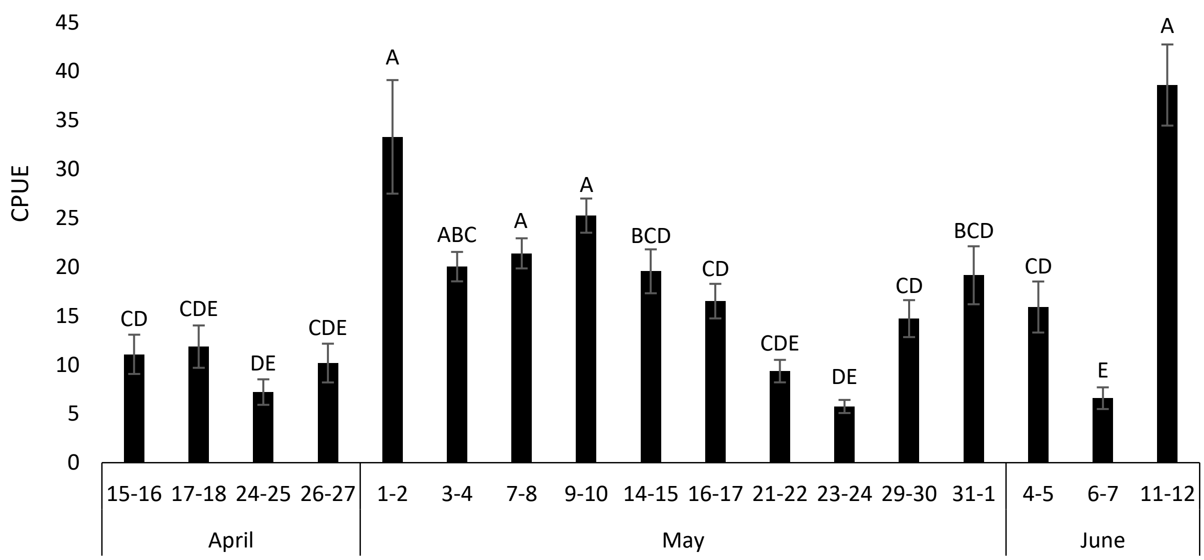

Figure 5. Mean (+SE) catch per unit effort (CPUE; Number/100m^3) for Diptera, Ephemeroptera, Plecoptera and Trichoptera for dates from April 15th to June 12th in 2018. Means with common letters are not significantly different (P > 0.0001).

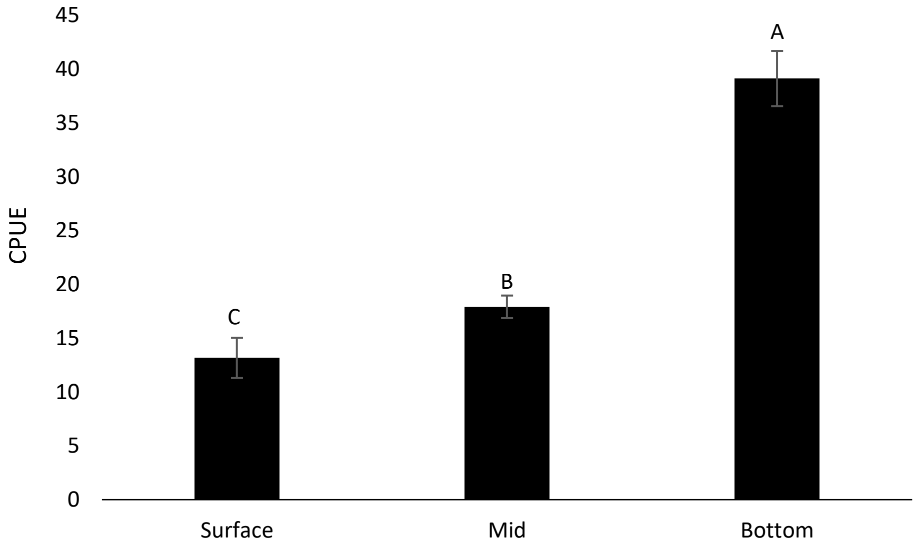

Figure 6. Mean (+SE) catch per unit effort (CPUE; Number/100m^3) for Diptera, Ephemeroptera, Plecoptera and Trichoptera for surface, middle and bottom of the water column from April 15th to June 14th. Means with common letters are not significantly different (P > 0.0001).

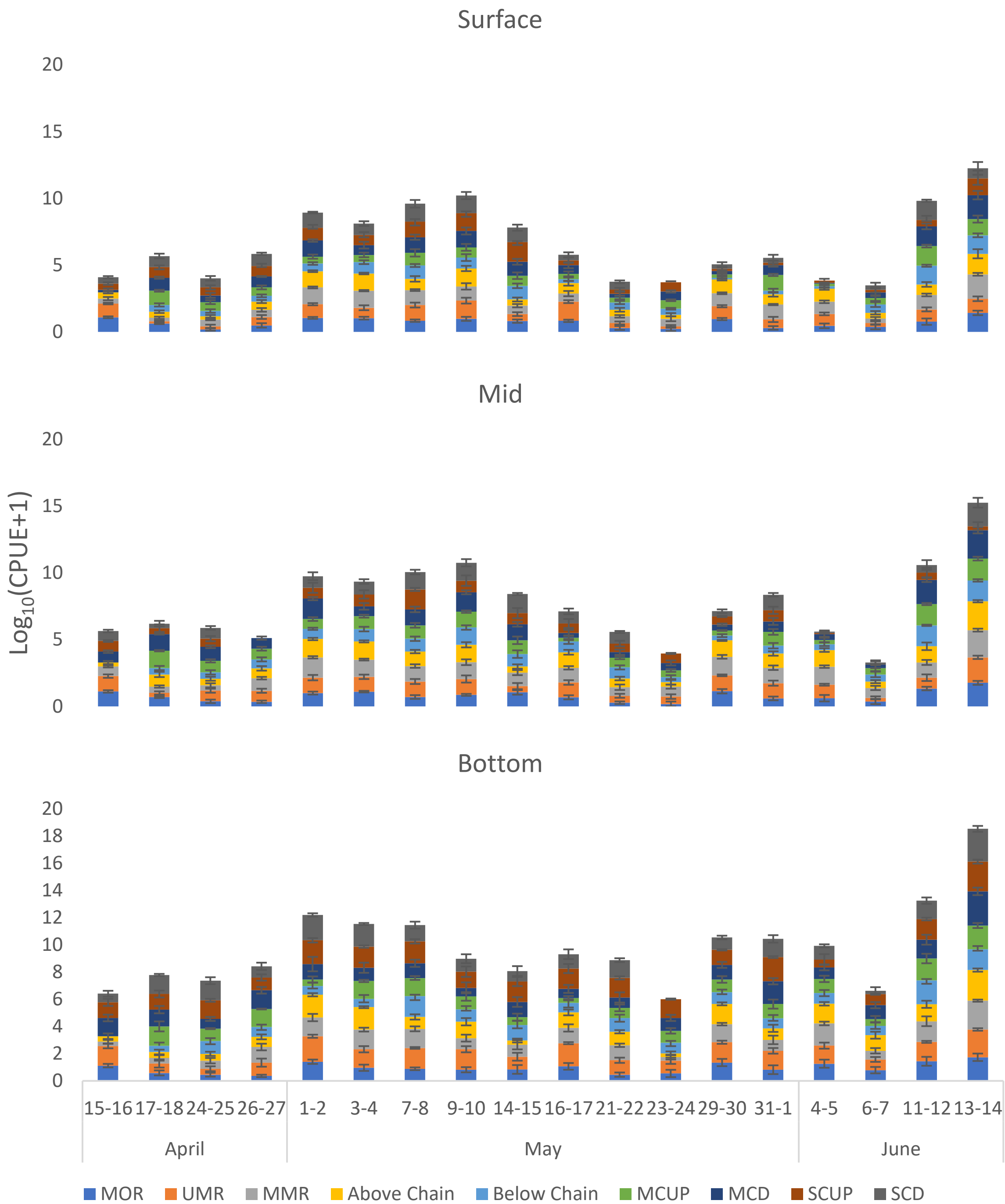

Figure 7. Mean (+SE) catch per unit effort (CPUE; Numer/100m^3) Log$_{10}$ transformed for Diptera, Ephemeroptera, Plecoptera and Trichoptera in relation to reach, date and water column position from April 15th to June 14th (MOR = Missouri River; UMR = Upper Mississippi River; MMR = Middle Mississippi River; Above Chain = Above chain of rocks; Below Chain = Below chain of rocks; MC Up = Main Channel Upstream; MC Down = Main Channel Downstream; SC Up = Side Channel Upstream; SC Down = Side Channel Downstream)

SUMMARY

This research supports the importance of restoration and conservation efforts in disturbed aquatic systems. Ecosystem wide restoration may be beneficial for fish and macroinvertebrate communities in small (e.g., headwater streams) and large (e.g., Mississippi River) systems. Knowledge gained from Chapter 1 research may inform future remediation efforts in similarly disturbed areas. Information from Chapter 2 illustrates the importance of macroinvertebrate availability to fish growth and survival. Improving habitat in the Middle Mississippi River may benefit macroinvertebrates as well as other fishes, especially *Scaphirhynchus* sturgeon.