8-17-2023

Assessing Fish Communities and Habitat Dynamics at the North Platte River-Lake Mcconaughy Interface: Implications for Conservation and Management

Thyme Leesa Taulaki
University of Nebraska at Kearney, thymecooke@gmail.com

ASSESSING FISH COMMUNITIES AND HABITAT DYNAMICS AT THE NORTH PLATTE RIVER-LAKE McCONAUGHY INTERFACE: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

A Thesis

Presented to the

Graduate Faculty of the Biology Department

and the

Faculty of the Graduate College

University of Nebraska

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

University of Nebraska at Kearney

By

Thyme Leesa Taulaki

August 2023

THESIS ACCEPTANCE

ASSESSING FISH COMMUNITIES AND HABITAT DYNAMICS AT THE NORTH PLATTE RIVER-LAKE McCONAUGHY INTERFACE: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

Acceptance for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Science, University of Nebraska at Kearney.

Supervisory Committee

Name	Department
Melissa Wuellner	Biology
Mark Pegg	School of Natural Resources (UNL)
Keith K	Biology

Melissa Wuellner

Supervisory Committee Chair

7/31/23

Date

ABSTRACT

The river-reservoir interface (RRI) provides dynamic habitat heterogeneity that influences fish communities within the reservoir and the tributary upstream. However, little is known about the North Platte River-Lake McConaughy interface. Thus, the objectives of this research were to: 1) describe fish assemblages in the North Platte River and relate their temporal differences to water quality and physical habitat parameters; and 2) compare young fish communities collected with different gears in the upper reservoir.

Twenty-nine species were collected across four habitat types in the North Platte River above Lake McConaughy. Main and side channel habitats were more consistently available throughout the summer. Backwater habitats declined in abundance, and back eddies disappeared. Species richness and Shannon's diversity were highest in backwaters. Fish communities were somewhat similar between the habitat types, but some species were more or less abundant in some habitats. Water quality did not differ between habitat types. However, discharge and water temperature appeared to influence community composition.

In upper Lake McConaughy, I captured 21 taxa across four sampling gears. Fewer species were captured with the gears used in the earlier time period compared to the gears used later time period. Species richness, Shannon's diversity, and relative abundance were highest for seines and lowest for tow nets. Boat-mounted electrofishing appeared to be the most efficient gear. Similarities were noted in fish communities between the two time periods, but abundance of individual species varied between time periods.

This study provides updated and new information on fish communities in the North Platte River-Lake McConaughy system. Selecting the sampling gear or gears that best meet sampling objectives is important for understanding fish communities in RRIs. With such sampling information, fisheries managers may be able to identify water management strategies that provide habitats for fish communities in unique ecotones such as the RRI.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to my advisors and committee members Dr. Melissa Wuellner, Dr. Keith Koupal, and Dr. Mark Pegg. Thank you for giving me this opportunity to pursue a master's degree and for challenging me as a graduate student and individual. You have helped me develop and broaden my knowledge and skills in fisheries biology, critical thinking, and scientific writing. Thank you for responding to all my weekend and late-night emails and for providing advice and guidance during my time at UNK. Without your effort and support, I would not have become the fisheries professional I am today.

Additionally, I would also like to thank the many wonderful people who assisted me in making this project possible. These people include Blake Logan, Logan Deitrich, Josh Kreitman, Brian Mason, Mikael Ranta, Will Schriener, Jenna Ruoss, and Amanda Medaries. Sampling would not have been possible without equipment from the Nebraska Game and Parks Commission, and I would specifically like to thank Rick Holland, Brad Eifert, Mark Staab, Matt Wieseler, and Darrol Eichner for their assistance and cooperation throughout my project. Thank you to my fellow graduate students for the comradery and bonds we established during my experience at UNK. I will remember our conversations and times shared together always! Additionally, I would like to thank the many people at IDFG and PSMFC who have encouraged and supported me throughout this process.

I would not be where I am today without the love and support of my family. Mom and Dad, you have always believed in me whole-heartedly. You remind me that I can do

anything I set my mind to, you provide me with boundless encouragement and optimism, and are always there to give me a gentle nudge forward. You are the ones who instilled in me a love and passion for the natural world, and I will forever be grateful for the sacrifices you have made for me to be the successful and independent woman I am today.

Finally, I want to thank my husband who has been by my side throughout my graduate school experience. Joe, you give me the courage to overcome any obstacle that I encounter. You have taught me that even when faced with challenges, confronting them head on with a positive attitude is key. Thank you for always putting a smile on my face, believing in me, and never letting me go back on my word.

TABLE OF CONTENTS

Chapter 3: Research Implications and Management Recommendations

CHAPTER 1:

INTRA ANNUAL CHANGES IN FISH ASSEMBLAGE COMPOSITION BETWEEN HABITATS IN THE NORTH PLATTE RIVER ABOVE LAKE McCONAUGHY, NEBRASKA

Thyme Taulaki

Department of Biology, University of Nebraska at Kearney

2401 11th Ave, Kearney, NE 68849, USA

Introduction

Rivers are complex, heterogeneous ecosystems influenced by natural processes and anthropogenic factors that occur at different spatial and temporal scales (Ward et al. 2002; Robinson and Uehlinger 2008; Brennan et al. 2019). Geomorphic processes shape rivers and form various habitats (Jacobson 2013; Zeiringer et al. 2018) that change within and between years due to hydrological variation and subsequent alterations in sediment transport that occur within and between seasons (Anderson et al. 2006; Słowik et al. 2021). Perhaps one of the most variable lotic systems are braided rivers, which exhibit dynamic habitat complexity related to changes in flow (Junk et al. 1989; Ward et al. 2002; Gray et al. 2006; Smith et al. 2016). However, many braided river systems are impacted by impoundment (Tockner et al. 2006).

Anthropogenic factors such as reservoir construction can influence hydrology of the river, thus affecting sediment transport and deposition (Harman and Stewardson 2005; Lins and Slack 2005). Sediment loads are often produced by bank erosion (Baxter 1977). When the river flows above a reservoir decrease, large loads of sediment are deposited, modifying channel morphology (Cooper et al. 2016). Thus, the interface of rivers and reservoirs represents a transition from lotic to lentic habitat (Baxter 1977). To date, most studies that have quantified changes to habitat and fish communities as a result of reservoir construction have focused downstream of the dam (e.g., Shields, Jr. et al. 2002; Kondolf et al. 2014; Yang et al. 2014). However, changes in the river upstream are important as well, as flow changes in the river-reservoir interface may lead to important changes in fish community structure (Pringle 1997).

Riverine fishes are adapted to physical changes in and availability of habitat and often use multiple habitat types throughout the year (Aadland 1993). For example, Muskellunge (*Esox masquinongy*) in the New River, Virginia, positively selected for deeper riverine habitats, but moved to shallower, nearshore habitats during times of increased water velocity (Brenden et al. 2006). Additionally, species richness and diversity have been linked to the availability of diverse habitats (Gorman and Karr 1978; Scheidegger and Bain 1995; Carlhavo et al. 1998; Gratwicke and Speight 2005; Santos et al. 2010). For example, habitat heterogeneity and connectivity in the River Rhine were linked to an increase in species richness (Stoffers et al. 2022). However, if habitats become inaccessible due to anthropogenic hydrological changes, then local extirpations of some species may occur (Page et al. 1997; Brauer et al. 2020), and abundance and diversity of riverine fish may decline (Miranda 2005; Buckmeier et al. 2014; Bower et al. 2019).

Physical and chemical features within riverine habitats may change through time which can alter fish presence (Robinson et al. 2002; Ahearn et al. 2004; Thorp et al. 2006). For example, habitats with higher vegetation complexity compared to those with little to no vegetation had increased fish abundance and richness in a lowland river (Grenouillet et al. 2002). Additionally, changes in water quality may contribute to changes in fish communities (Saalfeld et al. 2012; Parker et al. 2016), thus, impacting species richness and diversity within and across all habitats (Williams 1943). Site-level selection of fishes have been linked to water quality (Sutela et al. 2010; Wuellner et al. 2013). Although some research has been conducted on relationships between physicochemical features of rivers and fish assemblages (e.g., Maret and MacCoy 2002; Hughes et al. 2005), little is known regarding how changes in physical habitat and water quality influence fish diversity and richness in the river above a reservoir.

Limited research has been conducted on fish assemblages in the North Platte River upstream of Lake McConaughy, but the river is likely used by some species that also occur in the reservoir (Johnson 1942; Lynch and Roh 1996).The North Platte River from the Nebraska border to Lake McConaughy is approximately 190 km long. Kingsley Dam in Keith County, Nebraska, was constructed on the North Platte River in 1941 to create Lake McConaughy, the largest reservoir in the state (CNPPID 2017). The North Platte River in Nebraska above this reservoir offers a unique setting to study how fish communities may change within a short period of time (e.g., a few months) as the availability of habitats change frequently due to sandy sediments and river braiding (Soukup et al. 2009). Determining associations between the fish that occupy the river at least for part of the year and water quality and physical habitat can be useful to the management and conservation of fish and habitat above Lake McConaughy. Thus, the objective of this study was to describe fish assemblages in the North Platte River above Lake McConaughy and relate their temporal differences to water quality and physical habitat parameters.

Methods

The reach of the North Platte River sampled for this study began at the Oshkosh Bridge in Oshkosh, Nebraska, at 41°22’52.1” N 102°20’50.7” W and ended above Lake McConaughy at 41°17’40.24” N 102°00’24.16” W. Water quality was measured, and fish sampling was conducted across six periods encompassing the first and third weeks of each month between June and August 2020. The study reach was sectioned into three braided and three non-braided river segments (Figure 1). Within each section, aerial maps and on-the-ground verification were used to identify the availability of four habitat types: back eddies, backwaters, main channel, and side channels. Definitions for each habitat followed those provided by Armantrout (1998; Table 1). Initially, every available habitat type was to be sampled in each section of the river reach from Oshkosh, NE to above Lake McConaughy, but after the first sampling period, the high relative availability of habitats precluded complete sampling within each river section. Thus, more backwater and main channel habitats were sampled during the first period compared to others (Table 2). Due to time restrictions and limited access to the river, one replicate of each habitat type was randomly selected within the six sections of the study area for the remaining periods (Figure 2). However, not all habitats were found within each section, especially later in the summer when flows decreased. In these instances, all available habitats were sampled and, consequently, the number of locations for each habitat type was unequal (Table 2).

Water temperature (˚C), pH, salinity (ppt), and total dissolved solids (mg/L) were measured once at the surface for each location just prior to fish sampling using a YSI multi-meter™ (YSI Incorporated, Yellow Springs, OH). Discharge (m^3/s) was measured using the float method (Robins and Crawford 1954). An analysis of variance (ANOVA) was used to compare water quality and discharge between habitat types for the entire study. All variables were tested for normality prior to this analysis and were found to meet normal distribution. Fish were sampled using a 4.6 x 1.2 m seine with 0.6 cm^2-knotless mesh (Memphis Net and Twine, Memphis, TN). Quarter-arc seine hauls (Goldstein 1978; Brown and Ford 2002) were pulled at three randomly selected sites within each location based on accessibility and physical conditions (e.g., water depth, vegetation, and velocity). All fish captured were identified and enumerated. Total lengths (TL; mm) of the first ten individuals of each species were measured at each location. Fish not identified in the field were vouchered and identified later in the laboratory to the lowest possible taxonomic level. Generally, most individuals were identified to species; however, some individuals were only identified to family as they were potential hybrids or were degraded during storage. Those individuals not identified to species were omitted from final analyses.

Species richness and the mean and standard error for Shannon diversity (*H'*; Shannon 1948*)* were calculated for each habitat type across all sections by month. Comparisons of fish assemblages between habitats were examined using data across all sections and periods for each habitat. Jaccard's Similarity Index (Jaccard 1901) was calculated for all pairwise combinations of habitats using only presence-absence of species. Similarities in fish communities between habitat types based on abundances of species were calculated using non-metric multidimensional scaling (NMDS) along with a Bray-Curtis dissimilarity measure (Walters et al. 2003; Cassati et al. 2006; Li et al. 2011). In addition, I used a one-way analysis of similarity (ANOSIM, 99 permutations) to determine if fish communities differed between habitat types ($\alpha = 0.10$; Li et al. 2011;

Pan et al. 2012). Both the NMDS and the ANOSIM were completed in program *R* using packages “vegan” and “MASS” (R Core Team, 2020 version 4.0.0).

Individual species associations with differences in water temperature and velocity were visualized using a canonical correspondence analysis (CCA; Rakocinski 1996; Legendre and Legendre 2012). These two variables were used in the CCA as previous research has shown that these characteristics may influence fish community structure in lotic systems (Marchetti and Moyle 2001; Gillette et al. 2006; Essaid and Caldwell 2017) and were expected to differ between the four habitat types included in my study. A Monte-Carlo Permutation test with 99 permutations was used to determine whether there was significance at $\alpha = 0.10$ (Legendre and Legendre 2012).

Results

Water quality did not differ between habitat types as was expected. Results from the ANOVA indicated that pH was the only water quality variable to differ between habitat types ($F = 13.07$, $p < 0.001$). However, the range observed in pH across all habitat types is considered tolerable for most freshwater fish species (Howells et al. 1983). Water temperatures were generally warmest in backwaters and coolest in back eddies (Table 3), but the differences between habitat types were not significant ($F = 0.24$; $p = 0.87$). Salinity also did not differ between habitat types ($F = 0.48$; $p = 0.70$). Total dissolved solids were generally higher in backwater habitats and lowest in side channel habitats (Table 3), but no differences between habitats were found ($F = 0.18$; $p = 0.91$). Although water quality was not notably different, discharge was different between habitat types (F

= 93.74, $p < 0.001$). Average discharge was highest in the main channel and lowest in back eddies and backwaters as these two habitats had no flows (Table 3).

Overall, I collected 6,068 fish (222 within back eddies; 4,278 within backwaters; 1,073 within the main channel; and 493 within side channels). The fish collected across all habitat types and sampling periods represented 29 species. Fish omitted from final analyses included unknown Cyprinidae, Catostomidae, Leuciscidae, and *Lepomis* species that were only identified down to genus. Fish that were unidentifiable down to species were most likely included in the overall species richness. Fifteen and 16 species were collected in side channel and main channel habitats, respectively and most species (n = 14) were shared between the two habitats (Table 4). Species richness was nearly 3 times greater in backwaters compared to back eddies (Table 4). One species of conservation interest in Nebraska [Plains Topminnow (*Fundulus sciadicus*)] was sampled only in backwaters, and two invasive species [Common Carp (*Cyprinus carpio*) and Western Mosquitofish (*Gambusia affinis*)] were found in all habitat types but were most prominent in backwaters (Table 4). Other species found in all habitat types included Channel Catfish (*Ictalurus punctatus*), Creek Chub (*Semotilus atromaculatus*), Plains Killifish (*Fundulus zebrinus*), Red Shiner (*Cyprinella lutrensis*), River Carpsucker (*Carpiodes carpio*), and White Sucker (*Catostomus commersonii*; Table 4). One adult White Bass (*Morone chrysops*) was sampled in a side channel (Table 4). Backwaters had a substantially higher Shannon's diversity score compared to the other habitat types in June and July (Table 5). However, in August, backwaters had the lowest diversity score compared to the other habitat types (Table 5). Diversity scores for side channel, back eddy, and main channel habitats generally increased over time (Table 5).

Species presence was most similar between main channel and side channel habitats and least similar between backwater and back eddy habitats (Table 4; Table 6). In contrast, different patterns were noted when quantifying fish community similarities based on abundance according to the ANOSIM and NMDS (ANOSIM $R = 0.23$, stress = 0.16, $p = 0.001$; Figure 3). Backwaters had the largest ordinal space, indicating that species relative abundance was most variable in this habitat (Figure 3). In contrast, ordinal spaces between back eddies, the main channel, and side channels were smaller and had the highest overlap (Figure 3), indicating fish communities were more similar between these three habitat types (Figure 3).

The Monte Carlo permutation test indicated a significant relationship between species relative abundance and discharge and water temperature ($p = 0.01$). Eigenvalues for axis 1 (water temperature) and axis 2 (discharge) were 0.35 and 0.09, respectively, and the proportion of variation explained was 0.80 and 0.20. Species present only in backwaters appeared to orient along axis 2 because of low to no discharge (Figure 4). Species associated with higher discharge along axis 2 included Gizzard Shad (*Dorosoma cepedianum*), Bigmouth Shiner (*Notropis dorsalis*), Longnose Dace (*Rhinichthys cataractae*), and Emerald Shiner (*Notropis atherinoides*; Figure 4). Species that oriented towards cooler water temperatures included Northern Pearl Dace (*Margariscus nachtriebi*), Green Sunfish (*Lepomis cyanellus*), Black Crappie (*Pomoxis nigromaculatus*), and Plains Topminnow (Figure 4). Species present in all habitat types (i.e., Creek Chub, River Carpsucker, Plains Killifish, Red Shiner, and Channel Catfish) oriented around the middle of the biplot, indicating little association with either water temperature or discharge (Figure 4).

Discussion

The lack of notable differences in water quality between habitat types in the North Platte River above Lake McConaughy was not an expected result, however, may be explained by groundwater influences. The dynamics of ground water and surface water are closely intertwined in the North Platte River as this system receives substantial groundwater inputs from the High Plains regional aquifer (Wen and Chen 2006). Such continuous inputs have been shown to moderate surface water chemistry (Hynes 1983; Power et al. 1999; Sophocleous 2010; Li et al. 2016; Essaid and Caldwell 2017; Hamid et al. 2020). However, results from the CCA indicate that both temperature and discharge did seem to influence fish assemblage composition. Other studies have demonstrated how these variables are important in habitat selection by riverine fish (Bell et al. 1991; Marchetti and Moyle 2001; Gillette et al. 2006; Essaid and Caldwell 2017). For example, *Lepomis* spp. are typically found in warmer habitat types with lower flows (Werner 1977; Moyle and Cech 2004). However, during my study, Green Sunfish did not follow this expected pattern. Rather, the species associated with habitats exhibiting cooler water temperatures they typically avoid as a warmwater species (Beitinger et al. 1975; Cherry et al. 1975). The interaction between water temperature and flow is important in structuring habitat conditions and fish assemblages (Tockner et al. 2000) and may also influence fish diversity (Chu et al. 2008).

My study indicated that over time diversity decreased in backwaters and increased in other habitat types. An explanation for the change in diversity could be that backwaters serve as spawning and nursery habitat for some species. Spring flooding of backwaters as a result of natural hydrocycles associated with large rivers provides access to spawning habitat for many fish species (Wigen and Miranda 2010). Backwaters also provide still, shallow, and food-rich refuges for developing larvae (Scheaffer et al. 1986; Humphries et al. 1999; Falke et al. 2010). However, once young fish are large enough, they may leave backwater habitats to find juvenile and adult habitat elsewhere (Scott and Nielson 1989; McDonald et al. 2014). For example, Brewer (2011) found that in Missouri streams, age-0 Smallmouth Bass (*Micropterus dolomieu*) selected for habitat with warmer temperatures but gradually shifted towards habitat with cooler temperatures for older age classes. Some taxa may leave backwaters sooner than others depending on size, swimming ability, and habitat preferences (Hoxmeier and Devries 1997; Lyon et al. 2010). Additionally, some species are cued to seek other habitats under low flow conditions (Bunn and Arthington 2002). Thus, diversity might also have decreased in backwaters over time as a result of habitat isolation and fragmentation resulting from lower summer flows (Lyon et al. 2010; Acre 2015; Fuller et al. 2015). In my study, changes in diversity were recorded over a short time period (e.g., a few months) within a single year. However, identifying how fish assemblages change in response to interannual flow differences could improve the understanding of how specific taxa use this mosaic of habitats.

A paucity of sampling has been conducted on the North Platte River above Lake McConaughy and in the North Platte River region, but substantial changes in assemblage structure have been observed from the oldest known survey (Johnson 1942) to my study. For example, Johnson (1942) found a total of 13 species in the North Platte River at sites in Garden and Keith County, Nebraska, before the construction of Kingsley Dam. Almost half a century later, Lynch and Roh (1996) found an average of 26 species above the reservoir. The presence of nonnative and sportfish species has also increased over time as species including Western Mosquitofish, Black Bullhead (*Ameiurus melas*), Emerald Shiner, White Bass, Walleye (*Sander vitreus*), Channel Catfish, Largemouth Bass (*Micropterus salmoides*), and Bluegill (*Lepomis macrochirus*) have been documented in my study and by Lynch and Roh (1996). Collectively, these results demonstrate the changes in fish assemblages in the North Platte River region over the course of 80 years and how impoundment may influence species richness and diversity. However, because both nonnative and sportfish species have been documented, native species may be impacted. For example, Franssen and Tobler (2013) found increases in species richness from pre- to post-impoundment over a 45-year time period, resulting from declines in native fish supplanted by increases in invasive species in a region upstream of an Oklahoma Reservoir. Overall, it is important to note how riverine habitat resulting from impoundment may influence species richness and diversity and fish assemblage composition of native, nonnative, and sportfish species. Fisheries managers should consider this trend for a resource area when prioritizing total biodiversity, sportfish promotion, or the integrity of the fish community.

Overall, this study of the North Platte River above Lake McConaughy provides information regarding changes in fish assemblages between habitat types over time. This information may be useful for fisheries managers to consider for other riverine systems above large reservoirs across the U.S. The changes in diversity over time between habitat types potentially indicate that certain habitats are more important for fish during specific times of the year. The availability of backwater habitats created by natural changes in flow, even if temporary, may be important for providing spawning and nursery areas for many native riverine fishes (Ruppert et al. 1993) and sportfish migrating from the reservoir (Hladík and Kubečka 2003). Over time, as flows decrease in the river and backwaters become fragmented, fish may find refuge in other habitat types, including the main channel. Management should strive to mimic natural flows to maintain habitat heterogeneity (Tockner et al. 2000), because when the hydrograph is anthropogenically altered (e.g., impoundment), the availability of habitats may consequently decline and negatively affect species richness and diversity (Ward and Stanford 1995; Poff et al. 1997). Ultimately, managers should improve understanding on the variety of habitats that are more important to the development of different species within each river system. Opportunities to promote overall biodiversity, specific sportfish population, or native species are easier to achieve when the temporal associations within the complexity of habitats available are better understood.

Literature Cited

Aadland, L. 1993. Stream habitat types: Their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13:790–806.

Acre, M. 2015. Can a river-reservoir interface serve as nursery habitat for riverine fishes? M.S. Thesis. Texas Tech University. Lubbock, Texas.

Ahearn, D. S., R. W. Sheibley, R. A. Dahlgren, and K. E. Keller. 2004. Temporal dynamics of stream water chemistry in the last free-flowing river draining the western Sierra Nevada, California. Journal of Hydrology 295:47–63.

Anderson, K. E., A. J. Paul, E. McCauley, L. J. Jackson, J. R. Post, and R. M. Nisbet. 2006. Instream flow needs in streams and rivers: The importance of understanding ecological dynamics. Frontiers in Ecology and the Environment 4:309–318.

Armantrout, N. B. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society 13:790–806.

Baxter, R. M. 1977. Environmental effects of dams and impoundments. Annual Review of Ecology and Systematics 8:255–283.

Beitinger, T. L., J. J. Magnuson, W. H. Neill, and W. R. Shaffer. 1975. Behavioural thermoregulation and activity patterns in the Green Sunfish, *Lepomis cyanellus.* Animal Behaviour 23:222–229.

Bell, S. S., E. D. McCoy, and H. R. Mushinsky. 1991. Habitat structure: The physical arrangement of objects in space. Chapman and Hall, Dordrecht.

Bower, L., F. Keppeler, E. Cunha, Y. Quintana, D. Saenz, E. Lopez-Delgado, T. Bokhutlo, C. Arantes, M. Andrade, C. Rovertson, K. Mayes, and K. Winemiller. 2019. Effects of hydrology on fish diversity and assemblage structure in a Texan coastal plains river. Transactions of the American Fisheries Society 148:207–218.

Brauer, C. J., and L. B. Beheregaray. 2020. Recent and rapid anthropogenic habitat fragmentation increases extinction risk for freshwater biodiversity. Evolutionary Applications 13:2857–2869.

Brenden, T. O., B. R. Murphy, and E. M. Hallerman. 2006. Effect of discharge on daytime habitat use and selection by Muskellunge in the New River, Virginia. Transactions of the American Fisheries Society 135:1546–1558.

Brennan, S. R., D. E. Schindler, T. J. Cline, T. E. Walsworth, G. Buck, and D. P. Fernandez. 2019. Shifting habitat mosaics and fish production across river basins. Science 364:783–786.

Brewer, S. K. 2011. Groundwater influences on the distribution and abundance of riverine Smallmouth Bass, *Micropterus dolomieu*, in pasture landscapes of the midwestern USA. River Research and Applications 29:269–278.

Brown, L. R, and T. Ford. 2002. Effects of flow on the fish communities of a regulated California river: Implications for managing native fishes. River Research Applications 18:331–342.

Buckmeier, D. L., N. G. Smith, B. P. Fleming, and K. A. Bodine. 2014. Intra-annual variation in river-reservoir interface fish assemblages: Implications for fish conservation and management of regulated rivers. River Research and Applications 30:780–790.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492–507.

Central Nebraska Public Power District (CNPPID). 2017. Recreational resources within the central Nebraska public power and irrigation district. Available: https://www.cnppid.com/recreation/recreational-resources/ (August 2017).

Chu, C., N. E. Jones, N. E. Mandrak, A. R. Piggott, and C. K. Minns. 2008. The influence of air temperature, groundwater discharge, and climate change on the thermal diversity of stream fishes in southern Ontario watersheds. Canadian Journal of Fisheries and Aquatic Sciences 65:297–308.

Cherry, D. S., K. L. Dickinson, and J. Cairns Jr. 1975. Temperatures selected and avoided by fish at various acclimation temperatures. Journal of the Fisheries Board of Canada 32:485–495.

Cooper, A. R., D. M. Infante, K. E. Wehrly, L. Wang, and T. O. Brenden. 2016. Identifying indicatory and quantifying large-scale effects of dams on fishes. Ecological Indicators 61:646–657.

Essaid, H. I., and R. R. Caldwell. 2017. Evaluating the impact of irrigation on surface water–groundwater interaction and stream temperature in an agricultural watershed. Science of the Total Environment 599:581–596.

Falke, J. A., K. D. Fausch, K. R. Bestgen, and L. L. Bailey. 2010. Spawning phenology and habitat use in a Great Plains, USA, stream fish assemblage: An occupancy estimation approach. Canadian Journal of Fisheries and Aquatic Sciences 67:1942–1956.

Franssen, N. R., and M. Tobler. 2013. Upstream effects of a reservoir on fish assemblages 45 years following impoundment. Journal of Fish Biology 82:1659–1670.

Fuller, M. R., M. W. Doyle, and D. L. Strayer. 2015. Causes and consequences of habitat fragmentation in river networks. The Year in Ecology and Conservation Biology 1355:31–51.

Gillette, D. P., J. S. Tiemann, D. R. Edds, and M. L. Wildhaber. 2006. Habitat use by a Midwestern U.S.A. riverine fish assemblage: Effects of season, water temperature and river discharge. Journal of Fish Biology 68:1494–1512.

Goldstein, R. M. 1978. Quantitative comparison of seining and underwater observation for stream fishery surveys. The Progressive Fish-Culturist 40:108–111.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507–515.

Gratwicke, B., and M. R. Speight. 2005. The relationship between fish species richness, abundance, and habitat complexity in a range of shallow tropical marine habitats. Journal of Fish Biology 66:650–667.

Gray, D., M. R. Scarsbrook, and J. S. Harding. 2006. Spatial biodiversity patterns in a large New Zealand braided river. New Zealand Journal of Marine and Freshwater Research 40:631–642.

Grenouillet, G., D. Pont, and K. L. Seip. 2002. Abundance and species richness as a function of food resources and vegetation structure: Juvenile fish assemblages in rivers. Ecography 25:641–650.

Hamid, A., S. U. Bhat, and A. Jehangir. 2020. Local determinants influencing stream water quality. Applied Water Science 10:1–16.

Harman, C., and M. Stewardson. 2005. Optimizing dam release rules to meet environmental flow targets. River Research and Applications 21:113–129.

Hladík, M., and J. Kubečka. 2003. Fish migration between a temperate reservoir and its main tributary. Hydrobiologia 504:251–266.

Hoxmeier, R. H. J., and D. R. Devries. 1997. Habitat use, diet, and population structure of adult and juvenile Paddlefish in the lower Alabama River. Transactions of the American Fisheries Society 126:288–301.

Howells, G. D., D. J. A. Brown, and K. Sadler. 1983. Effects of acidity, calcium and aluminum on fish survival and productivity: A review. Journal of the Science of Food and Agriculture 34:559–570.

Hughes, R. M., J. N. Rinne, and B. Calamusso. 2005. Historical changes in large river fish assemblages of the Americas: A synthesis. American Fisheries Society Symposium 45:603–612.

Humphries, P., A. J. King, and J. D. Koehn. 1999. Fish, flows and flood plains: Links between freshwater fishes and their environment in the Murray-Darling River system, Australia. Environmental Biology of Fishes 56:129–151.

Hynes, H. B. N. 1983. Groundwater and stream ecology. Hydrobiologia 100:93–99.

Jaccard, P. 1901. Distribution of the Alpine flora in the Dranse's Basin and some neighbouring regions. Bulletin de la Societe vaudoise des Sciences Naturelles 37:241–272.

Jacobson, R. 2013. 12.2 Riverine habitat dynamics. Treatise on Geomorphology 12:6–19.

Johnson, R. E. 1942. The distribution of Nebraska fishes. Ph.D. Dissertations. University of Michigan, Ann Arbor.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Canadian Journal of Fisheries and Aquatic Sciences 106:110–127.

Kondolf, G., Y. Gao, G. Annandale, G. Morris, E. Jiang, J. Zhang, Y Cao, P. Carling, K. Fu, Q. Guo, R. Hotchkiss, C. Peteuil, T. Sumi, H. Wang, Z. Wang, B. Wu, and C. Yang. 2014. Sustainable sediment management in reservoirs and regulated rivers: Experience from five continents. Earth's Future 2:256–280.

Legendre, P., and L. Legendre. 2012. Canonical analysis. Numerical Ecology 3rd edition 575–633. Amsterdam: Elsevier.

Li, J., L. Huang, Y. Kano, and T. Yahara. 2011. Spatial and temporal variation of fish assemblages and their associations to habitat variables in the mountain stream of north Tiaoxi River, China. Environmental Biology of Fishes 93:403–417.

Li, R., M. Pun, J. Bradley, G. Ou, J. Schneider, B. Flyr, J. Winter, and S. Chinta. 2016. Evaluating hydrologically connected surface water and groundwater using a groundwater model. Journal of the American Water Resources Association 52:799–805.

Lins, H. F. and J. R. Slack. 2005. Seasonal and regional characteristics of U.S. streamflow trends in the United States from 1940-1999. Physical Geography 26:489–501.

Lynch, J. D. and B. R. Roh. 1996. An ichthyological survey of the forks of the Platte River in western Nebraska. Transactions of the Nebraska Academy of Sciences 23:65–84.

Lyon, J., I. Stuart, D. Ramsey, and J. O'Mahony. 2010. The effect of water level on lateral movements of fish between river and off-channel habitats and implications for management. Marine and Freshwater Research 61:271–278.

Marchetti, M. P., and P. B. Moyle. 2001. Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications 11:530–539.

Maret, T. R. and D. E. MacCoy. 2002. Fish assemblages and environmental variables associated with hard-rock mining in the Coeur d'Alene River Basin, Idaho. Transactions of the American Fisheries Society 131:865–884.

McDonald, E. A., A. S. McNaught, and E. F. Roseman. 2014. Use of main channel and two backwater habitats by larval fishes in the Detroit River. Journal of Great Lakes Research 40:69–80.

Miranda, L. E. 2005. Fish assemblages in oxbow lakes relative to connectivity with the Mississippi River. Transactions of the American Fisheries Society 134:1480–1489.

Moyle, P. B., and J. J. Cech, Jr. 2004. Fishes: An introduction to Ichthyology. New York. Pearson Benjamin Cummings.

Page, L. M., M. Pyron, and K. S. Cummings. 1997. Impacts of fragmentation on midwestern aquatic organisms. Pages 189–212 *in* M. W. Schwartz, editor. Conservation in Highly Fragmented Landscapes. Springer, Boston.

Pan, Y., R. M. Hughes, A. T. Herlihy, and P. R. Kaufmann. 2012. Non-wadeable river bioassessment: Spatial variation of benthic diatom assemblages in Pacific Northwest rivers, USA. Hydrobiologia 684:241–260.

Parker, J., J. Epifanio, A. Casper, and Y. Cao. 2016. The effects of improved water quality on fish assemblages in a heavily modified large river system. River Research and Applications 32:992–1007.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47:769–784.

Power, G., R. S. Brown, and J. G. Imhof. 1999. Groundwater and fish: Insights from northern North America. Hydrological Processes 13:401–422.

Pringle, C. M. 1997. Exploring how disturbance is transmitted upstream: Going against the flow. Journal of the North American Benthological Society 16:425–438.

Rakocinski, C. F., J. Lyczkowski-Schultz, and S. L. Richardson. 1996. Ichthyoplankton assemblage structure in Mississippi sound as revealed by canonical correspondence analysis. Estuarine, Coastal and Shelf Science 43:237–257.

Robins, C. R., and R. W. Crawford. 1954. A short accurate method for estimating the volume of stream flow. Journal of Wildlife Management 18:366–369.

Robinson, C. T., K. Tockner, and J. V. Ward. 2002. The fauna of dynamic riverine landscapes. Freshwater Biology 47:661–677.

Robinson, C. T. and U. Uehlinger. 2008. Experimental floods cause ecosystem regime shift in a regulated river. Ecological Applications 18:511–526.

Ruppert, J. B., R. T. Muth, and T. P. Nesler. 1993. Predation on fish larvae by adult Red Shiner, Yampa and Green Rivers, Colorado. The Southwestern Naturalist 38:397–399.

Saalfeld, D. T., E. M. Reutebuch, R. J. Dickey, W. C. Seesock, C. Webber, and D. R. Bayne. 2012. Effects of landscape characteristics on water quality and fish assemblages in the Tallapoosa River Basin, Alabama. Southeastern Naturalist 11:239–252.

Santos, A. B. I., B. F. Terra, and F. G. Araújo. 2010. Influence of the river flow on the structure of fish assemblage along the longitudinal gradient from river to reservoir. Zoologia 27: 732–740.

Scheaffer, W. A., and J. G. Nickum. 1986. Backwater areas as nursery habitats for fishes in Pool 13 of the upper Mississippi River. Hydrobiologia 136:131–139.

Scheidegger, K., and M. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia 1995:125–135.

Scott, M., and L. Nielson. 1989. Young fish distribution in backwaters and main-channel borders of the Kanawha River, West Virginia. Journal of Fish Biology 35:21–27.

Shannon, C. E. 1948. A mathematical theory of communication. The Bell System Technical Journal 27:379–423.

Shields, Jr., F., A. Simon, and L. Steffen. 2000. Reservoir effects on downstream river channel migration. Environmental Conservation 27:54–66.

Słowik, M., K. Kiss, S. Czigány, A. Gradwohl-Valkay, J. Dezső, Á. Halmai, A. Marciniak, R. Tritt, and E. Pirkhoffer. 2021. The influence of changes in flow regime caused by dam closure on channel planform evolution: Insights from flume experiments. Environmental Earth Sciences 80:165.

Smith, C. D., M. C. Quist, and R. S. Hardy. 2016. Fish assemblage structure and habitat associations in a large western river system. River Research and Applications 32:622–638.

Sophocleous, M. 2010. Review: Groundwater management practices, challenges, and innovations in the high plains aquifer, USA - lessons and recommended actions. Hydrogeology Journal 18:559–575.

Soukup, T. L., O. A. Aziz, G. A. Tootle, T. C. Piechota, and S. S. Wulff. 2009. Long lead-time streamflow forecasting of the North Platte River incorporating oceanic–atmospheric climate variability. Journal of Hydrology 368:131–142.

Stoffers, T., A. D. Buijse, G. W. Geerling, L. H. Jans, M. M. Schoor, J. J. Poos, J. A. J. Verreth, and L. A. J. Nagelkerke. 2022. Freshwater fish biodiversity restoration in floodplain rivers requires connectivity and habitat heterogeneity at multiple spatial scales. Science of the Total Environment 838:156509.

Sutela, T., T. Vehanen, and P. Jounela. 2010. Response of fish assemblages to water quality in boreal rivers. Hydrobiologia 641:1–10.

Thorp, J. H., M. C. Thims, and M. D. Delong. 2006. The riverine ecosystem synthesis: Biocomplexity in river networks across space and time. River Research and Applications 22:123–147.

Tockner, K., F. Malard, J. V. Ward. 2000. An extension of the flood pulse concept. Hydrological Processes 14:2861–2883.

Tockner, K., A. Apetzold, U. Karaus, C. Claret, and J. Zettel. 2006. Ecology of braided rivers. Braided Rivers, Process, Deposits, Ecology, and Management 339–359.

Walters, D. M., D. S. Leigh, M. C. Freeman, B. J. Freeman, and C. M. Pringle. 2003. Geomorphology and fish assemblages in a Piedmont river basin, U.S.A. Freshwater Biology 48:1950–1970.

Ward, J. V., and J. A. Stanford. 1995. The serial discontinuity concept: Extending the model to the floodplain rivers. River Research and Applications 10:159–168.

Ward, J. V., K. Tockner, D. B. Arscott, and C. Claret. 2002. Riverine landscape diversity. Freshwater Biology 47:517–539.

Wen, F., and X. Chen. 2006. Evaluation of the impact of groundwater irrigation on streamflow in Nebraska. Journal of Hydrology 327:603–617.

Werner, E. E. 1977. Competition and habitat shift in two sunfishes (Centrarchidae). Ecology 58:869–876.

Wigen, S. L., and L. E. Miranda. 2010. Importance of backwater habitats to fish assemblages in northwest Mississippi flood control reservoirs. Journal of the Southeastern Associations of Fish and Wildlife Agencies 64:198.

Williams, C. B. 1943. Area and the number of species. Nature 152:264–267.

Wuellner, M. R., R. G. Bramblett, C. S. Guy, A. V. Zale, D. R. Roberts, and J. Johnson. 2013. Reach and catchment-scale characteristics are relatively uninfluential in explaining the occurrence of stream fish species. Journal of Fish Biology 82:1497–1513.

Yang, S., J. Milliman, K. Xu, B. Deng, X. Zhang, and X. Luo. 2014. Downstream sedimentary and geomorphic impacts of the Three Gorges Dam on the Yangtze River. Earth-Science Reviews 138:469–486.

Zeiringer, B., C. Seliger, F. Greimel, and S. Schmutz. 2018. River hydrology, flow alterations, and environmental flow. Riverine Ecosystem Management 8:67–89.

Tables and Figures

Table 1. Habitats identified and sampled within the North Platte River (Nebraska) reach selected for this study. Definitions of habitats follow those of Armantrout (1998).

Habitat Type	Definition
Back eddy	A pool formed and maintained by strong eddy current
Backwater	Pool formed by water backing upstream from an obstruction; abandoned channel that remains connected to the main channel
Main channel	Primary watercourse containing the major streamflow
Side channel	Extension off main channel that can become a backwater under low flow conditions

Table 2. Number of habitats sampled for each sampling period in the North Platte River from Oshkosh, Nebraska, to Lake McConaughy from June to August 2020.

		Habitat			
Sampling period	Dates	Back eddy	Backwater	Main channel	Side channel
1	6/1 – 6/7	1	14	8	3
2	6/15 – 6/24	1	5	6	5
3	7/6 – 7/16	1	4	6	5
4	7/21 – 7/28	1	4	6	5
5	8/4 – 8/10	1	4	6	5
6	8/18 – 8/28	0	4	6	5
Totals		5	35	39	28

Table 3. Mean water quality measurements for each habitat sampled in the North Platte River between Oshkosh, Nebraska and Lake McConaughy, Nebraska. Means were calculated across all periods sampled during June – August 2020. Numbers in parentheses represent one standard error.

	Water quality				
Habitat	Water temperature (˚C)	Salinity (ppt)	Total dissolved solids (mg/l)	pH	Discharge (m^3/s)
Back eddy	24.3 (1.5)	0.4 (0.0)	634.6 (9.8)	8.3 (0.1)	0.0 (NA)
Backwater	25.3 (0.6)	0.4 (0.0)	636.5 (12.4)	8.0 (0.1)	0.0 (NA)
Main channel	24.6 (0.3)	0.4 (0.0)	629.4 (14.3)	8.3 (0.0)	10.1 (0.8)
Side channel	25.1 (0.5)	0.4 (0.0)	626.6 (10.7)	8.3 (0.0)	1.1 (0.2)

Table 4. Fish species presence (denoted by an “x”) across habitats (back eddy, backwater, main channel, side channel) in the North Platte River from Oshkosh, Nebraska to Lake McConaughy, June-August 2020. Code denotes those used in Figures 3 and 4.

			Habitat			
Common name	Scientific name	Code	Back eddy	Backwater	Main channel	Side channel
Bigmouth Shiner	*Notropis dorsalis*	BMS		x	x	x
Black Bullhead	*Ameiurus melas*	BBH		x		
Black Crappie	*Pomoxis nigromaculatus*	BLC		x		
Bluegill	*Lepomis macrochirus*	BLG		x		
Brook Stickleback	*Culaea inconstans*	BRS		x		
Central Stoneroller	*Campostoma anomalum*	CSR		x		
Channel Catfish	*Ictalurus punctatus*	CCF	x	x	x	x
Common Carp	*Cyprinus carpio*	COC	x	x	x	x
Creek Chub	*Semotilus atromaculatus*	CCH	x	x	x	x
Emerald Shiner	*Notropis atherinoides*	EMS			x	x
Fathead Minnow	*Pimephales promelas*	FHM		x	x	
Gizzard Shad	*Dorosoma cepedianum*	GZD		x	x	x
Green Sunfish	*Lepomis cyanellus*	GSF		x		
Iowa Darter	*Etheostoma exile*	IDR		x		
Largemouth Bass	*Micropterus salmoides*	LMB		x		
Longnose Dace	*Rhinichthys cataractae*	LND			x	
Northern Pearl Dace	*Margariscus nachtriebi*	NPD		x		
Orangespotted Sunfish	*Lepomis humilis*	OSS		x		
Plains Killifish	*Fundulus zebrinus*	PFK	x	x	x	x
Plains Topminnow	*Fundulus sciadicus*	PTM		x		
Red Shiner	*Cyprinella lutrensis*	RES	x	x	x	x
River Carpsucker	*Carpiodes carpio*	RCS	x	x	x	x
River Shiner	*Gambusia affinis*	RIS		x	x	x
Sand Shiner	*Notropis stramineus*	SSH		x	x	x
Stonecat	*Noturus flavus*	STC	x		x	x
Western Mosquitofish	*Gambusia affinis*	WMF	x	x	x	x
White Bass	*Morone chrysops*	WHB				x
White Crappie	*Pomoxis annularis*	WHC		x		
White Sucker	*Catostomus commersonii*	WHS	x	x	x	x

Table 5. Mean Shannon diversity scores (H') by month (June – August 2020) in each of the four habitats sampled in the North Platte River from Oshkosh, Nebraska, to Lake McConaughy. Diversity scores were calculated for each location sampled and then averaged for each habitat by month. Numbers in parentheses represent one standard error.

	Habitat			
Month	Back eddy	Backwater	Main channel	Side channel
June	0.00 (NA)	1.65 (0.00)	0.31 (0.00)	0.52 (0.00)
July	1.31 (0.01)	1.78 (0.00)	1.17 (0.01)	0.67 (0.00)
August	1.39 (0.02)	0.33 (0.00)	1.42 (0.01)	1.28 (0.01)

Table 6. Jaccard's scores (*J*) between the four habitats (back eddy, backwater, main channel, and side channel) in the North Platte River from Oshkosh, Nebraska, to Lake McConaughy. Species presence data was combined for all sampling dates.

Habitat comparison	*J*
Back eddy-Backwater	26.92
Back eddy-Main channel	50.00
Back eddy-Side channel	53.33
Backwater-Main channel	46.43
Backwater-Side channel	46.15
Main channel-Side channel	82.35

Figure 1. Map of the North Platte River from Oshkosh, NE to Lake McConaughy and the six designated sampling sections, alternating between braided and non-braided river segments (Photo Credit: Google Earth Pro 2022). The orange lines indicate beginning and end points of sampling sections.

Figure 2. An example of habitat locations within a designated sampling section (Section 1) of the North Platte River from Oshkosh, Nebraska to Lake McConaughy (Photo Credit: Google Earth Pro 2022). The orange lines indicate the beginning and end of Section 1. Green points indicate three habitat locations (backwater, main channel, and side channel) sampled within this section.

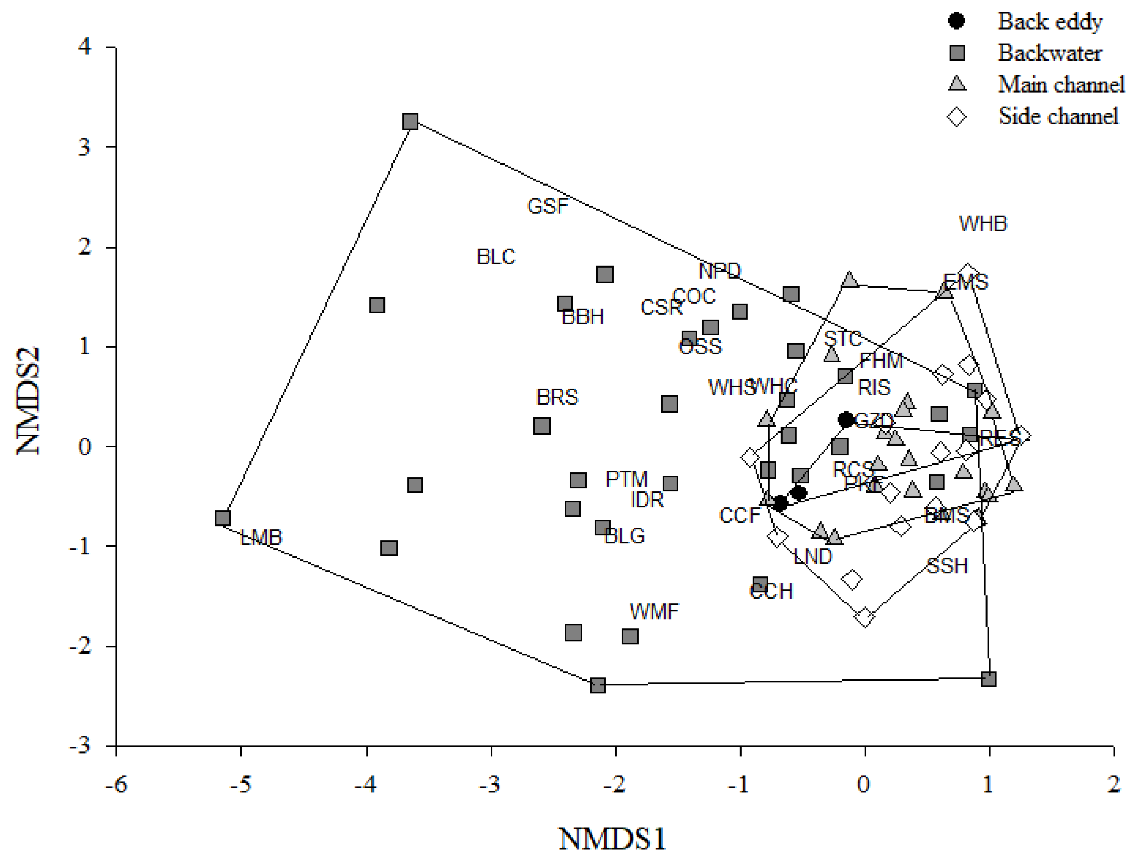

Figure 3. Plot of non-metric multidimensional scaling (NMDS) of fish species within the four habitats of the North Platte River between Oshkosh, Nebraska and Lake McConaughy during June-August 2020. Polygons represent convex hulls around each habitat in ordinal space. Acronyms of species denoted in Table 1.

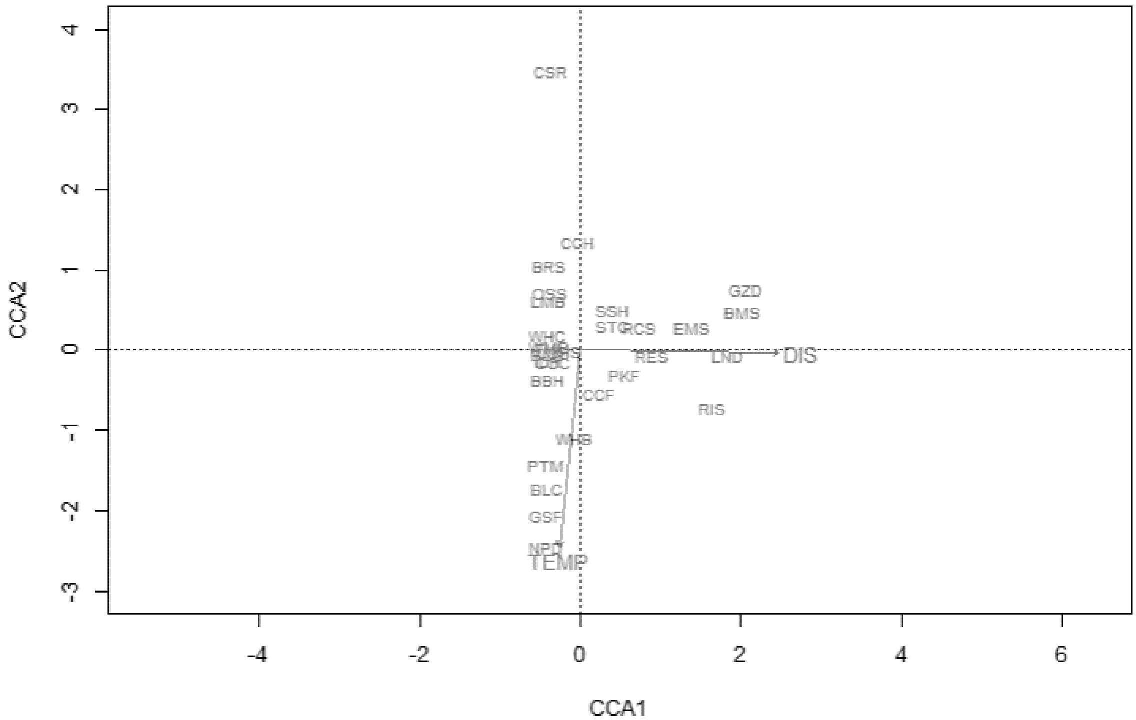

Figure 4. Plot of canonical correspondence analysis (CCA) relating to fish species distribution and discharge (DIS) and water temperature (TEMP) in the North Platte River from Oshkosh, Nebraska, to Lake McConaughy from June – August 2020. Acronyms of species denoted in Table 1.

CHAPTER 2:

SAMPLING YOUNG FISH IN UPPER LAKE MCCONAUGHY DURING EARLY AND LATE SUMMER WITH FOUR GEARS

Thyme Taulaki

Department of Biology, University of Nebraska at Kearney

2401 11th Ave, Kearney, NE 68849, USA

Introduction

The river-reservoir interface (RRI) is an ecotone that encompasses a gradual transition from lotic to lentic conditions (Kimmel et al. 1990). The RRI is not a definitive point but rather shifts as river hydrology and reservoir operation varies within and between years (Buckmeier et al. 2014; Guedes et al. 2020). The lower end of the RRI is the upper reservoir, an area that reflects more lentic conditions and where flow is usually undetectable or nearly so. This section of the RRI provides unique physical and chemical features compared to the river above (Kimmel et al. 1990) which, in turn, influences the fish found therein (Kimmel and Groeger 1984).

The upper reservoir can be more productive than the river (Acre 2015). As the water from the river enters the reservoir, water velocity slows and the sediment that was suspended and transported in the water column is deposited (Gore 1977; Schleiss et al. 2016). Such changes may lead to higher concentrations of total suspended solids, nitrates, and phosphates (Kennedy and Walker 1990). Nogueira et al. (2002) found that the upper part of the Jurumirim Reservoir, Brazil, was the most nutrient rich area of the reservoir due to the nutrients entering from the main tributary river and settling in the upper reservoir. Allochthonous inputs in the upper reservoir have been found to contribute to higher abundance and biomass of young-of-the-year fish (González et al. 2010) and overall higher species richness and diversity (Gido et al. 2002; Britto and Carvalho 2006; Santos et al 2010).

In addition to nutrient enrichment, sediment dynamics may also contribute to the creation of physical fish habitat, including those necessary for spawning, rearing, feeding, and cover (Williams 1991; Slipke and Maceina 2005; Patton and Lyday 2008; Hladík et al. 2008; Graeb et al. 2009; Buckmeier et al. 2014) that are often lost from rivers when reservoirs are created (Buckmeier et al. 2014). Kaemingk et al. (2007) found that a sediment delta in the Missouri River provided nursery and refuge habitat for some juvenile and small-bodied fishes. Richardson et al. (2021) found that young age classes are likely to use sediment deltas as refuge from predators and adverse conditions. Overall, fish species richness and diversity are supported by sediment dynamics when a reservoir is created (Carvalho et al. 1998; Oliveira et al. 2004; Kaemingk et al. 2007).

While sedimentation may be important to supporting RRI fish communities in some ways, it may be a hindrance to accessing and sampling fish within this zone, particularly during warmer, drier months when reservoir water levels recede. The choice of gears used in standardized sampling depends on habitat and the fish themselves. Factors such as water depth and the presence of submergent and emergent vegetation may make some habitat inaccessible and limit the efficiency of many gears such as seines, boat-mounted electrofishing, gill nets, and trawling (Winfield 2004; Patton and Lyday 2008). In addition, body size, behavior, and swimming capabilities of each fish species and life stage are important considerations when selecting a gear (Boyer et al. 2017). Previous studies of adult fish communities in the RRI have used multiple gears. Buckmeier et al. (2014) and Smith et al. (2023) used seines, gill nets, and boat electrofishing. In addition, Smith et al. (2023) used experimental gill nets, mini-fyke nets, and minnow traps and collected more species overall than Buckmeier et al. (2014). To sample larval fish in a Texas reservoir, Acre (2015) used both a modified push net and quatrefoil light traps and found that species richness and abundance as indexed from push nets was lower than light traps, likely due to the lack of areas available for push-net sampling. However, light traps may be selective for species that are positively phototaxic (Floyd et al. 1984). Overall, the choice of using a single gear or multiple gears may influence fish community assessments.

To my knowledge, only a few studies have focused on the identification of appropriate gears for targeting young fish in RRIs, particularly in the upper reservoir (Acre 2015; Carvalho et al. 1998; Kaemingk et al. 2017; Gilbert and Pease 2019). Indexing larval and juvenile fish abundance in the upper reservoir can aid in understanding habitat use by different species, taxa, or guilds (Gilbert and Pease 2019) and be used to quantify year-class strength (Stige et al. 2013). Thus, the objective of my study was to compare larval and juvenile fish communities collected with different gears in the upper part of Lake McConaughy, Nebraska.

Methods

Lake McConaughy was created when the Central Nebraska Public Power and Irrigation District impounded the North Platte River via the construction of Kingsley Dam in 1941. The reservoir is located approximately 8 km north of Ogallala, Nebraska, in Keith County and provides irrigation for over 45,000 ha of agricultural land and hydroelectric power across the entire state. Lake McConaughy is the largest reservoir in Nebraska and is approximately 35.2 km long and 6.4 km wide, with a surface area of 14,164 ha at conservation pool. The reservoir has become a popular fishery in the state, and the species of highest management priority are Walleye (*Sander vitreus*) and White Bass (*Morone chrysops*; McCarraher et al. 1971).

A total of six sampling events were conducted semiweekly in 2021 within upper Lake McConaughy. The initial sampling event was on the fourth week of May and sampling concluded in August. The vulnerability of larval and juvenile fish to different sampling gears changes as they grow (Beamesderfer and Rieman 1988). Consequently, two sampling periods (categorized as “early” or “late”) were established for this project. The early period was between May 13 and June 29 (n = 4 samples) and the late period was between July 14 and August 5 (n = 2 samples). The two gears used to collect fish in the early period included a plankton tow net and quadrafoil larval light traps, and the two gears used in the late period included boat-mounted electrofishing and a seine. The upper reservoir was divided longitudinally into 15 equidistant (200 m long) zones along the north and south shorelines (Figure 1). Six zones were randomly selected on both the north and south shoreline during each period. A plankton tow net (1 x 3 m circular frame; 1000-µm bar mesh; 3 m long) was towed at one location in each of the 6 zones in a circular motion behind a boat perpendicular to the shoreline for 5 min at a speed of ≤ 0.67 m/s, targeting a minimum water depth of 2 m once. A flow meter (General Oceanics model R2030) was mounted in the mouth of the tow net to quantify the volume of water filtered. A Watermark® Quadrafoil larval light trap (Forestry Suppliers, Jackson, MS) with chemical light sticks was set in each zone in approximately 1 m of depth 1 hr prior to sunset and retrieved the following morning. Soak time was recorded from set to pull in order to ensure that sampling efforts were relatively equal. A Smith-Root electrofishing boat (7.5 generator-powered pulsator control box; 5–8 A pulsed DC at 100–200 V) was run along a transect parallel to the shoreline in each zone for 5 min, starting 1 hr before sunset and ending before sunrise. Additionally, three quarter-arc seine hauls (7.62 x 1.22 m; 0.32-cm bar mesh) were conducted from morning to mid-day within each zone. Locations were adjusted so suitable seine hauls could be made without major obstructions and were moved each sampling period within the zone.

Collected fish were identified to the lowest possible taxonomic level, and the first 20 individuals of each identified taxa were measured for total length (TL; mm). Fish not identified in the field were vouchered and preserved in ethanol and identified and measured later in the laboratory. Identification of larval and juvenile fish was determined using Auer (1982) and Hrabik et al. (2015). Relative abundance was indexed either as density (tow net = number of individuals/L) or catch per unit effort (light traps = number of individuals/trap set; electrofishing = number of individuals/transect; and seines = number of individuals/total number of seine hauls). Several metrics were used to compare fish communities between the four gears and between early and late periods. Species richness, Shannon-Weiner diversity (*H'*; Shannon 1948), and the coefficient of variation (CV) of the abundance index (catch per unit effort or density) were calculated for each gear by combining data for all zones across all sampling periods.

To visualize whether fish communities were similar or different between the early and late periods, I used a non-metric multidimensional scaling (NMDS) ordination using Bray-Curtis distance metrics (Kruskal and Wish 1978; Gido et al. 2009). The NMDS was only performed for species that occurred in > 5% of samples for both periods to reduce the influence of rare species on the final ordination (Legendre and Gallagher 2001; Poos and Jackson 2012). All abundance data were combined between the two gears used within each period (Perkin and Bonner 2014; Senecal et al. 2015). A one-way analysis of similarity (ANOSIM; 999 permutations) was used to determine if overlap of fish communities were significant ($\alpha = 0.10$; Liu et al. 2021). A stress value was calculated to determine the goodness-of-fit. Stress values of < 0.20 are considered reliable for analysis and indicate that species distribution in space is not similar (Kruskal and Wallis 1952). Plots and computations were produced using the Vegan and MASS packages in R version 4.0.0.

Results

Overall, I collected 2,319 fish (731 with tow nets, 260 with light traps, 51 with electrofishing, and 1,277 with seines) across all sampling sites and periods, representing 21 taxa. Gizzard Shad (*Dorosoma cepedianum*) was the only species sampled with all four gears (Table 1). Seven species were considered rare as their abundance was < 5% of samples for both periods. Additionally, 6 of the 7 rare species were collected in only one gear (Table 1). Black Bullhead (*Ameiurus melas*; n = 1), Channel Catfish (*Ictalurus punctatus*; n =1), Freshwater Drum (*Aplodinotus grunniens*; n = 1), Green Sunfish (*Lepomis cyanellus*; n = 1) and Smallmouth Bass (*Micropterus dolomieu s*; n = 1) were only collected with seines; and River Shiner (*Notropis blennius*; n = 1) were only collected with light traps. Largemouth Bass (*Micropterus salmoides*) were collected with both light traps (n = 1) and seines (n = 2). Species richness, Shannon-Weiner diversity, and relative abundance were highest for seines and lowest for tow nets (Table 2). The coefficient of variation was highest for plankton tow nets and lowest for boat-mounted electrofishing (Table 2).

The NMDS plot showed that fish communities overlapped somewhat between sampling periods (Figure 2), but the ANOSIM indicated that the communities between these two sampling periods were different (stress = 0.07; ANOSIM R = 0.40; $p = 0.001$). Seven species were only captured in the late period, and 7 species were captured with at least one gear during both periods (Table 1; Figure 2). Abundance of species captured during both periods may have differed, depending on the species, thus influencing the shape and overlap of the NMDS polygons. The axes on the NMDS plot indicated that Alewife (*Alosa pseudoharengus*) abundance was greater during the early period, whereas Walleye (*Sander vitreus*) and White Bass (*Morone chrysops*) were more abundant during the later period (Figure 2).

Discussion

Overall, I found the upper reservoir to have relatively high species richness. A total of 21 taxa were sampled, including many native, nonnative, and recreationally important species. My findings are consistent with the results of previous studies examining fish community composition in the RRI (Kaemingk et al. 2007; Acre 2015; Gilbert and Pease 2019). For example, Schreck (2010) found similar richness numbers in the Niobrara River delta and determined that both the Niobrara and White River deltas in South Dakota supported a diversity of small-bodied native, sportfish, and introduced species. Interestingly, many of the species I sampled in this study (n = 14) were similar to what I sampled in the North Platte River above Lake McConaughy the year before (see

Chapter 1 of this thesis). The remaining taxa were only found in the upper reservoir and included Alewife, Freshwater Drum, Quillback (*Carpiodes cyprinus*), Shorthead Redhorse (*Moxostoma macrolepidotum*), Smallmouth Bass, Walleye, and Hybrid Striped Bass (*Morone chrysops x M. saxatilis*). The combination of similar and different species sampled in the upper reservoir indicates upper Lake McConaughy may be an important spawning and rearing area for riverine- and reservoir-obligate species in the RRI. Additionally, connectivity between ecosystems and the ease at which fish, nutrients, organic matter, and other substances can move between them is important in structuring communities (Ward et al. 1999). The upper reservoir serves as a part an ecotone that connects river and reservoir ecosystems, where both lentic and lotic species may co-exist, using habitat temporally (Oliveira et al.2004). Thus, the upper reservoir may play an important role in fish diversity, community structure, and overall ecosystem integrity.

Substantial differences in species richness and diversity, abundance, and gear efficiency were observed between the four gears used in my study. To my knowledge, this is the first study that has used this complement of gears to sample fish communities in an upper reservoir, and the results of my study can be used to inform similar sampling in other systems. Seines appeared to capture the most species at the highest abundance and be one of the most efficient gears of the four selected. However, seines surprisingly failed to capture River Shiner (*Notropis blennius*), which are frequently captured in lotic systems with this gear (Neebling and Quist 2011). Seines also failed to capture Walleye but have been used to capture this species in other reservoir systems (Uphoff et al. 2013; DeBoer and Pope 2015), although electrofishing has been suggested as a preferred sampling gear elsewhere (Miller et al. 2018). Tow nets appeared to have the lowest sampling efficiency between all the gears, only capturing Alewife and Gizzard Shad. Some studies have demonstrated that tow nets can be effective at sampling young fish in both pelagic and littoral reservoir habitat (Sammons and Bettoli 1998; Claramunt et al. 2005). However, sediment berms, aquatic vegetation, downed trees, and lodged tree trunks found in the upper reservoir of Lake McConaughy and similar areas, can create obstructions when using tow nets, even in shallow waters (Conrow et al. 1990; Claramunt et al. 2005). Compared to tow nets, light traps are less limited by obstructions due to their passive nature (Zigler and Dewey 1995). However, the effectiveness of light traps depends on fish possessing positive phototaxic behaviors, which has been shown to differ between species (Mueller et al. 1993) and life stages (Bulkowski and Meade 1983). In addition, other aquatic organisms were captured by light traps during my study including a zooplankton species not documented before in Lake McConaughy (Keith Koupal, *personal communication*). Although there were inherent limitations of the gears used in my study, it is important to recognize that each gear will have associated costs and benefits. Further, depending on the given project objective or sampling protocol, certain gears may be more suitable under certain circumstances.

Community composition in the upper reservoir may have been influenced by the selection of gears used in the early and late periods. To accommodate for growth of fish over time, gears were changed mid-season and compared within and between periods. Results from the ANOSIM indicated a significant difference in communities between the early and late periods, though the NMDS indicated some similarities. Several reasons may explain this somewhat conflicting finding. The first reason is related to the difference in proportional abundance of those species captured in both time periods. For example, a high abundance of Alewife and a low abundance of River Carpsucker (*Carpiodes carpio*) sampled in the early period, appeared to influence the shape of the NMDS polygons. In addition, because Walleye comprised the majority of fish sampled with electrofishing, the shape of the NMDS polygons were also influenced. Second, the use of some gears may result in difficulties in species identification. Sampling early in the season targeted larval fish, which are difficult to identify to species (Kalous et al. 2010). Ko et al. (2013) found that identification accuracy at the family and species level was 80.1 and 13.5%, respectively, when testing larval fish identification among five laboratories. In addition, the impingement of larval fish in some gears (e.g., tow nets) and their preservation in media such as ethanol may result in body distortions that further complicate species identification (Puncher et al. 2015). Thus, species richness and diversity in the early period of my study may be underrepresented. Third, the exclusion of several species from the NMDS due to low abundances may have influenced final community analysis (Cao et al. 2001; Poos and Jackson 2012). Although it is common practice to remove rare species for NMDS analysis (Walters et al. 2003; Pyron and Lauer 2004; Poos and Jackson 2012), more overlap in the NMDS plot likely occurred between the periods as a result. Rare species may only be perceived as rare because of sampling methods (Arscott et al. 2006); thus, the removal of rare species may have underrepresented the overall assessment of the community.

The use of standardized gears over time is important to assess the structure and dynamics of fish communities in upper reservoirs. The best gear or gears will capture all or nearly all fish species present in proportion to their abundance in an efficient way. Considerations for selecting a gear include characteristics of the fish (e.g., life stage, body size, behaviors), the habitat, and the objectives of the assessment. Using multiple gears is common when assessing community composition (Weaver et al. 1993; Knight and Bain 1996; Shoup et al. 2003). Ideally, multiple gears should be used so that few to no species are missed in sampling efforts. However, time and financial resources may require that sampling be limited to one gear. Based on the results of this study, I recommend that seines be used to assess fish communities in upper reservoirs, at minimum. Light traps and boat-mounted electrofishing may be helpful to add if possible. Tow nets might be useful if the objective is to index the availability of prey species such as Gizzard Shad and Alewife (Madenjian and Jude 1985; Michaletz, et al. 1995) but provide very limited added information into assessment of the fish community. Overall, this study provides some guidance for fisheries managers to consider when sampling fish communities in upper reservoirs.

Literature Cited

Acre, M. 2015. Can a river-reservoir interface serve as nursery habitat for riverine fishes? M.S. Thesis. Texas Tech University. Lubbock, Texas.

Arscott, D. B., J. K. Jackson, and E. B. Kratzer. 2006. Role of rarity and taxonomic resolution in a regional and spatial analysis of stream macroinvertebrates. Journal of the North American Benthological Society 25:977–997.

Auer, N. A. 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Special Publication 82-3, Great Lakes Fishery Commission, Ann Arbor, Michigan.

Beamesderfer, R. C., and B. E. Rieman. 1988. Size selectivity and bias in estimates of population statistics of Smallmouth Bass, Walleye, and Northern Squawfish in a Columbia River reservoir. North American Journal of Fisheries Management 8:505–510.

Boyer, J. K., C. S. Guy, M. A. H. Webb, T. B. Hornton, and T. E. McCahon. 2017. Gear comparison for sampling age-0 Mountain Whitefish in the Madison River, Montana. North American Journal of Fisheries Management 37:189–195.

Britto, S. G. C., and E. D. Carvalho. 2006. Ecological attributes of fish fauna in the Taquaruçu Reservoir, Paranapanema River (upper Paraná, Brazil): Composition and spatial distribution. Acta Limnologica Brasiliensia 18:377–388.

Buckmeier, D. L., N. G. Smith, B. P. Fleming, and K. A. Bodine. 2014. Intra-annual variation in river-reservoir interface fish assemblages: Implications for fish conservation and management of regulated rivers. River Research and Applications 30:780–790.

Bulkowski, L., and J. W. Meade. 1983. Changes in phototaxis during early development of Walleye. Transactions of the American Fisheries Society 112:445–447.

Cao, Y., D. P. Larsen, and R. S. Thorne. 2001. Rare species in multivariate analysis for bioassessment: Some consideration. Journal of the North American Benthological Society 20:144–153.

Carvalho E. D., V. F. Batista da Silva, C. Y. Fujihara, R. Henry, and F. Foresti. 1998. Diversity of fish species in River Paranapanema–Jurumirim Reservoir transition region (São Paulo, Brazil). Italian Journal of Zoology 65:325–330.

Claramunt, R. M., D. E. Shoup, and D. H Wahl. 2005. Comparison of push nets and tow nets for sampling larval fish with implications for assessing littoral habitat utilization. North American Journal of Fisheries Management 25:86–92.

Conrow, R., A. V. Zale, and R. W. Gregory. 1990. Distributions and abundances of early life stages of fishes in a Florida lake dominated by aquatic macrophytes. Transactions of the American Fisheries Society 119:521–528.

DeBoer, J. A., and K. L. Pope. 2015. Factors influencing recruitment of Walleye and White Bass to three distinct early ontogenetic stages. Ecology of Freshwater Fish 25:504–517.

Floyd, K. B., R. D. Hoyt, and S. Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Transactions of the American Fisheries Society 113:217–223.

Gido, K. B., C. W. Hargrave, W. J. Matthews, G. D. Schnell, D. W. Pogue, and G. W. Sewell. 2002. Structure of littoral-zone fish communities in relation to habitat, physical, and chemical gradients in a southern reservoir. Environmental Biology of Fishes 63:253–263.

Gido, K. B., J. F. Schaefer, and J. A. Falke. 2009. Convergence of fish communities from the littoral zone of reservoirs. Freshwater Biology 54:1163–1177.

Gilbert, M. D., and A. A. Pease. 2019. Use of fragmented reservoir habitat by larval fish assemblages across years with contrasting hydrological conditions. Environmental Biology of Fishes 102:857–871.

González, M. J., L. B. Knoll, and M. J. Vanni. 2010. Differential effects of elevated nutrient and sediment inputs on survival, growth and biomass of a common larval fish species (*Dorosoma cepedianum*). Freshwater Biology 55:654–669.

Gore, J. A. 1977. Reservoir manipulations and benthic macroinvertebrates in a prairie river. Hydrobiologia 55:113–123.

Graeb, B. D., D. W. Willis, and B. D. Spindler. 2009. Shifts in Sauger spawning locations after 40 years of reservoir ageing: Influence of a novel delta ecosystem in the Missouri River, USA. River Research Applications 25:153–159.

Guedes, G. H. S., T. M. Mattos, G. S. Camilo, W. Uehara, D. L. P. Ferreira, and F. G. Araújo. 2020. Artificial flow regime promotes abiotic and biotic gradients: Testing the concept of longitudinal zonation in an off-river reservoir. Ecohydrology and Hydrobiology 20:256–264.

Hladík, M., J. Kubečka, T. Mrkvička, M. Čech, V. Draštík, J. Frouzová, E. Hohausová, J. Matěna, V. Matěnová, M. Kratochvíl, J. Peterka, M. Prchalová, and M. Vašek. 2008. Effects of the construction of a reservoir on the fish assemblage in an inflow river. Czech Journal of Animal Science 53:537–547.

Hrabik, R. A., S. C. Schainost, R. H. Stasiak, and E. J. Peters. 2015. The fishes of Nebraska. Conservation and Survey Division, School of Natural Resources, University of Nebraska-Lincoln. Lincoln, Nebraska, USA.

Kaemingk, M. A., B. D. S. Graeb, C. W. Hoagstrom, and D. W. Willis. 2007. Patterns of fish diversity in a mainstem Missouri River reservoir and associated delta in South Dakota and Nebraska, USA. River Research and Applications 23:786–791.

Kalous, L., V. Šlechtová, M. Petrtyl, and K. M. Čech. 2010. Do small fish mean no voucher? Using a flatbed desktop scanner to document larval and small specimens before destructive analyses. Journal of Applied Ichthyology 26:614–617.

Kennedy, R. H., and W. W. Walker. 1990. Reservoir Nutrient Dynamics. Pages 109–131 *in* K. W. Thornton, B. L. Kimmel, and F. E. Payne, editors. Reservoir limnology: Ecological perspectives. John Wiley and Sons, Inc., New York.

Kimmel, B. L., and A. W. Groeger. 1984. Factors controlling primary production in lakes and reservoirs: A perspective. Lake and Reservoir Management 1:277–281.

Kimmel, B. L., O. T. Lind, and L. J Paulson. 1990. Reservoir primary production. Pages 133–193 *in* K. W. Thornton, B. L. Kimmel, and F. E. Payne, editors. Reservoir limnology: Ecological perspectives. John Wiley and Sons, Inc., New York.

Knight, J. G., and M. B. Bain. 1996. Sampling fish assemblages in a forested floodplains wetland. Ecology of Freshwater Fish 5:76–85.

Ko, H. L., Y. T. Wang, T. S. Chiu, M. A. Lee, M. Y. Leu, K. Z. Chang, and W. Y. Chen. 2013. Evaluating the accuracy of morphological identification of larval fishes by applying DNA barcoding. PLoS ONE 8:e53451.

Kruskal, W. H., and W. A. Wallis. 1952. Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association 47:583–621.

Kruskal, J. B., and M. Wish. 1978. Multidimensional scaling. Sage Publications, Sage University Paper Series on Quantitative Application in the Social Sciences, 07–0111, Beverly Hills, California.

Legendre, P., and E. D. Gallagher. 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129:217–280.

Liu, F., F. Yu, Z. Xia, Q. Qin, C. Xu, J. Wang, and H. Liu. 2021. Changes in fish assemblages following the implementation of a complete fishery closure in the Chishui River. Fisheries Research 243:106099.

Madenjian, C. P., and D. J. Jude. 1985. Comparison of sleds versus plankton nets for sampling fish larvae and eggs. Hydrobiologia 124:275–281.

McCarraher, D. B., M. L. Madsen, and R. E. Thomas. 1971. Ecology and fishery management of McConaughy Reservoir, Nebraska. Pages 299–311 *in* G. E. Hall, editor. Reservoir fisheries and limnology. American Fisheries Society, Special Publication 8, Bethesda, Maryland.

Michaletz, P., J. Boxrucker, S. Hale, and J. R. Jackson. 1995. Comparison of four trawls for sampling juvenile shad. North American Journal of Fisheries Management 15:918–923.

Miller, B. T., C. W. Schoenebeck, and K. D. Koupal. 2018. Gear- and season-specific catch rates of age-0 Walleyes and White Bass: Standard sampling recommendations for Great Plains reservoirs. North American Journal of Fisheries Management 38:903–910.

Mueller, G., M. Horn, J. Kahl Jr., T. Burke, and P. Marsh. 1993. Use of larval light traps to capture Razorback Sucker (*Xyrauchen texanus*) in Lake Mohave, Arizona-Nevada. The Southwestern Naturalist 38:399–402.

Neebling, T. E., and M. C. Quist. 2011. Comparison of boat electrofishing, trawling, and seining for sampling fish assemblages in Iowa's non-wadeable rivers. North American Journal of Fisheries Management 31:390–402.

Nogueira, M. G., R. Henry, and F. E. Maricatto. 2002. Spatial and temporal heterogeneity in the Jurumirim Reservoir, São Paulo, Brazil. Lakes and Reservoirs: Science, Policy, and Management for Sustainable Use 4:107–120.

Oliveira, E. F., E. Goulart, and C. V. Minte-Vera. 2004. Fish diversity along spatial gradients in the Itaipu Reservoir, Paraná, Brazil. Brazilian Journal of Biology 64:447–458.

Patton, T., and C. Lyday. 2008. Ecological succession and fragmentation in a reservoir: Effects of sedimentation on habitats and fish communities. American Fisheries Society, Symposium 62, Bethesda, Maryland.

Perkin, J. S., and T. H. Bonner. 2016. Historical changes in fish assemblage composition following water quality improvement in the mainstem Trinity River of Texas. River Research and Applications 32:85–99.

Poos, M. S., and D. A. Jackson. 2012. Addressing the removal of rare species in multivariate bioassessments: The impact of methodological choices. Ecological Indicators 18:82–90.

Puncher, G. N., F. Alemany, H. Arrizabalaga, A. Cariani, and F. Tinti. 2015. Misidentification of Bluefin Tuna larvae: A call for caution and taxonomic reform. Reviews of Fish Biology and Fisheries 25:485–502.

Pyron, M., and T. E. Lauer. 2004. Hydrological variation and fish assemblage structure in the middle Wabash River. Hydrobiologia 525:203–213.

Richardson, J. S., T. Michalski, and M. Becu. 2021. Stream inflows to lake deltas: A tributary junction that provides a unique habitat in lakes. Freshwater Biology 66:2021–2029.

Sammons, S. M., and P. W. Bettoli. 1998. Larval sampling as a fisheries management tool: Early detection of year-class strength. North American Journal of Fisheries Management 18:137–143.

Santos, A. B. I., B. F. Terra, and F. G. Araújo. 2010. Influence of the river flow on the structure of fish assemblage along the longitudinal gradient from river to reservoir. Zoologia 27:732–740.

Schleiss, A. J., M. J. Franca, C. Juez, and G. De Cesare. 2016. Reservoir sedimentation. Journal of Hydraulic Research 54:595–614.

Shoup, D. E., R. E. Carlson, R. T. Heath, and M. W. Hershner. 2003. Comparison of the species composition, catch rate, and length distribution of the catch from trap nets with three different mesh and throat size combinations. North American Journal of Fisheries Management 23:462–469.

Schreck, W. J. 2010. Seasonal use of Missouri River reservoir deltas by fishes. Master's thesis. South Dakota State University. Brookings, South Dakota.

Senecal, A. C., A. W. Walters, and W. A. Hubert. 2015. Historical data reveal fish assemblage shifts in an unregulated prairie river. Ecosphere 6:1–13.

Shannon, C. E. 1948. A mathematical theory of communication. The Bell System Technical Journal 27:379–423.

Slipke, J. W., and M. J. Maceina. 2005. The influence of river connectivity on the fish community and sport fish abundance in Demopolis Reservoir, Alabama. Proceedings of the Annual Conference Southeastern Association Fish and Wildlife Agencies 59:282–291.

Smith, N. G., D. L. Buckmeier, B. P. Fleming, A. R. Grubh, M. D. Homer, Jr., and S. M. Robertson. 2023. Spatial variability in the fish assemblage of a large river-reservoir ecosystem. North American Journal of Fisheries Management 43:313–326.

Stige, L. C., M. E. Hunsicker, K. M. Bailey, N. A. Yaragina, and G. L. Hunt, Jr. 2013. Predicting fish recruitment from juvenile abundance and environmental indices. Marine Ecology Progress Status 480:245–261.

Uphoff, C. S., C. W. Scheonebeck, W. W. Hoback, K. D. Koupal, and K. L. Pope. 2013. Degree-day accumulation influences annual variability in growth of age-0 Walleye. Fisheries Research 147:394–398.

Walters, D. M., D. S. Keigh, M. C. Freeman, B. J. Freeman, and C. M. Pringle. 2003. Geomorphology and fish assemblages in a Piedmont river basin, U.S.A. Freshwater Biology 48:1950–1970.

Ward, J. V., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: Ecotones and connectivity. Regulated Rivers: Research and Management 15:125–139.

Weaver, M. J., J. J. Magnuson, and M. K. Clayton. 1993. Analyses for differentiating littoral fish assemblages with catch data from multiple sampling gears. Transactions of the North American Fisheries Society 122:1111–1119.

Williams, H. F. L. 1991. Character and growth of deltaic deposits in Lewisville Lake, Texas. Texas Journal of Science 43:377–389.

Winfield, I. J. 2004. Fish in the littoral zone: Ecology, threats, and management. Limnologica 34:124–131.

Zigler, S. J., and M. R. Dewey. 1995. Management briefs: Phototaxis of larval and juvenile Northern Pike. North American Journal of Fisheries Management 15:651–653.

Tables and Figures

Table 1. Fish taxa presence (denoted by an “X”) across gears (light trap, tow net, electrofishing, and seine) in upper Lake McConaughy, Nebraska, May–August 2021. The species abbreviations here are the same as those used in Figure 2.

Common name	Scientific name	Taxa abbreviation	Gear			
			Light trap	Tow net	Electrofishing	Seine
Alewife	*Alosa pseudoharengus*	ALE	X	X		X
Black Bullhead	*Ameiurus melas*	BBH				X
Channel Catfish	*Ictalurus punctatus*	CCF				X
Common Carp	*Cyprinus carpio*	COC	X		X	X
Emerald Shiner	*Notropis atherinoides*	EMS			X	X
Freshwater Drum	*Aplodinotus grunniens*	FWD				X
Gizzard Shad	*Dorosoma cepedianum*	GZD	X	X	X	X
Green Sunfish	*Lepomis cyanellus*	GSF				X
Largemouth Bass	*Micropterus salmoides*	LMB	X			X
Plains Killifish	*Fundulus zebrinus*	PFK				X
Quillback	*Carpiodes cyprinus*	QBK				X
Red Shiner	*Cyprinella lutrensis*	RES				X
River Carpsucker	*Carpiodes carpio*	RCS	X			X
River Shiner	*Notropis blennius*	RIS	X			
Sand Shiner	*Notropis stramineus*	SSH	X			X
Shorthead Redhorse	*Moxostoma macrolepidotum*	SHR				X
Smallmouth Bass	*Micropterus dolomieu*	SMB				X
Walleye	*Sander vitreus*	WAE			X	
White Bass	*Morone chrysops*	WHB	X		X	X
White Sucker	*Catostomus commersonii*	WHS	X			X
Hybrid Striped Bass	*Morone chrysops x M. saxatilis*	WXB			X	X

Table 2. Species richness, mean Shannon-Weiner diversity index (H) and abundance (catch per unit effort or density), and the coefficient of variation (CV) for each gear calculated across all locations and sampling periods in upper Lake McConaughy from May to August 2021. Numbers in parentheses represent one standard error. Units of effort for each sampling gear are in parentheses behind the type of gear.

Gear (Effort unit)	Richness	H	Abundance	CV
Plankton tow nets (#/L)	2	0.41 (0.00)	0.04 (0.02)	116
Watermark® Quadrafoil larval light traps (#/trap)	9	0.67 (0.01)	5.42 (2.23)	82
Boat-mounted electrofishing (#/transect)	6	1.37 (0.02)	0.43 (0.03)	8
Shoreline seine (#/total number of hauls)	19	1.57 (0.00)	17.74 (1.46)	12

Figure 1: Sampling zones for the north and south shore in the upper reservoir of Lake McConaughy, Nebraska, from May to August 2021 for all gears. Orange X's represent light trap, electrofishing, and seining locations. Green circles represent tow net locations.

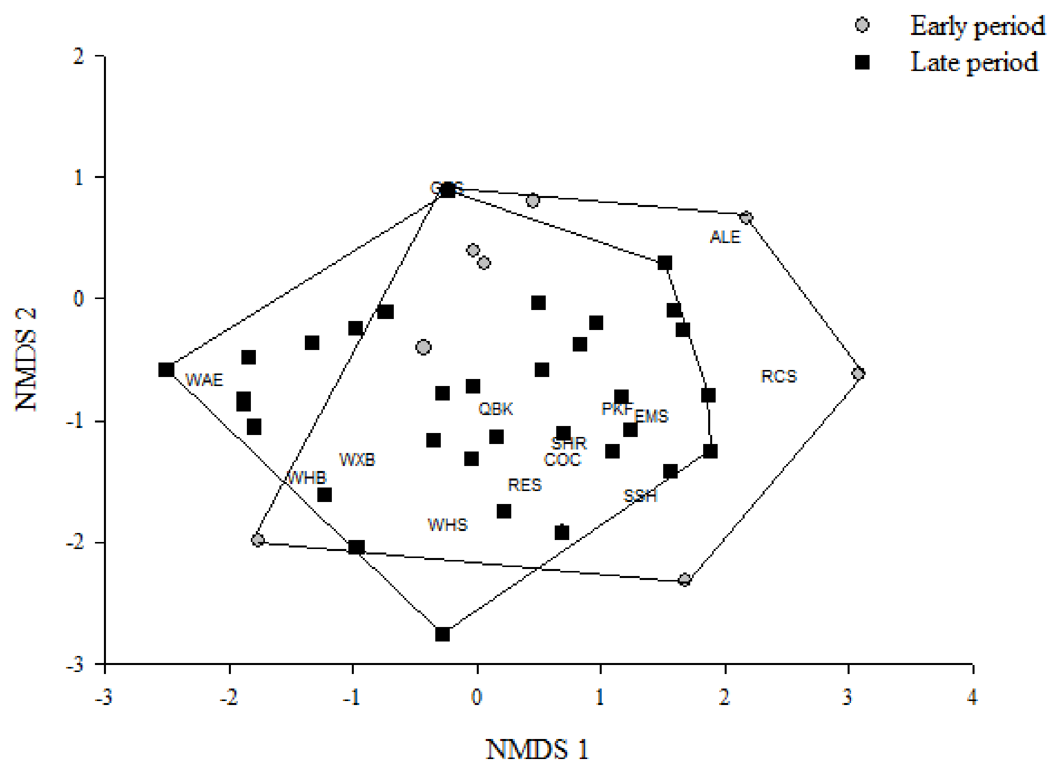

Figure 2. Plot of non-metric multidimensional scaling (NMDS) of the abundances of fish species sampled between early and late periods in upper Lake McConaughy, Nebraska, from May to August 2021. Note that gears differed for each period as described in the methods. Polygons represent convex hulls around periods in ordinal space. Acronyms of species are denoted in Table 1.

Chapter 3:

Research Implications and Management Recommendations

Thyme Taulaki

Department of Biology, University of Nebraska at Kearney

2401 11th Ave, Kearney, NE 68849, USA

Introduction

High species richness, diversity, and abundance and the presence of various life stages in the North Platte River-Lake McConaughy interface suggests that this area may be important in supporting young-of-the-year, native, small-bodied, and sportfish species. Because the RRI represents physical, chemical, ecological, and biological connections between river and reservoir environments, better understanding of habitat availability dynamics and how fish communities within this area change in response can be informative for management of these systems. To my knowledge, this study is the first to conduct sampling on fish communities in the North Platte River-Lake McConaughy interface with a focus on young and small-bodied species.

Habitat and Fish Dynamics in Rivers

Previous sampling of fish communities in the North Platte River above Lake McConaughy is sparse. Interestingly, when comparing the fish species collected in those minimal studies (i.e., Johnson 1942; Lynch and Roh 1996) to what I found, few species appear to have been lost in the last 80 years. This result is somewhat surprising given that other studies have found that fish diversity has declined over decades in other regulated rivers (Taylor et al. 2001; Kominoski et al. 2017). Two reasons may explain higher diversity in impounded systems. First, impoundment can result in continuous changes in flow and habitat availability (Ward and Stanford 1979; Quist et al. 2005). Second, new species are often intentionally or accidentally introduced into reservoirs after they are created (Franssen and Tobler 2013). Future research should continue to sample the North

Platte River-Lake McConaughy RRI to monitor fish communities but more frequently in order to detect any potential changes in native and introduced species in this area.

Sampling Fish Communities in Upper Reservoirs

Areas in the upper reservoir may be difficult to access for both the fish themselves and for sampling fish communities under low-flow conditions. The use of traditional sampling gears such as trawls, electrofishing, and seines have inherent limitations in dynamic, transitional areas (Acre 2015). The gears selected for my study were chosen for the original purpose of collecting age-0 White Bass, but bycatch of other species in these gears is common (Sammons and Bettoli 1998; Miller et al. 2018; Boehm et al. 2020). The lack of White Bass captured throughout this study may be related to the declining presence of this species within the reservoir (Darrol Eichner, *personal communication*) or perhaps related unknown gear collection bias. The efficiency of each gear used in my study was variable, but certain gears appeared to be better for capturing more of the fish community. Based on my results, I recommend using seines to sample young fish in the upper reservoir as this gear captured the most species and the highest abundance and diversity. Each gear that I used had inherent benefits and limitations. For example, although boat-mounted electrofishing appeared to have the highest sampling precision, size selectivity may be an associated bias when using this gear (Dolan and Miranda 2011). In addition, some species may only be sampled with one or two different gears and not others (e.g., Walleye were only captured with boat electrofishing). Thus, it may be advantageous to use multiple gears in some cases. However, using multiple gears requires more time and effort than single gears and may not be required to meet particular objectives. Future research should focus on developing efficient ways to sample the upper reservoir that meets the objective of a given study.

The exclusion of rare species in the multivariate analyses may have influenced the overall community composition in my study. Although studies using multivariate analyses to compare fish communities suggest the exclusion of rare species to reduce noise and redundant information (Marchant 1999; Cao et al. 2001; Poos and Jackson 2012), it may be beneficial to include these species in the analysis to fully represent the fish community and identify whether there are important indicator species of ecosystem health (Faith and Norris 1989; Cao et al. 2001). Most analyses need a minimum number of fish and the exclusion of rare taxa can result in unequal community representations (Barbour and Gerritsen 1996; Miranda et al. 2014). However, studies have found that the inclusion of rare species regardless of abundance was beneficial for representing the overall community. Cao et al. (1998) found that the deletion of rare species resulted in an underestimation of species richness between sampling sites. Ruetz, III et al. (2007) found that the inclusion of rare species in an NMDS ordination did not change the conclusion that species composition differed between different gears used to sample fish. Overall, defining if and how to exclude taxa from an analysis depends on the assessment objective (Lavoi et al. 2009; Li et al. 2012). However, fisheries managers should consider the inclusion of rare species in multivariate analyses when comparing fish communities between habitats or collected with different sampling gears.

Study Limitations

The transitional nature of the RRI has been a challenge for sampling in other studies as this dynamic area can shift and change size over time (Volke et al. 2015; Pennock et al. 2020). Thus, defining the boundaries of the RRI and comparing these areas over time or to each other can be difficult. Within the timeframe of my study, I was only able to sample for one summer each in the North Platte River and upper Lake McConaughy. More sampling within both areas within and between years would allow for observing how changes in dynamics of the RRI influence community composition. The timeframe chosen for sampling in both areas (May through August) was originally chosen for the purpose of targeting White Bass. White Bass have been found to spawn as late as May or June in some areas, depending on reservoir inflows, water levels, and water temperature (Riggs 1953; Quist et al. 2002). Once hatched, White Bass may exhibit rapid growth and begin schooling before migrating back to the reservoir or being carried downstream (Walden 1964; Quist 2002). Other species within the fish community spawn or hatch at other times or grow at different rates, making them more or less vulnerable to the gears used in my study (Whiteside et al. 1985; Tischler et al. 2000; Fulford et al. 2006). In addition, other gears not tested in my study could have been used (e.g., backpack or tote barge electrofishing) but would likely have biases and limitations of their own (Jackson and Noble 1995; Onorato et al. 2011). Thus, it may be possible that my study missed some species that were present in the upper reservoir as a result of the gears or the timeframe chosen for this study. However, based on historical comparisons, I believe that I captured most, if not all, the species that were present.

Future Directions and Research

The mosaic of habitats within the river above the reservoir is important in supporting high species richness, including native, small-bodied native, and sportfish species. However, the dynamic nature of the river can alter the availability and access to these habitats and for fish to move into the upper reservoir, particularly during low flow conditions. River discharge may naturally increase or decrease within and between seasons or years due to patterns in precipitation, and riverine fishes are adapted to hydrological cycles as well as floods and drought (Lytle and Poff 2004). However, in managed systems such as those regulated by dams and diversions, altered hydrology may exacerbate flow dynamics (Galat and Lipkin 2000). In such affected systems, species richness and diversity can be supported by maintaining habitat diversity and access (Gorman and Karr 1978; Scheidegger and Bain 1995; Carvalho et al. 1998; Gratwicke and Speight 2005; Santos et al. 2010). However, in the North Platte River-Lake McConaughy RRI, little is known about the availability of habitats at different flow regimes and reservoir water elevations. Greater effort should be put towards habitat monitoring in this highly dynamic system. Understanding how a river system will respond to flow pulses is challenging (Richter et al. 2006; Caruso et al. 2013) however, newer technologies offer promise for assessing dynamic systems. For example, Harrison et al. (2017) used high-resolution imaging from remote sensing as a tool to quantify geomorphic and habitat response to controlled flow pulses in a regulated semiarid river and found that this process generated complex and interconnected habitats across various spatial scales. Information on habitat availability can be used in conjunction with historic and predicted water management for this system to anticipate where and when habitat improvement efforts may be most effective. In an ideal world, controlled flow releases could be used by managers to offset negative impacts of dams on regulated river systems by rebuilding and maintaining diverse habitats that fish can access during critical times (Opperman et al. 2010; Grams et al. 2013), but those options may not be feasible for this system.

Habitat modeling can identify specific flows and reservoir elevations that would have limited availability of specific habitats; however, such projects and associated costs can be difficult to justify (Erwin et al. 2017). Thus, improving fish monitoring and sampling design is advised in addition to habitat modeling. My study provided information on habitat dynamics and community composition in relation to flow using some, but not all, possible gears. Future research should test other gears such as backpack electrofishing (Vaux et al. 2011), push nets (Acre and Grabowski 2015), and pop nets (Paradis et al. 2011) for assessing fish communities in the North Platte River-Lake McConaughy RRI. In addition, studying the movement of fishes between these two areas of the RRI can provide important information on the spatial and temporal use of habitats by fish, which can also inform the management of water in this system.

Literature Cited

Acre, M. 2015. Can a river-reservoir interface serve as nursery habitat for riverine fishes? M.S. Thesis. Texas Tech University. Lubbock, Texas.

Acre, M. R., and T. B. Grabowski. 2015. Development of paired push nets from jet-propelled kayaks to sample ichthyoplankton. North American Journal of Fisheries Management 35:925–929.

Barbour, M. T., and J. Gerritsen. 1996. Subsampling of benthic samples: A defense of the fixed-count method. Journal of the North American Benthological Society 15:386–391.

Boehm, H. I. A., J. C. Gostiaux, G. J. A. Hansen, J. M. Hennessy, and D. A. Isermann. 2020. Indexing age-0 Walleye abundance in northern Wisconsin lakes before fall. North American Journal of Fisheries Management 40:910–921.

Cao, Y., D. D. Williams, and N. E. Williams. 1998. How important are rare species in aquatic community ecology and bioassessment? Limnology and Oceanography 43:1402–1409.

Cao, Y., D. P. Larsen, and R. S. Thorne. 2001. Rare species in multivariate analysis for bioassessment: Some consideration. Journal of the North American Benthological Society 20:144–153.

Caruso, B. S., C. Pithie, and L. Edmondson. 2013. Invasive riparian vegetation response to flow regimes and flood pulses in a braided river floodplain. Journal of Environmental Management 125:156–168.

Carvalho E. D., V. F. Batista da Silva, C. Y. Fujihara, R. Henry, and F. Foresti. 1998. Diversity of fish species in River Paranapanema–Jurumirim Reservoir transition region (São Paulo, Brazil). Italian Journal of Zoology 65:325–330.

Dolan, C. R., and L. E. Miranda. 2011. Immobilization thresholds of electrofishing relative to fish size. Transactions of the American Fisheries Society 132:969–976.

Erwin, S. O., R. B. Jacobson, and C. M. Elliott. 2017. Quantifying habitat benefits of channel reconfigurations on a highly regulated river system, Lower Missouri River, USA. Ecological Engineering 103:59–75.

Faith, D. P., and R. H. Norris. 1989. Correlation of environmental variables with patterns of distribution and abundance of common and rare freshwater macroinvertebrates. Biological Conservation 50:77–98.

Franssen, N. R., and M. Tobler. 2013. Upstream effects of a reservoir on fish assemblages 45 years following impoundment. Journal of Fish Biology 82:1659–1670.

Fulford, R. S., J. A. Rice, and F. P. Binkowski. 2006. Examination of sampling bias for larval Yellow Perch in southern Michigan. Journal of Great Lakes Research 32:434–441.

Galat, D. L., and R. Lipkin. 2000. Restoring ecological integrity of great rivers: Historical hydrographs aid in defining reference conditions for the Missouri River. Hydrobiologia 422:29–48.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507–515.

Grams, P. E., D. J. Topping, J. C. Schmidt, J. E. Hazel Jr., and M. Kaplinski. 2013. Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design. Journal of Geophysical Research: Earth Surface 118:361–381.

Gratwicke, B., and M. R. Speight. 2005. The relationship between fish species richness, abundance, and habitat complexity in a range of shallow tropical marine habitats. Journal of Fish Biology 66:650–667.

Harrison, L. R., A. Pike, and D. A. Boughton. 2017. Coupled geomorphic and habitat response to a flood pulse revealed by remote sensing. Ecohydrology 10:e1845.

Jackson, J. R., and R. L. Noble. 1995. Selectivity of sampling methods for juvenile Largemouth Bass in assessments of recruitment processes. North American Journal of Fisheries Management 15:408–418.

Johnson, R. E. 1942. The distribution of Nebraska fishes. Ph.D. Dissertations. University of Michigan. Ann Arbor, Michigan.

Kominoski, J. S., A. Ruhi, M. M. Hagler, K. Petersen, J. L. Sabo, T. Sinha, A. Sankarasubramanian, and J. D. Olden. 2017. Patterns and drivers of fish extirpations in rivers of the American Southwest and Southeast. Global Change Biology 24:1175–1185.

Lavoi, I., P. J. Dillon, and S. Campeau. 2009. The effect of excluding diatom taxa and reducing taxonomic resolution on multivariate analyses and stream bioassessment. Ecological Indicators 9:213–225.

Li, J., L. Huang, L. Zou, Y. Kano, T. Sato, and T. Yahara. 2012. Spatial and temporal variation of fish assemblages and their associating to habitat variables in a mountain stream of north Tiaoxi River, China. Environmental Biology of Fishes 93:403–417.

Lynch, J. D., and B. R. Roh. 1996. An ichthyological survey of the forks of the Platte River in western Nebraska. Transactions of the Nebraska Academy of Sciences 23:65–84.

Lytle, D. A., and N. L. Poff. 2004. Adaptation to natural flow regimes. Trends in Ecology and Evolution 19:94–100.

Marchant, R. 1999. How important are rare species in aquatic community ecology and bioassessment? A comment on the conclusions of Cao et al. Limnology and Oceanography 44:1840–1842.

Miller, B. T., C. W. Schoenebeck, and K. D. Koupal. 2018. Gear-and season-specific catch rates of age-0 Walleyes and White Bass: Standard sampling recommendations for Great Plains reservoirs. North American Journal of Fisheries Management 38:903–910.

Onorato, D. P., R. A. Angus, and K. R. Marion. 2011. Comparison of small-mesh seines and a backpack electrofisher for evaluating fish populations in a North-Central Alabama stream. North American Journal of Fisheries Management 18:361–373.

Opperman, J. J., R. Luster, B. A. McKenney, M. Roberts, and A. W. Meadows. 2010. Ecologically functional floodplains: Connectivity, flow regime, and scale. Journal of the American Water Resources Association 46:211–226.

Paradis, Y., M. Mingelbier, P. Brodeur, and P. Magnan. 2011. Comparisons of catch and precision of pop nets, push nets, and seines for sampling larval and juvenile Yellow Perch. North American Journal of Fisheries Management 28:1554–1562.

Pennock, C. A., B. A. Hines, D. S. Elverud, T. A. Francis. M. C. McKinstry, B. J. Schleicher, and K. B. Gido. 2020. Reservoir fish assemblage structure across an aquatic ecotone: Can river-reservoir interfaces provide conservation and management opportunities? Fisheries Management and Ecology 28:1–13.

Poos, M. S., and D. A. Jackson. 2012. Addressing the removal of rare species in multivariate bioassessments: The impact of methodological choices. Ecological Indicators 18:82–90.

Quist, M. C., C. S. Guy, and R. J. Bernot. 2002. Ecology of larval White Bass in a large Kansas Reservoir. North American Journal of Fisheries Management 22:637–542.

Quist, M. C., W. A. Hubert, and F. J. Rahel. 2005. Fish assemblage structure following impoundment of a Great Plains river. Western North American Naturalist. 65:53–63.

Richter, B. D., A. T. Warner, J. L. Meyer, and K. Lutz. 2006. Collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22:297–318.

Riggs, C. D. 1953. Studies of the life history of the White Bass, *Lepibema chrysops* (Rafinesque), with species reference to Shafer Lake, Indiana. Ph.D. Dissertation. University of Michigan, Ann Arbor.

Ruetz III, C. R., D. G. Uzarski, D. M. Krueger, and E. S. Rutherford. 2007. Sampling a littoral fish assemblage: Comparison of small-mesh fyke netting and boat electrofishing. North American Journal of Fisheries Management 27:825–831.

Sammons, S. M., and P. W. Bettoli. 1998. Larval sampling as a fisheries management tool: Early detection of year-class strength. North American Journal of Fisheries Management 18:137–143.

Santos, A. B. I., B. F. Terra, and F. G. Araújo. 2010. Influence of the river flow on the structure of fish assemblage along the longitudinal gradient from river to reservoir. Zoologia 27:732–740.

Scheidegger, K., and M. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia 1995:125–135.

Taylor, C. A., J. H. Knouft, and T. M. Hiland. 2001. Consequences of stream impoundment on fish communities in a small North American drainage. Regulated Rivers Research and Management 17:687–698.

Tischler, G., H. Gassner, and J. Wanzenböck. 2000. Sampling characteristics of two methods for capturing age-0 fish in pelagic lake habitats. Journal of Fish Biology 57:1474–1487.

Vaux, P. D., T. R. Whittler, G. DeCesare, and J. P. Kurtenbach. 2011. Evaluation of backpack electrofishing unit for multiple lake surveys of fish assemblage structure. North American Journal of Fisheries Management 20:168–179.

Volke, M. A., M. L. Scott, W. C. Johnson, and M. D. Dixon. 2015. The ecological significance of emerging deltas in regulated rivers. BioScience 65:598–611.

Walden, H. 1964. Familiar Freshwater Fishes of America. Harper & Row Publishers Inc., New York, New York.

Ward, J. V., and A. Stanford. 1979. The ecology of regulated streams. Plenum Publishing, New York, New York.

Whiteside, M. C., C. M. Swindoll, and W. L. Doolittle. 1985. Factors affecting the early life history of Yellow Perch, *Perca flavescens*. Environmental Biology of Fishes 12:47–56.