Larval Fish Sampling and Scaphirhynchus Sturgeon Drift Dynamics in the Mississippi and Missouri Rivers

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LARVAL FISH SAMPLING AND *SCAPHIRHYNCHUS* STURGEON DRIFT DYNAMICS IN THE MISSISSIPPI AND MISSOURI RIVERS

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Master of Science, Biology

By

Hae Hyun Kim

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***SCAPHIRHYNCHUS* STURGEON DRIFT SAMPLING AND DYANAMICS IN THE MISSISSIPPI AND MISSOURI RIVERS**

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ABSTRACT

Humans have been altering the natural ecosystem for centuries. These alterations provide many socioeconomic benefits (e.g., navigation and flood-control). However, these alterations can have negative ecological consequences. Large rivers across the country have been manipulated to facilitate various human activities. Rivers are dynamic systems governed by various abiotic and biotic factors. Ultimately these alterations change the natural biogeochemical cycles and reduce available habitats. These impacts likely affect riverine fishes' ability to carry out their lifecycle. Riverine organisms, and particularly fish, have adapted to survive in free-flowing systems. Population dynamics (i.e., recruitment, growth and mortality) are the basis of fisheries management. Understanding these parameters allows for proper fisheries management. Larval fish data are often used to infer fish reproduction, recruitment and range. As such, it is important to understand and effectively sample larval fishes. Few studies have evaluated methods for larval fish sampling in large rivers. As such, we sought to develop a sampling method that effectively and efficiently captures free-drifting fish larvae in large rivers. We then used this method to sample *Scaphirhynchus* sturgeon in the Missouri and Mississippi rivers. We were able to capture a wide range of free-drifting larval fish taxa in our drift nets. Our nets were able to capture 12 of 16 (75%) fish families present in the Middle Mississippi River. We then used *Scaphirhynchus* sturgeon catch information to model various spatial and temporal interactions. Of the models evaluated, year to year variations best explained *Scaphirhynchus* sturgeon catch rates. Understanding fish early-life history is imperative for proper fisheries management. We present a sampling methodology for collecting free-drifting larval fishes. Further, we applied these methods to evaluate *Scaphirhynchus* sturgeon drift dynamics in the Missouri and Mississippi rivers. These methods have broad application potential and can help guide various management strategies.

KEYWORDS: larval fish**,** *Scaphirhynchus* sturgeon, sampling, habitat, Missouri River, Mississippi River

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This thesis is dedicated to my grandmother, who truly never understood my job. Regardless. she always supported me, her thoughts and prayers are why I am here today.

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CHAPTER 1: OVERVIEW

The following thesis is comprised of two manuscripts intended for publication. Chapter two: A useful methodology for assessing vertical distributions of drifting larval fishes in large rivers, evaluates a free-drifting larval fish sampling method for large rivers. Here we evaluated the use of large ichthyoplankton nets for sampling in large rivers. Chapter three: *Scaphirhynchus* Sturgeon Drift in the Missouri and Mississippi Rivers, uses catch data from these gears. Here we evaluated *Scaphirhynchus* sturgeon drift dynamics and how it may inform habitat restoration on the Middle Mississippi River. Both manuscripts are intended to be submitted to North American Journal of Fisheries Management and follow their guidelines.

CHAPTER 2: A USEFUL METHODOLOGY FOR ASSESSING VERTICAL DISTRIBUTIONS OF DRIFTING LARVAL FISHES IN LARGE RIVERS

Introduction

Since the beginning of modern civilization humans have altered the natural ecosystem (Vitousek et al. 1997). Specifically, aquatic environments have been manipulated for various uses (e.g., transportation, flood control; Vitousek et al. 1997; Ricciardi and Rasmussen 1999). Aquatic system disturbances vary across spatial (e.g., floodplain loss) and temporal (e.g., seasonal flood pulses) scales (Chen and Simmons 1986; Sparks et al. 1990; Sparks 1995; Theling 1995; Ickes et al. 2005). Ultimately, these changes have influenced fish populations (Ricciardi and Rasmussen 1999; Jelks et al. 2008). Riverine fishes rely on specific conditions to survive, recruit and reproduce (Muth and Schmulbach 1984; Sparks 1995; Robinson et al. 1998; D'Amours et al. 2001). Most riverine fishes require a free-drifting and settling period for successful reproduction (Muth and Schmulbach 1984; Robinson et al. 1998; D'Amours et al. 2001). Throughout this period, larvae hatch as a free-drifting embryo and ultimately settle (i.e., become able to maintain position).

Understanding fish population dynamics (i.e., recruitment, growth and mortality) is important in managing any fishery (Ricker 1975; Van Den Avyle 1993). Recruitment represents the most difficult life-history transition for fishes (i.e., Type III survivorship; Ricker 1975; Winemiller and Rose 1992; Pritt et al. 2014). Successful recruitment drives subsequent year-classes (Houde 1994). As such, sampling larval fishes can provide biologists insights into adult populations (Bilkovic et al. 2002; Pritt et al. 2014). However, effective sampling is necessary to study and understand larval fishes (Neal et al. 2012; Pritt et al. 2014).

Fish sampling methods are generally classified as active (e.g., electro-fishing) or passive (e.g., gillnets). Active larval fish sampling methods may include trawling (e.g., Herzog et al. 2005; Hrabik et al. 2007; Herzog et al. 2009) or using seines (Neal et al. 2012). While passive methods may use lighted traps (e.g., Pritt et al. 2014) or drift nets (e.g., Braaten et al. 2008; DeLonay et al. 2016). These gears target various life-stages, sizes and species. Further, these gears may be limited in certain environments. In the Mississippi and Missouri rivers, a Missouri Style Trawl (i.e., a modified slingshot balloon trawl) is commonly used to sample benthic larval fishes (e.g., sturgeon spp (Acipenseridae), Paddlefish *Polyodon spathula* and chub spp. (Cyprinidae); Herzog et al. 2005; Hrabik et al. 2007; Herzog et al. 2009) This active method targets larval fish that have settled. As such, this method may be size limited and may not effectively sample free-drifting fishes (Herzog et al. 2005, 2009).

There is a lack of knowledge regarding fish early-life histories. Most larval fish research has been limited to lentic systems (e.g., Pritt et al. 2014). Most studies in lotic systems have been limited to streams (e.g., Neal et al. 2012). Few studies have assessed larval fish sampling in large rivers (e.g., Mississippi River). Further, no studies have developed sampling methods for free-drifting fish larvae in the Mississippi River. Traditional drift sampling requires the net to be affixed to its sampling location (i.e., stream bottom) or the surface (Elliot 1970). As such, spatial coverage (i.e., throughout the water column) is limited. Accessibility has made it difficult to sample free-drifting larval fishes in large rivers (e.g., Mississippi River). We sought to develop a sampling methodology for free-drifting larval fishes, capable of sampling the highly variable depth and flows in large rivers. Further, this methodology minimizes effort (i.e., time) per sample and expands researcher's ability to collect samples throughout a sampling period. Here

we present a sampling methodology for free-drifting larval fishes. This method expands the spatial scales (i.e., longitudinal, latitudinal, and vertical) drift nets can sample in large rivers.

Methods

Ichtyoplankton nets (1000µ mesh) were affixed to rectangular metal frames (0.5m x 0.75m; 0.375m^2), similar to Braaten et al. (2008). General Oceanics mechanical flowmeters were used to measure water volume filtered (General Oceanics, Miami, Florida, USA) and a sounding weight (45.5kg) was affixed to maintain position. Nets measured approximately 3m long and tapered into a cod end (0.07m x 0.08m). A boat mounted electric winch deployed and retrieved nets. Nets were deployed across each study reach (i.e., latitudinal coverage), depending on river width, 3 to 4 sites were sampled encompassing the channel and its borders. At each site, two nets (i.e., port and starboard side) were deployed in the surface, the middle and bottom of the river (i.e., vertical coverage). Relative position was maintained by the boat operator. A boat mounted Garmin® Panoptix Live Scope™ sonar (www.Garmin.com) was used to ensure nets were properly sampling the water column (Figure 1). Nets were typically deployed for two to five minutes depending on flow and organic materials (e.g., coarse particulate organic matter). All samples were fixed in a 95% ethanol solution. All samples were collected by the U.S. Fish and Wildlife Service and did not require Missouri State University IUCAC protocols.

Our study reaches extended from below the Cora Island unit on the Missouri River and below Mel Price Lock and Dam, downstream to below the Mosenthein Island complex (Figure 1). Overall, nine distinct reaches were sampled, (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 (Figure 1).

Results

We collected approximately 3,400 drift samples from April 15 – June 14 in 2018, across all study reaches. Over 360,000m^3 of Mississippi and Missouri river water was successfully sampled (i.e., filtered). Fish were collected from all study reaches and throughout the water column (i.e., surface, middle, bottom). We successfully deployed and sampled a wide range of depths (3.6m – 36.4m). We collected 142,234 larval fishes, 142,122 (99.9%) were teleost fishes. Paddlefish and sturgeon (likely *Scaphirhynchus* spp.) catch was low, 46 (0.0323%) and 119 (0.0837%), respectively. We observed fish across 12 fish families (i.e., Acipenseridae, Polyodontidae, Lepisosteidae, Hiodontidae, Clupeidae, Cyprinidae, Catostomidae, Ictaluridae, Moronidae, Centrarchidae, Percidae, Sciaenidae).

Discussion

From its headwaters to the Gulf of Mexico, approximately 188 fish species, across 31 families have been recorded and observed in the Mississippi River (Schramm 2004; Schramm et al. 2016). The Missouri River confluence to the Ohio River confluence (i.e., Middle Mississippi River) contains 121 fish species (Schramm 2004; Schramm et al. 2016). Schramm et al. (2016) describes 31 families across the entire Mississippi River, however, some are anadromous, catadromous (e.g., American Eel *Anguilla rostrata*) or only infrequently occupy the lower portions (e.g., Bull Shark *Carcharhinus leucas*). Commonly occurring fishes in the Middle

Mississippi River encompass 16 families (Schramm 2004; Schramm et al. 2016). Our gear collected 12 of the 16 families (75%) present in the Middle Mississippi River. Those families not represented in our samples, Petromyzontidae, Amiidae, Anguillidae, and Poecillidae, likely were not vulnerable to our gear due to life-history and or low abundance.

The Middle Mississippi River is unimpounded and represents a more channelized and faster river relative to impounded upper reaches (Chen and Simmons 1986; Sparks et al. 1990; Sparks 1995; Theling 1995; Ickes et al. 2005; Schramm et al. 2016). Traditional larval fish sampling methods are spatially (i.e., vertically) or logistically limited. Few studies have successfully deployed drift net on the river bottom; however, these systems were shallower and slower than our study sites (e.g., Braaten et al. 2008; DeLonay et al. 2016). Our modifications (i.e., electric winches and maintain relative position via boat operator) allowed greater spatial coverage (i.e., surface, middle, and bottom) and allowed us to collect more samples in less time. Ultimately, providing a more time efficient and representative river sample.

Larval fish sampling can provide important fish management insights. Abundance and range can inform spawning and nursery habitats. Further, larval data can inform adult stock abundances. Biologists have used larval fish data to inform management of commercially and recreationally important fishes (e.g., Bilkovic et al. 2002). Larval fish sampling can provide range and abundance information for species of concern (e.g., sturgeons Acipenseridae; Hrabik et al. 2007). Additionally, it can help managers understand invasive fish expansions (e.g., Haupt and Phelps 2016). Future studies should improve taxonomic resolution (i.e., identification to species) and would allow for finer scale catch assessment. Assessing variation in species capture vulnerability (i.e., detection probability) can inform species level differences and may guide

management (Herzog et al. 2005, 2009; Pritt et al. 2014). We present an effective method of capturing a wide range of fishes during early life in large rivers.

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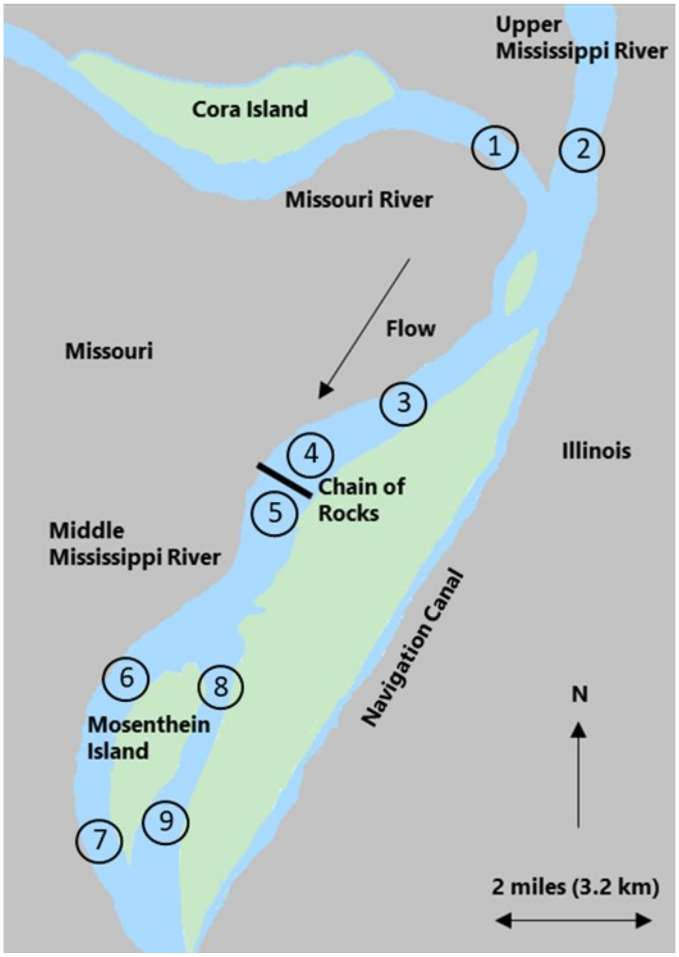

Figure 1. – Study reaches from the Missouri River confluence to below Mosenthein Island complex. Reaches are listed with corresponding numbers; (1) Missouri River, (2) Upper Mississippi River below Mel Price Lock and Dam, (3) below the Missouri River confluence, (4) above the Chain of Rock complex, (5) 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.

CHAPTER 3: *SCAPHIRHYNCHUS* STURGEON DRIFT DYNAMICS IN THE MISSISSIPPI AND MISSOURI RIVERS

Introduction

North America contains diverse ecoregions and high fish biodiversity (Allan and Flecker 1993; Abell et al. 2000; Jelks et al. 2008). However, the biotic richness and diversity are threatened by various anthropogenic impacts (Vitousek et al. 1997; Ricciardi and Rasmussen 1999). Humans have altered natural ecosystems and specifically rivers for various uses (e.g., navigation, irrigation, flood control; Vitousek et al. 1997). Ultimately, changing the natural biogeochemical cycles (Vitousek et al. 1997; Ricciardi and Rasmussen 1999). Large rivers (e.g., Mississippi River) are dynamic systems governed by various biotic and abiotic factors (Chen and Simmons 1986; Lubinski et al. 1991; Theiling 1995). In the Mississippi River, disturbance and modifications vary spatially (i.e., longitudinally) and produce varying ecological complications (Chen and Simmons 1986; Sparks et al. 1990; Sparks 1995; Theling 1995; Ickes et al. 2005). However, some ecological issues are system wide (e.g., sedimentation and flow alteration; Chen and Simmons 1986; Theiling 1995; Sparks 1995; Ickes et al. 2005).

Large river fishes have adapted to spawn in a free-flowing environment and often require a drift and settling period (Muth and Schmulbach 1984; Robinson et al. 1998; D'Amours et al. 2001). Drift times vary across species and survival during this period drives annual recruitment and ultimately population structure in river systems (Ricker 1975; Robinson et al. 1998; D'Amours et al. 2001). Large-scale hydrological alterations can have negative effects on riverine fish reproduction and subsequently, recruitment (Sparks et al. 1990; Ickes et al. 2005). In the Mississippi River, certain taxa (e.g., sturgeon spp.) are more sensitive to river alterations due to

their life-history traits (e.g., long-lived, slow maturing; Boreman 1997; Pikitch et al. 2005; Tripp et al. 2019). Of the 24 extant Acipenseriformes species, two sympatric species of Scaphirhynchus sturgeon co-exist in the Mississippi River (Schramm 2004; Hrabik et al. 2007; Tripp et al 2009; Schramm et al. 2016). Shovelnose Sturgeon Scaphirhynchus platorynchus and Pallid Sturgeon S. albus co-occur in the Lower Mississippi River and the Middle Mississippi River but do not co-occur in the upper reaches. In the Middle Mississippi River (open-river at St. Louis downstream to Ohio River confluence at Cairo, IL) both shovelnose and pallid sturgeon co-occur and successfully reproduce (Hrabik et al. 2007; Tripp et al. 2009). The Middle Mississippi River represents a distinctive habitat where inputs from the Upper Mississippi River and Missouri River work synergistically with various intra- abiotic and biotic factors. Both sturgeons are thought to exhibit similar life history and reproduction strategies (Wildhaber et al. 2007). Abundance of both sturgeon species have declined; however, Shovelnose Sturgeon are considered more common while Pallid Sturgeon are considered rare and may be close to extirpation (Colombo et al. 2007). Sturgeon declines in the Mississippi River were likely due to recruitment failures and increased mortality due to overfishing and habitat modifications (Dryer and Sandvol 1993).

In 1990, low sturgeon abundances prompted the U. S. Fish and Wildlife Service (USFWS) to place the Pallid Sturgeon on the U.S. federally endangered species list (USFWS 1990; Dryer and Sandvol 1993). Although Pallid Sturgeon was listed as an endangered species, commercial exploitation continued to occur, likely due to the similar appearance to the Shovelnose Sturgeon (Colombo et al. 2007). As such, Shovelnose Sturgeon was subsequently listed as threatened and all sturgeon commercial harvest was prohibited where the two species co-occur (i.e., Middle Mississippi River) under the Similarity of Appearance Act.

Given the imperiled nature of these species, various studies have been conducted through academic, state, and federal agencies (Tripp et al. 2019). Specifically, *Scaphirhynchus* sturgeon adult population demographics (Quist et al. 2002; Kilgore et al. 2007), early life-history (Braaten and Fuller 2007; Braaten et al. 2008, Phelps et al. 2012), reproduction (Colombo et al. 2007; DeLonay et al. 2009), habitat use and movement (Bramblett and White 2001; Hurley et al. 2004), and diet (Hoover et al. 2004) have been studied (Tripp et al. 2012). However, no studies have evaluated *Scaphirhynchus* sturgeon drifting dynamics in the Middle Mississippi River. This is especially important as recruitment failures and additive mortality has been identified as the leading causes of low *Scaphirhynchus* sturgeon abundances (Dryer and Sandvol 1993; Colombo et al. 2007). Additionally, the Chain of Rocks formation and the Mosenthein Island complex represent some of the most important river features in the Mississippi River (Dobney 1928; Pinter et al. 2004). These large river macrohabitat features may be important for free drifting and settling *Scaphirhynchus* sturgeon larvae from both the Missouri River and Upper Mississippi River. We sought to evaluate *Scaphirhynchus* sturgeon drift dynamics in the Middle Mississippi River, determine relative *Scaphirhynchus* sturgeon contributions from the Missouri River and the Upper Mississippi River, and evaluate drift differences downstream of the Missouri River and Upper Mississippi River confluences.

Methods

Study site. Several distinct study reaches (N = 9) were selected to assess relative *Scaphirhynchus* sturgeon inputs from the lower Missouri River and Upper Mississippi River and their potential contribution to the Middle Mississippi River. Study reaches extended from below the Cora Island unit in the (1) lower Missouri River (MOR), below Mel Price lock and dam on

the (2) Upper Mississippi River (UMR), (3) below the Missouri River confluence (MMR), (4) above the Chain of Rock complex (ACH), (5) below the Chain of Rock complex (BCH), (6) main channel on upper end of Mosenthein Island complex (MCU), (7) main channel on the lower end of Mosenthein Island complex (MCD), (8) side channel on upper Mosenthein Island Complex (SCU), and (9) side channel on the lower end of the Mosenthein Island complex (SCD; Figure 1).

Drift sampling. Ichthyoplankton nets (1000µ mesh) with rectangular openings (0.5m x 0.75m; 0.375m^2) were used to sample free-drifting *Scaphirhynchus* sturgeon larvae in 2018 and 2019, similar to Braaten et al. (2008, 2010) and DeLonay et al. (2009). Each net was approximately 3m long and tapered into a cod end (0.07m x 0.08m). Sounding weights (45.5kg) were attached to each net to maintain position in current. General Oceanics mechanical flowmeters (General Oceanics, Miami, Florida, USA) estimated volume filtered for each sample. Nets were deployed and retrieved using a boat mounted electric winch. Once deployed, relative position was maintained by boat operator using engine thrust to match the combined river current and gear drag. Additionally, a boat mounted Garmin® Panoptix Live Scope™ sonar (www.Garmin.com) confirmed proper deployment and sampling (Figure 2). Nets were deployed across nine distinct sampling reaches, depending on river width, three to four fixed sites were sampled encompassing the channel and its borders. Reaches one, two, three, four and five had four fixed site sampling locations while sites six, seven, eight and nine (i.e., Mosenthein Island complex sites) had three fixed site sampling locations (Figure 2). At each fixed site, two nets (i.e., port and starboard side) were deployed in the surface, the middle and bottom of the river (i.e., vertical coverage). However, surface samples were omitted in 2019 due to no *Scaphirhynchus* sturgeon captures. Each net typically sampled for two to five minutes depending

on flow and organic material collected. All samples were rinsed and fixed in 95% ethanol for further processing in the lab. All samples were collected by the U.S. Fish and Wildlife Service and did not require Missouri State University IUCAC protocols.

Data analysis. All larval fish were sorted into Acipenseriformes (i.e., Paddlefish, Shovelnose Sturgeon, and Pallid Sturgeon) and non-Acipenseriformes and all non-Acipenseriformes fishes were enumerated. Paddlefish were able to be identified however, due to size and morphological similarities, *Scaphirhynchus* sturgeon could not be identified to species. *Scaphirhynchus* sturgeon drift densities were calculated as *catch-per-unit-effort* (CPUE):

$$CPUE = \frac{\#\ Fish}{100m^3}$$

We Log_{10}(CPUE+1) transformed all *Scaphirhynchus* sturgeon CPUE for further analysis. Surface and mid-water samples were also omitted from further analysis. No *Scaphirhynchus* sturgeon were captured in the surface and on average bottom samples yielded 20 times greater *Scaphirhynchus* sturgeon CPUE relative to mid-water samples (Table 1). We generated four single variable models and three multi-variable models evaluating temporal and spatial *Scaphirhynchus* sturgeon drift (Table 2). Study reach (1) and fixed sampling location (2) (i.e., lateral position on river) models were developed to evaluate spatial drift differences. Date (3) and year (4) were chosen to model temporal *Scaphirhynchus* sturgeon drift differences. Subsequently, to assess overall spatial and temporal variables, three additional multivariable models were developed. We evaluated the interaction of study reach and location (5) to assess overall spatial *Scaphirhynchus* sturgeon drift, date by year interaction was created (6) to assess overall temporal *Scaphirhynchus* sturgeon drift and to assess spatial and temporal factors simultaneously, a global (7) model (i.e., influence of reach x location x date x year) was developed. All models were developed using an analysis of variance (ANOVA) procedure in

SAS 9.4 software (SAS 2015). Model fit was assessed using Akaike's information criterion (AIC) calculated from the sum of square errors reported in the ANOVA procedure (Burnham and Anderson 2002).

Results

From April to June, 2,276 nets were successfully deployed (excluding surface samples) in 2018. In 2019 we successfully deployed 1,586 nets from April to June. *Scaphirhynchus* sturgeon CPUE varied from 0 – 33.3 fish/100^3m in 2018 and 0 – 128.4 fish/100^3m in 2019. *Scaphirhynchus* sturgeon were successfully captured in all study reaches in 2019. However, no *Scaphirhynchus* sturgeon were captured in the UMR and SCD reaches in 2018. We successfully captured various sizes of larval *Scaphirhynchus* sturgeon (Figure 3). *Scaphirhynchus* sturgeon ranged from 8mm to 43mm TL, with an average length of 15mm (±0.33mm; Figure 3). In 2018, *Scaphirhynchus* sturgeon were first captured on May 14 and catches continued until June (i.e., end of sampling season). In 2019, one *Scaphirhynchus* sturgeon (21mm) was captured on April 26, however, catches did not consistently begin until May 21. *Scaphirhynchus* sturgeon catch rates were highly variable across reaches, location (i.e., fixed sampling site), date and year (Figure 4). Among our seven models, the year model had the greatest support (Table 2). The interactive models had the lowest support, with the global model representing the lowest support (Table 2). Year to year variability best explained *Scaphirhynchus* sturgeon CPUE variation. Whereas, all other spatiotemporal models showed little support (Table 2).

Discussion

Our results show that larval *Scaphirhynchus* sturgeon are present in the Middle Mississippi River. The range of lengths collected likely represent length at hatch to start of exogenous feeding (i.e., settled). Our results suggest that the Missouri River and the Upper Mississippi River are contributing *Scaphirhynchus* sturgeon to the Middle Mississippi River. Additionally, larval *Scaphirhynchus* sturgeon may be originating within the Middle Mississippi River (i.e., within Chain of Rock complex). Regardless of origin, larval *Scaphirhynchus* sturgeon are drifting into the Middle Mississippi River and are likely dependent on nursery (e.g., feeding and rearing) habitats located in the Middle Mississippi River. *Scaphirhynchus* sturgeon, and especially, Pallid Sturgeon, are endangered and recovery is likely hindered by loss of nursery habitat, unsuccessful reproduction and low recruitment (Dryer and Sandvol 1993; Columbo et al. 2007; Braaten et al. 2008; Tripp et al. 2019).

The Middle Mississippi River represents a highly channelized river modified by various river training structures (e.g., dikes; Sparks et al. 1990; Theiling 1995; Schramm 2004; Ickes et al. 2005). Further, much of the floodplain (>90%) is blocked by levees (Theiling 1995; Schramm 2004; Ickes et al. 2005; Phelps et al. 2014). As such, *Scaphirhynchus* sturgeon nursery habitats may be lacking throughout the Middle Mississippi River. However, directly below the Missouri River confluence to below Mosenthein Island complex no navigational channel is maintained. Rather, traffic is routed through the Chain of Rocks canal. As such, the non-channelized area represents an ideal location for habitat restoration. Our findings indicated *Scaphirhynchus* sturgeon larvae drift through this portion of the Middle Mississippi River. Regardless of origin (i.e., Missouri River, Upper Mississippi River, within Chain of Rocks), *Scaphirhynchus* sturgeon

are likely dependent on quality nursery habitats for survival and successful recruitment in this section of river.

Our results suggested *Scaphirhynchus* sturgeon CPUE (i.e., density) is best explained by year to year variability. River conditions were highly variable year to year during our study. In 2019, the river was consistently above the National Weather Service Floodstage height (30ft). Discharge and gauge height was consistently greater in 2019 and represented one of the worst flooding events in the Mississippi River basin. Ultimately, various biotic and abiotic factors influenced by the river likely influenced our results. Rivers are dynamics systems governed by various biotic (e.g., invasive species) and abiotic (e.g., flood) factors. Ultimately, these factors work synergistically and compose the river ecosystem. Our study highlights the need for ecosystem wide habitat restoration that provides functional habitat atvarious river stages. *Scaphirhynchus* sturgeon larvae are drifting through the Middle Mississippi River and thus require sufficient nursery habitat throughout the river to survive and recruit. Due to the lack of traffic from the Missouri River confluence to the Mosenthein Island complex, this area represents an ideal location for habitat restoration. Restoration should focus on restoring river processes that facilitate larval *Scaphirhynchus* sturgeon retention and survival throughout the Middle Mississippi River and especially around the Chain of Rock complex.

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Table 1. – Average *Scaphirhynchus* sturgeon CPUE (SE, *N*) across water depths for 2018 and 2019. No *Scaphirhynchus* sturgeon were captured in the surface samples in 2018 and was omitted from 2019 sampling. *Scaphirhynchus* sturgeon CPUE was 20 times higher on average for bottom sets, relative to surface and mid water column sets.

Water Column	2018	2019	Average
Surface	0 (0, 1024)		
Mid	0.0305 (0.263, 1024)	0.00552 (0.0711, 800)	0.0197 (0.184, 1824)
Bottom	0.253 (1.950, 1024)	0.580 (5.16, 800)	0.396 (3.721, 1824)

Table 2. – Model fit rankings assessed with Akaike's information criterion (AIC). Spatial and temporal variables and their interactions were modeled to determine Scaphirhynchus sturgeon drifting dynamics. *K* represents the number of parameters used in the model, Δ_i represents AIC score differences among all model compared to best fit model. W_i shows the relative strength of each model.

Model	*N*	*K*	AIC	Δ_i	W_i
Year	1824	2	-1049.5	0	0.982876
Location	1824	2	-1041.4	8.1	0.017124
Reach	1824	2	-1016.3	33.2	6.07E-08
Date	1824	2	-1014.4	35.1	2.35E-08
Temporal (Date x Year)	1824	2	-1012.2	37.3	7.81E-09
Spatial (Reach x Location)	1824	2	-983.2	66.3	3.94E-15
Global (Reach x Location x Date x Year)	1824	2	-378.8	670.7	2.2E-146

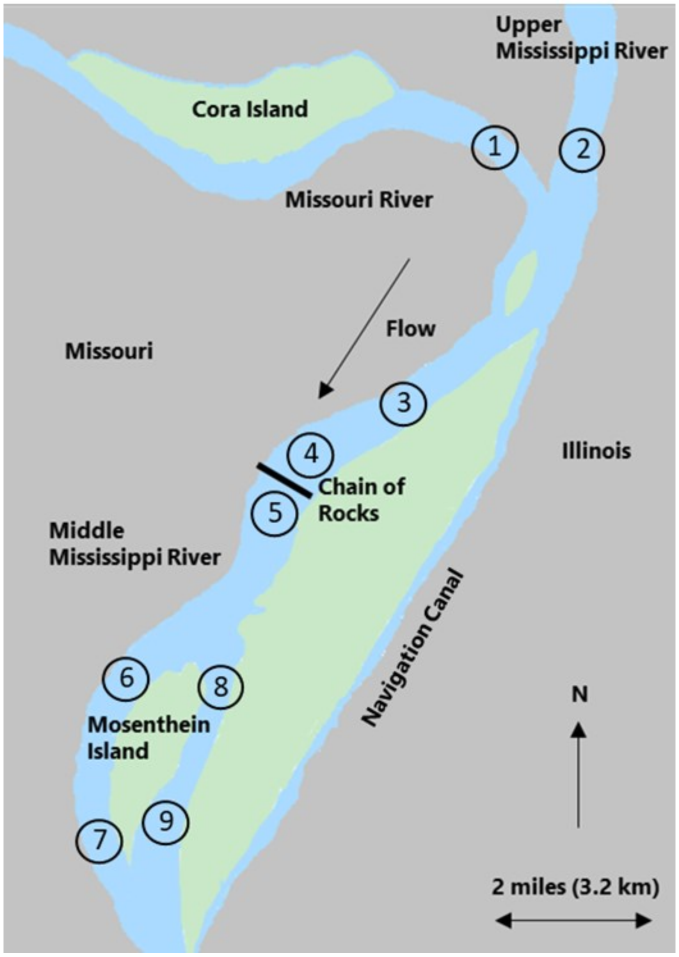

Figure 1. – Study reaches encompassing the Missouri River and the Upper Mississippi River confluences. Sampling reaches denoted as, (1) Missouri River, (2) Upper Mississippi River below Mel Price Lock and Dam, (3) below the Missouri River confluence, (4) above the Chain of Rock complex, (5) below the 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 one to five had four fixed sampling locations each while reaches six to nine had three fixed sampling locations each (i.e., lateral coverage).

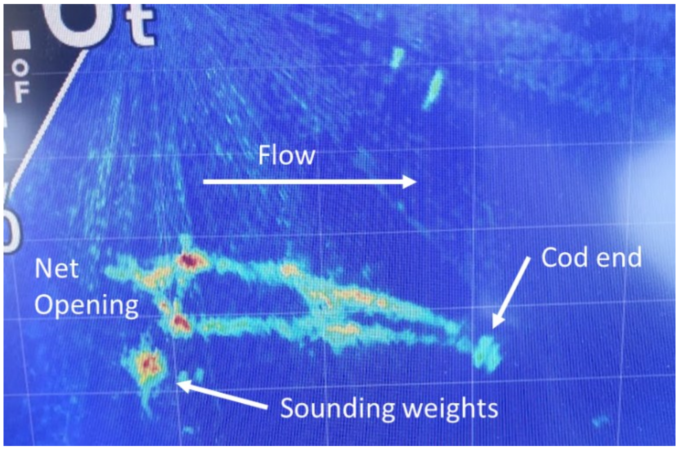

Figure 2. – Garmin® Panoptix Live Scope™ sonar (www.Garmin.com) screenshot displaying proper driftnet deployment. This image depicts a standard mid-column sampling. Water is flowing into the net opening and volume is measured using General Oceanics mechanical flowmeter (General Oceanics, Miami, Florida, USA).

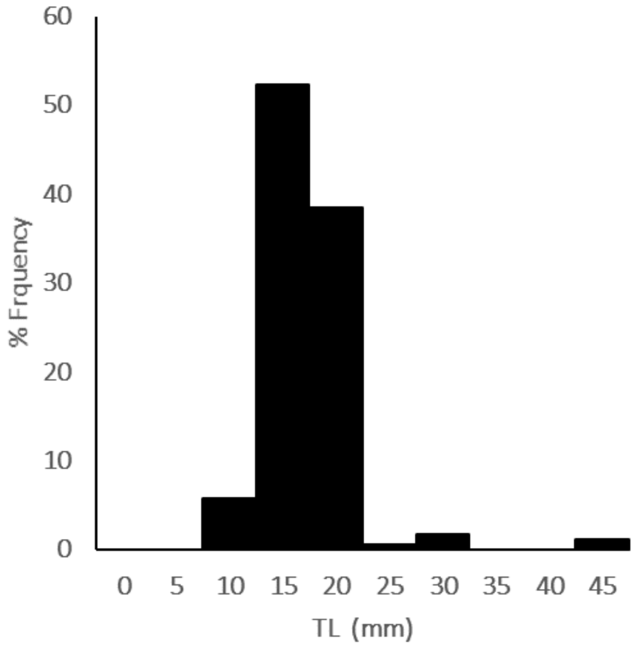

Figure 3. – *Scaphirhynchus* sturgeon percent frequency length histogram. Data represents all *Scaphirhynchus* sturgeon captured across all study reaches from 2018 and 2019. Lengths ranged from 8mm – 43mm, averaging 15mm (±0.33mm) with one 43mm individual collected.

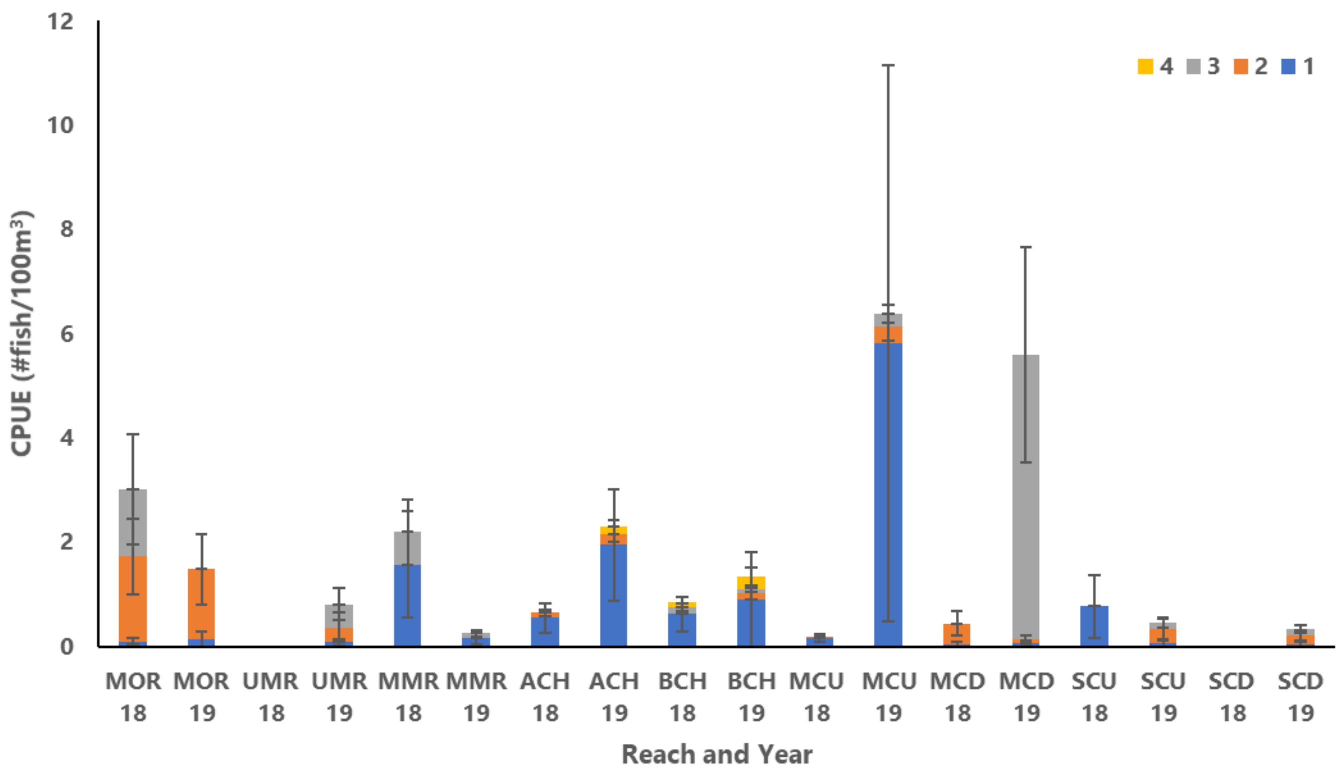

Figure 4. – Average *Scaphirhynchus* sturgeon CPUE (±SE) across all study reaches for 2018 and 2019. Fixed sampling location (i.e., lateral coverage) numbering begins on the right descending bank and increases into the thalweg and the left descending bank. Note some study reaches only had three fixed sites, where others had four. Catches are variable across years and reaches.

Chapter 4: SUMMARY

Successful reproduction, survival and subsequent recruitment drive year class strength. As such, understanding early-life history is imperative for managing any fish species. Given the importance of early-life history, there is still a paucity of information regarding this stage. Here we present a sampling methodology that can obtain free-drifting larval fishes in large rivers. Our method builds on various methods presented by others (e.g., Braaten et al. 2008, 2010). However, our modifications allowed us to obtain a greater spatial resolution in a shorter time period. This method can inform a wide range of fish management scenarios (e.g., invasive fishes, game fishes, endangered fishes). We then applied this methodology to evaluate drifting dynamics of an imperiled species.

In the case of *Scaphirhynchus* sturgeon, we found that drift dynamics and relative densities are highly variable. *Scaphirhynchus* sturgeon catch rates are influenced by various abiotic and biotic factors that changed year to year. Most importantly, we observed that *Scaphirhynchus* sturgeon drift through an unchannelized stretch of the Middle Mississippi River. *Scaphirhynchus* sturgeon are originating in the lower Missouri River, the Upper Mississippi River and within the Middle Mississippi River (i.e., the unchannelized stretch). Regardless of origin, *Scaphirhynchus* sturgeon drifting into the Middle Mississippi River require sufficient nursery habitats. The aforementioned unchannelized zone presents a novel opportunity to conduct habitat restoration. However, habitat restoration cannot focus on any single reach or location. Rather, our study highlights the need for ecosystem wide restoration.

Rivers have been modified for centuries (Chen and Simmons 1986; Lubinski et al. 1991; Theiling 1995; Vitousek et al. 1997). While these modifications provide socioeconomic benefits,

there are some ecological consequences (Chen and Simmons 1986; Sparks et al. 1990; Sparks 1995; Theling 1995; Ickes et al. 2005). As such, the need to monitor these changes is important. Understanding larval fish abundance and range can inform biotic responses to the river.

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