Minnesota River Backwater Fish Communities

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Authors

Michael Vaske*, Anthony R. Sindt
Minnesota Department of Natural Resources, Fish and Wildlife Division, 20596 Hwy 7, Hutchinson, MN 55350

Michael Wolf
Minnesota Department of Natural Resources, Fish and Wildlife Division, 204 Main Street East, Baudette, MN 56623

Kayla Stampfle
Minnesota Department of Natural Resources, Fish and Wildlife Division, 1200 Warner Road, St. Paul, MN 55106

Eric Katzenmeyer
Minnesota Department of Natural Resources, Ecological & Water Resources Division, 20596 Hwy 7, Hutchinson, MN 55350

*Corresponding author: michael.vaske@state.mn.us

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I. Common and scientific name of fish species referred to in this study.

Common name	Scientific name	Common name	Scientific name
Bighead Carp	*Hypophthalmichthys nobilis*	Iowa Darter	*Etheostoma exile*
Bigmouth Buffalo	*Ictiobus cyprinellus*	Johnny Darter	*Etheostoma nigrum*
Bigmouth Shiner	*Notropis dorsalis*	Largemouth Bass	*Micropterus salmoides*
Black Buffalo	*Ictiobus niger*	Logperch	*Percina caprodes*
Black Bullhead	*Ameiurus melas*	Longnose Gar	*Lepisosteus osseus*
Black Crappie	*Pomoxis nigromaculatus*	Mooneye	*Hiodon tergisus*
Blackchin Shiner	*Notropis heterodon*	Northern Pike	*Esox lucius*
Blacknose Dace	*Rhinichthys obtusus*	Northern Redbelly Dace	*Phoxinus eos*
Bluegill	*Lepomis macrochirus*	Orangespotted Sunfish	*Lepomis humilis*
Bluntnose Minnow	*Pimephales notatus*	Paddlefish	*Polyodon spathula*
Bowfin	*Amia calva*	Pumpkinseed	*Lepomis gibbosus*
Brassy Minnow	*Hybognathus hankinsoni*	Quillback	*Carpiodes cyprinus*
Brook Silverside	*Labidesthes sicculus*	River Carpsucker	*Carpiodes carpio*
Brook Stickleback	*Culaea inconstans*	Sand Shiner	*Notropis stramineus*
Brown Bullhead	*Ameiurus nebulosus*	Sauger	*Sander canadensis*
Bullhead Minnow	*Pimephales vigilax*	Shorthead Redhorse	*Moxostoma macrolepidotum*
Central Mudminnow	*Umbra limi*	Shortnose Gar	*Lepisosteus platostomus*
Channel Catfish	*Ictalurus punctatus*	Silver Carp	*Hypophthalmichthys molitrix*
Common Carp	*Cyprinus carpio*	Silver Redhorse	*Moxostoma anisurum*
Common Shiner	*Luxilus cornutus*	Slenderhead Darter	*Percina phoxoceoala*
Creek Chub	*Semotilus atromaculatus*	Smallmouth Buffalo	*Ictiobus bubalus*
Emerald Shiner	*Notropis atherinoides*	Spotfin Shiner	*Cyprinella spiloptera*
Fathead Minnow	*Pimephales promelas*	Spottail Shiner	*Notropis hudsonius*
Flathead Catfish	*Pylodictis olivaris*	Stonecat	*Noturus flavus*
Freshwater Drum	*Aplodinotus grunniens*	Tadpole Madtom	*Noturus gyrinus*
Gizzard Shad	*Dorosoma cepedianum*	Walleye	*Sander vitreus*
Golden Redhorse	*Notemigonus crysoleucas*	Weed Shiner	*Notropis texanus*
Golden Shiner	*Notemigonus crysoleucas*	White Bass	*Morone chrysops*
Green Sunfish	*Lepomis cyanellus*	White Crappie	*Pomoxis annularis*
Highfin Carpsucker	*Carpiodes velifer*	White Sucker	*Catostomus commersonii*
Hornyhead Chub	*Nocomis biguttatus*	Yellow Bullhead	*Ameiurus natalis*
Hybrid Sunfish	*Lepomis spp.*	Yellow Perch	*Perca flavescens*

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Executive Summary

Project activity 3: Inventory backwater fish communities of the Minnesota River.

Project Objectives

- Characterize fish communities in Minnesota River backwaters.
- Refine survey protocols for assessing Minnesota River backwater fish communities.

Significant Outcomes

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

Abstract

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

Introduction

Floodplains are an important component of river ecosystems, and backwater habitats (e.g., oxbow lakes, floodplain wetlands, billabongs) within the floodplain serve vital ecosystem functions. The connection between the main channel and its floodplain during flood events allows for the exchange of nutrients, organic matter, and organisms (Ward 1989). Junk et al. (1989) proposed that lateral exchange between the floodplain and main channel is the primary process influencing riverine biota. Junk et al. (1989) also noted the correlation between timing and duration of flood-pulses with life cycles of biota that utilize the floodplain for various purposes (e.g., spawning, foraging, refuge). In addition to structuring the biota of river systems, backwater habitats can influence water quality and chemistry by acting as sinks for nitrates (James et al. 2008) and phosphorus (Thomaz et al. 2007). Uptake and utilization of nutrients in backwaters results in a bottom-up cascade of increased productivity of zooplankton (Ward 1989; Fisher 2011), macroinvertebrates (Eckblad et al. 1984; Murdock and Dodds 2007), and fishes (Stockner et al. 2000; Slipke et al. 2005).

All backwaters provide some form of habitat for aquatic organisms, but not all backwater habitats are alike. Size, depth, substrate, connectivity, distance from river channel, macrophyte cover, and other physical features influence the species that utilize the habitat (Ward et al. 1999; Zeug and Winemiller 2007; Shoup and Wahl 2009). We speculate that river kilometer (i.e., location along the longitudinal gradient of the river), surface area, and connectivity with the main channel are the most important factors influencing fish communities in Minnesota River backwaters. Changes in hydrologic characteristics resulting from climate change and land use practices can also greatly influence the functionality of backwater habitats (Bowen et al. 2003; Dembkowski and Miranda 2014). For example, timing, frequency, magnitude, and duration of flood events regulate connectivity of backwaters to the river channel and consequently access by fish (Junk et al. 1989; Ward 1989; Bayley 1995; King et al. 2003). Furthermore, increased sediment transport from uplands can deposit and fill in backwaters altering or eliminating important ecosystem functions (Cooper and Bacon 1980; Waters 1995).

The Minnesota River floodplain contains hundreds of perennial and intermittent backwater habitats that provide valuable habitat for fish and other organisms. For fish, these backwaters can serve multiple functions from providing spawning and nursery habitat (King et al. 2003; Zeug and Winemiller 2007; Shoup and Wahl 2009), to zooplankton rich areas for foraging (Wahl et al. 2008; Burdis and Hoxmeier 2011; Fisher 2011), and refuge from high-flow conditions (Schwartz and Herricks 2005). For example, many nest building centrarchids (e.g., Bluegill, Black Crappie) utilize the lentic environment of backwaters for spawning (Sabo and Kelso 1991; Shoup and Wahl 2009). Backwater habitats typically support greater zooplankton diversity and densities than main-channel habitats (Nickel 2014) and thus provide important foraging habitat for planktivorous riverine species such as Bigmouth Buffalo, Gizzard Shad, and Paddlefish (Lazzaro 1987; Hoxmeier and DeVries 1997; Jennings and Zigler 2000). Some Minnesota River fish species such as Bowfin, Central Mudminnow, and Weed Shiner are almost exclusively found within backwater habitats (Shoup and Wahl 2009).

Backwater habitats are important for native fishes, but are also utilized by invasive species such as invasive carps (i.e., Bighead Carp, Silver Carp; Sampson et al. 2009). Invasive carps are known to extensively utilize backwater habitats for feeding and as nursery habitat for juveniles (Pegg et al. 2002; Kolar et al. 2007). Invasive carps are not established in the Minnesota River, but if they become established, they could compete with native fishes for space and food resources found in backwater habitats (Schrank et al. 2003; Sampson et al. 2009). Documenting fish communities found in Minnesota River backwaters prior to invasive carp establishment will provide the opportunity to understand how invasive carps impact backwater ecosystems if they do become established.

Despite the importance of the Minnesota River floodplain and backwaters, very few studies have evaluated their ecosystem function and fish communities. During 2006, the Minnesota Department of Natural Resources (DNR) conducted the first comprehensive evaluation of Minnesota River backwater fish communities, but efforts were focused along the lower 76 km of the Minnesota River. A more recent study by Nickel (2014) evaluated seasonal trends in biotic assemblages in three backwater lakes. However, these studies did not capture the spatial and physical diversity of backwater lakes found within the Minnesota River floodplain nor evaluate variability among years. During 2016-2018, funding from the Environment and Natural Resource Trust Fund (ENRTF; lccmr.org) provided the Minnesota Department of Natural Resources (DNR) with the capacity to further evaluate and inventory fish communities inhabiting a diversity of

Minnesota River backwaters distributed throughout the floodplain. Outcomes of this project increase understanding of the ecological function of Minnesota River backwater habitats and utilization of backwater habitats by Minnesota River fishes. Additionally, outcomes provide the DNR and other agencies with refined protocols for monitoring backwater fish communities and the ability to identify changes in backwater fish communities attributed to altered hydrology and habitat or establishment of invasive species.

Study Site

The Minnesota River originates from Big Stone Lake on the border of Minnesota and South Dakota, and flows approximately 515 km (320 miles) to its confluence with the Mississippi River in St. Paul, Minnesota. Five dams alter the flow of the upper Minnesota River while the lower 386 km (240 miles) are free-flowing. Granite Falls Dam is the furthest downstream dam, and acts as a significant barrier to fish movement with at least 18 fewer fish species found upstream.

The Minnesota River Valley was formed during the Pleistocene by Glacial River Warren, which was created by a breach of Glacial Lake Agassiz (Teller et al. 2002; Lepper et al. 2007). This breach event created the present-day Minnesota River Valley, where the Minnesota River meanders along a 3-4 km wide valley containing highly erodible layers of glacial sediments (e.g., clay, silt, sand; Lepper et al. 2007; Belmont 2011; Gran et al. 2011). Over the past century, the Minnesota River has experienced an increase in discharge, resulting in a more erosive river (Schottler et al. 2014; Kelly et al. 2017). The highly erodible soils coupled with the erosive nature of the Minnesota River has resulted in the formation of a complex floodplain that contains many oxbow lakes and other unique backwater habitats.

The Minnesota River floodplain contains hundreds of backwaters of various shapes, sizes, connection types, and geomorphic histories. We used aerial imagery, ArcMap tools (Esri, Redlands, CA; v10.6), DNR staff knowledge, and other tools to identify a candidate set of Minnesota River backwaters for conducting fisheries assessments. Candidate backwaters were selected along the entire length of the Minnesota River (downstream of Lac qui Parle) and varied in size, depth, type (oxbow, wetland, floodplain), and connectivity (frequently, annually, infrequently, rarely). Our goal was to sample at least 12 backwater habitats including backwaters located upstream of Granite Falls Dam, and to re-visit some backwaters that were assessed during previous studies (i.e., Schmidt and Polomis 2007; Nickel 2014).

Methods

Fish sampling

We conducted fisheries assessments in backwaters during summer–fall 2016, spring–fall 2017, and spring–fall 2018. Surveys occurred at any time during the year, except during extreme high-water or low-water periods. Most surveys were conducted after spring flows connected backwaters to the main-channel and after most fish species concluded spawning.

Fish communities were sampled using a suite of gears including boat electrofishing, standard lake survey gill nets, large mesh gill nets, fyke nets (19.0 mm, 9.5 mm, and 3.2 mm bar mesh), and seines (15.2 m x 1.2 m x 3.2 mm). Daytime boat electrofishing was conducted with an ETS MBS-2DP Electrofishing Systems unit (Electrofishing Systems LLC, Madison, Wisconsin). Pulsed DC electricity was cycled at 60 Hz with voltage output adjusted

Table 1. Target sample effort based on backwater lake surface area.

Gear	< 6 hectares	6–40 hectares	> 40 hectares
Boat electrofishing	Entire shoreline (10 minute runs)	Four 20 minute runs or entire shoreline	Four 20 minute runs
Standard gill nets	3	4	6
Large mesh gill nets	1	2	2
19.0 mm fyke net	3	3	4
9.5 mm fyke net	3	3	4
3.2 mm fyke net	3	3	4
Seine	4	6	8

to achieve desired fish response. Two netters used 0.5 m diameter nets with 0.3 cm bar mesh and 3.0 m long handles to capture stunned fish. Standard 76.2 m long by 1.8 m deep gill nets constructed with five 15.4 m panels of 1.9 cm, 2.5 cm, 3.2 cm, 3.8 cm, and 5.1 cm bar mesh were used when adequate depth was available. Large mesh monofilament gill nets were used to sample large bodied fishes. Large mesh gill nets were 91.4 m long by 2.0 m deep, constructed of six panels of 6.4 cm, 7.6 cm, 8.9 cm, 10.2 cm, 11.4 cm, and 12.7 cm bar mesh. Three different size mesh (19.1 mm, 9.5 mm, and 3.2 mm bar mesh) single-frame modified-fyke nets were also used to sample backwater fishes. The two larger sized mesh fyke nets had 1.5 m x 0.8 m frames and 10. 7 m leads, while the smallest mesh fyke nets had 1.0 m x 0.9 m frames and a 7.6 m lead. Small bodied fishes and young-of-year fishes were sampled using a 15.2 m x 1.2 m seine with a 1.2-m^3 bag made of 3.2 mm delta mesh. The desired sampling effort for each survey was dependent on backwater surface area (Table 1).

All large-bodied fish captured during surveys were measured for total length (nearest 1 mm) and weighed (g). Small bodied fishes were counted and weighed in batches for each species. A minimum and maximum length was recorded for all small-bodied fish species. Any unique or unidentified fish were preserved in ethanol and returned to the lab for identification. A typical backwater survey was conducted over three or four consecutive days depending upon weather conditions, habitat conditions (e.g., size), and catch rates.

Abiotic measurements

In addition to evaluating backwater fish communities, we also measured abiotic habitat characteristics associated with each backwater. We measured maximum water depth, Secchi depth, water conductivity, and a temperature and dissolved oxygen profile. Additionally, we visually estimated the dominant substrate types, percent coverage of submergent and emergent vegetation, dominant types of aquatic macrophytes, surrounding land cover types, and percent of surface area that was flooded terrestrial vegetation. We also documented the connectivity of the backwater with the main channel and estimated the ease of fish passage through the connection.

Along with recording surrounding land cover types for each backwater in the field, we also quantified land cover types at larger scales using Arc-GIS (Esri, Redlands, CA; v10.6). We evaluated land cover at various distances by drawing concentric bands (50-, 500-, 1,000-, and 5,000-m) around each backwater. The 50-m band was considered the riparian zone of the backwater and the 500-, 1,000-, and 5,000

Table 2. List of Minnesota River backwaters sampled during 2016–2018. Connectivity is a qualitative ranking of how frequently backwaters connect with the main channel (1 = rarely connected, 2 = infrequently connected, 3 = frequently connected). Backwaters surveyed by Schmidt and Polomis (2007) are denoted with * and backwaters surveyed by Nickel (2014) are denoted with **.

Backwater	Area (hectares)	River kilometer	Max depth (m)	Connectivity	Fish species richness
Anderson Lake**	6	283	2.7	3	24
Beckendorf Lake	25	336	1.7	1	17
Belle Plaine Oxbow	4	82	4.7	1	14
Blue Lake*	106	32	1.4	2	23
Franklin Oxbow	3	290	1.4	3	25
Gifford Lake*	76	51	4.1	2	30
Hwy 14 Oxbow	2	433	2.4	3	24
Long Lake*	28	63	2.0	2	27
Mack Lake	6	275	2.0	3	22
Montevideo Oxbow	4	407	1.2	3	28
New Ulm Oxbow	8	219	3.2	3	23
Sulfur Lake	3	306	4.6	1	29

m bands were considered proxies for the land-cover within each backwater watershed. Land cover data was provided by the Multi-Resolution Land Cover Consortium's (MRLC) 2011 National Land Cover Dataset (NLCD; Homer et. al 2015). Land cover classes within the riparian zone included agriculture, forest-cover, wetlands, and human disturbance (e.g., urban development, and impervious surfaces). Land cover classes within the broader bands included agriculture, forest-cover, wetlands, human disturbance, and open water. Land cover class percentages were calculated for each band using spatial analyst tools in Arc-GIS. Summaries of land cover types are provided for each backwater in Appendices 1.3-12.3.

Fish assemblage descriptors

We used non-metric multidimensional scaling ordination (NMDS; Clarke 1993) to examine patterns in backwater fish communities and relationships with environmental parameters. Non-metric multidimensional scaling ordination is a nonparametric technique that uses rank order information to identify similarities within a data set (Kenkel and Orloci 1986). Rare taxa that occurred in less than 5% of the backwaters were excluded from NMDS analyses. Fish abundance (total catch) data were square root transformed to reduce the influence of dominant taxa. To test for significant relationships between backwater fish communities and environmental parameters we identified significant vectors with $\alpha=0.05$.

We further described backwater fish communities by summarizing ecological niches of fish species present based on the Index of Biotic Integrity (IBI) metrics used by the Minnesota Pollution Control Agency (MPCA 2014). An IBI is a numerical way of characterizing biological integrity, utilizing attributes of the biological community that respond to disturbances in predictable ways to measure the effects of both natural and anthropogenic disturbances (Karr et al. 1981). We summarized ecological niches for

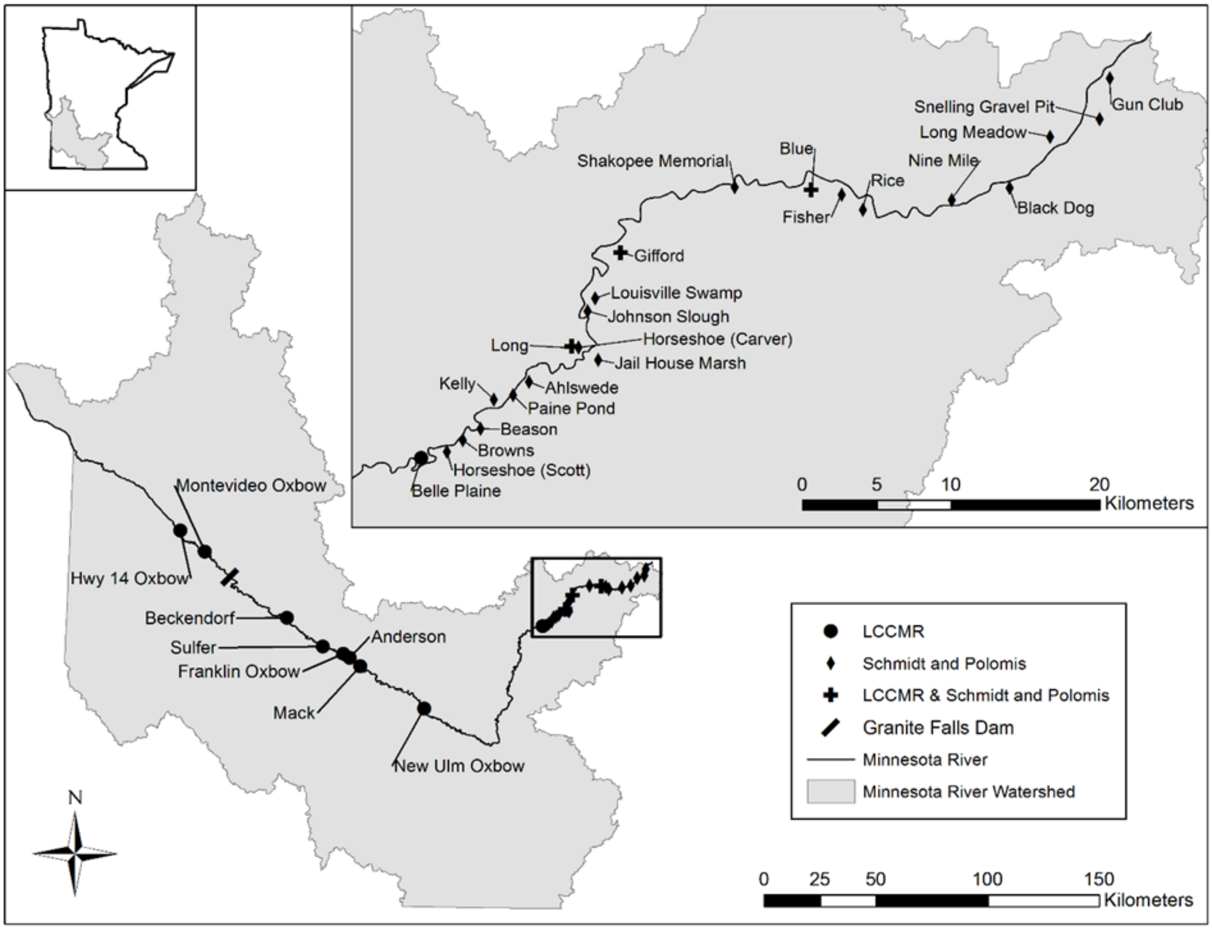

Figure 1. Location of 12 Minnesota River backwaters surveyed during 2016–2018 (i.e., LCCMR) and backwaters surveyed by Schmidt and Polomis (2007).

individual species present (Table S1) in each sampled backwater (Appendix 1.2-12.2).

Results

A total of 12 Minnesota River backwaters that represent the spatial and physical diversity of backwaters within the Minnesota River floodplain were sampled during August 2016–September 2018 (Figure 1; Table 2). Backwaters varied from 2 to 106 ha in surface area, from 1.2 to 4.6 m in maximum depth, and associated rkm from 32 to 433 (Table 2). Fish species richness varied 14–30 among backwaters, with a total of 51 unique species captured that represent 14 fish families. We compared the 51 species sampled during this study with species captured by Schmidt and Polomis (2007) and Nickel (2014) and found that Black Crappie, Common Carp, and Bluegill are captured in almost every (94–97%) backwater fisheries survey (Table 3). We also captured several “rarer” backwater species during our surveys, including Blackchin Shiner, Longnose Gar, and Mooneye. The 51 species captured have a wide diversity of feeding habits, spawning behaviors, pollution tolerances, and preferred habitats and varied from small darter species, such as Johnny Darters, to large predators, such as Flathead Catfish (Table S1, Table 4).

Table 3. Percent occurrence of 61 fish species sampled from Minnesota River backwaters during this study, Schmidt and Polomis (2007), Nickel (2014), and all surveys combined (including re-surveyed backwaters).

Species	This study	Schmidt & Polomis (2007)	Nickel (2014)	Combined
Bigmouth Buffalo	100	65	100	80
Black Crappie	100	90	100	94
Common Carp	100	95	100	97
Black Bullhead	92	80	100	86
Bluegill	92	95	100	94
Orangespotted Sunfish	92	90	100	91
Emerald Shiner	83	75	100	80
Walleye	83	70	100	77
White Crappie	83	65	100	74
Freshwater Drum	75	70	100	74
Gizzard Shad	75	85	100	83
Largemouth Bass	75	90	100	86
River Carpsucker	75	20	100	46
Spotfin Shiner	67	65	100	69
Yellow Perch	67	60	67	63
Bluntnose Minnow	58	35	100	49
Channel Catfish	58	40	33	46
Fathead Minnow	58	55	67	57
Golden Shiner	58	70	33	63
Green Sunfish	58	90	67	77
Northern Pike	58	70	100	69
Yellow Bullhead	58	50	100	57
Hybrid Sunfish	50	85	100	74
Shorthead Redhorse	50	35	100	46
Smallmouth Buffalo	50	60	33	54
White Sucker	50	40	100	49
Bowfin	33	80	33	60
Central Mudminnow	33	35	0	31
Johnny Darter	33	50	33	43
Sand Shiner	33	35	67	37
Shortnose Gar	33	35	67	37

The majority of species sampled (38 of 51) are generally considered to prefer pool habitats while species that prefer both pool and riffle habitats represented 24.5% of the total catch, and species that prefer riffle habitats accounted for less than 1% of the total catch (Table 4).

Land cover within the riparian zone of all sampled backwaters primarily consists of wetlands and forests, with low amounts of agriculture and human disturbance. When expanding to the 500 m zone, the amount of wetlands and forests decreases and the

Table 3. Continued

Species	This study	Schmidt & Polomis (2007)	Nickel (2014)	Combined
White Bass	33	20	33	26
Common Shiner	25	0	33	11
Pumpkinseed	25	95	33	66
Silver Redhorse	25	0	100	17
Spottail Shiner	25	0	0	9
Weed Shiner	25	25	0	23
Brook Stickleback	17	5	0	9
Brown Bullhead	17	10	0	11
Flathead Catfish	17	10	0	11
Quillback	17	25	33	23
Sauger	17	5	33	11
Slenderhead Darter	17	10	0	11
Tadpole Madtom	17	40	33	31
Blackchin Shiner	8	0	0	3
Brassy Minnow	8	15	0	11
Bullhead Minnow	8	15	0	11
Creek Chub	8	20	33	17
Highfin Carpsucker	8	0	33	6
Longnose Gar	8	0	0	3
Mooneye	8	0	0	3
Bigmouth Shiner	0	5	0	3
Black Buffalo	0	5	0	3
Blacknose Dace	0	5	0	3
Brook Silverside	0	20	0	11
Golden Redhorse	0	0	100	9
Hornyhead Chub	0	20	0	11
Iowa Darter	0	60	0	34
Logperch	0	15	0	9
Northern Redbelly Dace	0	5	0	3
Stonecat	0	0	67	6

amount of agricultural land use increases. This trend continues at the 1,000 m and 5,000 m zones, where wetlands and forests represent a small proportion of land cover (Table 5).

The NMDS ordination reveals a significant influence of river kilometer (i.e., distance from the mouth of the Minnesota River) on fish communities found in Minnesota River backwater habitats during this study (R^2 = 0.17, P < 0.05; Figure 2). For instance, upstream backwaters are more often associated with greater abundances of

Table 4. Overview of ecological niches of fish sampled in 12 Minnesota River backwaters during 2016–2018.

Niche	Total species	Total catch	Percent composition
Feeding guild			
Filter Feeder	1	603	5.3
Generalist	2	9	0.1
Herbivore	2	111	1.0
Insectivore	27	6,924	60.8
Omnivore	7	1,401	12.3
Piscivore	12	2,346	20.6
Spawning behavior			
Complex/No Parental Care	2	9	0.1
Complex/Parental Care	21	7,717	67.7
Simple Lithophil	7	200	1.8
Simple Miscellaneous	21	3,468	30.4
Pollution tolerance			
Intolerant	6	147	1.3
Tolerant	9	2,524	22.2
Preferred habitat			
Pools	38	8,604	75.5
Pools and Riffles	12	2,788	24.5
Riffles	1	2	0.02
Headwaters	1	2	0.02
Large Rivers	20	852	7.5
Pioneer	5	1,089	9.6

minnow and darter species while downstream backwaters are associated with greater abundances of sucker and centrarchid species. The NMDS analysis did not identify significant relationships between sampled fish communities and connectivity to the main channel or surface area. However, when we included fish communities sampled in Minnesota River backwaters by Schmidt and Polomis (2007), the significant influence of river kilometer remained (R^2 = 0.07, $P < 0.05$) and the influence of backwater surface area was also identified as significant (R^2 = 0.06, $P < 0.05$; Figure 3).

To help refine protocols for monitoring backwater fish communities, we visually compared fish species captured by each sample gear with a Venn diagram (Figure 4). We determined that seining and boat electrofishing are the most effective methods for sampling the greatest number of fish species in backwater habitats. For instance, 40 of the 51 species were captured with 3.2 mm delta mesh seines while 38 of the 51 species were captured by boat electrofishing. Overall, 98% of the fish species captured during this study were captured at least once with a combination of these two gears.

Anderson Lake

Anderson Lake is a 6 hectare flow-through backwater located at rkm 283 with a maximum depth of 2.7 m at the time of the survey (Figure 1; Table 2). Connection with the main channel is frequent, with connecting channels located at the west (upstream) and

Table 5. Summary of landscape and riparian level land cover properties determined for twelve backwater lakes in the Minnesota River floodplain.

Land cover type	Mean %	CV	Min %	Max %
Riparian Zone				
Agriculture	16	94	0	46
Forest	25	93	0	61
Wetlands	49	65	0	97
Human disturbance	10	164	0	54
Watershed - 500 m band				
Agriculture	26	53	2	54
Forest	16	50	0	26
Wetlands	29	48	9	60
Human disturbance	9	69	3	22
Open water	19	63	5	38
Watershed - 1,000 m band				
Agriculture	33	37	13	54
Forest	14	52	1	26
Wetlands	25	38	8	43
Human disturbance	12	92	3	37
Open water	17	51	4	31
Watershed - 5,000 m band				
Agriculture	58	30	13	74
Forest	11	46	2	19
Wetlands	10	37	4	16
Human disturbance	14	108	4	60
Open water	7	65	2	14

east (downstream) ends of the backwater. Anderson Lake was previously sampled in 2012 by Nickel (2014). We conducted a fisheries assessment of Anderson Lake during June 2018 using fyke nets, seines, and boat electrofishing. A total of 258 individual fish were sampled, representing 24 species and 9 families (Appendix 1.1). Spotfin Shiner represented 25% of the total catch and four of the five most abundant species were cyprinids (Spotfin Shiner, Bluntnose Minnow, Bullhead Minnow, and Fathead Minnow). Fifty-five percent of the species captured from Anderson Lake are considered lentic or “pool” species, including Central Mudminnow, Bluegill, and Crappie (Appendix 1.2). In fact, very few species captured from Anderson Lake are strongly associated with flowing water (e.g., redhorse spp., Sauger, and Slenderhead Darter). This is surprising because we believe Anderson Lake frequently connects with the main channel of the Minnesota River. NMDS analysis indicated the Anderson Lake backwater fish community is most similar to Sulfur Lake and is one of the few backwaters where we captured Common Shiner (Figure 2). Nickel (2014) also frequently captured Bluntnose Minnow and Bigmouth Buffalo from Anderson Lake, but reported catching 15 other species throughout the year that we did not sample during our assessment. Riparian zone land cover of this backwater is dominated by wetlands (90%), which decreases to 12% at the

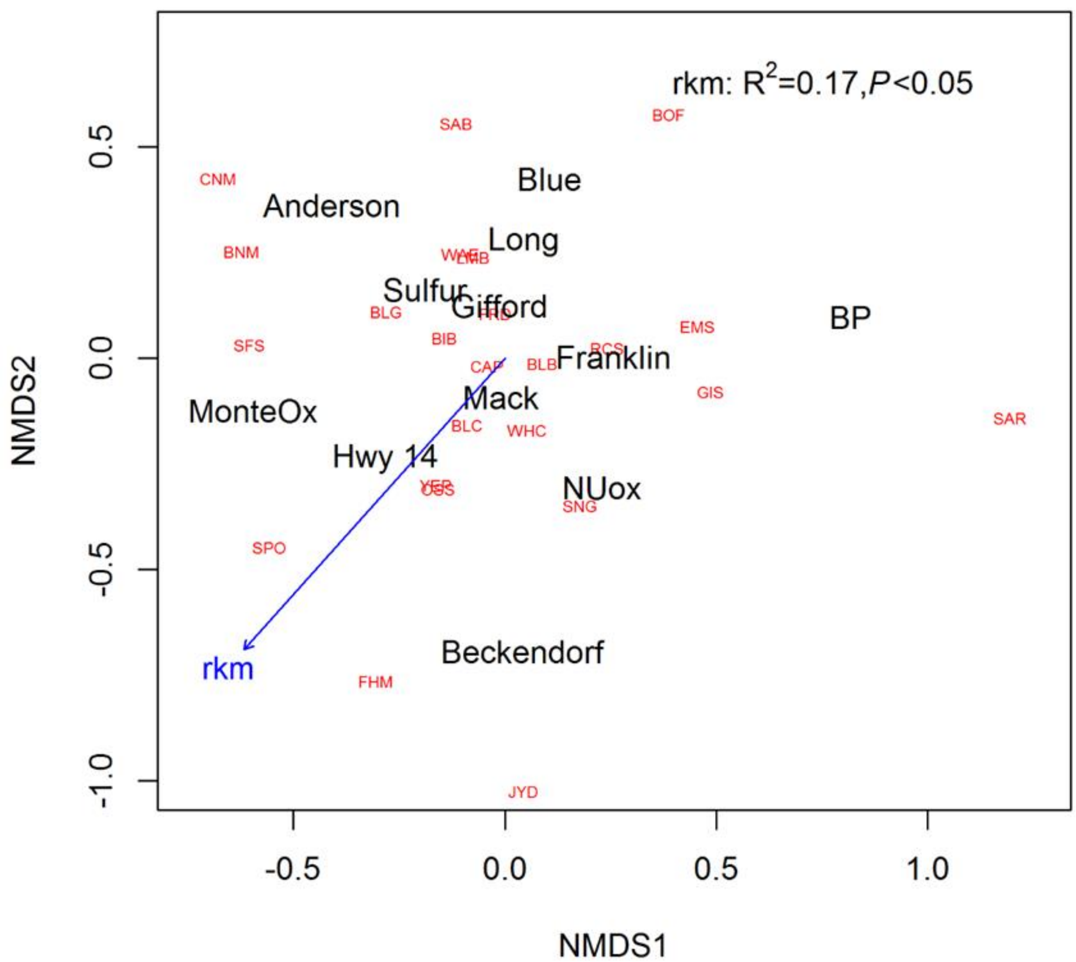

Figure 2. Non-metric multidimensional scaling ordination for fish communities sampled in 12 Minnesota River backwaters. Backwaters (black) further away in ordination space are more dissimilar than backwaters that are close to one another. Backwater sites near fish species (red) in ordination space are associated with greater catches while fish species further away from backwater sites are associated with lower catches. River kilometer (rkm; P <0.05) is a significant vector associated with backwater fish communities.

5,000 m zone where agriculture represents 70% of the land cover (Appendix 1.3).

Beckendorf Lake

Beckendorf Lake is a 25 hectare floodplain lake located at rkm 336 with a maximum depth of 1.7 m at the time of the survey (Figure 1; Table 2). Connection with the Minnesota River is infrequent, with connection only occurring during flood events through a small intermittent channel located on the southeast end of the lake. We conducted a fisheries assessment of Beckendorf Lake during June 2017 using fyke nets, seines, and boat electrofishing. A Total of 1,306 individual fish were sampled,

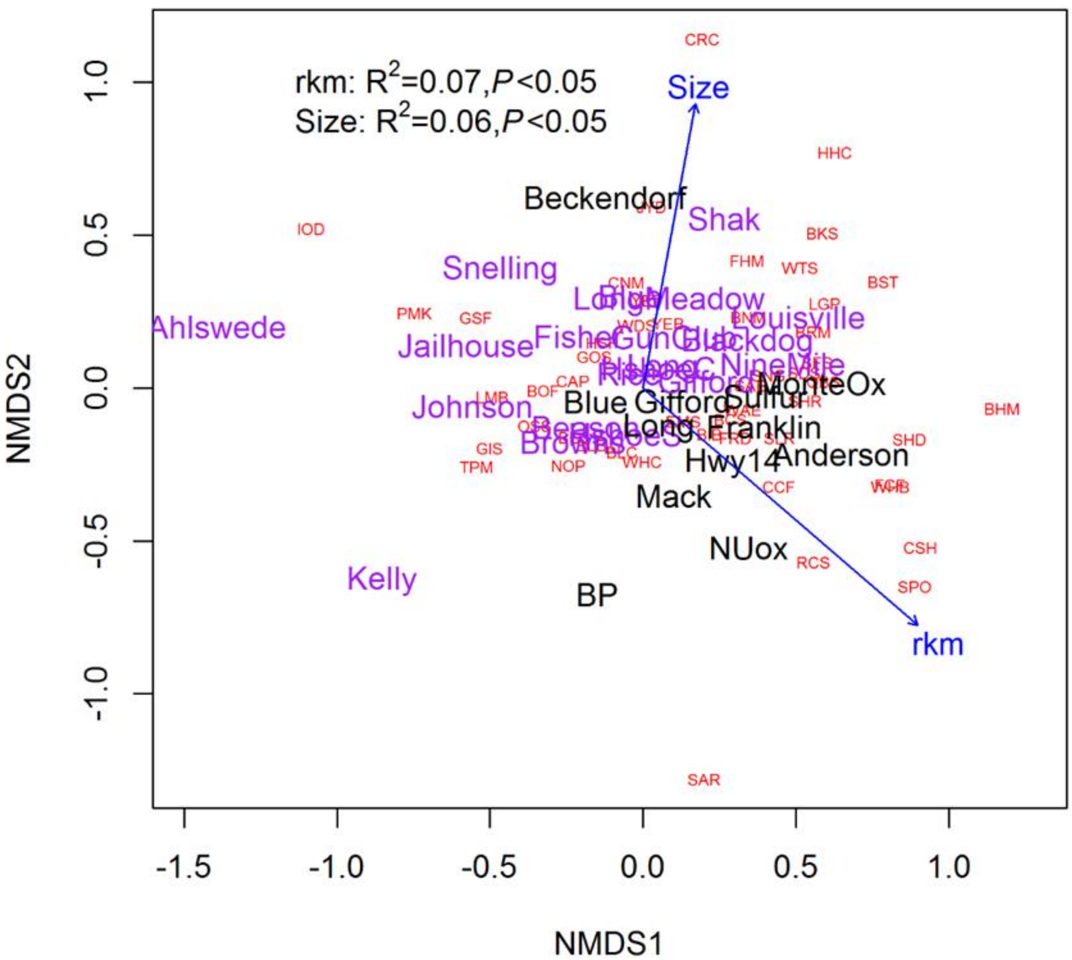

Figure 3. Non-metric multidimensional scaling ordination including 12 backwaters (black) surveyed during 2016–2018 for this study and 20 backwaters (purple) surveyed by Schmidt and Polomis (2007). River kilometer (rkm; *P* <0.05) and size (*P* <0.05) are significant vectors associated with backwaters fish communities.

representing 17 species and 8 families (Appendix 2.1). Fathead Minnows represented 52% of the total catch, and two of the five most abundant species were centrarchids (e.g., Black Crappie, and Orangespotted Sunfish). Beckendorf Lake is the only backwater where we sampled Creek Chubs, but Creek Chubs were present in 17% of previous Minnesota River backwater surveys (Table 3). Forty-six percent of the fish species sampled from Beckendorf Lake are considered lentic species, including Black Crappie, Orangespotted Sunfish, White Crappie and Yellow Perch (Appendix 2.2). NMDS analysis indicated that Beckendorf Lake is most similar to the New Ulm Oxbow and generally has a similar fish community as other upstream backwaters (Figure 2). Riparian zone land cover surrounding Beckendorf Lake is dominated by wetlands (69%), which

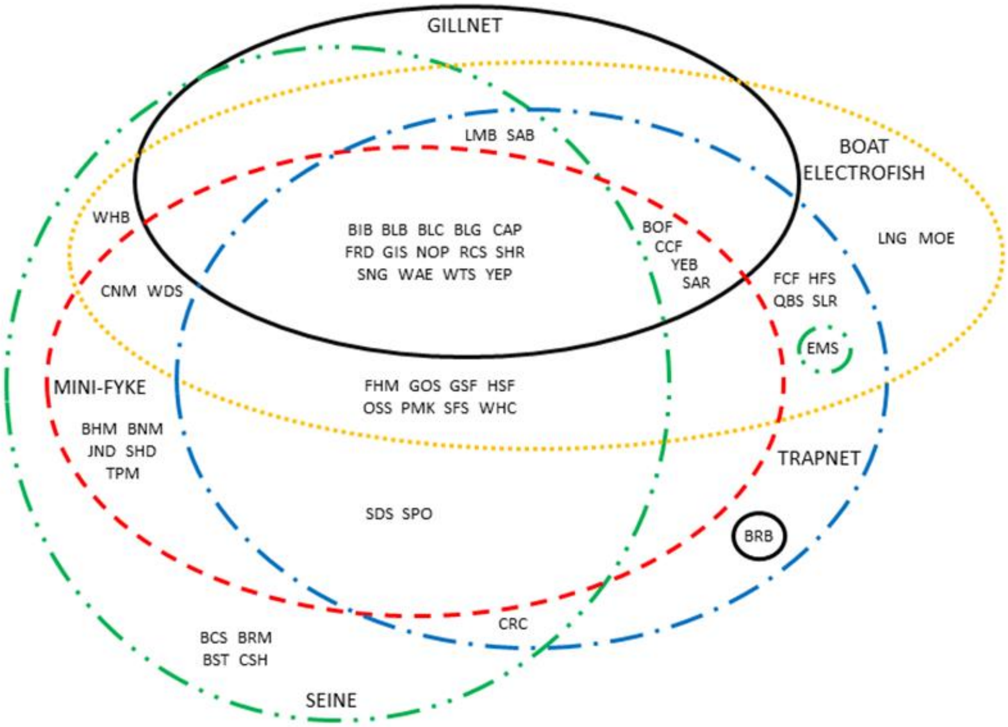

Figure 4. Venn diagram depicting which fish sampling gears (boat electrofishing, gill nets, mini-fyke nets, seines, and trap nets) captured each of 51 fish species from 12 Minnesota River backwaters surveyed during 2016–2018. Three letter fish species codes are defined in Table S2. Note that Emerald Shiners were captured with boat electrofishing, trap nets, and seines and Brown Bullheads were captured with gill nets and trap nets.

decreases to 8 percent at the 5,000 m zone where agriculture represents 72% of the land cover (Appendix 2.3).

Belle Plaine

The Belle Plaine backwater (rkm 82) is located along Hwy 25 north of Belle Plaine, MN (Figure 1; Table 2). It is a remnant oxbow lake that formed prior to 1938 (oldest aerial photo available) and has a surface area of 4 hectares and a maximum depth of 4.7 m at the time of the survey (Table 2). Connectivity with the main channel is low, only connecting during periods of high water via overland flow. We conducted a fisheries assessment of the Belle Plaine backwater during September 2016 using fyke nets, gillnets, and boat electrofishing. A total of 103 individual fish were sampled, representing 14 species and 8 families (Appendix 3.1). Gizzard Shad, Emerald Shiner, and Black Crappie were the three most abundant species sampled. The fish community in the Belle Plaine backwater consists mostly of “lentic” fish species, with all 14 species preferring pool habitats. However, seven large river fish species (e.g., Bigmouth Buffalo, River Carpsucker, and Sauger) were also sampled (Appendix 3.2). Ordination analysis indicated that the Belle Plaine fish community is most similar to the Franklin Oxbow, and is associated with presence of Sauger (Figure 2). Human disturbance is high (54%) in the riparian zone surrounding the Belle Plaine backwater, while forest-cover

(15%) and wetland (31%) land cover types are low (Appendix 3.3).

Blue Lake

Blue Lake is a 106 hectare floodplain lake located at rkm 32 with a maximum depth of 1.4 m at the time of the survey (Figure 1; Table 2). A connection with the main channel exists on the west side of the lake, but due to the presence of a water control structure, connectivity is considered moderate (Table 2). Blue Lake also has connections to Fisher Lake and Rice Lake, which are located to the east. Blue Lake was previously sampled by Schmidt and Polomis (2007). We conducted a fisheries assessment of Blue Lake during September 2018 using fyke nets, seines, and gillnets. A total of 660 individual fish were sampled, representing 23 species and 9 families (Appendix 4.1). Blue Lake appears to be important habitat for centrarchid species which were one-third of the total species sampled. Bluegill (32%) and Black Crappie (18%) were the most abundant species. Interestingly, Weed Shiner were the third most abundant species, representing 16% of the total catch. Weed Shiners were surveyed in three of the twelve study backwaters, and 23 percent of all other Minnesota River backwater surveys (Table 3). Brown Bullheads were also sampled from Blue Lake which were only sampled from one other backwater during this study. Schmidt and Polomis (2006) sampled two Brown Bullhead during their survey on Blue Lake, and similarly only sampled them in one other backwater. Schmidt and Polomis (2007) also reported catching high numbers of Spotfin Shiners and Golden Shiners, however both species represented one percent or less of our total catch. Nearly all species (99.8%) sampled from Blue Lake are considered lentic or “pool” species (Appendix 4.2). The Blue Lake fish community was most similar to Long Lake, and was most associated with high catches of Smallmouth Buffalo and Bowfin (Figure 2). Riparian zone land cover surrounding Blue Lake is primarily forest-cover (56%) and wetlands (41%), which decreases at larger scales out to the 5,000 m zone where human disturbance (60%) becomes the most common land cover type (Appendix 4.3).

Franklin Oxbow

Franklin Oxbow is a 3 hectare oxbow lake located at rkm 290, just upstream from the Franklin boat ramp (Figure 1; Table 2). The Franklin Oxbow maintains an almost constant connection with the main channel during normal water levels, and had a maximum depth of 1.4 m at the time of the survey (Table 2). We conducted a fisheries assessment of Franklin Oxbow during October 2016 using fyke nets, seines, and boat electrofishing. A total of 638 individual fish were sampled, representing 25 species and 8 families (Appendix 5.1). Gizzard Shad represented 32 percent of the total catch while Spotfin Shiner and Orangespotted Sunfish both represented 19 percent of the total catch. These species were commonly sampled in other backwater surveys, however several unique species were sampled from the Franklin Oxbow. The Franklin Oxbow is the only backwater where we sampled Highfin Carpsucker and Mooneye, and one of two backwaters where we sampled Quillback. These species are considered “riverine” species, and were sampled in few Minnesota River backwaters (Table 3). These species and seven other large river species are likely more common in the Franklin Oxbow than the other backwaters we sampled due to the high level of connectivity with the main channel (Appendix 5.2). Two pollution intolerant species (Highfin Carpsucker and Mooneye) were sampled during the survey. Wetlands are the dominant land cover type in the riparian zone (97%) but agriculture land cover increases at larger scales (Appendix 5.3)

Gifford Lake

Gifford Lake is a 76 hectare floodplain lake located at rkm 51 and had a maximum depth of 4.1 m at the time of the survey (Figure 1; Table 2). Two channels connect Gifford Lake with the main channel, one at the south end and the other at the north end. Connectivity is considered moderate due to the presence of a water control structure located at the north end (and possibly the south end). Gifford Lake was previously sampled by Schmidt and Polomis (2007). We conducted a fisheries assessment of Gifford Lake using fyke nets and seines (May 2017) and boat electrofishing (June 2017). A total of 1,044 individual fish were sampled, representing 30 species and 9 families (Appendix 6.1). Black Bullhead were the most abundant species, representing 41% of the total catch, followed by Bluegill (18%) and Common Carp (7%). A wide variety of species were sampled including six catostomid species, eight centrarchid species, and eight cyprinid species. Schmidt and Polomis (2007) reported catching Logperch and Slenderhead Darter in Gifford Lake, which we did not capture during our survey and are seldom caught in other Minnesota River backwaters (Table 3). Gifford Lake is also one of three backwaters where we sampled Weed Shiners. Ninety-seven percent of the fish community sampled from Gifford Lake are considered lentic or “pool” species, but we also captured 10 large river species (Appendix 6.2). The fish community in Gifford Lake is most similar to Sulfur Lake and is associated with higher catches of Freshwater Drum (Figure 2). Riparian zone land cover is primarily wetlands (61%), but quickly decreases at larger scales to around 16-19% in the 500-5,000 m zones where agriculture (40%) becomes the dominant land cover type at the 5,000 m zone (Appendix 6.3).

Highway 14 Oxbow

The Highway 14 Oxbow is a 2 hectare oxbow lake located at rkm 433 (38 rkm upstream of the Granite Falls Dam; Figure 1; Table 2). Connectivity with the main channel is high, remaining connected during normal water levels through a connection at the downstream end of the oxbow. However, the mouth of the backwater appears to be filling with sediment. The majority of the backwater was relatively deep, with a maximum depth of 2.4 m during the time of the survey (Table 2). We conducted a fisheries assessment of the Highway 14 Oxbow using fyke nets and seines during June 2018 and boat electrofishing during July 2018. A total of 1,514 individual fish were sampled, representing 24 species and 9 families (Appendix 7.1). Centrarchid species were very abundant in the Highway 14 Oxbow, with Black Crappie representing 84% of the total catch, and Bluegill (second most abundant species) representing 4% of the total catch. Based on the abundance of Black Crappie and Bluegill, it is apparent that centrarchid species utilize this backwater for spawning and nursery habitat. Several other centrarchid species were captured during the survey including Orangespotted Sunfish, Largemouth Bass, Hybrid Sunfish, and White Crappie. Seven large river species were captured during the survey, and represented 3% of the total catch (Appendix 7.2). The fish community inhabiting the Highway 14 Oxbow was most similar to the Montevideo Oxbow with uniquely high catches of Yellow Perch and Orangespotted Sunfish (Figure 2). Riparian zone land cover is primarily forest (48%) and wetlands (33%), with both types decreasing to 11% in the 5,000 m zone (Appendix 7.3).

Long Lake

Long Lake is a 28 hectare floodplain lake located at rkm 63 with a maximum depth of 2.0 m at the time of the survey (Figure 1; Table 2). Connectivity with the main channel is considered moderate, connecting during high water periods via overland flow. There are also several channels located along the northeast end of the backwater, but connection frequency of those channel is unknown. Long Lake also has a connection to Horseshoe Lake via a channel located at the north end. Long Lake was previously sampled in 2006 by Schmidt and Polomis (2007). We conducted a fisheries assessment of Long Lake during September 2018 using fyke nets, seines, and gillnets. A total of 1,202 individual fish were sampled, representing 27 species and 10 families (Appendix 8.1). Bluegill, Black Bullhead, and Sand Shiner were the three most abundant species, and combined represented 73% of the total catch. Sand Shiner were not sampled in Long Lake by Schmidt and Polomis (2007) but they represented 20% of our total catch. Other species that were sampled in Long Lake that were infrequently sampled in other backwaters surveyed include Bowfin, Silver Redhorse, Brown Bullhead, Tadpole Madtom, and Shortnose Gar (Table 3). Schmidt and Polomis (2007) reported catching three darter species that we did not sample including Iowa Darter, Johnny Darter, and Logperch. Although the majority of species in Long Lake are considered lentic, three species considered "riverine" represented 21% of the total catch (Appendix 8.2). The fish community in Long Lake was most similar to Blue Lake, the only other backwater where we captured Brown Bullheads which are infrequently sampled in Minnesota River backwaters. Riparian zone land cover contains high percentages of agriculture (46%) and forest-cover (46%), with both types decreasing in the 500-1,000 m zones (Appendix 8.3).

Mack Lake

Mack Lake is a 6 hectare floodplain backwater located at rkm 275 and had a maximum depth of 2.0 m at the time of the survey (Figure 1; Table 2). Connectivity is considered high with numerous channels connecting to the main channel and other surrounding backwaters. We conducted a fisheries assessment of Mack Lake during September 2016 using fyke nets, seines, and boat electrofishing. A total of 698 individual fish were sampled, representing 22 species and 9 families (Appendix 9.1). Black Bullhead represented 31% of the total catch, and three of the five most abundant species are centrarchids including Bluegill, Orangespotted Sunfish, and Black Crappie. Centrarchid species are generally considered lentic species, and lentic species represented 99 percent of the total catch from Mack Lake (Appendix 9.2). The lack of riverine species is surprising due to the frequent connection with the main channel. The Mack Lake fish community was most similar to Franklin Oxbow and Highway 14 Oxbow which are all associated with higher catches of Black Crappie, White Crappie, and Common Carp (Figure 2). Land cover in the riparian zone of Mack Lake consists of moderate amounts of forest-cover (37%) and wetlands (29%), which decrease at the 5,000 m zone to 10% and 9%, respectively (Appendix 9.3).

Montevideo Oxbow

The Montevideo Oxbow is located at rkm 407 (12 rkm upstream of the Granite Falls Dam), and has a surface area of 4 hectares and a maximum depth of 1.2 m at the time of the survey (Figure 1; Table 2). Connectivity is high, maintaining an almost constant connection with the main channel at the downstream end of the oxbow. We conducted a fisheries assessment of the Montevideo Oxbow during August 2016 using fyke nets and seines. A total of 3,363 individual fish were sampled, representing 28 species and 9 families (Appendix 10.1). Bluegill and Spotfin Shiner were the two most abundant species, representing 48% and 36% of the total catch, respectively. Several species that were infrequently sampled in other backwater were surveyed in the Montevideo Oxbow including Central Mudminnow, Johnny Darter, Tadpole Madtom, Brook Stickleback, Spottail Shiner, Sand Shiner, and Brassy Minnow (Table 3; Appendix 10.1). Even though Bluegills and other centrarchid species were in high abundance, a mix of species classified as lentic (58%) and riverine (42%) were captured during the survey (Appendix 10.2). The NMDS analysis indicated that the Montevideo Oxbow fish community was most similar to the Highway 14 Oxbow (Figure 2). Land cover in the riparian zone is dominated by wetlands (69%), but decreases at larger scales to 10% in the 5,000 m zone where agriculture (74 %) is the dominant land cover type (Appendix 10.3).

New Ulm Oxbow

The New Ulm Oxbow is located at rkm 219, has a surface area of 8 hectares, and a maximum depth of 3.2 m at the time of the survey (Figure 1; Table 2). Connectivity is considered high, maintaining a constant connection with the main channel at both ends of the oxbow. We conducted a fisheries assessment of the New Ulm Oxbow using fyke nets (July 2017) and boat electrofishing (August 2017). A total of 303 individual fish were sampled, representing 23 species and 10 families (Appendix 11.1). Orangespotted Sunfish represented 20% of the total catch, while five of the six most abundant species are considered riverine species including Gizzard Shad, Bigmouth Buffalo, River Carpsucker, Shortnose Gar, and Freshwater Drum. Spottail Shiner are typically only captured from oxbow lakes with frequent connections to the main channel (Table 3). Ten large river species were sampled from the New Ulm Oxbow, representing 33% of the total catch (Appendix 11.2). Both Sauger and Slenderhead Darter were sampled from the New Ulm Oxbow and were only sampled in one other backwater during this project. Both species are considered “riverine”, and have been sampled infrequently captured during other Minnesota River backwater surveys. The fish community in the New Ulm Oxbow was most similar to the fish community in Mack Lake (Figure 2). Land cover in the riparian zone of the New Ulm Oxbow consists primarily of wetlands (69%), which quickly decrease at larger scales to 11% in the 5,000 m zone where agriculture (57%) becomes the dominant land cover type (Appendix 11.3).

Sulfur Lake

Sulfur Lake is located at rkm 306, and has a surface area of 3 hectares and a maximum depth of 4.6 m during the time of the survey (Figure 1; Table 2). Connectivity is considered low, only connecting with the main channel during high water periods via overland flow. We conducted a fisheries assessment of Sulfur Lake during May and June 2017 using fyke nets, gill nets, seines, and boat electrofishing. A total of 304 individual fish were sampled, representing 29 species and 7 families (Appendix 12.1). Spotfin Shiner were the most abundant species in Sulfur Lake, representing 18% of the total catch, followed by Bigmouth Buffalo (15%) and Bluegill (12%). Lentic or “pool” species represented 74% of the total catch while the remaining 26% are classified as “riverine” species (Appendix 12.2). Besides Sulfur Lake, we only sampled Quillback in one other backwater (Table 3). Land cover in the riparian zone of Sulfur Lake is primarily wetlands (55%), which decreases to 16% in the 5,000 m zone, where agriculture (65%) becomes the dominant land cover type (Appendix 12.3).

Discussion

Through funding provided by the ENRTF we evaluated fish communities inhabiting a diversity of Minnesota River backwaters distributed throughout the floodplain. This dataset will be useful for monitoring future changes in backwater fish communities and increasing understanding ecological function of Minnesota River backwater habitats. The results of this study highlight the diversity of habitat types and fish species present within the Minnesota River floodplain. Evaluated backwaters varied in surface area from 2 to 106 ha, maximum depth from 1.2 to 4.6 m, and in connectivity with the main channel from infrequently (e.g., Beckendorf, Belle Plaine) to almost always (e.g., Franklin Oxbow, New Ulm Oxbow). Fifty-one unique fish species representing 14 families were sampled from evaluated backwaters and represent a diversity of feeding habits, spawning behaviors, pollution tolerances, and preferred habitat types.

We utilized a suite of sampling gears to assess backwater fish communities including boat electrofishing, fyke nets, seines, and gill nets. Each sample gear is selective for certain species or sizes of fish (Murphy and Willis 1996), but we reduced overall sampling biases by using multiple methods to capture fish. To help refine backwater fish community sampling protocols, we compared fish species sampled by each gear type for all surveys combined. Seines captured the most species (40 of 51 species) while gillnets (standard and large mesh combined) captured the fewest species (21 of 51). Seining and boat electrofishing combined captured 98% of the unique fish species sampled during this study. Thus, similar to Knight and Bain (1996) and Clement et al. (2014) we recommend using seines and boat electrofishing as the primary methods for assessing fish species diversity in Minnesota River backwaters. Knight and Bain (1996) reported that electrofishing was the most effective gear for assessing floodplain wetland fish communities and that electrofishing accounted for the most fish (total catch), almost all taxa, and a broad range of fish sizes. Clement et al. (2014) reported that fine mesh seines were responsible for the majority of fish captured in small Michigan lakes, and were effective at sampling small to medium sized fish. The use of boat electrofishing and seining targets both small and large bodied fishes, and will likely provide the most efficient assessment of backwater fish assemblages. Unfortunately, seining can be ineffective in steep sided or heavily vegetated backwaters while some backwaters may be inaccessible by a large electrofishing boat. In those instances, fyke nets, gill nets, and backpack electrofishing might be the best options for characterizing the fish community.

Physical features play an important role in structuring backwater fish communities, such as surface area, depth, substrate, macrophyte cover, location, and connectivity (Ward et al. 1999; Miranda 2005; Zeug and Winemiller 2007; Shoup and Wahl 2009). We hypothesized that river kilometer (i.e., distance from river mouth), surface area, and connectivity are among the most influential characteristics structuring fish communities in Minnesota River backwaters. Based on ordination analyses, we concluded that river kilometer and surface area significantly influence Minnesota River backwater fish communities, but not necessarily our subjective determination of connectivity. The insignificant influence of connectivity on backwater fish communities in the Minnesota River was unexpected based on its well documented influence in other studies (Junk et al. 1989; Galat et al. 1998; Winemiller et al. 2000; Petry et al. 2003; Slipke et al. 2005). For instance, Dembkowski and Miranda (2011) highlighted the importance of connectivity in a study on two disjoined segments of an oxbow lake. They reported a more diverse fish community in the smaller more frequently connected segment compared to a larger isolated segment. Miranda (2005) also noted that more species were observed in oxbow lakes that connect to the Mississippi River than in lakes isolated from the river. Despite inconclusive results from our analyses, we suspect connectivity does play an important role in structuring fish communities in Minnesota River backwaters and a larger scale study may help reveal the importance of this influence.

Altered hydrology resulting from land use and climate change may impact Minnesota River backwater fish communities. Over the past century land use practices such as subsurface and surface drainage have increased, and annual precipitation and magnitude of single rain events have increased. These factors result in increased discharge, more flood events, and altered flood pulse timing and duration. It is well understood that these factors are important to the ecological function of backwaters and in structuring fish communities that inhabit them (Junk et al. 1989; Ward 1989; Bayley 1995; Bowen et al. 2003; King et al. 2003). Increased precipitation and discharge may also lead to increased runoff and erosion, leading to increased turbidity, sediment transport, and deposition (Lenhart et al. 2011; Lauer et al. 2017). Increased sediment deposition can accelerate sedimentation of backwaters, reduce primary productivity (Cooper and Bacon 1980), and can degrade critical habitats for spawning and foraging (Waters 1995; Henley et al. 2000). For example, Berkman and Rabeni (1987) documented reduced spawning success of substrate and pelagic spawners from deposition of sediment over eggs, while fish that exhibit parental care (i.e., fin fanning and mouthing) were more successful in turbid habitats.

Climate change and altered hydrology are not the only factors threatening changes to Minnesota River backwater ecosystems and fish communities. Impacts from invasive carps such as Bighead Carp and Silver Carp are expected if they become established in the Minnesota River. Invasive carps utilize backwaters for feeding and nursery habitat (Pegg et al. 2002; Kolar et al. 2007) and could compete with native fishes for food and space resources (Schrank et al. 2003; Cooke et al. 2009). Sampson et al. (2009) documented diet overlap among Bighead Carp, Silver Carp, Paddlefish, Bigmouth Buffalo, and Gizzard Shad in backwater lakes along the Illinois River and Mississippi River and reported that invasive carps could have negative impacts on crustacean zooplankton communities. Sass et al. (2014) documented a reduction in cladoceran and copepod abundance associated with establishment of invasive carps in the Illinois River. Changes in the zooplankton community may have implications for the food web and native species that rely on zooplankton during various life stages. Increased competition and reduced availability of zooplankton resources may also reduce the growth and condition of native fishes. For example, Irons et al. (2007) reported significant declines in body condition of Gizzard Shad and Bigmouth Buffalo following the establishment of invasive carps in the Illinois River. The extent of the impact invasive carps may have on Minnesota River backwater fish communities is difficult to predict, but they will likely have measurable impacts.

The Minnesota River floodplain provides valuable habitat for fishes and other organisms and plays a critical role in the large river ecosystem. Unfortunately, the extent of impacts from climate change, land use alteration, and invasive species on Minnesota River backwater fish communities is unknown. Collection of fish community data from a diversity of Minnesota River backwaters increases understanding of Minnesota River backwater ecosystems and utilization by fishes. Outcomes of this project provide the DNR and other agencies with refined protocols for monitoring backwater fish communities and the ability to identify changes in backwater fish communities attributed to future perturbations such as altered hydrology, land use changes, or establishment of invasive species.

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Supplemental Materials

Table S 1. Ecological niches of fish sampled in Minnesota River backwaters during 2016–2018.

Species	Feeding guild	Spawning behavior	Pollution tolerance	Preferred river habitat
Amiidae Family				
Bowfin	Piscivore	Complex/parental care		Pools, large rivers
Catostomidae Family				
Bigmouth Buffalo	Insectivore	Simple miscellaneous		Pools, large rivers
Highfin Carpsucker	Insectivore	Simple miscellaneous	Intolerant	Pools, large rivers
Quillback	Omnivore	Simple miscellaneous		Pools
River Carpsucker	Omnivore	Simple miscellaneous		Pools, large rivers
Shorthead Redhorse	Insectivore	Simple lithophil		Pools, large rivers
Silver Redhorse	Insectivore	Simple lithophil		Pools, large rivers
Smallmouth Buffalo	Insectivore	Simple miscellaneous		Pools, large rivers
White Sucker	Omnivore	Simple lithophil	Tolerant	Pools and riffles
Centrarchidae Family				
Black Crappie	Piscivore	Complex/parental care		Pools
Bluegill	Insectivore	Complex/parental care		Pools
Green Sunfish	Insectivore	Complex/parental care	Tolerant	Pools, pioneer
Largemouth Bass	Piscivore	Complex/parental care		Pools
Orangespotted Sunfish	Insectivore	Complex/parental care		Pools
Pumpkinseed	Insectivore	Complex/parental care		Pools
White Crappie	Piscivore	Complex/parental care		Pools
Clupeidae Family				
Gizzard Shad	Filter feeder	Simple miscellaneous		Pools

Species	Feeding guild	Spawning behavior	Pollution tolerance	Preferred river habitat
Cyprinidae Family				
Blackchin Shiner	Insectivore	Simple miscellaneous	Intolerant	Pools and riffles
Bluntnose Minnow	Omnivore	Complex/parental care	Tolerant	Pools and riffles, pioneer
Brassy Minnow	Herbivore	Simple miscellaneous		Pools
Bullhead Minnow	Omnivore	Complex/parental care		Pools, large rivers
Common Carp	Omnivore	Simple miscellaneous	Tolerant	Pools
Common Shiner	Generalist feeder	Complex/no parental care		Pools and riffles
Creek Chub	Generalist feeder	Complex/no parental care	Tolerant	Pools and riffles, pioneer
Emerald Shiner	Insectivore	Simple lithophil		Pools, large rivers
Fathead Minnow	Omnivore	Complex/parental care	Tolerant	Pools and riffles, pioneer
Golden Shiner	Insectivore	Simple miscellaneous	Tolerant	Pools
Sand Shiner	Insectivore	Simple miscellaneous		Pools and riffles
Spotfin Shiner	Insectivore	Simple miscellaneous		Pools and riffles
Spottail Shiner	Insectivore	Simple miscellaneous	Intolerant	Pools and riffles
Weed Shiner	Herbivore	Simple miscellaneous	Intolerant	Pools, large rivers
Esocidae Family				
Northern Pike	Piscivore	Simple miscellaneous		Pools
Gasterosteidae Family				
Brook Stickleback	Insectivore	Complex/parental care		Pools, headwaters
Hiodontidae Family				
Mooneye	Insectivore	Simple miscellaneous	Intolerant	Pools, large rivers

Species	Feeding guild	Spawning behavior	Pollution tolerance	Preferred river habitat
Ictaluridae Family				
Black Bullhead	Insectivore	Complex/parental care	Tolerant	Pools
Brown Bullhead	Insectivore	Complex/parental care		Pools
Channel Catfish	Piscivore	Complex/parental care		Pools, large rivers
Flathead Catfish	Piscivore	Complex/parental care		Pools and riffles, large rivers
Tadpole Madtom	Insectivore	Complex/parental care		Pools and riffles
Yellow Bullhead	Insectivore	Complex/parental care		Pools
Lepisosteidae Family				
Longnose Gar	Piscivore	Simple miscellaneous		Pools, large rivers
Shortnose Gar	Piscivore	Simple miscellaneous		Pools, large rivers
Moronidae Family				
White Bass	Piscivore	Simple miscellaneous		Pools, large rivers
Percidae Family				
Johnny Darter	Insectivore	Complex/parental care		Pools and riffles, pioneer
Sauger	Piscivore	Simple lithophil		Pools, large rivers
Slenderhead Darter	Insectivore	Simple lithophil	Intolerant	Riffles, large rivers
Walleye	Piscivore	Simple lithophil		Pools, large rivers
Yellow Perch	Insectivore	Simple miscellaneous		Pools
Sciaenidae Family				
Freshwater Drum	Insectivore	Simple miscellaneous		Pools, large rivers
Umbridae Family				
Central Mudminnow	Insectivore	Complex/parental care	Tolerant	Pools

Table S 2. List of the 51 fish species (and three letter species codes) sampled in twelve Minnesota River backwaters during 2016–2018.

Species			
Bigmouth Buffalo **(BIB)**	Common Carp **(CAP)**	Largemouth Bass **(LMB)**	Slenderhead Darter **(SHD)**
Black Bullhead **(BLB)**	Common Shiner **(CSH)**	Longnose Gar **(LNG)**	Smallmouth Buffalo **(SAB)**
Black Crappie **(BLC)**	Creek Chub **(CRC)**	Mooneye **(MOE)**	Spotfin Shiner **(SFS)**
Blackchin Shiner **(BCS)**	Emerald Shiner **(EMS)**	Northern Pike **(NOP)**	Spottail Shiner **(SPO)**
Bluegill **(BLG)**	Fathead Minnow **(FHM)**	Orangespotted Sunfish **(OSS)**	Tadpole Madtom **(TPM)**
Bluntnose Minnow **(BNM)**	Flathead Catfish **(FCF)**	Pumpkinseed **(PMK)**	Walleye **(WAE)**
Bowfin **(BOF)**	Freshwater Drum **(FRD)**	Quillback **(QBS)**	Weed Shiner **(WDS)**
Brassy Minnow **(BRM)**	Gizzard Shad **(GIS)**	River Carpsucker **(RCS)**	White Bass **(WHB)**
Brook Stickleback **(BST)**	Golden Shiner **(GOS)**	Sand Shiner **(SDS)**	White Crappie **(WHC)**
Brown Bullhead **(BRB)**	Green Sunfish **(GSF)**	Sauger **(SAR)**	White Sucker **(WTS)**
Bullhead Minnow **(BHM)**	Highfin Carpsucker **(HFS)**	Shorthead Redhorse **(SHR)**	Yellow Bullhead **(YEB)**
Central Mudminnow **(CNM)**	Hybrid Sunfish **(HSF)**	Shortnose Gar **(SNG)**	Yellow Perch **(YEP)**
Channel Catfish **(CCF)**	Johnny Darter **(JND)**	Silver Redhorse **(SLR)**	

Table S 3. (**See attached file**) Complete fish assessment data from 12 Minnesota River backwaters sampled during 2016–2018.

Appendices

Anderson Lake

Appendix 1.1. Summary of fish species sampled from Anderson Lake including total number captured, percent composition, and length range (mm).

Anderson Lake Fish Survey Fyke net and seine: 6/13/2018 Electrofishing: 6/14/2018

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Spotfin Shiner	*Cyprinella spiloptera*	64	25%	-
Bigmouth Buffalo	*Ictiobus cyprinellus*	48	19%	516 - 654
Bluntnose Minnow	*Pimephales notatus*	31	12%	-
Bullhead Minnow	*Pimephales vigilax*	23	9%	-
Fathead Minnow	*Pimephales promelas*	12	5%	-
Freshwater Drum	*Aplodinotus grunniens*	12	5%	173 - 408
Walleye	*Sander vitreus*	12	5%	402 - 597
Sand Shiner	*Notropis stramineus*	7	3%	-
Smallmouth Buffalo	*Ictiobus bubalus*	7	3%	391 - 567
Black Crappie	*Pomoxis nigromaculatus*	5	2%	175 - 199
Central Mudminnow	*Umbra limi*	5	2%	-
Orangespotted Sunfish	*Lepomis humilis*	5	2%	-
Bluegill	*Lepomis macrochirus*	4	2%	-
Common Carp	*Cyprinus carpio*	4	2%	469 - 640
Emerald Shiner	*Notropis atherinoides*	4	2%	-
River Carpsucker	*Carpiodes carpio*	4	2%	412 - 516
White Crappie	*Pomoxis annularis*	3	1%	196 - 260
Yellow Bullhead	*Ameiurus natalis*	2	1%	-
Black Bullhead	*Ameiurus melas*	1	0.4%	-
Common Shiner	*Luxilus cornutus*	1	0.4%	-
Largemouth Bass	*Micropterus salmoides*	1	0.4%	-
Longnose Gar	*Lepisosteus osseus*	1	0.4%	705
Shortnose Gar	*Lepisosteus platostomus*	1	0.4%	-
White Bass	*Morone chrysops*	1	0.4%	333
	Total	258		
	Species	24		
	Families	9		

Appendix 1.2. Overview of ecological niches of fish sampled from Anderson Lake.

Anderson Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	-	-	-
Generalist	1	1	0.4
Herbivore	-	-	-
Insectivore	11	159	61.6
Omnivore	5	74	28.7
Piscivore	7	24	9.3
Spawning Behavior			
Complex/No Parental Care	1	1	0.4
Complex/Parental Care	11	92	35.7
Simple Lithophil	2	16	6.2
Simple Miscellaneous	10	149	57.8
Tolerance			
Intolerant	5	53	20.5
Tolerant	-	-	-
Preferred Habitat			
Pools	19	143	55.4
Pools and Riffles	5	115	44.6
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	10	113	43.8
Pioneer	2	43	16.7

Appendix 1.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Anderson Lake.

Anderson Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	4
Forest-cover	4
Wetlands	90
Human Disturbance	2
500 meter	
Agriculture	28
Forest-cover	18
Wetlands	39
Human Disturbance	5
Open Water	10
1000 meter	
Agriculture	40
Forest-cover	13
Wetlands	31
Human Disturbance	3
Open Water	13
5000 meter	
Agriculture	70
Forest-cover	8
Wetlands	12
Human Disturbance	5
Open Water	4

Beckendorf Lake

Appendix 2.1. Summary of fish species sampled from Beckendorf Lake including total number captured, percent composition, and length range (mm).

Beckendorf Lake Fish Survey Fyke net and seine: 6/26/2017 Electrofishing: 6/29/2017

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Fathead Minnow	*Pimephales promelas*	685	52%	63 - 64
Gizzard Shad	*Dorosoma cepedianum*	142	11%	70 - 325
Black Crappie	*Pomoxis nigromaculatus*	132	10%	106 - 331
Orangespotted Sunfish	*Lepomis humilis*	105	8%	72 - 101
Black Bullhead	*Ameiurus melas*	83	6%	93 - 305
White Crappie	*Pomoxis annularis*	33	3%	151 - 302
Yellow Perch	*Perca flavescens*	31	2%	-
Common Carp	*Cyprinus carpio*	19	1%	178 - 854
Johnny Darter	*Etheostoma nigrum*	18	1%	-
Green Sunfish	*Lepomis cyanellus*	16	1%	100 - 155
Bluegill	*Lepomis macrochirus*	11	1%	82 - 175
Golden Shiner	*Notemigonus crysoleucas*	9	1%	73 - 153
Bigmouth Buffalo	*Ictiobus cyprinellus*	8	1%	433 - 646
Yellow Bullhead	*Ameiurus natalis*	6	0.5%	126 - 275
Creek Chub	*Semotilus atromaculatus*	4	0.3%	60 - 89
White Sucker	*Catostomus commersonii*	3	0.2%	215 - 450
Shortnose Gar	*Lepisosteus platostomus*	1	0.1%	650
	Total	1306		
	Species	17		
	Families	8		

Appendix 2.2. Overview of ecological niches of fish sampled from Beckendorf Lake.

Beckendorf Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	142	11
Generalist	1	4	0.3
Herbivore	-	-	-
Insectivore	9	287	22
Omnivore	3	707	54
Piscivore	3	166	13
Spawning Behavior			
Complex/No Parental Care	1	4	0.3
Complex/Parental Care	9	1089	84
Simple Lithophil	1	3	0.2
Simple Miscellaneous	6	210	16
Tolerance			
Intolerant	-	-	-
Tolerant	7	819	63
Preferred Habitat			
Pools	13	596	46
Pools and Riffles	4	710	54
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	2	9	1
Pioneer	4	723	55

Appendix 2.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Beckendorf Lake.

Beckendorf Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	8
Forest-cover	20
Wetlands	69
Human Disturbance	3
500 meter	
Agriculture	45
Forest-cover	23
Wetlands	24
Human Disturbance	3
Open Water	5
1000 meter	
Agriculture	44
Forest-cover	25
Wetlands	20
Human Disturbance	5
Open Water	7
5000 meter	
Agriculture	72
Forest-cover	14
Wetlands	8
Human Disturbance	4
Open Water	2

Belle Plaine

Appendix 3.1. Summary of fish species sampled from backwater near Belle Plaine, MN, including total number captured, percent composition, and length range (mm).

Belle Plaine Fish Survey Fyke net: 9/29/2016 Electrofishing and gill net: 9/30/2016

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Gizzard Shad	*Dorosoma cepedianum*	40	39%	61 - 146
Emerald Shiner	*Notropis atherinoides*	27	26%	54 - 84
Black Crappie	*Pomoxis nigromaculatus*	14	14%	104 - 158
Black Bullhead	*Ameiurus melas*	8	8%	95 - 130
Bluegill	*Lepomis macrochirus*	2	2%	43 - 136
Common Carp	*Cyprinus carpio*	2	2%	182 - 336
Northern Pike	*Esox lucius*	2	2%	435 - 465
River Carpsucker	*Carpiodes carpio*	2	2%	134 - 149
Bigmouth Buffalo	*Ictiobus cyprinellus*	1	1%	142
Bowfin	*Amia calva*	1	1%	235
Channel Catfish	*Ictalurus punctatus*	1	1%	595
Golden Shiner	*Notemigonus crysoleucas*	1	1%	84
Sauger	*Sander canadensis*	1	1%	417
Walleye	*Sander vitreus*	1	1%	407
	Total	103		
	Species	14		
	Families	8		

Appendix 3.2 Overview of ecological niches of fish sampled from backwater near Belle Plaine, MN.

Belle Plaine Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	40	39
Generalist	-	-	-
Herbivore	-	-	-
Insectivore	5	39	38
Omnivore	2	4	4
Piscivore	6	20	19
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	5	26	25
Simple Lithophil	3	29	28
Simple Miscellaneous	6	48	47
Tolerance			
Intolerant	-	-	-
Tolerant	3	11	11
Preferred Habitat			
Pools	14	103	100
Pools and Riffles	-	-	-
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	7	34	32
Pioneer	-	-	-

Appendix 3.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding backwater near Belle Plaine, MN.

Belle Plaine	
Land cover type	**Percent**
Riparian Zone	
Agriculture	0
Forest-cover	15
Wetlands	31
Human Disturbance	54
500 meter	
Agriculture	2
Forest-cover	19
Wetlands	33
Human Disturbance	7
Open Water	38
1000 meter	
Agriculture	13
Forest-cover	26
Wetlands	22
Human Disturbance	13
Open Water	25
5000 meter	
Agriculture	56
Forest-cover	19
Wetlands	5
Human Disturbance	14
Open Water	7

Blue Lake

Appendix 4.1. Summary of fish species sampled from Blue Lake including total number captured, percent composition, and length range (mm).

Blue Lake Fish Survey Seine: 9/5/2018 Fyke net and gill net: 9/6/2018

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Bluegill	*Lepomis macrochirus*	213	32%	82-214
Black Crappie	*Pomoxis nigromaculatus*	119	18%	124-367
Weed Shiner	*Notropis texanus*	108	16%	-
Gizzard Shad	*Dorosoma cepedianum*	59	9%	131-214
Northern Pike	Esox lucius	22	3%	549-884
Largemouth Bass	*Micropterus salmoides*	21	3%	-
Green Sunfish	*Lepomis cyanellus*	18	3%	153
Pumpkinseed	*Lepomis gibbosus*	18	3%	95-196
Common Carp	*Cyprinus carpio*	15	2%	496-805
Bowfin	*Amia calva*	12	2%	564-744
Hybrid Sunfish	*Lepomis spp.*	11	2%	61-176
Yellow Perch	*Perca flavescens*	10	2%	151-253
Golden Shiner	*Notemigonus crysoleucas*	8	1%	-
Freshwater Drum	*Aplodinotus grunniens*	7	1%	296-441
Brown Bullhead	*Ameiurus nebulosus*	4	0.6%	300-343
Smallmouth Buffalo	*Ictiobus bubalus*	4	0.6%	116-147
Walleye	*Sander vitreus*	3	0.5%	323-625
Black Bullhead	*Ameiurus melas*	3	0.5%	-
Spotfin Shiner	*Cyprinella spiloptera*	1	0.2%	-
Bigmouth Buffalo	*Ictiobus cyprinellus*	1	0.2%	440
Shorthead Redhorse	*Moxostoma macrolepidotum*	1	0.2%	461
Orangespotted Sunfish	*Lepomis humilis*	1	0.2%	90
White Crappie	*Pomoxis annularis*	1	0.2%	99
	Total	660		
	Species	23		
	Families	9		

Appendix 4.2. Overview of ecological niches of fish sampled from Blue Lake.

Blue Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	59	9
Generalist	-	-	-
Herbivore	1	108	16
Insectivore	14	300	45
Omnivore	1	15	2
Piscivore	6	178	27
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	11	421	64
Simple Lithophil	2	4	1
Simple Miscellaneous	10	235	36
Tolerance			
Intolerant	1	108	16
Tolerant	4	44	7
Preferred Habitat			
Pools	22	659	99.8
Pools and Riffles	1	1	0.2
Riffles	-	-	-
Headwaters	7	136	21
Large Rivers	1	18	3
Pioneer	-	-	-

Appendix 4.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Blue Lake.

Blue Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	4
Forest-cover	56
Wetlands	41
Human Disturbance	0
500 meter	
Agriculture	19
Forest-cover	14
Wetlands	16
Human Disturbance	15
Open Water	36
1000 meter	
Agriculture	14
Forest-cover	10
Wetlands	8
Human Disturbance	37
Open Water	31
5000 meter	
Agriculture	13
Forest-cover	8
Wetlands	4
Human Disturbance	60
Open Water	14

Franklin Oxbow

Appendix 5.1. Summary of fish species sampled from the Franklin Oxbow including total number captured, percent composition, and length range (mm).

Franklin Oxbow Fish Survey
Seine: 10/5/2016
Fyke net: 10/6/2016
Electrofishing: 10/7/2016

Common name	Scientific name	Number	Percent	Length range (mm)
Gizzard Shad	*Dorosoma cepedianum*	205	32%	51 - 300
Spotfin Shiner	*Cyprinella spiloptera*	123	19%	25 - 65
Orangespotted Sunfish	*Lepomis humilis*	119	19%	31 - 80
River Carpsucker	*Carpiodes carpio*	36	6%	356 - 558
Emerald Shiner	*Notropis atherinoides*	33	5%	38 - 77
Freshwater Drum	*Aplodinotus grunniens*	32	5%	92 - 299
Bluegill	*Lepomis macrochirus*	25	4%	28 - 107
White Crappie	*Pomoxis annularis*	19	3%	74 - 235
Black Crappie	*Pomoxis nigromaculatus*	14	2%	60 - 249
Highfin Carpsucker	*Carpiodes velifer*	4	1%	320 - 411
Shorthead Redhorse	*Moxostoma macrolepidotum*	4	1%	85 - 458
Fathead Minnow	*Pimephales promelas*	3	0.5%	30 - 46
Green Sunfish	*Lepomis cyanellus*	3	0.5%	51 - 57
Smallmouth Buffalo	*Ictiobus bubalus*	3	0.5%	464 - 576
Bluntnose Minnow	*Pimephales notatus*	2	0.3%	31 - 58
Common Carp	*Cyprinus carpio*	2	0.3%	391 - 543
Largemouth Bass	*Micropterus salmoides*	2	0.3%	101 - 244
Walleye	*Sander vitreus*	2	0.3%	481 - 538
Bigmouth Buffalo	*Ictiobus cyprinellus*	1	0.2%	558
Channel Catfish	*Ictalurus punctatus*	1	0.2%	298
Hybrid Sunfish	*Lepomis spp.*	1	0.2%	116
Johnny Darter	*Etheostoma nigrum*	1	0.2%	68
Mooneye	*Hiodon tergisus*	1	0.2%	258
Quillback	*Carpiodes cyprinus*	1	0.2%	410
White Sucker	*Catostomus commersonii*	1	0.2%	280
	Total	638		
	Species	25		
	Families	8		

Appendix 5.2. Overview of ecological niches of fish sampled from the Franklin Oxbow.

Franklin Oxbow Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	205	32
Generalist	-	-	-
Herbivore	-	-	-
Insectivore	13	350	55
Omnivore	6	45	7
Piscivore	5	38	6
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	11	190	30
Simple Lithophil	4	40	6
Simple Miscellaneous	10	408	64
Tolerance			
Intolerant	2	5	1
Tolerant	5	11	2
Preferred Habitat			
Pools	20	508	80
Pools and Riffles	6	130	20
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	10	117	18
Pioneer	4	9	1

Appendix 5.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding the Franklin Oxbow.

Franklin Oxbow	
Land cover type	**Percent**
Riparian Zone	
Agriculture	0
Forest-cover	1
Wetlands	97
Human Disturbance	1
500 meter	
Agriculture	22
Forest-cover	4
Wetlands	60
Human Disturbance	4
Open Water	9
1000 meter	
Agriculture	37
Forest-cover	5
Wetlands	43
Human Disturbance	5
Open Water	10
5000 meter	
Agriculture	70
Forest-cover	7
Wetlands	14
Human Disturbance	6
Open Water	3

Gifford Lake

Appendix 6.1. Summary of fish species sampled from Gifford Lake including total number captured, percent composition, and length range (mm).

Gifford Lake Fish Survey
Seine: 5/22/2017
Fyke net: 5/23/2017
Electrofishing: 6/12/2017

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Black Bullhead	*Ameiurus melas*	432	41%	110 - 201
Bluegill	*Lepomis macrochirus*	193	18%	41 - 201
Common Carp	*Cyprinus carpio*	78	7%	167 - 720
Largemouth Bass	*Micropterus salmoides*	57	5%	91 - 380
Gizzard Shad	*Dorosoma cepedianum*	49	5%	25 - 371
Bigmouth Buffalo	*Ictiobus cyprinellus*	40	4%	321 - 645
White Crappie	*Pomoxis annularis*	38	4%	190 - 285
Orangespotted Sunfish	*Lepomis humilis*	37	4%	43 - 98
Spotfin Shiner	*Cyprinella spiloptera*	22	2%	36 - 73
Freshwater Drum	*Aplodinotus grunniens*	18	2%	144 - 597
Emerald Shiner	*Notropis atherinoides*	15	1%	71 - 85
Black Crappie	*Pomoxis nigromaculatus*	10	1%	107 - 279
Golden Shiner	*Notemigonus crysoleucas*	10	1%	80 - 111
Green Sunfish	*Lepomis cyanellus*	10	1%	65 - 152
Bowfin	*Amia calva*	9	1%	350 - 672
River Carpsucker	*Carpiodes carpio*	5	0.5%	175 - 496
Yellow Bullhead	*Ameiurus natalis*	4	0.4%	217 - 330
Bluntnose Minnow	*Pimephales notatus*	2	0.2%	-
Pumpkinseed	*Lepomis gibbosus*	2	0.2%	111 - 117
Smallmouth Buffalo	*Ictiobus bubalus*	2	0.2%	271 - 372
White Sucker	*Catostomus commersonii*	2	0.2%	294 - 368
Blackchin Shiner	*Notropis heterodon*	1	0.1%	63
Central Mudminnow	*Umbra limi*	1	0.1%	88
Hybrid Sunfish	*Lepomis spp.*	1	0.1%	135
Sand Shiner	*Notropis stramineus*	1	0.1%	-
Shorthead Redhorse	*Moxostoma macrolepidotum*	1	0.1%	351
Silver Redhorse	*Moxostoma anisurum*	1	0.1%	380
Walleye	*Sander vitreus*	1	0.1%	374
Weed Shiner	Notropis texanus	1	0.1%	-
Yellow Perch	*Perca flavescens*	1	0.1%	115
	Total	1044		

Species	30
Families	9

Appendix 6.2. Overview of ecological niches of fish sampled from Gifford Lake.

Gifford Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	49	5
Generalist	-	-	-
Herbivore	1	1	0.1
Insectivore	19	792	76
Omnivore	4	87	8
Piscivore	5	115	11
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	13	796	76
Simple Lithophil	5	20	2
Simple Miscellaneous	12	228	22
Tolerance			
Intolerant	2	2	0.2
Tolerant	7	535	51
Preferred Habitat			
Pools	25	1016	97
Pools and Riffles	5	28	3
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	10	93	9
Pioneer	2	12	1

Appendix 6.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Gifford Lake.

Gifford Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	23
Forest-cover	61
Wetlands	0
Human Disturbance	16
500 meter	
Agriculture	26
Forest-cover	19
Wetlands	9
Human Disturbance	12
Open Water	34
1000 meter	
Agriculture	31
Forest-cover	17
Wetlands	19
Human Disturbance	10
Open Water	23
5000 meter	
Agriculture	40
Forest-cover	16
Wetlands	6
Human Disturbance	26
Open Water	12

Hwy 14 Oxbow

Appendix 7.1. Summary of fish species sampled from the Highway 14 Oxbow including total number captured, percent composition, and length range (mm).

Hwy 14 Oxbow Fish Survey Fyke net and seine: 6/27/2018 Electrofishing: 7/2/2018

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Black Crappie	*Pomoxis nigromaculatus*	1270	84%	124 - 282
Bluegill	*Lepomis macrochirus*	55	4%	85 - 203
Fathead Minnow	*Pimephales promelas*	49	3%	-
Yellow Perch	*Perca flavescens*	23	2%	-
Orangespotted Sunfish	*Lepomis humilis*	17	1%	-
Bigmouth Buffalo	*Ictiobus cyprinellus*	13	1%	454 - 753
Black Bullhead	*Ameiurus melas*	12	1%	66 - 318
Common Carp	*Cyprinus carpio*	10	1%	438 - 731
Largemouth Bass	*Micropterus salmoides*	10	1%	147 - 191
Northern Pike	*Esox lucius*	10	1%	114 - 874
Emerald Shiner	*Notropis atherinoides*	8	1%	-
Walleye	*Sander vitreus*	7	0.5%	445 - 517
Freshwater Drum	*Aplodinotus grunniens*	6	0.4%	227 - 470
Spottail Shiner	*Notropis hudsonius*	6	0.4%	-
Shorthead Redhorse	*Moxostoma macrolepidotum*	4	0.3%	374 - 440
Channel Catfish	*Ictalurus punctatus*	3	0.2%	453 - 555
White Bass	*Morone chrysops*	3	0.2%	-
White Sucker	*Catostomus commersonii*	2	0.1%	385 - 429
Brook Stickleback	*Culaea inconstans*	1	0.1%	-
Golden Shiner	*Notemigonus crysoleucas*	1	0.1%	-
Hybrid Sunfish	Lepomis spp.	1	0.1%	-
Spotfin Shiner	*Cyprinella spiloptera*	1	0.1%	-
White Crappie	*Pomoxis annularis*	1	0.1%	152
Yellow Bullhead	*Ameiurus natalis*	1	0.1%	225
	Total	1514		
	Species	24		
	Families	9		

Appendix 7.2. Overview of ecological niches of fish sampled from the Highway 14 Oxbow.

Hwy 14 Oxbow Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	-	-	-
Generalist	-	-	-
Herbivore	-	-	-
Insectivore	14	149	10
Omnivore	3	61	4
Piscivore	7	1304	86
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	11	1420	94
Simple Lithophil	4	21	1
Simple Miscellaneous	9	73	5
Tolerance			
Intolerant	1	6	0.4
Tolerant	5	74	5
Preferred Habitat			
Pools	20	1456	96
Pools and Riffles	4	58	4
Riffles	-	-	-
Headwaters	1	1	0.1
Large Rivers	7	44	3
Pioneer	1	49	3

Appendix 7.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding the Highway 14 Oxbow.

Hwy 14 Oxbow	
Land cover type	**Percent**
Riparian Zone	
Agriculture	12
Forest-cover	48
Wetlands	33
Human Disturbance	8
500 meter	
Agriculture	29
Forest-cover	19
Wetlands	29
Human Disturbance	5
Open Water	19
1000 meter	
Agriculture	41
Forest-cover	14
Wetlands	24
Human Disturbance	5
Open Water	15
5000 meter	
Agriculture	61
Forest-cover	11
Wetlands	11
Human Disturbance	8
Open Water	8

Long Lake

Appendix 8.1. Summary of fish species sampled from Long Lake including total number captured, percent composition, and length range (mm).

Long Lake Fish Survey Seine: 9/11/2018 Fyke net and gill net: 9/12/2018

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Bluegill	*Lepomis macrochirus*	333	28%	90-181
Black Bullhead	*Ameiurus melas*	306	25%	22-301
Sand Shiner	*Notropis stramineus*	241	20%	
Black Crappie	*Pomoxis nigromaculatus*	128	11%	126-359
Northern Pike	Esox lucius	34	3%	349-972
Bowfin	*Amia calva*	23	2%	302-653
Yellow Bullhead	*Ameiurus natalis*	21	2%	202-341
White Crappie	*Pomoxis annularis*	16	1%	160-356
Common Carp	*Cyprinus carpio*	15	1%	240-595
Gizzard Shad	*Dorosoma cepedianum*	10	1%	172-421
Largemouth Bass	*Micropterus salmoides*	10	1%	155-440
Pumpkinseed	*Lepomis gibbosus*	9	1%	102-156
Freshwater Drum	*Aplodinotus grunniens*	9	1%	306-444
Brown Bullhead	*Ameiurus nebulosus*	9	1%	177-260
Bigmouth Buffalo	*Ictiobus cyprinellus*	9	1%	411-667
Bluntnose Minnow	*Pimephales notatus*	7	0.6%	
Smallmouth Buffalo	*Ictiobus bubalus*	4	0.3%	143-264
Hybrid Sunfish	*Lepomis spp.*	3	0.2%	165-171
Yellow Perch	*Perca flavescens*	2	0.2%	202-212
Emerald Shiner	*Notropis atherinoides*	2	0.2%	
River Carpsucker	*Carpiodes carpio*	2	0.2%	523-530
Shortnose Gar	*Lepisosteus platostomus*	2	0.2%	390-446
Tadpole Madtom	*Noturus gyrinus*	2	0.2%	
Silver Redhorse	*Moxostoma anisurum*	1	0.1%	367
Orangespotted Sunfish	*Lepomis humilis*	2	0.2%	
Walleye	*Sander vitreus*	1	0.1%	176
Channel Catfish	*Ictalurus punctatus*	1	0.1%	591
	Total	1202		
	Species	27		
	Families	10		

Appendix 8.2. Overview of ecological niches of fish sampled from Long Lake.

Long Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	10	1
Generalist	-	-	-
Herbivore	-	-	-
Insectivore	15	954	79
Omnivore	3	24	2
Piscivore	8	215	18
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	14	870	72
Simple Lithophil	3	5	0.4
Simple Miscellaneous	10	328	27
Tolerance			
Intolerant	-	-	-
Tolerant	3	328	27
Preferred Habitat			
Pools	24	953	79
Pools and Riffles	3	250	21
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	10	55	5
Pioneer	1	7	1

Appendix 8.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Long Lake.

Long Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	46
Forest-cover	46
Wetlands	1
Human Disturbance	6
500 meter	
Agriculture	32
Forest-cover	23
Wetlands	15
Human Disturbance	5
Open Water	25
1000 meter	
Agriculture	34
Forest-cover	19
Wetlands	18
Human Disturbance	5
Open Water	23
5000 meter	
Agriculture	48
Forest-cover	19
Wetlands	8
Human Disturbance	12
Open Water	13

Mack Lake

Appendix 9.1. Summary of fish species sampled from Mack Lake including total number captured, percent composition, and length range (mm).

Mack Lake Fish Survey Electrofishing and seine: 9/7/2016 Fyke net: 9/8/2016

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Black Bullhead	*Ameiurus melas*	219	31%	109 - 310
Bluegill	*Lepomis macrochirus*	91	13%	25 - 159
Common Carp	*Cyprinus carpio*	87	12%	95 - 670
Orangespotted Sunfish	*Lepomis humilis*	67	10%	40 - 96
Black Crappie	*Pomoxis nigromaculatus*	48	7%	66 - 256
Gizzard Shad	*Dorosoma cepedianum*	48	7%	96 - 254
White Crappie	*Pomoxis annularis*	35	5%	95 - 321
Bigmouth Buffalo	*Ictiobus cyprinellus*	16	2%	118 - 418
Freshwater Drum	*Aplodinotus grunniens*	16	2%	104 - 405
Yellow Bullhead	*Ameiurus natalis*	15	2%	183 - 247
Largemouth Bass	*Micropterus salmoides*	14	2%	89 - 416
Emerald Shiner	*Notropis atherinoides*	12	2%	44 - 96
Golden Shiner	*Notemigonus crysoleucas*	9	1%	52 - 77
Yellow Perch	*Perca flavescens*	8	1%	92 - 175
River Carpsucker	*Carpiodes carpio*	5	1%	232 - 546
Common Shiner	*Luxilus cornutus*	2	0.3%	41 - 43
Bluntnose Minnow	*Pimephales notatus*	1	0.1%	62
Fathead Minnow	*Pimephales promelas*	1	0.1%	51
Northern Pike	*Esox lucius*	1	0.1%	625
Spotfin Shiner	*Cyprinella spiloptera*	1	0.1%	36
Walleye	*Sander vitreus*	1	0.1%	380
White Bass	*Morone chrysops*	1	0.1%	265
	Total	698		
	Species	22		
	Families	9		

Appendix 9.2. Overview of ecological niches of fish sampled from Mack Lake.

Mack Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	48	7
Generalist	1	2	0.3
Herbivore	-	-	-
Insectivore	10	454	65
Omnivore	4	94	13
Piscivore	6	100	14
Spawning Behavior			
Complex/No Parental Care	1	2	0.3
Complex/Parental Care	9	491	70
Simple Lithophil	2	13	2
Simple Miscellaneous	10	192	28
Tolerance			
Intolerant	-	-	-
Tolerant	5	317	45
Preferred Habitat			
Pools	18	693	99
Pools and Riffles	4	5	1
Riffles	-	-	-
Headwaters	-	-	-
Large Rivers	6	51	7
Pioneer	2	2	0.3

Appendix 9.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Mack Lake.

Mack Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	34
Forest-cover	37
Wetlands	29
Human Disturbance	0
500 meter	
Agriculture	28
Forest-cover	26
Wetlands	21
Human Disturbance	4
Open Water	21
1000 meter	
Agriculture	36
Forest-cover	17
Wetlands	21
Human Disturbance	3
Open Water	24
5000 meter	
Agriculture	71
Forest-cover	10
Wetlands	9
Human Disturbance	5
Open Water	6

Montevideo Oxbow

Appendix 10.1. Summary of fish species sampled from the Montevideo Oxbow including total number captured, percent composition, and length range (mm).

Montevideo Oxbow Fish Survey
Seine: 8/24/2016
Fyke net: 8/25/2016

Common name	Scientific name	Number	Percent	Length range (mm)
Bluegill	*Lepomis macrochirus*	1608	48%	83 - 131
Spotfin Shiner	*Cyprinella spiloptera*	1199	36%	24 - 72
Orangespotted Sunfish	*Lepomis humilis*	189	6%	33 - 80
Fathead Minnow	*Pimephales promelas*	96	3%	33 - 66
Bluntnose Minnow	*Pimephales notatus*	59	2%	33 - 48
Black Crappie	*Pomoxis nigromaculatus*	40	1%	59 - 312
Common Carp	*Cyprinus carpio*	33	1%	32 - 612
Green Sunfish	*Lepomis cyanellus*	27	1%	29 - 114
Spottail Shiner	*Notropis hudsonius*	17	0.5%	51 - 112
Sand Shiner	*Notropis stramineus*	12	0.4%	32 - 42
Black Bullhead	*Ameiurus melas*	11	0.3%	90 - 155
Emerald Shiner	*Notropis atherinoides*	11	0.3%	41 - 52
White Sucker	*Catostomus commersonii*	11	0.3%	64 - 463
Shorthead Redhorse	*Moxostoma macrolepidotum*	9	0.3%	405 - 499
Northern Pike	*Esox lucius*	8	0.2%	495 - 834
Yellow Bullhead	*Ameiurus natalis*	6	0.2%	105 - 318
Bigmouth Buffalo	*Ictiobus cyprinellus*	5	0.1%	53 - 77
River Carpsucker	*Carpiodes carpio*	4	0.1%	84 - 633
Freshwater Drum	*Aplodinotus grunniens*	3	0.1%	106 - 370
Walleye	*Sander vitreus*	3	0.1%	353 - 383
Channel Catfish	*Ictalurus punctatus*	2	0.1%	276 - 386
Common Shiner	*Luxilus cornutus*	2	0.1%	51 - 59
Tadpole Madtom	*Noturus gyrinus*	2	0.1%	40 - 52
Yellow Perch	*Perca flavescens*	2	0.1%	91 - 100
Brassy Minnow	*Hybognathus hankinsoni*	1	0.03%	66
Brook Stickleback	*Culaea inconstans*	1	0.03%	50
Central Mudminnow	*Umbra limi*	1	0.03%	96
Johnny Darter	*Etheostoma nigrum*	1	0.03%	60
	Total	3363		
	Species	28		
	Families	9		

Appendix 10.2 Overview of ecological niches of fish sampled from the Montevideo.

Montevideo Oxbow Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	-	-	-
Generalist	1	2	0.06
Herbivore	1	1	0.03
Insectivore	17	3104	92
Omnivore	5	203	6
Piscivore	4	53	2
Spawning Behavior			
Complex/No Parental Care	1	2	0.06
Complex/Parental Care	13	2043	61
Simple Lithophil	4	34	1
Simple Miscellaneous	10	1284	38
Tolerance			
Intolerant	1	17	1
Tolerant	7	238	7
Preferred Habitat			
Pools	19	1964	58
Pools and Riffles	9	1399	42
Riffles	-	-	-
Headwaters	1	1	0.03
Large Rivers	7	37	1
Pioneer	4	183	5

Appendix 10.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding the Montevideo Oxbow.

Montevideo Oxbow	
Land cover type	**Percent**
Riparian Zone	
Agriculture	31
Forest-cover	0
Wetlands	69
Human Disturbance	0
500 meter	
Agriculture	54
Forest-cover	0
Wetlands	29
Human Disturbance	11
Open Water	6
1000 meter	
Agriculture	54
Forest-cover	1
Wetlands	31
Human Disturbance	10
Open Water	4
5000 meter	
Agriculture	74
Forest-cover	2
Wetlands	10
Human Disturbance	10
Open Water	3

New Ulm Oxbow

Appendix 11.1. Summary of fish species sampled from the New Ulm Oxbow including total number captured, percent composition, and length range (mm).

New Ulm Oxbow Fish Survey Fyke net: 7/31/2017 Electrofishing: 8/7/2017

Common name	Scientific name	Number	Percent	Length range (mm)
Orangespotted Sunfish	*Lepomis humilis*	62	20%	33 - 85
Gizzard Shad	*Dorosoma cepedianum*	38	13%	55 - 302
Bigmouth Buffalo	*Ictiobus cyprinellus*	27	9%	313 - 600
Black Crappie	*Pomoxis nigromaculatus*	26	9%	119 - 260
River Carpsucker	*Carpiodes carpio*	25	8%	380 - 554
Shortnose Gar	*Lepisosteus platostomus*	20	7%	305 - 662
Freshwater Drum	*Aplodinotus grunniens*	19	6%	55 - 335
White Crappie	*Pomoxis annularis*	19	6%	63 - 195
Bluegill	*Lepomis macrochirus*	15	5%	34 - 184
Common Carp	*Cyprinus carpio*	14	5%	318 - 715
Green Sunfish	*Lepomis cyanellus*	7	2%	90 - 95
Spottail Shiner	*Notropis hudsonius*	6	2%	63 - 73
Largemouth Bass	*Micropterus salmoides*	5	2%	203 - 324
Spotfin Shiner	*Cyprinella spiloptera*	5	2%	44 - 82
Northern Pike	*Esox lucius*	4	1%	525 - 782
Sauger	*Sander canadensis*	3	1%	376 - 432
Channel Catfish	*Ictalurus punctatus*	2	1%	369 - 497
Black Bullhead	*Ameiurus melas*	1	0.3%	96
Emerald Shiner	*Notropis atherinoides*	1	0.3%	62
Flathead Catfish	*Pylodictis olivaris*	1	0.3%	259
Johnny Darter	*Etheostoma nigrum*	1	0.3%	-
Slenderhead Darter	*Percina phoxoceoala*	1	0.3%	-
White Bass	*Morone chrysops*	1	0.3%	100
	Total	303		
	Species	23		
	Families	10		

Appendix 11.2. Overview of ecological niches of fish sampled from the New Ulm Oxbow.

New Ulm Oxbow Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	38	13
Generalist	-	-	-
Herbivore	-	-	-
Insectivore	11	145	48
Omnivore	2	39	13
Piscivore	9	81	27
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	10	139	46
Simple Lithophil	3	5	2
Simple Miscellaneous	10	159	52
Tolerance			
Intolerant	2	7	2
Tolerant	3	22	7
Preferred Habitat			
Pools	19	289	95
Pools and Riffles	4	13	4
Riffles	1	1	0.3
Headwaters	-	-	-
Large Rivers	10	100	33
Pioneer	2	8	3

Appendix 11.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding the New Ulm Oxbow.

New Ulm Oxbow	
Land cover type	**Percent**
Riparian Zone	
Agriculture	16
Forest-cover	8
Wetlands	76
Human Disturbance	0
500 meter	
Agriculture	19
Forest-cover	8
Wetlands	34
Human Disturbance	22
Open Water	17
1000 meter	
Agriculture	27
Forest-cover	8
Wetlands	25
Human Disturbance	27
Open Water	13
5000 meter	
Agriculture	57
Forest-cover	9
Wetlands	11
Human Disturbance	17
Open Water	5

Sulfur Lake

Appendix 12.1. Summary of fish species sampled from Sulfur Lake including total number captured, percent composition, and length range (mm).

Sulfur Lake Fish Survey Fyke net and gill net: 5/24/2017 Electrofishing and seine: 6/1/2017

Common name	**Scientific name**	**Number**	**Percent**	**Length range (mm)**
Spotfin Shiner	*Cyprinella spiloptera*	55	18%	38 - 78
Bigmouth Buffalo	*Ictiobus cyprinellus*	46	15%	251 - 724
Bluegill	*Lepomis macrochirus*	36	12%	25 - 186
Largemouth Bass	*Micropterus salmoides*	28	9%	91 - 446
Common Carp	*Cyprinus carpio*	19	6%	399 - 644
Fathead Minnow	*Pimephales promelas*	17	6%	45 - 69
Black Crappie	*Pomoxis nigromaculatus*	15	5%	89 - 292
Green Sunfish	*Lepomis cyanellus*	15	5%	49 - 136
Orangespotted Sunfish	*Lepomis humilis*	15	5%	38 - 88
Gizzard Shad	*Dorosoma cepedianum*	12	4%	130 - 290
Golden Shiner	*Notemigonus crysoleucas*	12	4%	33 - 110
River Carpsucker	*Carpiodes carpio*	5	2%	451 - 525
White Crappie	*Pomoxis annularis*	5	2%	72 - 205
Bluntnose Minnow	*Pimephales notatus*	3	1%	40 - 55
White Sucker	*Catostomus commersonii*	3	1%	186 - 349
Black Bullhead	*Ameiurus melas*	2	1%	107 - 258
Emerald Shiner	*Notropis atherinoides*	2	1%	-
Smallmouth Buffalo	*Ictiobus bubalus*	2	1%	568 - 589
Walleye	*Sander vitreus*	2	1%	394 - 430
Channel Catfish	*Ictalurus punctatus*	1	0.3%	368
Central Mudminnow	*Umbra limi*	1	0.3%	79
Flathead Catfish	*Pylodictis olivaris*	1	0.3%	447
Hybrid Sunfish	*Lepomis spp.*	1	0.3%	155
Quillback	*Carpiodes cyprinus*	1	0.3%	365
Slenderhead Darter	*Percina phoxoceoala*	1	0.3%	58
Shorthead Redhorse	*Moxostoma macrolepidotum*	1	0.3%	354
Silver Redhorse	*Moxostoma anisurum*	1	0.3%	410
Weed Shiner	*Notropis texanus*	1	0.3%	64
Yellow Perch	*Perca flavescens*	1	0.3%	115
	Total	304		
	Species	29		
	Families	7		

Appendix 12.2. Overview of ecological niches of fish sampled from Sulfur.

Sulfur Lake Ecological Niches			
Niche	**Species Total**	**Total Catch**	**Percent Composition**
Feeding Levels			
Filter Feeder	1	12	4
Generalist	-	-	-
Herbivore	1	1	0.3
Insectivore	15	191	63
Omnivore	6	48	16
Piscivore	6	52	17
Spawning Behavior			
Complex/No Parental Care	-	-	-
Complex/Parental Care	13	140	46
Simple Lithophil	6	10	3
Simple Miscellaneous	10	154	51
Tolerance			
Intolerant	2	2	1
Tolerant	8	72	24
Preferred Habitat			
Pools	23	224	74
Pools and Riffles	5	79	26
Riffles	1	1	0.3
Headwaters	-	-	-
Large Rivers	11	63	21
Pioneer	3	35	12

Appendix 12.3. Land cover within concentric bands (i.e., 50–5,000 m) surrounding Sulfur Lake.

Sulfur Lake	
Land cover type	**Percent**
Riparian Zone	
Agriculture	12
Forest-cover	2
Wetlands	55
Human Disturbance	30
500 meter	
Agriculture	10
Forest-cover	23
Wetlands	41
Human Disturbance	18
Open Water	7
1000 meter	
Agriculture	22
Forest-cover	14
Wetlands	37
Human Disturbance	17
Open Water	10
5000 meter	
Agriculture	65
Forest-cover	9
Wetlands	16
Human Disturbance	7
Open Water	3