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Zooplanktonic Community Dynamics of the Minnesota River with an Ichthyoplankton Gear Comparison

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Zooplanktonic Community Dynamics of the Minnesota River with an Ichthyoplankton Gear Comparison

by
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of the requirements for the
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Department of Biological Sciences
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This thesis, completed by Nathaniel J. Lederman, has been examined and approved.

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Abstract

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The Minnesota River, like many large rivers, has been functionally altered by human activities and climate change. The Minnesota Pollution Control Agency has designated 271 kilometers (50.3%) of the 539 kilometer Minnesota River as "biologically impaired." However, assessing biological communities in large rivers is often difficult and limited to examination of upper trophic levels (e.g., piscivorous fishes). Few studies examined zooplanktonic communities, largely due to difficulties associated with sampling. Because of the need to improve assessment strategies for biological impairments in the Minnesota River, the zooplanktonic community, including crustaceous zooplankton, rotifers, macroinvertebrates, and ichthyoplankton was evaluated within an impaired and unassessed reaches. Securing a better understand of the early life history of Minnesota River fishes has become a priority to state management agencies. However, to secure necessary data, icthyoplankton sampling strategies must be improve and thus several gears were evaluated during this study.

The zooplanktonic community was sampled from May 2014 to August 2014 and April 2015 to August 2015 in a stretch deemed impaired and an unassessed stretch in the Minnesota River. Gears utilized to sample biota included benthic and surface slednets, light traps with glow–stick or LED light sources, and a Wisconsin vertical trawl. Based on an analysis of similarities, zooplanktonic community composition was more similar between reaches for crustaceous zooplankton (R = 0.02), ichthyoplankton with the slednets (R = 0.03), macroinvertebrates with the light traps (R = 0.00), macroinvertebrates with the slednets (R = -0.04), and rotifers (R = -0.05) than different. Assessments indicate zooplanktonic communities in both impaired and unassessed reaches of the Minnesota River appear to be degraded as they were similar in a reach deemed impaired and an unassessed reach. Although the total number of zooplanktonic biota captured in both reaches was low, variations in catch rates were noted with changes in hydrology. However, the gears sampled more different portions of the ichthyoplankton community (R = 0.51) than similar portions, demonstrating the value of utilizing multiple gears.

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List of Abbreviations

ANOSIM.....Analysis of similarities

CPUE..... Catch per unit effort

CV ..... Coefficient of variation

h ..... Hour

IBI .....Index of Biotic Integrity

km .....Kilometer

kg ..... Kilogram

L..... Liter

LT.....Light trap

m .....Meters

MNSU .....Minnesota State University, Mankato

MN DNR .....Minnesota Department of Natural Resources

MPCA.....Minnesota Pollution Control Agency

NMDS .....Non-metric multidimensional scaling

PVC .....Polyvinyl chloride

RKM..... River Kilometer

SE.....Standard error

SN ..... Slednet

spp..... Multiple unidentified species

µm .....Micron

USGS.....United States Geological Survey

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Introduction

The Minnesota River originates at Big Stone Lake in the prairie region of Minnesota on the South Dakota border and just south of the Laurentian Divide at the Traverse Gap portage (MN DNR 2013). The Minnesota River then flows through some of the richest agricultural land in Minnesota (possibly the world) and is responsible for draining 43,771 km^2 or nearly 20% of the state (Musser et al. 2009). Like most large Midwest rivers, however, human activities and climate change have altered Minnesota River functionality (Nelson 2015).

Several dams in the upper reach of the Minnesota River create lentic conditions from river kilometer (RKM) 529.3 to RKM 414.7 at the Granite Falls Dam (MN DNR 2013). Within the Minnesota River Basin, approximately 79% of the land has predominantly been converted from prairie, wetland, and forest to agricultural row cropping (Figure 1). The Minnesota Pollution Control Agency (MPCA 2007) noted that the lower river segments from RKM 23.7 to RKM 0 have been channelized for navigation to facilitate barge traffic from the Mississippi River.

The Minnesota River can be divided into three relatively distinct regions: impounded, free flowing, and channelized. Impounded segments of the Minnesota River are used to manage floodwater levels, but also provide important wildlife management

areas and recreational opportunities (Musser et al. 2009). However, dams often cause losses in fish species richness, and prevent upstream migrations and recolonization of

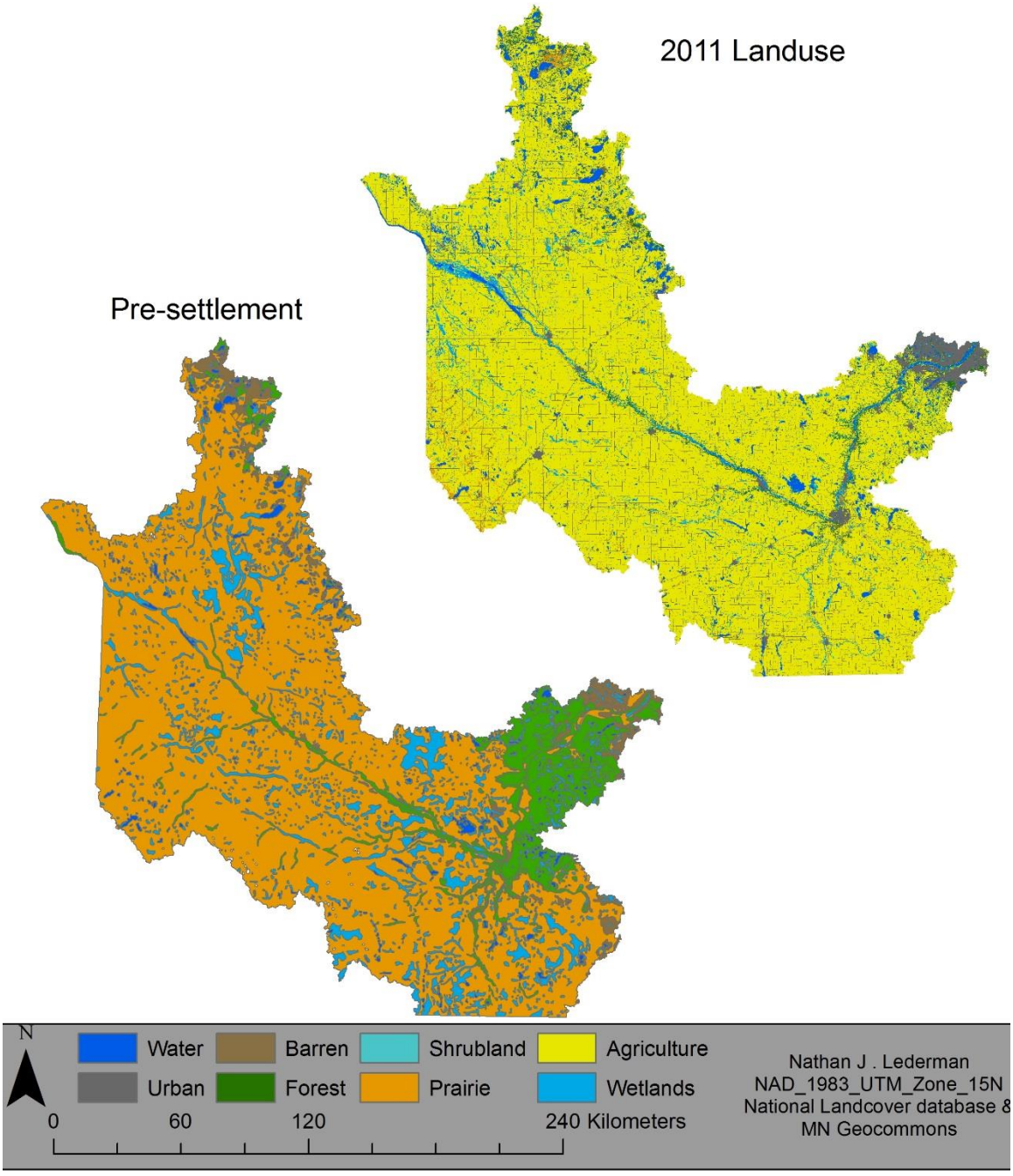

Figure 1. Landuse in the Minnesota River Basin within the state of Minnesota prior to European settlement (MN Geocommons) and in 2011 (National Land Cover Database).

fishes (Katano et al. 2006). Permanent vegetation removal across the landscape has reduced nutrient filtration and water retention capacity, resulting in degraded runoff that can alter instream habitat and catalyze biodiversity losses (Lepers et al. 2005). In addition, channelization causes significant losses in river habitat (Brooker 1981) and has been shown to reduce species richness and diversity (Oscoz et al. 2005).

To complicate the challenges already facing the Minnesota River, a naturalized population of invasive Common Carp *Cyprinus carpio* is present. Other invasive species, such as Bighead Carp *Hypophthalmichthys nobilis*, Silver Carp *H. molitrix*, and Zebra Mussels *Dreissena polymorpha* are in close proximity and have the potential to colonize the Minnesota River (MN DNR 2013). Invasive species are prolific and have the ability to rapidly alter communities (Sakai et al. 2001) and fundamentally modify ecological processes (Mack et al. 2000).

Tremendous resources have been directed to address some of the major biological stressors in the Minnesota River Basin. From 1992 to 2002, US$1.2 billion were spent implementing land conservation measures, including 4,135 easements encompassing 61,617 hectares of the watershed (Sigford 2002). Easements are critical components of sediment and nutrient loading reduction plans and improve wildlife habitat and flood attenuation on private lands. Conservation effort within the Minnesota River watershed has resulted in decreasing trends in total suspended solids,

total phosphorus and orthophosphorus concentrations, however, nitrite-nitrogen concentrations continue to increase (Johnson et al. 2009).

In 2014, 271 km (50.3%) of 539 km of the Minnesota River were assessed and listed as impaired biologically (MPCA 2014). The remaining segments have not been monitored sufficiently to be listed as impaired or unimpaired and are therefore often simply referred to as the "unassessed" segments. According to the MPCA (2014), a biological impairment occurs when biota within that reach are not as diverse, or as numerous, as they should be, and the functional groups and numerical community composition are dominated by tolerant species typical of impaired reaches. Status designations are based on benthic macroinvertebrates and adult and juvenile fish index of biological integrity (IBI) surveys completed by the MPCA.

Indices of biological integrity score the ability a particular system to support and maintain a balanced, integrated, and functionally organized community, comparable to that of a natural state (Frey 1975). Strength of an IBI lies in its ability to integrate information from the individual, population, community, zoogeographic and ecosystem levels into a single ecology-based and relevant score (Karr et al. 1986). Investigating other lower trophic levels (e.g., zooplankton, limnetic macroinvertebrates, and ichthyoplankton), between reaches can determine if they align with that of the higher trophic levels investigated by the MPCA.

The zooplanktonic community (i.e., crustaceous zooplankton, rotifer, larval fishes, and limnetic macroinvertebrates) provide critical energy flow pathways from microbial to upper trophic levels (Naiman et al. 1998; Fisher et al. 2001; Gajbhiye 2002). Larval fishes (i.e., ichthyoplankton) are also important vectors for energy transfer between invertebrates and higher trophic level piscivores. However, larval fish early life history is a critical survival period, and mortality events impact recruitment and frequently determine year-class strength (Chambers and Trippel 1997; Brander et al. 2001). Fisher et al. (2001) demonstrated the critical energy transfer mechanisms facilitated by the zooplanktonic community and the challenges of securing these data among Missouri River backwaters. Securing much needed baseline data on zooplanktonic community dynamics in the Minnesota River has been difficult, but is needed to greatly improve our capacity to assess management efforts and impacts of potential invasive species naturalization.

Data credibility requires that appropriate and adequate sampling be conducted, and therefore sampling gears and strategies must be trusted and reliable. Sampling zooplanktonic communities, particularly larval fishes, is often met with limited success, and when combined with the challenges of sampling large river systems, effective sampling is tenuous (Johnson et al. 1995). Thus, gear evaluations are needed to provide researchers with additional information to formulate the most effective monitoring plan by better understanding the biases and potential of each gear type (Brown et al. 2012).

Objectives

This study aims to

1) Compare zooplanktonic communities in an impaired and an unassessed reach of the Minnesota River (Chapter 1)

2) evaluate ichthyoplankton sampling gears in the Minnesota River (Chapter 2) and,

3) examine operational costs of the ichthyoplankton sampling gears for use in a long-term Minnesota River monitoring program (Chapter 3).

Chapter 1: Evaluation of Zooplanktonic Communities of an Impaired and an Unassessed Reach of a Midwest river, the Minnesota River

Abstract

Ecological functions and biotic communities of large rivers have been fundamentally altered by anthropogenic modification and climate change. The Minnesota Pollution Control Agency assessed 271 of the 539 km of the Minnesota River with fish and benthic macroinvertebrate indices of biotic integrity, and as of 2014, deemed all 271 km as impaired biologically. Comparing zooplanktonic communities in impaired and unassessed reaches could indicate if the unassessed stretches have similar biotic composition and lend insight into system-wide conditions. Minnesota River zooplanktonic community samples were collected from May to August 2014 and April to August 2015. Analyses of similarities indicated that community compositions were relatively more similar than different for crustaceous zooplankton (R = 0.02), ichthyoplankton sampled with slednets (R = 0.03), macroinvertebrates from light traps (R = 0.00) and slednets (R = -0.04), and rotifers (R = -0.05) between the impaired and unassessed reaches. The limited biotic richness and low abundances observed in both reaches could be the result of sampling gear limitations, but may also suggest a system-level impairment. However, zooplanktonic community densities and richness were noted to vary with hydrologic conditions, suggesting that hydrology may at least partially be driving Minnesota River zooplanktonic community dynamics. Therefore, management efforts to restore and maintain natural hydrologic regimes and subsequent floodplain connections may be important to improving biological conditions.

Introduction

Nearly all rivers in the upper Midwest have been degraded to some extent by a wide variety of human activities, including channelization for navigation or maximizing tillable land, establishment of dams for flood control and hydropower development, land use changes within upstream watersheds, and wastewater disposal (Nilsson et al. 2005). Channelizing rivers, for example, reduces flooding, degrades the lateral connection to the flood plain (Brookes 1981), and starves systems of lateral nutrient cycling that has direct and indirect roles in biotic functioning (Junk et al. 1989). Dams regulate flow, too often reduce hydrologic stage variability, and increase hydrograph predictability (Morris et al. 1968). As a result, alternations in flow quantity and timing shift away from natural hydrographs that are critical components in water supply, water quality, and the ecological function of a riverine system (Poff et al. 1997). Land conversion from forest, perennial grassland, and wetlands has also increased peak runoff rates, as well as sediment and pollutant loading to surface water resources (Blann et al. 2009). Altering the natural loading, transport, utilization and storage of organic matter in which biota are thought to adjust in a predictable fashion too causing changes to biotic assemblage patterns (Vannote et al. 1980).

The Minnesota River has been substantially altered by human activities (Musser et al. 2009). Four dams currently impound upstream portions of the Minnesota River and approximately 79% of pre-settlement permanent vegetation and wetlands have been converted to row-crop agriculture. The Minnesota River has also been impacted by

point and non-point source pollutants, streambank erosion, tile drainage, commercial/industrial processes, and wastewater treatment plants effluents (Mulla 1998). Physical degradation of river systems is problematic, however, challenges in some waterways have also been exacerbated by the establishment of invasive species.

One such invasive species, the Common Carp *Cyprinus carpio*, is naturalized within the Minnesota River Basin and more invasive species are threatening the system including Bighead Carp *Hypophthalmichthys nobilis*, Silver Carp *H. molitrix*, and Zebra Mussels *Dreissena polymorpha* (MN DNR 2013). Invasive species often lack natural enemies, have broad environmental tolerance, and exhibit high reproductive output (Kulhanek et al. 2011) that facilitate exploitation of open niches. Naturalizing invasive species populations can rapidly proliferate and cause abrupt changes to the biotic community (Sakai et al. 2001) that can severely damage biodiversity (Manchester and Bullock 2000).

Efforts have been taken to regulate, evaluate, and restore riverine degradation caused by channelization, dams, invasive species, land use, and wastewater transport. In 1973, the Clean Water Act required all states to assess status and impairment levels of their surface waters (Federal Water Pollution Control Act of 1973). The 1996 National Invasive Species Act also provided funding for prevention and control research, regional management organization, and education and technical assistance programs aimed to prevent invasive species from entering inland waters (National Invasive Species Act 1996). In Minnesota, passage of the Clean Water Legacy Act in 2006 secured funding for

programs geared to protect, enhance, and restore water quality in lakes, rivers, and streams and to protect groundwater from degradation (Clean Water Legacy Act 2015).

Tremendous resources have been dedicated to addressing the major stressors to the Minnesota River Basin to meet objectives of the legislation noted above. From 1992 to 2002 alone, $1.2 billion were spent implementing land conservation measures in the Minnesota River watershed, including 4,135 easements to protect sensitive lands (Sigford 2002). Properly managed easements help improve water quality by reducing soil erosion and pollutant loading, but these lands also improve wildlife habitat and increase flood attenuation capacity on private property. Minnesota River water quality improvement management efforts are resulting in decreasing trends in total suspended solids, total phosphorus, and orthophosphorus concentrations, however, nitrite-nitrogen concentrations continue to increase (Johnson et al. 2009). Water quality is important for biological integrity, but ecologists have also developed various indices for evaluating overall system quality using biotic communities as well (Sparks 1995).

An index of biological integrity (IBI) is a common bioassessment/biomonitoring technique that provides a framework for translating biological community data into terms of the system's ability to support and maintain a balanced, integrated, and functionally organized community (Frey 1975; Sparks 1995). An IBI evaluates community characteristics [e.g., community composition, habitat, life history, reproductive strategies, organisms tolerance, trophic catch per unit effort (CPUE), individual taxa percentages, and taxa richness] that relate community characteristics to the biotic

integrity and environmental quality of that stream or river (Karr 1981). Biotic integrity is the umbrella concept that encompasses the needs of well-functioning systems (Fischman 2004). The strength of an IBI being its ability to integrate information from individual, population, community, zoogeographic and ecosystem levels into a single ecologically based and relevant score (Karr et al. 1986).

Several IBIs for rivers and streams have been developed and differ based on the major taxa groups measured, including fish (Karr 1981), macroinvertebrates (Hilsenhoff 1988), phytoplankton (Williams et al. 2009) and zooplankton (Kane et al. 2009). The Minnesota Pollution Control Agency (MPCA) has also developed a fish and benthic macroinvertebrates IBI with metrics developed and calibrated specifically to the regionalized structure and function of Minnesota River communities. Bouchard (2014) noted that metrics were systematically tested for inclusion based on responsiveness to disturbance (i.e., ability to detect disturbance), strong signal (i.e., variance among sites), and low noise level (i.e., variance within sites). The fish IBI metrics determine biological impairment utilizing twelve metrics that address fish based taxa composition, habitats, life histories, reproductive strategies, tolerance levels, and trophic statuses (Table 1). The benthic macroinvertebrate IBI evaluates eight metrics that investigate taxa composition, taxa richness, tolerance levels and trophic status (Table 1).

Table 1. Index of biotic integrity metrics used by the Minnesota Pollution Control Agency to calculate a fish based IBI and macroinvertebrate IBI for southern rivers, such as the Minnesota River. Response indicates the positive or negative relationship between the metric score and the index of biotic integrity score.

Metric type	Metric description	Category	Response
Fishes			
Individual percentage	Percent Insectivorous individuals (excludes tolerant species)	Trophic	Positive
Richness	Simple lithophilic taxa	Reproductive	Positive
Individual percentage	Percent generalist feeder individuals	Trophic	Negative
Taxon percentage	Percent very tolerant taxa	Tolerance	Negative
Taxon percentage	Percent serial spawner taxa	Reproductive	Negative
Individual percentage	Percent tolerant individuals	Tolerance	Negative
Individual percentage	Percent short-lived individuals	Life history	Negative
Taxon percentage	Percent sensitive taxa	Tolerance	Positive
Taxon percentage	Percent detritivorous taxa	Trophic	Negative
Richness	Piscivorous taxa	Trophic	Positive
Individual percentage	Combined relative abundance of the two most abundant taxa	Composition	Negative
Individual percentage	Percent of individuals with deformities, eroded fins, lesions, tumors	Composition	Negative
Macroinvertebrates			
Taxon percentage	Relative abundance of dominant five taxa in subsample (Chironomid genera treated individually)	Composition	Increase
Individual percentage	Measure of pollution based on tolerance values assigned to each individual taxon within Minnesota	Tolerance	Increase
Taxon percentage	Taxa richness of macroinvertebrates with tolerance values less than or equal to 4	Tolerance	Decrease
Richness	Taxa richness of Odonata	Richness	Decrease
Taxon percentage	Taxa richness of predators	Richness	Decrease
Taxon percentage	Total taxa richness of macroinvertebrates	Richness	Decrease
Individual Percentage	Relative abundance of non-Hydropsychid Trichoptera individuals in subsample	Composition	Decrease
Individual percentage	Relative abundance of macroinvertebrate individuals in the subsample with tolerance values equal to or greater than 8	Tolerance	Increase

Values for each IBI metric are compared to a biocriteria threshold representing biological conditions, structures, and functions of aquatic communities from a reference stream that best represents a comparable natural system (Bouchard 2014). If the IBI score exceeds that biocriteria, environmental conditions are deemed sufficient to support a full biological community. However, IBI scores that fail to reach biocriteria thresholds are assumed to have insufficient environmental conditions to enable a full biological community, and are thus categorized as impaired (Anderson et al. 2012). Using the approach described above, 271 km of the 539 km of the Minnesota River were assessed and deemed biologically impaired (Figure 2; MPCA 2014).

Use of IBI scores has been criticized for failing to be sensitive enough to adequately identify impairments, a perceived lack of ecological meaning, predictability, and diagnostic power, and applicability in water resources regulation (Sutter 1993). Investigating other taxa groups (e.g., limnetic macroinvertebrates and crustaceous zooplankton) and life stages (e.g., larval fishes) could reveal if this impairment status is consistent through the lower trophic levels of the Minnesota River. However, only one study was identified that previously investigated the zooplanktonic community in the Minnesota River, and impairment status was not the primary focus (Nickel 2014).

At the community level, zooplankton abundance provides central information on trophic structure and dynamics (Kelso et al. 2012). Zooplankters are integral components of aquatic food webs, severing as top-down, and bottom-up regulators (Jeppesen et al. 2011). Plankton are, however, sensitive to environmental change

Figure 2. Minnesota River reaches listed as biologically impaired (light gray) by the Minnesota Pollution Control Agency in 2014. Impairment determinations were based on fish and macroinvertebrate index of biotic integrity scores.

(Schindler 1987) and because the biota are important energy resources for fish and other organisms, ripple effects across the food web can occur (Medeiros and Arthington 2008). Zooplanktonic community likely serves as a critical food source during the development of ichthyoplankton (Helfman et al. 1997).

The ichthyoplanktonic portion of fishes life history plays a vital role in the overall abundance of juvenile and adult populations, growth, mortality, and recruitment (Hjort 1914). The icthyoplanktonic stages are a sensitive and vulnerable life stage, because small size and thin skin leave the larval fish with minimal recourse in the face of rapidly changing conditions (Blaxter 1974). Therefore, survival during the ichthyoplanktonic stage is pivotal for the overall recruitment and size of the adult population (Snyder 1985). However, ichthyoplankton abundance is affected by various environmental and community interaction factors, such as sudden shifts in temperature, availability of food resources, and limnetic macroinvertebrates predation (Bailey 1984; Kelso et al. 2012).

Poulton et al. (1995) noted that limnetic macroinvertebrates should play a significant role in any bioassessment for evaluating the overall status of a water resource. Some limnetic macroinvertebrates contribute to nutrient cycling by breaking down course organic materials into fine particulate matter, or even dissolved organic matter (Cummins 1974). As consumers in the lower and intermediate trophic levels, limnetic macroinvertebrates can serve as important conduits propagating effects both up and down trophic levels (Wallace and Webster 1996; Fisher et al. 2001).

Evaluations of zooplanktonic community in the Minnesota River could provide information on lower trophic levels that would help facilitate biological impairment evaluations. Securing a more comprehensive understanding of the variability within trophic levels in relation to impairment status and the importance of a natural hydrologic regime is an important data need. In addition, there is an increasing need for baseline information to gauge the effects of potential invasive species naturalization.

Therefore, the objective of this chapter is to

- contrast zooplanktonic composition between a biologically impaired and an unassessed reach of the Minnesota River.

It was hypothesized that

- the biologically impaired reach of the Minnesota River will have less diverse and higher densities of tolerant crustaceous zooplankton, limnetic macroinvertebrates and larval fish, due to presumed degraded ecological functionality of that reach.

Methods

Data collection

Zooplanktonic communities were sampled approximately biweekly in the Minnesota River from 15 May to 15 August 2014 and 23 April to 15 August 2015 (Figure 3). Sampling did not occur from 11 June to 4 July 2014 due to high water and from 8 July to 3 August 2015.

Two portions of the Minnesota River were sampled, including one stretch that was IBI-assessed and categorized as biologically impaired (hereinafter referred to as impaired). The other stretch was selected from the river segments that were not assessed with IBIs (hereinafter referred to as unassessed). To accommodate more efficient use of resources, site selection was influenced by proximity to MN DNR intensive study sites on the Minnesota River each year. During 2014, sample reaches were near Franklin, RKM 298 and Savage, RKM 24 (Figure 4). While in 2015, sample reaches were near Henderson, RKM 105 and New Ulm, RKM 234 (Figure 4). Ten sampling transects spaced at 200-m intervals were arranged systematically on the left downstream bank. Transects spanned the entire channel width diagonally upstream to the right downstream bank (Figure 4).

Crustaceous Zooplankton and Rotifers

Near the bank at the downstream end of each transect (N=10), crustaceous zooplankton and rotifers were sampled using a Wisconsin Style vertical tow net (13-cm diameter mouth, with a 200-ml dolphin bucket with 80-µm mesh). Contents from the dolphin bucket were rinsed into a 250-ml sample jar and immediately preserved in 90%

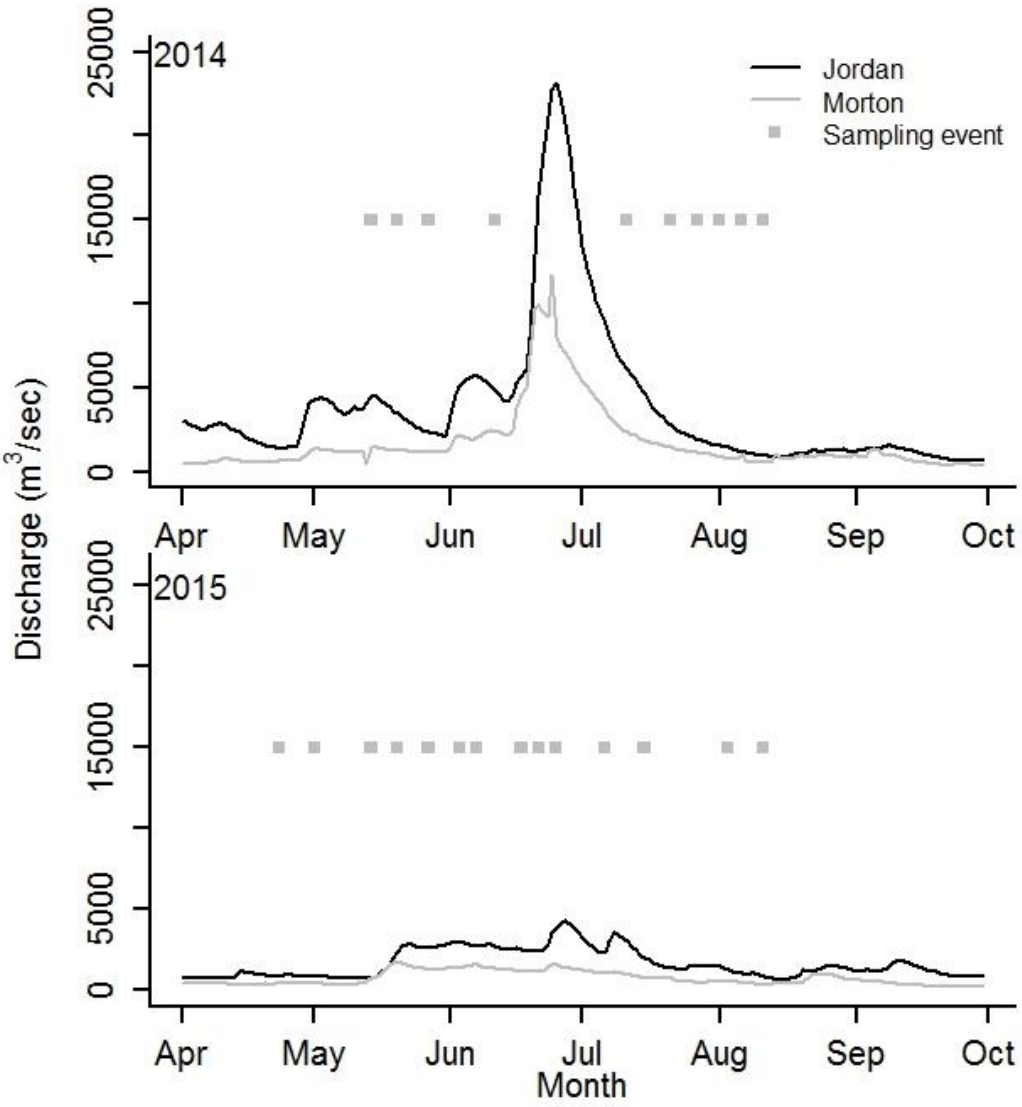

Figure 3. Daily mean flow (converted to m^3/s from ft^3/s values) for the Minnesota River gauging stations near Jordan, MN (USGS 05330000) ; (black line) and near Morton, MN (USGS 0533000) ; (grey line) during the **(top)** 2014 sampling season and **(bottom)** 2015 sampling season. Discrete sampling events throughout each year are represented by grey squares.

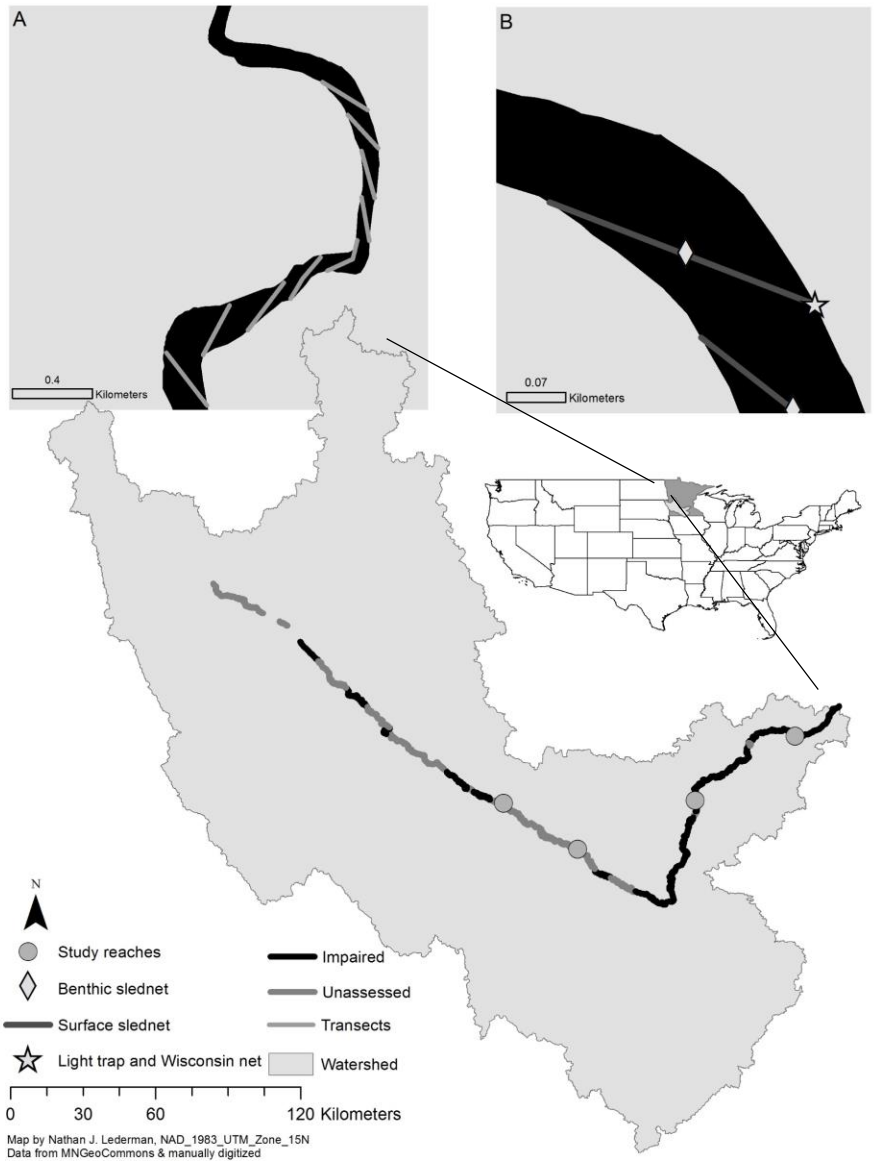

Figure 4. Minnesota River reaches sampled in 2014 (black dots) and 2015 (white dots) in the biologically impaired (light gray segments) unassessed reach (dark grey) of the Minnesota River by the Minnesota Pollution Control. **(A)** Generalized distribution of sampling transects within a reach. **(B)** Placement of sampling gears within a single transect. Star represents a light trap and a Wisconsin net, the diamond represents the benthic trawl and line represents the distance of a surface trawl. During the 2014 sampling year only the light trap glow-stick, surface slednet and Wisconsin net were used. While in 2015 the light trap light source was either a glow-stick or LED and the slednet could have been a surface or benthic and Wisconsin net were used.

ethyl alcohol (Kelso et al. 2012). Samples were then transported back to the laboratory and filtered through an 80-µm mesh sieve and rinsed into a 50-ml beaker with water. Samples were then transferred into a Wildco Ward acrylic counting wheel (model number 3-1810-E80) with a disposable 7.5-ml transfer pipet.

After transfer into counting wheel, zooplankton and rotifers were identified, enumerated and measured under a Olympus SZ61 dissecting microscope with the aid of the computerized Zooplankton Sonar© software program provided by the MN DNR. Zooplankton identification was aided with keys by Balcer et al. (1984), Haney et al. (2013), LaMay et al. (2013), and Smith (2001). Adult copepods were identified to suborder and immature copepods counted as nauplii or copepodites. Cladocerans and rotifers were identified to genus, with the exception of Chydoridae, were identified to family.

Macroinvertebrates and ichthyoplankton

At the downstream end of each transect, near the bank and directly below the water surface in water ≥ 1-m in depth, a quatrefoil LT (41.4-cm high x 21.5-cm wide with 2-mm slot openings; Floyd et al. 1984) was placed targeting limnetic macroinvertebrates (hereinafter macroinvertebrates) and ichthyoplankton. Light traps were set between 0800 and 1100 h and retrieved about 24 h later. In 2014, a single, 12-h photochemical light stick was used in each LT. After reviewing data from the first year of sampling, modifications were made to include a brighter light source in an attempt to better penetrate turbid conditions in the 2015 field season. In 2015, either one 12-h

photochemical light stick or a 120x43-mm LED light with 2 green LED lamps and a polycarbonate resin body were randomly selected as the light source in each LT.

A slednet (SN; 30-cm tall, 46-cm wide, 1-m long with a 1,000-ml dolphin bucket with 500-µm mesh) designed by Nickel (2014) was used to sample at each transect during both years of the study. A General Oceanics mechanical flow meter (Model number 2030R) was suspended in the mouth of the net and used to estimate volume of water sampled in m^3. In 2014, surface SN samples were collected from the upper 0.5 m of the water column at each transect during each sample period. Surface SNs were towed across the entire length of each transect in an upstream manner parallel to the side of the boat a speed ~1.6 km/h greater than the discharge of the river.

In 2015, a detachable sounding weight system (27.2-kg) was added to the SN so the gear could be used to sample 0.5 m from the bottom of the river. The weighted benthic SN samples could be collected and the weight easily detached allowing for quick transition to surface SN sample collections. During each sampling period in 2015, one surface SN or one benthic SN tow was completed at each transect. Surface and benthic SN samples were randomly selected among the 10 transects (N=5 for each SN type each sample date). Surface SN collections were completed using the same methods as 2014. For transects sampled with the benthic SN, the boat was anchored in the thalweg of the transect, the sounding weight apparatus was attached, and the SN was manually deployed from the side of the boat. The benthic SN was fished in the thalweg drift for 5

min to passively sample ichthyoplankton and macroinvertebrates 0.5 m from the bottom. After five minutes had elapsed, the benthic SN was manually pulled back to the surface.

Contents collected from LT and SN gears during both years were fixed and preserved using methodology established by the United States Geological Survey (USGS: J. Larson, United States Geological Services Upper Midwest Environmental Sciences Center, personal communication) and the MN DNR (J. Waters, Minnesota Department of Natural Resources, personal communication). The protocol included immediate fixation of captured biota in 10% buffered formalin. After 24 to 48 h, sample contents were filtered through a 53-µm sieve, rinsed back into the same sample bottle, and preserved with 90% ethyl alcohol. Macroinvertebrate and ichthyoplankton specimens were identified using an Olympus SZ61 dissecting microscope. Macroinvertebrates were identified, typically to order, with keys by Bouchard (2004) and Merritt et al. (2008). Ichthyoplankton were identified, usually to genus, using the keys by Auer (1982), and Fuiman et al. (1983) and Wallus and Simon (1990, 1994, 2003, 2005, 2006, and 2008).

Ichthyoplankton from 2014, were sent to Thomas Simon at Indiana State University for verification and to provide case specimens to aid in the 2015 identifications. Due to aggregation of samples to meet fiscal constraints, percent agreement between expert identification and my identifications could not be determined. However, families and genera were represented in both the professional and my identifications in similar abundances, expect for Hiodontidae genera

identifications. My Hiodontidae specimens were reanalyzed and adjustments made. The 2015 samples were not expert-verified due to time and logistical constantans.

Analyses

The two different light sources for the LT samples and the two SN sampling methods were analyzed collectively as LT and SN samples. Precedent for combining samples comes from Pritt et al. (2015) that combined their surface and benthic net samples when they described the ichthyoplankton community in the Detroit and St. Clair rivers. Additionally, Radwell and Camp (2009) found LED light sources performed as well as a disposable photochemical light stick for capturing aquatic insects and was a suitable alternative.

Data were aggregated based on the prevailing hydrologic condition at the time of sampling. These aggregations were based on evidence presented by Nickel (2014) that community structure of the biota varied based on the hydrologic stage being sampled. Historically, the Minnesota River has had two major peaks flows, one after the snowmelt and one during summer rain events (Figure 5). Therefore, data were aggregated based on their relationship to the first ascending limb, the second ascending limb, major descending limb and the consequent steady state (Figure 5 and Table 2).

Crustaceous zooplankton and rotifer densities were reported as number/L for all taxa captured. Macroinvertebrate and ichthyoplankton catches by LT were summarized as number/trap night for each taxon. Macroinvertebrate and ichthyoplankton captured in SNs were recorded as number/100m^3 of water.

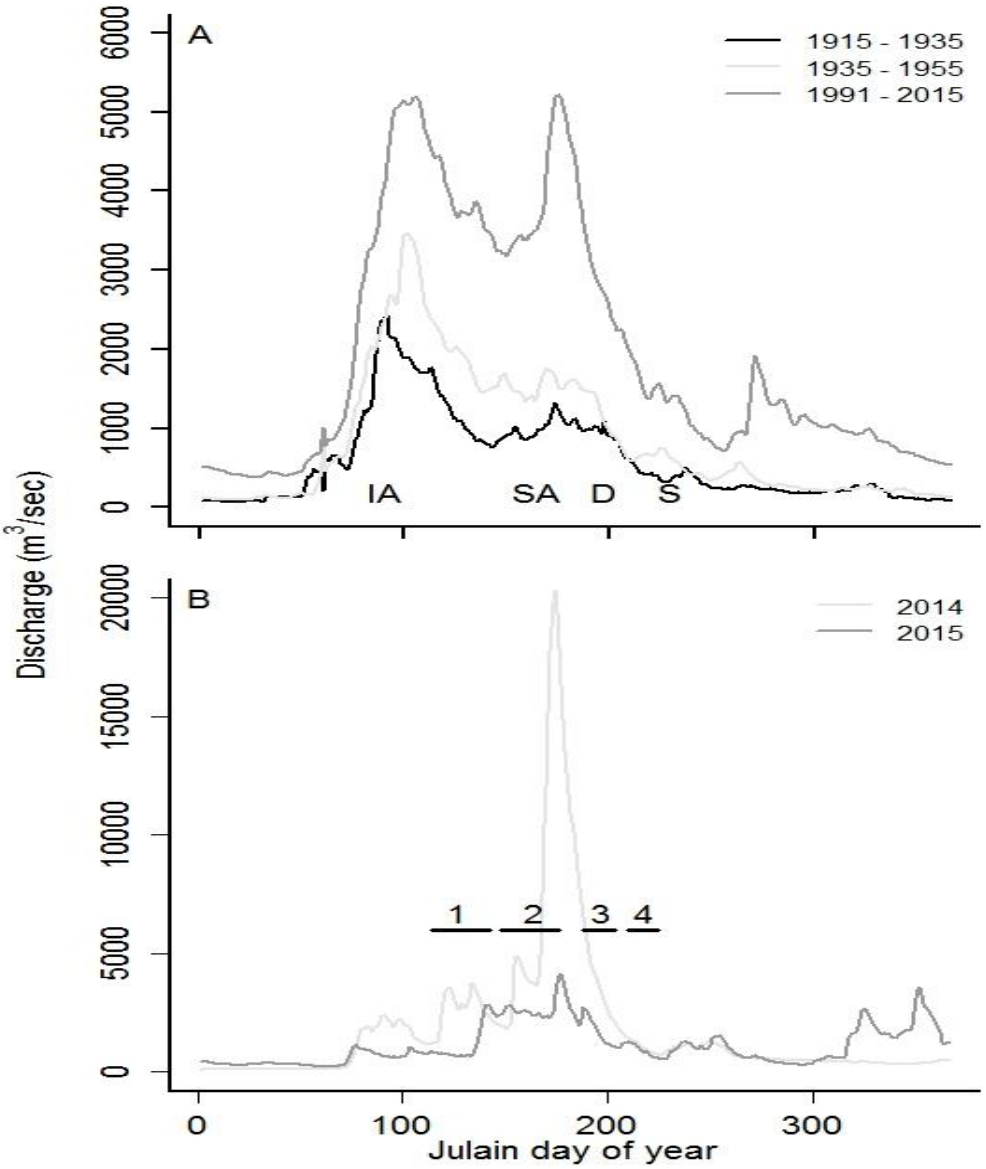

Figure 5. Daily mean flow (converted ft3/sec to m3/sec values) for the Minnesota River gauging stations (USGS 05325000) in Mankato, MN. **(A)** Historical daily mean flow from 1915-1935, 1935- 1955 and 1991-2015 of the Minnesota River. IA indicates typical location of first ascending limb, SA indicates typical location of secondary rise when overbank flooding occurs, D indicates the typical major descend and S indicates typical steady state. **(B)** 2014 and 2015 hydrographs with indicating the four periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] when zooplankton, macroinvertebrates, and ichthyoplankton occurred during those two years.

Table 2. Daily mean flow (m^3/sec), hydrograph direction, and water temperature (C°) for the sampling reaches in Minnesota River in all four periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] during 2014 and 2015. Discharge and flow direction for the impaired reach collected from USGS gauging station (05330000) near Jordan, MN and the unassessed reach from USGS gauging station 05316580 near Morton, MN. Water temperature collected in the field at each reach during sampling.

Period	Reach	Year	Discharge (m^3/s)	Flow direction	Water Temperature (C°)
1					
	Impaired	2014	1130	Falling	13.8
	Unassessed	2014	4710	Falling	13.0
	Impaired	2015	2760-2360	Falling	13.3-15.6
	Unassessed	2015	1230-5350	Rising	8.3-13.7
2					
	Impaired	2014	15900	Rising	20.0
	Unassessed	2014	3720	Rising	17.8
	Impaired	2015	8320-8900	Rising	17.8-23.8
	Unassessed	2015	4300-5060	Rising	20.5-22.2
3					
	Impaired	2014	9120	Falling	23.7
	Unassessed	2014	7620	Falling	23.6
	Impaired	2015	6300	Falling	26.6
	Unassessed	2015	3200	Falling	23.8
4					
	Impaired	2014	5250-2310	Falling	23.5-23.8
	Unassessed	2014	3610-3040	Falling	23.2-24.3
	Impaired	2015	4100	Falling	25.0
	Unassessed	2015	950	Falling	25.4

Qualitatively, data for each taxa group (e.g., crustaceous zooplankton, rotifers, macroinvertebrates, and ichthyoplankton) were assessed using a non-metric multidimensional scaling's (NMDS; Kruskal 1964). To examine community compositional similarities between reaches, NMDS evaluations were completed for each taxa group within each gear type for all periods combined, for each year individually and for both years combined. The NMDS used the Bray-Curtis dissimilarities, a technique considered robust for ecological analysis (Chirhart 2014). The NMDS scaling "maps" results in such a way that the rank order between reaches represents the rank order of the similarities/dissimilarities between reaches (Morris and Ball 2006). This method allowed for the relationships between reach type and taxa community present to be evaluated. Dimensionalities of plots were determined when plots of final stress versus number of dimensions showed that a greater number of axes resulted in small reductions in stress. The NMDS were performed using the program R software 3.1.2 and the vegan package.

Additionally, an analysis of similarities (ANOSIM) was performed for each taxa group by the Wisconsin net, LT and SN in each year and both years cumulatively, to compare communities between unassessed and impaired reach. This non-parametric randomization procedure determines if significant community differences exist between groups (in this case reaches) as samples within groups should be more similar in composition than samples from different groups (Clarke 1988). An *R*-statistic with a range of -1 to 1 and a *P*-value are calculated. With the *R*-statistic itself being useful for a comparative measure of the degree of separation (Clarke 1988). An *R*-statistic close to 1

suggest dissimilarity among groups, while an *R*-statistic close to 0 suggest even distribution.

Data pairs (unassessed and impaired reaches) within each period and each gear type (e.g., SN, LT, Wisconsin net), for each taxa group, were tested for normality using a Shapiro-Wilk test. If data were not normally distributed, data were log-transformed [log10 (n+1)] in an attempt to conform to normality and reduce heterogeneity variance. Transformed data were again tested for normality. If normality assumptions were met, taxa densities of each zooplanktonic taxa group between reaches and within each gear type were analyzed with a two-way analysis of variance (ANOVA) with reach type and period as the main factors. If significant interactions were detected between periods and reach type, further analyses between reaches were completed within each period and gear. If the data sets could not reach the normality assumptions, analyses between reaches within gear type were compared using Mann Whitney U tests to compare two groups (t-test procedure, SigmaPlot 11.0). For all comparisons, a $P < 0.05$ indicated statistical significance.

Results

Crustaceous zooplankton

In total, 1,147 crustaceous zooplankters from 371,887 l of water were captured, representing thirteen different taxa grouping in the impaired and unassessed reaches over the two years. During 2014, 739 crustaceous zooplankters were captured with 503 from the impaired reach and 202 from the unassessed reach. Those zooplankters represented all thirteen taxa groupings in the unassessed and impaired reach. During

2015 however, fewer total crustaceous zooplankters were captured with 206 from the impaired reach and 236 from the unassessed reach, representing 11 taxa groupings in the unassessed and impaired reach.

Total crustaceous zooplankton densities varied among hydrologic periods. Greatest crustaceous zooplankton densities were during period one (first ascending limb) and period three (major descending limb) in both reach types and in both years (Figure 6). The greatest densities of crustaceous zooplankton for were found in the impaired reach during period 1 of 2014 and in period 3 of 2014 for the unassessed reach. Decreases crustaceous zooplankton densities during periods two (second ascending limb) and four (steady state). Similar densities of crustaceous zooplankton occurred during periods two and four in both years and reach types (Figure 6).

Moina sp. was the only crustaceous zooplankton taxa not found in the unassessed reach, but was found in the impaired reach. Numerically, only seven taxa groups represented more than 5% of the catch. Those taxa were Cyclopoida representing 38%, Ostracoda representing 14%, Copepoda nauplii representing 10%, *Daphnia* spp. representing 8%, and Chydoridae, Calanoida and *Bosmina* spp. each representing 7% (Figure 7).

The NMDS plot displayed weak ties between reach type and zooplankton community present. The impaired and unassessed were on almost the exact same

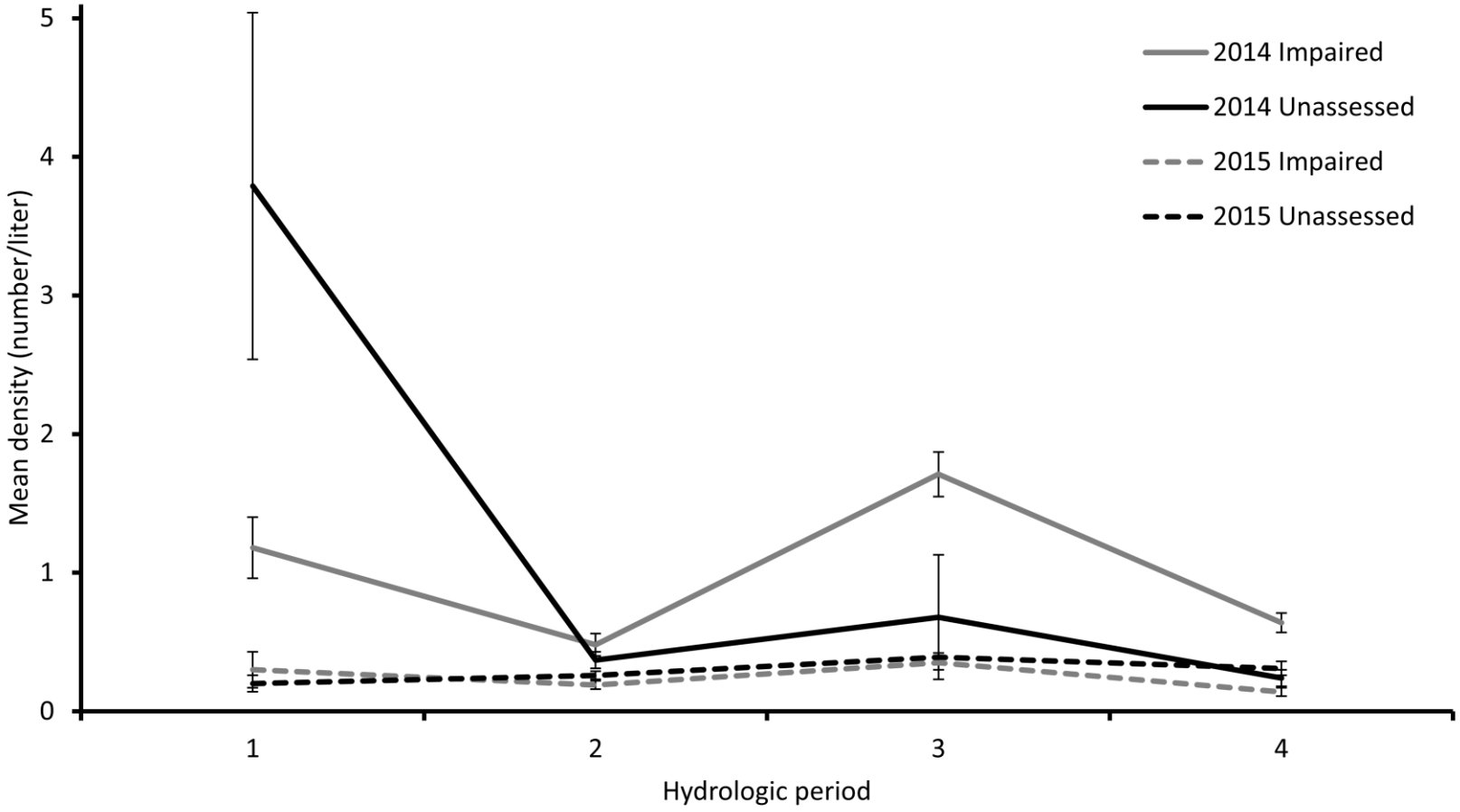

Figure 6. Mean zooplankton density (number/liter) among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015.

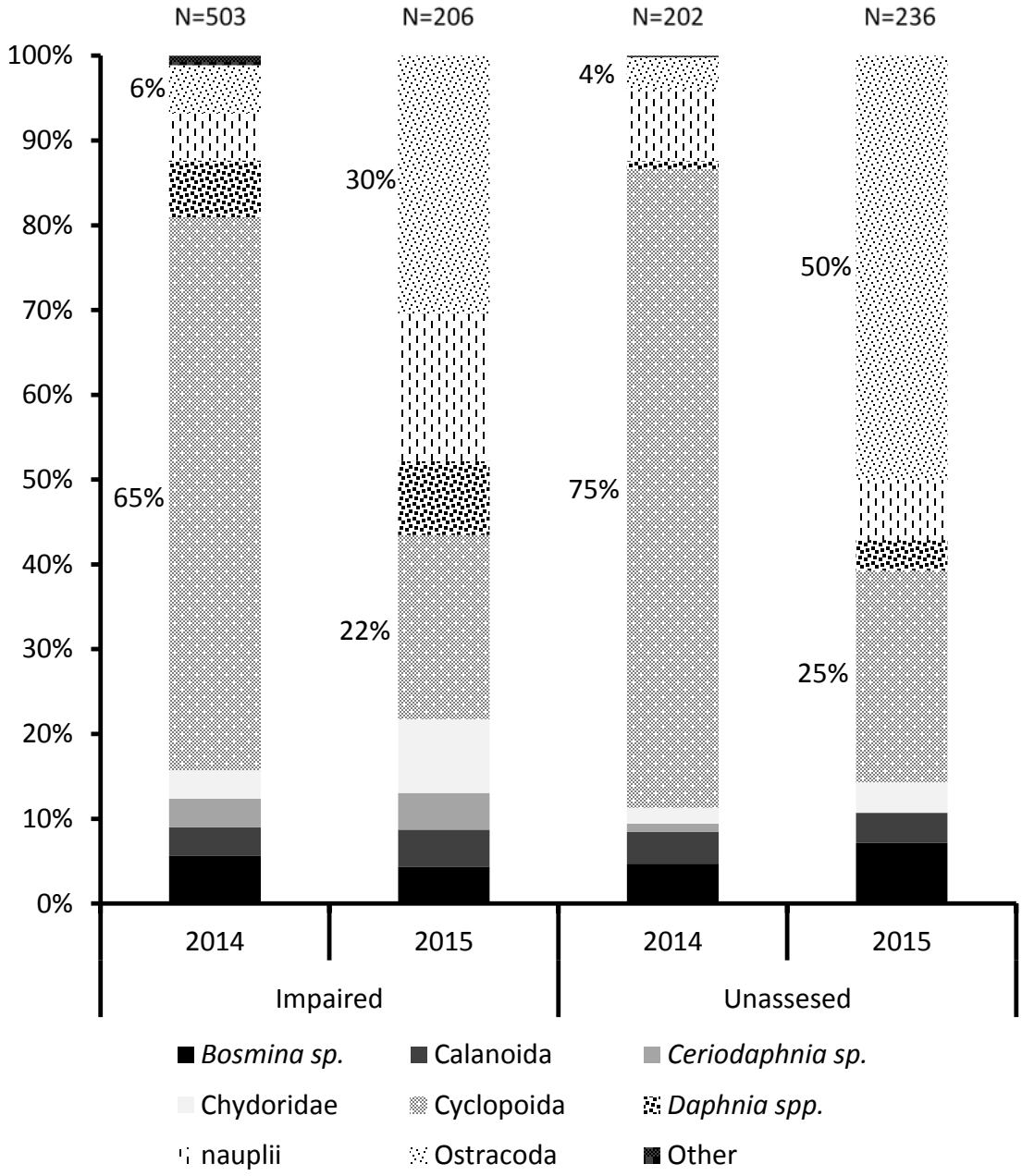

Figure 7. Percent each taxa group represented in the total catch of zooplankton trawls in the Minnesota River during the 2014 and 2015 field seasons. Other classification comprised of taxa groups numerically making up < 5% of the total catch represented by *Moina* sp., *Pontoporeia* sp., *Sida crystalline*, *Simocephalus* spp. and *Diaphanosoma* spp. N is the total number of individual zooplankters captured during that year for that particular reach and the percentages are the taxa groups that represented >50% of the community.

points on both the NMDS axis 1 and 2 for each year separately and both years combined (Figure 8). The 95% confidence ellipses nearly overlapped and encompassed the same area on the plot, indicating similar zooplankton communities between the impaired and unassessed reaches of the Minnesota River.

Analysis of similarities results revealed no significant differences between communities sampled between the unassessed and impaired reaches for 2014 (ANOSIM: $R = 0.04$; $P = 0.33$) and both years cumulatively (ANOSIM: $R = 0.02$, $P = 0.28$). However, a significant difference was detected in 2015 between the impaired and unassessed reaches (ANOSIM: $R = 0.18$; $P = 0.03$), but the R-value was still close to 0. Due to similarities in community structure among years, analyses among periods included combined data from both years.

Period one

Zooplankton densities differed significantly in five of the 11 taxa groupings during period one between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015. Differences were detected in Cyclopoida ($U = 14$, df = 2, $P = 0.01$), *Daphnia* spp. ($U = 19$, df = 2, $P = 0.02$), *Bosmina* spp. ($U = 23$, df = 2, $P = 0.04$), Chydoridae ($U = 19$, df = 2, $P = 0.02$) and *Diaphanosoma* spp. ($U = 18$, df = 2, $P = 0.01$). The unassessed reach had significantly greater mean densities per liter of Cyclopoida (1.11±0.44, [mean±SE]) and *Bosmina* spp. (0.07±0.03) compared to the impaired Cyclopoida (0.26±0.08) and *Bosmina* spp. (0.04±0.02; Table 3). While the impaired

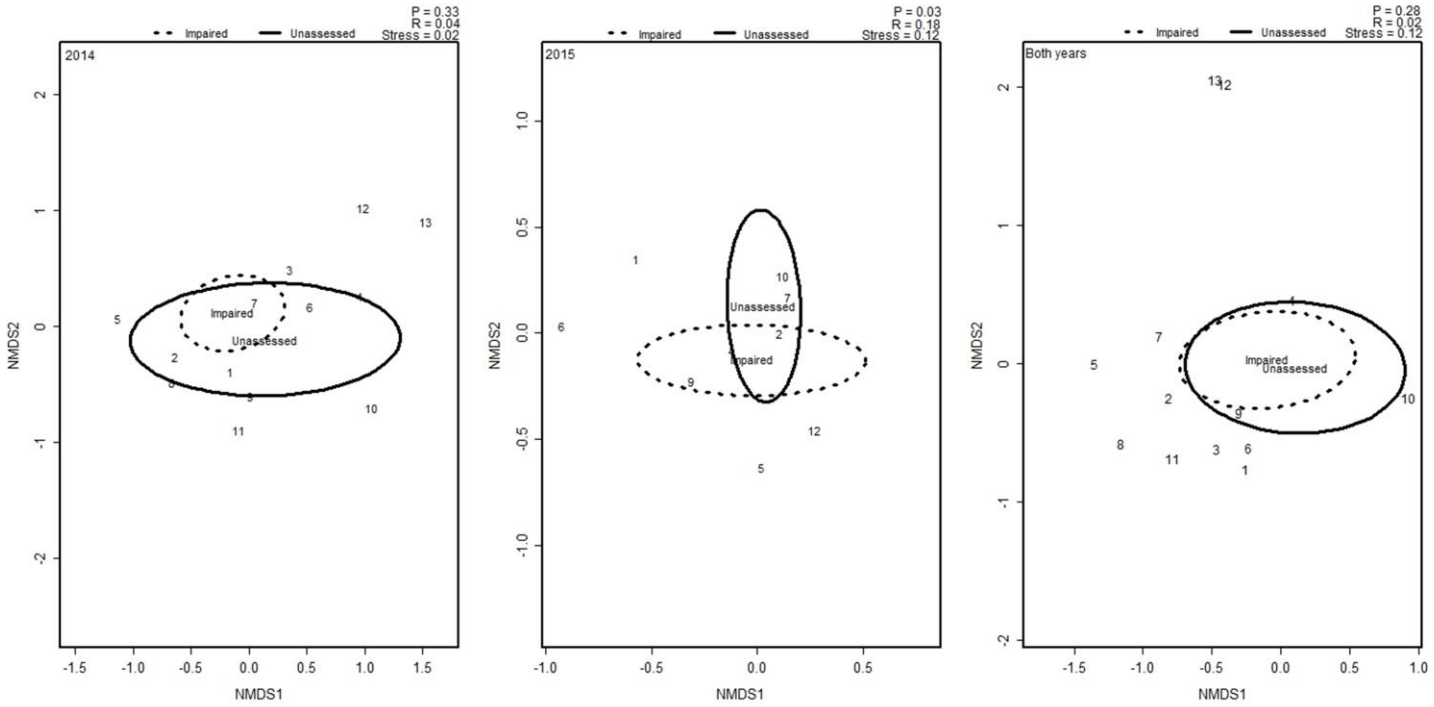

Figure 8. NMDS ordinations plotted with mean zooplankton densities (number/liter) per sampling trip of taxa groups captured in the Minnesota River during 2014 and 2015 between the impaired and unassessed reaches. Ellipses around each reach type denote the 95% confidence interval for that reach type. Each ordination is a separate ordination for only 2014, only 2015 and both years cumulatively. Therefore, comparison among ordinations is not appropriate. The numbers correspond to a particular taxa group: 1: *Bosmina* spp. 2: Calanoida 3: *Ceriodaphnia* spp. 4: Chydoridae 5: Cyclopoida 6: *Daphnia* spp. 7: *Diaphanosoma* spp. 8: *Moina* sp. 9: Nauplii 10: Ostracoda 11: *Pontoporeia* sp. 12: *Sida crystalline* 13: *Simocephalus* spp.

Table 3. Mean density (number/liter) of zooplankton taxa sampled in the impaired (N=40) and unassessed (N=40) reaches of Minnesota River during period one (first ascending limb) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Taxa group	Impaired	Unassessed	*P*-value
***Bosmina* spp.**	**0.04(0.02)**	**0.07(0.03)**	**0.04**
Calanoida	0.03(0.01)	0.05(0.02)	0.10
Ceriodaphnia spp.	0.06(0.03)	0.01(0.01)	0.59
Chydoridae	**0.03(0.01)**	**0.00(0.00)***	**0.02**
Cyclopoida	**0.26(0.08)**	**1.11(0.44)**	**0.01**
***Daphnia* spp.**	**0.08(0.02)**	**0.01(0.01)**	**0.02**
***Diaphanosoma* spp.**	**0.03(0.01)**	**0.00(0.00)***	**0.01**
Nauplii	0.06(0.01)	0.09(0.04)	0.56
Ostracoda	0.05(0.01)	0.09(0.03)	0.10
Sida crystallina	0.00(0.00)	0.00(0.00)*	0.37
Simocephalus spp.	0.00(0.00)*	0.00(0.00)	0.37

reach had significantly greater mean densities per liter of *Daphnia* spp. (0.08±0.02), Chydoridae (0.03±0.01) and *Diaphanosoma* spp. (0.03±0.01) compared to the unassessed *Daphnia* spp. (0.01±0.01), Chydoridae (0.00±0.00), and *Diaphanosoma* spp. (0.00±0.00); (Table 3).

Period two

Zooplankton densities differed significantly in three of the 11 taxa groups captured during period two between the impaired and unassessed reaches of the Minnesota River in 2014 and 2015. Significant differences were detected in the *Daphnia* spp. (U = 643, df = 2, P = 0.04), Chydoridae (U = 591, df = 2, P = 0.02), and Ostracoda (U = 600, df = 2, P = 0.05). The impaired reach had significantly greater mean densities of *Daphnia* spp. (0.02±0.01) and Chydoridae (0.03±0.01) compared to the unassessed reach densities for the *Daphnia* spp. (0.00±0.00) and Chydoridae (0.01±0.01; Table 4). However, the unassessed reach had significantly greater densities of Ostracoda (0.08±0.01) compared to the Ostracoda densities (0.06±0.01) of the impaired reach (Table 4).

Period three

Crustaceous zooplankton densities were significantly different in five of the ten taxa groupings captured during period three between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015. Significant differences were detected in the *Bosmina* spp. (U = 114, df = 2, P = 0.02), Cyclopoida (U = 119, df = 2, P = 0.05), *Daphnia* spp.(U = 95, df = 2, P = 0.01), *Diaphanosoma* spp. (U = 96, df = 2, P =

Table 4. Mean density (number/liter) of zooplankton taxa sampled in the impaired (N=40) and unassessed (N=40) reaches of Minnesota River during period two (second ascending limb) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Taxa group	**Impaired**	**Unassessed**	***P*-value**
Bosmina spp	0.02(0.01)	0.01(0.01)	0.79
Calanoida	0.01(0.01)	0.02(0.01)	0.91
Ceriodaphnia spp.	0.00(0.00)*	0.00(0.00)*	0.19
Chydoridae	**0.03(0.01)**	**0.01(0.01)**	**0.02**
Cyclopoida	0.08(0.02)	0.13(0.03)	0.25
***Daphnia* spp.**	**0.02(0.01)**	**0.00(0.00)***	**0.04**
Diaphanosoma spp	0.00(0.00)*	0.00(0.00)*	0.11
Nauplii	0.04(0.02)	0.04(0.01)	0.73
Ostracoda	**0.06(0.01)**	**0.08(0.01)**	**0.05**
Sida crystallina	0.00(0.00)*	0.00(0.00)*	0.58
Simocephalus spp.	0.00(0.00)	0.00(0.00)*	0.16

<0.01) and Nauplii (*U* = 52, df = 2, *P* = <0.01). The impaired reach had significantly more *Bosmina* spp. (0.05±0.01), Cyclopoida (0.62±0.13), *Daphnia* spp. (0.04±0.01), *Diaphanosoma* spp. (0.03±0.01) and Nauplii (0.09±0.02) compared to the unassessed reach captures of *Bosmina* spp. (0.01±0.01), Cyclopoida (0.31±0.22), *Daphnia* spp. (0.01±0.01), *Diaphanosoma* spp. (0.00±0.00), and Nauplii (0.02±0.02; Table 5).

Period four

Crustaceous zooplankton densities during were significantly different in six of the 12 taxa groupings captured during period four between the impaired and unassessed reaches. Significant differences were detected in *Ceriodaphnia* spp. (*U* = 311, df = 2, *P* = 0.01), Chydoridae (*U* = 328, df = 2, *P* = 0.03), Cyclopoida (*U* = 145, df = 2, *P* = <0.01), *Daphnia* spp. (*U* = 318, df = 2, *P* = 0.01), *Diaphanosoma* spp. (*U* = 377, df = 2, *P* = 0.01) and *Simocephalus* spp. (*U* = 279, df = 2, *P* = 0.02). The impaired reach captured significantly more *Ceriodaphnia* spp. (0.01±0.01), Cyclopoida (0.31±0.06), *Daphnia* spp. (0.01±0.01), *Diaphanosoma* spp. (0.00±0.00) and Simocephalus spp. (0.02±0.01) compared to the unassessed reach's *Ceriodaphnia* spp. (0.00±0.00), Cyclopoida (0.02±0.01), *Daphnia* spp. (0.00±0.00), *Diaphanosoma* spp. (0.00±0.00) and Simocephalus spp. (0.00±0.00) densities (Table 6). While the unassessed reach captured significantly more Chydoridae (0.02±0.01) compared to the impaired reach's Chydoridae (0.00±0.00; Table 6).

Table 5. Mean density (number/liter) of zooplankton taxa sampled in the impaired (N=20) and unassessed (N=20) reaches of Minnesota River during period three (major descending limb) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Taxa group	Impaired	Unassessed	*P*-value
***Bosmina* spp.**	**0.05(0.01)**	**0.01(0.01)**	**0.02**
Calanoida	0.03(0.01)	0.02(0.01)	0.15
Ceriodaphnia spp.	0.01(0.01)	0.01(0.01)	0.69
Chydoridae	0.03(0.01)	0.04(0.20)	0.39
Cyclopoida	**0.62(0.13)**	**0.31(0.22)**	**0.05**
***Daphnia* spp.**	**0.04(0.01)**	**0.01(0.01)**	**0.01**
***Diaphanosoma* spp.**	**0.03(0.01)**	**0.00(0.00)***	**<0.01**
Moina sp.	0.00(0.00)*	0.00(0.00)	0.98
Nauplii	**0.09(0.02)**	**0.02(0.02)**	**<0.01**
Ostracoda	0.11(0.02)	0.11(0.02)	0.62
Sida crystallina	0.00(0.00)*	0.01(0.01)	0.97

Table 6. Mean density (number/liter) of zooplankton taxa sampled in the impaired (N=30) and unassessed (N=30) reaches of Minnesota River during period four (steady state) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Taxa group	**Impaired**	**Unassessed**	***P*-value**
Bosmina spp.	0.03(0.01)	0.03(0.02)	0.20
Calanoida	0.00(0.00)*	0.01(0.01)	0.22
***Ceriodaphnia* spp.**	**0.01(0.01)**	**0.00(0.00)***	**0.01**
Chydoridae	**0.00(0.00)***	**0.02(0.01)**	**0.03**
Cyclopoida	**0.31(0.06)**	**0.04(0.01)**	**<0.01**
***Daphnia* spp.**	**0.01(0.01)**	**0.00(0.00)***	**0.01**
***Diaphanosoma* spp.**	**0.00(0.00)***	**0.00(0.00)**	**0.05**
Nauplii	0.02(0.01)	0.04(0.01)	0.17
Ostracoda	0.06(0.02)	0.12(0.03)	0.24
Pontoporeia sp.	0.00(0.00)	0.00(0.00)*	0.15
Sida crystallina	0.00(0.00)*	0.00(0.00)*	0.98
***Simocephalus* spp.**	**0.02(0.01)**	**0.00(0.00)***	**<0.01**

Rotifers

In total, 518 rotifers were captured after sampling 371,887 l of water, representing fifteen different taxa groupings in both the impaired and unassessed reaches over the two years. During 2014, 219 rotifers were captured with 139 from the impaired reach and 80 from the unassessed reach both represented by 15 genera. In 2015, 299 rotifers were captured with 166 from the impaired and 133 from the unassessed representing 13 genera in both reaches. Cumulatively, all 15 genera were sampled in the impaired reach but only 13 of the 15 were sampled in the unassessed reach. Mean rotifer densities varied among hydrologic periods. Greatest mean rotifer densities were during period three (major descending limb) in both reach type and in both years (Figure 9). Overall, limited densities were found in both reaches with greater densities in the impaired reach during 2014 and 2015.

During 2014, the impaired reach catch was dominated by *Ascomorpha* sp. In 2015, *Lecean* sp. and *Gastrous* sp. dominated the community in the impaired reach (Figure 10). While in 2014 and 2015, the unassessed reach had greater evenness in community structure as *Ascomorpha* sp., *Asplanchna* sp., *Conochilus* sp., *Lecane* sp., *Monstyla* sp., and *Synchaeta* sp. accounted for similar proportions of the community (Figure 10).

Due to limited catch of rotifers, NMDS ordinations for each year individually were unable to be ran and reach a convergent solution, no matter the number of dimensions, or how the data were aggregated and means taken. However, mean by

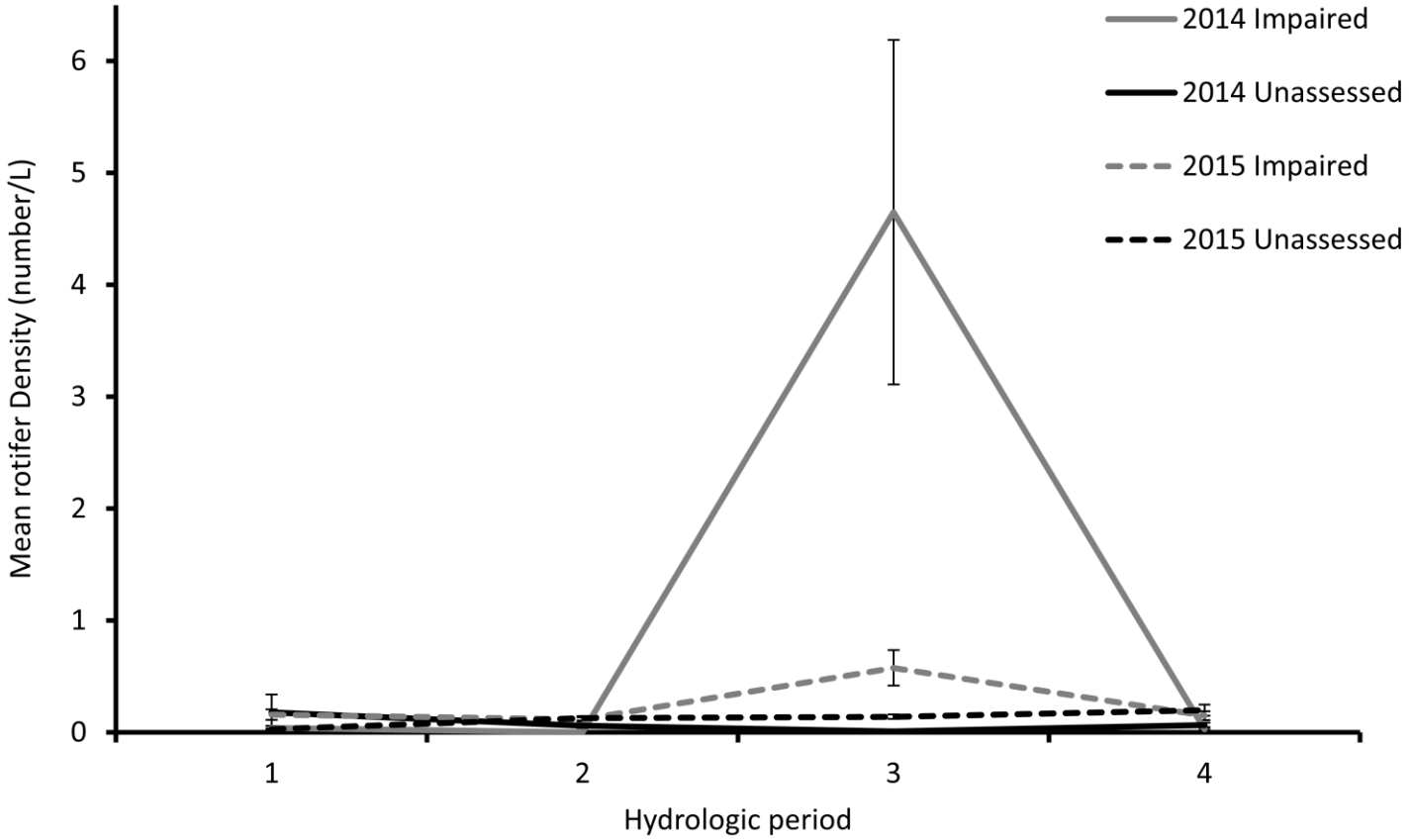

Figure 9. Mean rotifer density (number/liter) among hydrologic periods [first ascending limb(period one), second ascending limb(period two), major descending limb (period three), steady state (period four)] between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015.

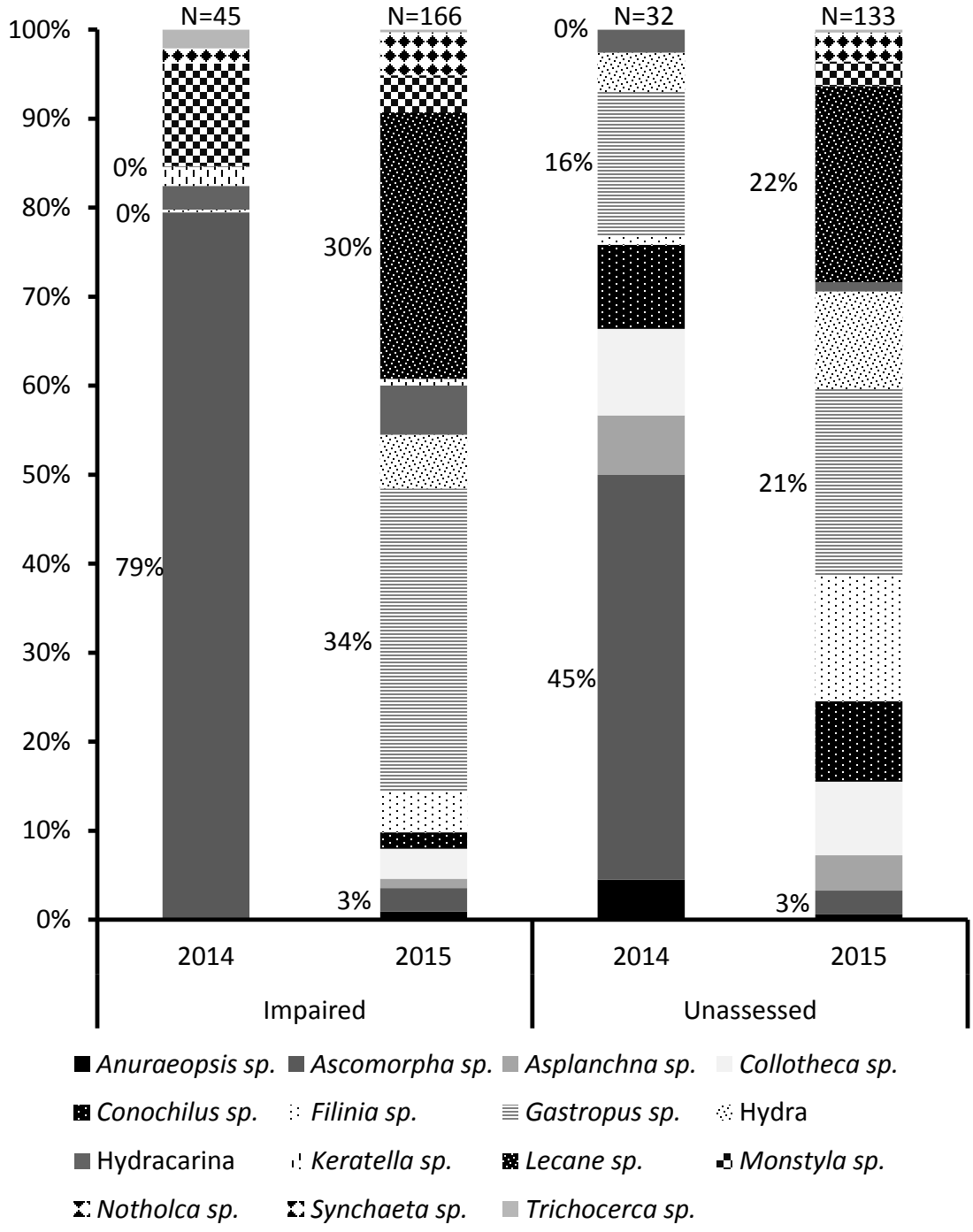

Figure 10. Percent each genera of rotifers represented in the total catch of zooplankton trawls in the Minnesota River during the 2014 and 2015 field seasons within the impaired and unassessed reaches. N is the total number of individual rotifers captured during that year for that particular reach and the percentages are the taxa groups that represented >50% of the community.

sample date for both years cumulatively was able to reach a convergent solution (Figure 11). The mean by sample date for both years NMDS plot displayed weak ties between reach type and rotifer community present. The impaired and unassessed were on almost the exact same points on both the NMDS axis 1 and 2. The 95% confidence ellipses nearly completely overlapped and encompassed the same area on the plot, indicating similar rotifer communities being sampled between the impaired and unassessed reaches of the Minnesota Rive are similar. The ANOSIM displays no significant difference between the unassessed and impaired reaches for the rotifer communities (ANOSIM: R = -0.05; P = 0.90). Due to these similarities among years and the limited catch, analyses among period used both years cumulatively.

Period one

Rotifer densities differed significantly in one of the 10 genera sampled during period one between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (Table 7). The significant difference was detected in *Asplanchna* sp. (U = 288, df =2, P = 0.01). The impaired reach captured significantly greater densities of *Asplanchna* sp. (0.04±0.02) compared with the unassessed reach densities of *Asplanchna* sp. (0.00±0.00); (Table 7).

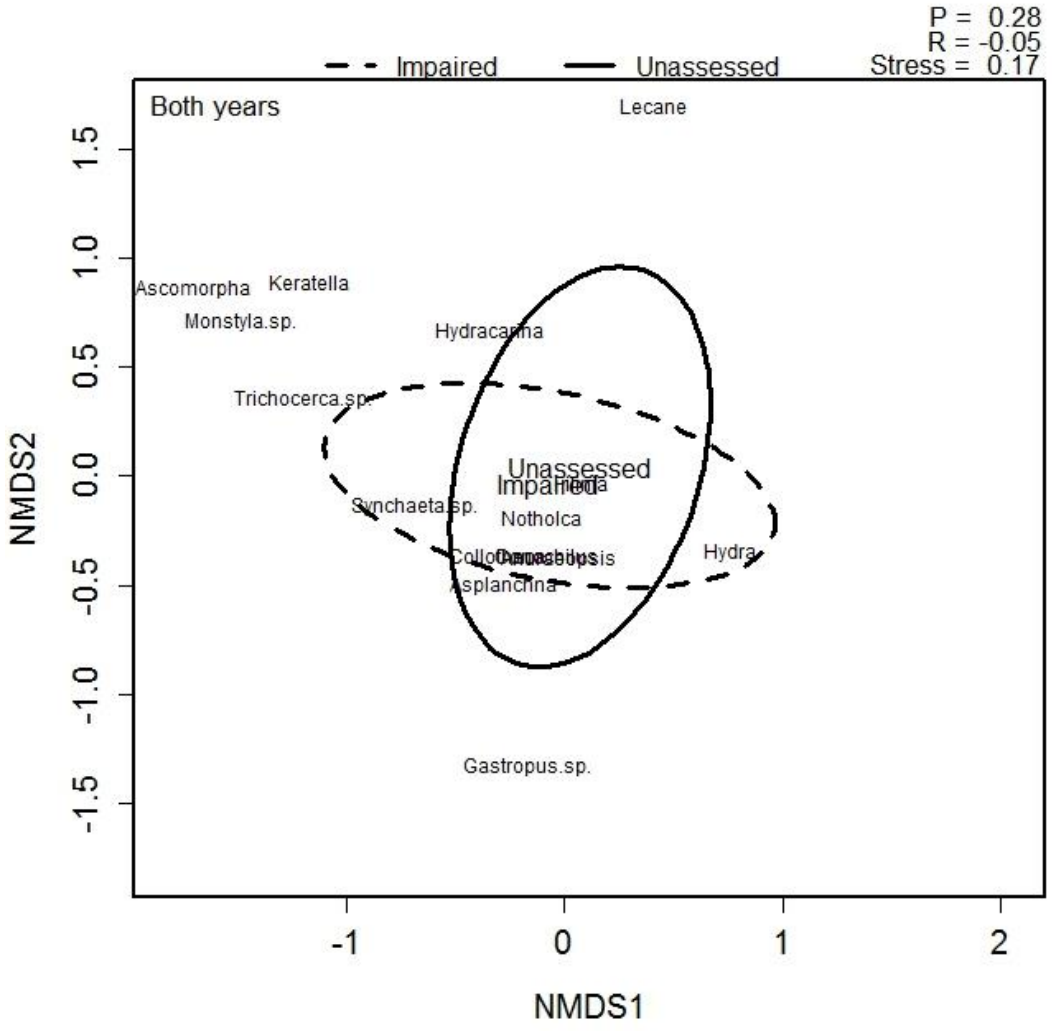

Figure 11. NMDS ordinations plotted with rotifer genera densities (number/liter) captured in the Minnesota River during 2014 and 2015 between locations. Ellipses around each reach type denote the 95% confidence interval for that reach type.

Table 7. Mean density (number/liter) of rotifer taxa sampled in the impaired (N=40) and unassessed (N=40) reaches of Minnesota River during period one (first ascending limb) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Genera	**Impaired**	**Unassessed**	***P*-value**
Ascomorpha sp.	0.03(0.01)	0.01(0.01)	0.17
***Asplanchna* sp.**	**0.04(0.02)**	**0.00(0.00)***	**0.01**
Gastropus sp.	0.00(0.00)*	0.00(0.00)	0.15
Hydra	0.01(0.01)	0.00(0.00)*	0.84
Hydracarina	0.01(0.01)	0.00(0.00)*	0.23
Keratella sp.	0.00(0.00)*	0.00(0.00)	0.96
Lecane sp.	0.00(0.00)	0.06(0.06)	0.35
Monstyla sp.	0.01(0.01)	0.00(0.00)*	0.84
Notholca sp.	0.00(0.00)*	0.00(0.00)	0.53
Trichocerca sp.	0.01(0.01)	0.00(0.00)	0.07

Period two

Rotifer densities differed significantly in two of the 14 genera sampled during period two between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (Table 8). Significant differences were detected in Hydra (*U* = 586, df =2, *P* = 0.01) and *Trichocerca* sp. (*U* = 720, df = 2, *P* = 0.04). The impaired reach captured significantly more *Trichocerca* sp. (0.01±0.00) compare the unassessed reach *Trichocerca* sp. (0.00±0.00); (Table 8). While the unassessed reach captured significantly greater densities of Hydra (0.02±0.01) compared to the impaired reach Hydra densities (0.00±0.00); (Table 8).

Period three

Rotifer densities differed significantly in two of the 13 genera sampled during period three between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (Table 9). Significant differences were detected in *Ascomorpha* sp. (*U* = 54.50, df = 2, *P* =<0.01) and *Monstyla* sp. (U = 122, df = 2, *P* = 0.01). The impaired reach had significantly greater densities for both *Ascomorpha* sp. (2.02±0.76) and *Monstyla* sp. (0.27±0.14) compared to the unassessed densities of *Ascomorpha* sp. (0.01±0.01) and *Monstyla* sp. (0.00±0.00; Table 9).

Period four

Rotifer densities differed significantly in one of 13 genera sampled during period four between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (Table 10). Significant difference was detected in the *Synchaeta* sp. (*U* = 345,

Table 8. Mean density (number/liter) of rotifer taxa sampled in the impaired (N=40) and unassessed (N=40) reaches of Minnesota River during period two (second ascending limb) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Genera	**Impaired**	**Unassessed**	***P*-value**
Anuraeopsis sp.	0.00(0.00)*	0.00(0.00)	0.33
Ascomorpha sp.	0.01(0.01)	0.02(0.01)	0.08
Asplanchna sp.	0.02(0.01)	0.02(0.01)	0.69
Collotheca sp.	0.01(0.01)	0.00(0.00)*	0.45
Conochilus sp.	0.01(0.010	0.01(0.01)	0.63
Filinia sp.	0.00(0.00)*	0.00(0.00)	0.33
Hydra	**0.00(0.00)***	**0.02(0.01)**	**0.01**
Hydracarina	0.00(0.00)	0.00(0.00)	0.43
Keratella sp.	0.00(0.00)*	0.00(0.00)*	0.19
Lecane sp.	0.00(0.00)	0.00(0.00)	0.47
Monstyla sp.	0.01(0.01)	0.01(0.01)	0.35
Notholca sp.	0.00(0.00)*	0.00(0.00)*	0.17
Synchaeta sp.	0.01(0.01)	0.01(0.01)	0.46
***Trichocerca* sp.**	**0.00(0.00)***	**0.00(0.00)***	**0.04**

Table 9. Mean density (number/liter) of rotifer taxa sampled in the impaired (N=20) and unassessed (N=20) reaches of Minnesota River during period three (major descending limb) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Genera	Impaired	Unassessed	*P*-value
Ascomorpha	**2.02(0.76)**	**0.01(0.01)**	**<0.01**
Asplanchna	0.07(0.03)	0.01(0.01)	0.08
Collotheca	0.01(0.01)	0.00(0.00)*	0.13
Conochilus	0.01(0.01)	0.02(0.01)	0.40
Filinia	0.00(0.00)	0.00(0.00)*	0.33
Hydra	0.00(0.00)*	0.00(0.00)	0.98
Hydracarina	0.05(0.04)	0.01(0.01)	0.86
Keratella	0.05(0.05)	0.00(0.00)	0.17
Lecane	0.00(0.00)	0.01(0.01)	0.42
***Monstyla* sp.**	**0.27(0.14)**	**0.00(0.00)***	**0.01**
Notholca	0.01(0.01)	0.01(0.01)	0.75
Synchaeta sp.	0.05(0.04)	0.00(0.00)*	0.09
Trichocerca sp.	0.06(0.05)	0.00(0.00)*	0.12

Table 10. Mean density (number/liter) of rotifer taxa sampled in the impaired (N=30) and unassessed (N=30) reaches of Minnesota River during period four (steady state) of the 2014 and 2015 sampling. For each taxa grouping, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches and an asterisk (*) indicates taxa group was sampled but in mean densities <0.01/liter.

Genera	**Impaired**	**Unassessed**	***P*-value**
Ascomorpha	0.03(0.01)	0.03(0.01)	0.71
Asplanchna	0.02(0.01)	0.02(0.01)	0.57
Collotheca	0.00(0.00)*	0.00(0.00)*	0.33
Conochilus	0.00(0.00)*	0.01(0.01)	0.17
Gastropus sp.	0.00(0.00)*	0.00(0.00)	0.33
Hydra	0.00(0.00)*	0.00(0.00)*	1.00
Hydracarina	0.00(0.00)*	0.00(0.00)*	0.57
Keratella	0.00(0.00)*	0.00(0.00)	0.33
Lecane	0.00(0.00)*	0.00(0.00)*	0.40
Monstyla sp.	0.00(0.00)*	0.01(0.01)*	0.36
Notholca	0.00(0.00)*	0.00(0.00)	0.16
***Synchaeta* sp.**	**0.01(0.01)**	**0.02(0.01)**	**0.03**
Trichocerca sp.	0.00(0.00)*	0.00(0.00)*	0.99

df = 2, *P* = 0.03). The unassessed reach had significantly greater *Synchaeta* sp. (0.02±0.01) compared to the impaired reach *Synchaeta* sp. (0.01±0.01); (Table 10).

Macroinvertebrates

Slednet

Cumulatively over the two years, and between both reach types, 9,349 macroinvertebrates were captured from the Minnesota River representing 26 different orders. The impaired reach produced 5,635 macroinvertebrates cumulatively over the two years, representing by 21 different orders with 2,728 and 2,901 during 2014 and 2015 respectively. Whereas, 3,714 macroinvertebrates were captured from the unassessed reach cumulatively over the two years, representing 23 orders with 986 and 2,734 during 2014 and 2015 respectively.

Total macroinvertebrate densities varied among periods and between reach types. During both years, mean relative densities in period one (first ascending limb) for both reach types were nearly identical (Figure 12). During both years, increases in total relative macroinvertebrate densities occurred in the impaired reach first, occurring during period two (second ascending limb) and dropping in period three (major descending limb) and four (steady state; Figure 12). The unassessed reach had mean relative macroinvertebrate densities that were lower than the impaired reach in period one (steady state), but densities increased to greater than the impaired reach in period 3 and 4 for both years (Figure 12).

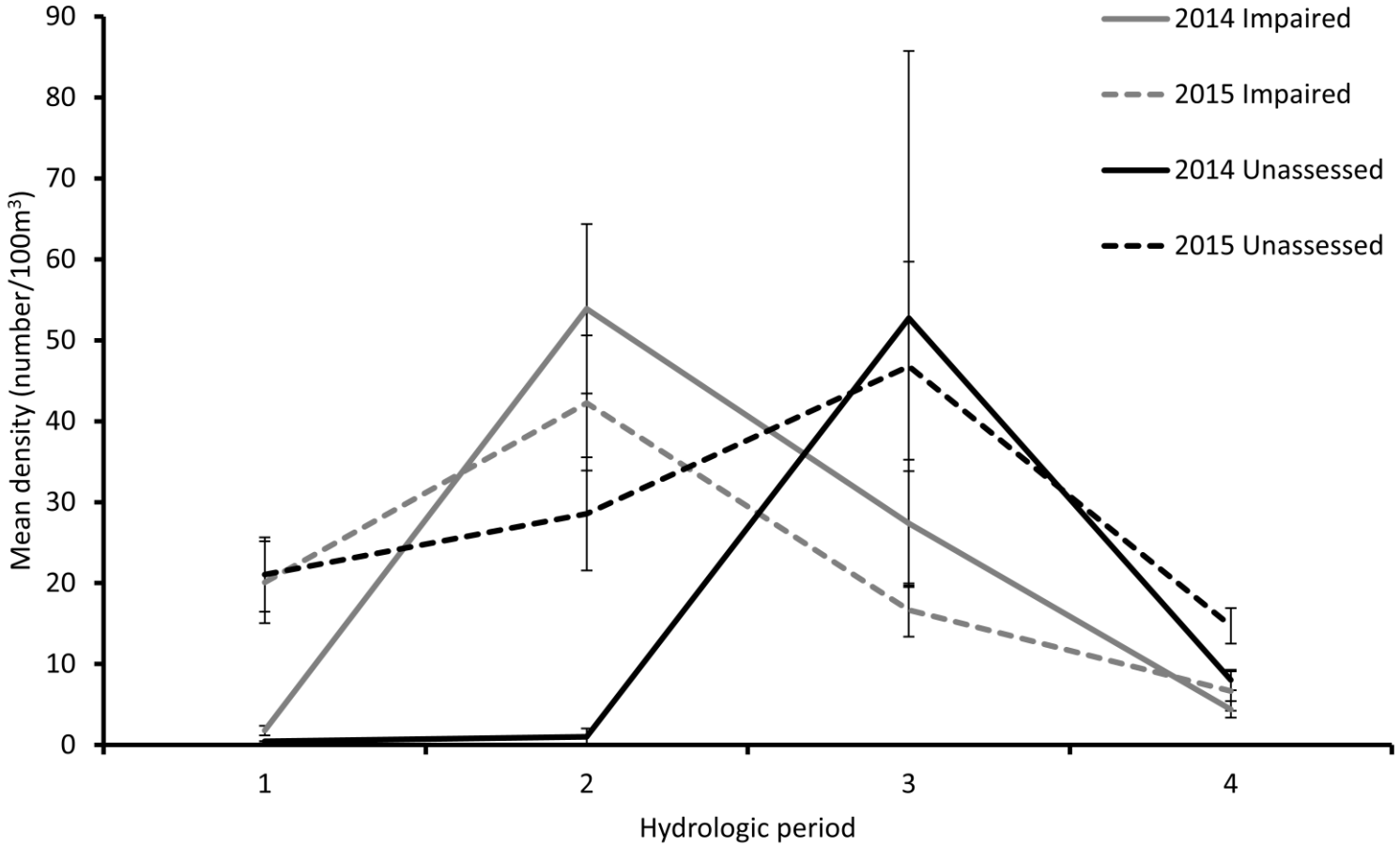

Figure 12. Mean macroinvertebrate density (number/100 m^3) among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015.

Of the orders captured with the SN, only ten represented > 1% of the total catch among the four hydrologic periods. Those orders were Arachnida, Coleoptera, Collembola, Diptera, Ephemeroptera, Gastropoda, Hemiptera, Hydracarina, Hymenoptera, and Trichoptera (Figure 13). Of those orders representing > 1%, Diptera, Ephemeroptera, accounted for ~50% of the captures in the impaired and unassessed reaches during both years (Figure 14). During 2014, Hemiptera made up a greater percent of the total catch in the impaired reach (44%) compared to impaired reach in 2015 (2%); (Figure 14). While in 2015, Gastropoda made up a greater percent of the total catch in both the impaired (21%) and unassessed (17%) reach compared the impaired (4%) and unassessed (3%) reach in 2014 (Figure 14).

The NMDS plots showed weak ties to the reach type and the macroinvertebrate community. Reaches varied slightly along NMDS axis 2 and NMDS axis 1 in 2014, 2015 and both years combined (Figure 15). The 95% confidence ellipses nearly completely overlapped indicating similar macroinvertebrate communities being sampled between the impaired and unassessed reaches of the Minnesota River. Analysis of similarities results revealed no significant difference between the unassessed and impaired reach between communities sampled in 2014 (ANOSIM: R = -0.05; P = 0.49), 2015 (ANOSIM: R = -0.03; P = 0.59) and both year cumulatively (ANOSIM: R = -0.04; P = 0.76). Due to these similarities among years, analyses among period used both years cumulatively.

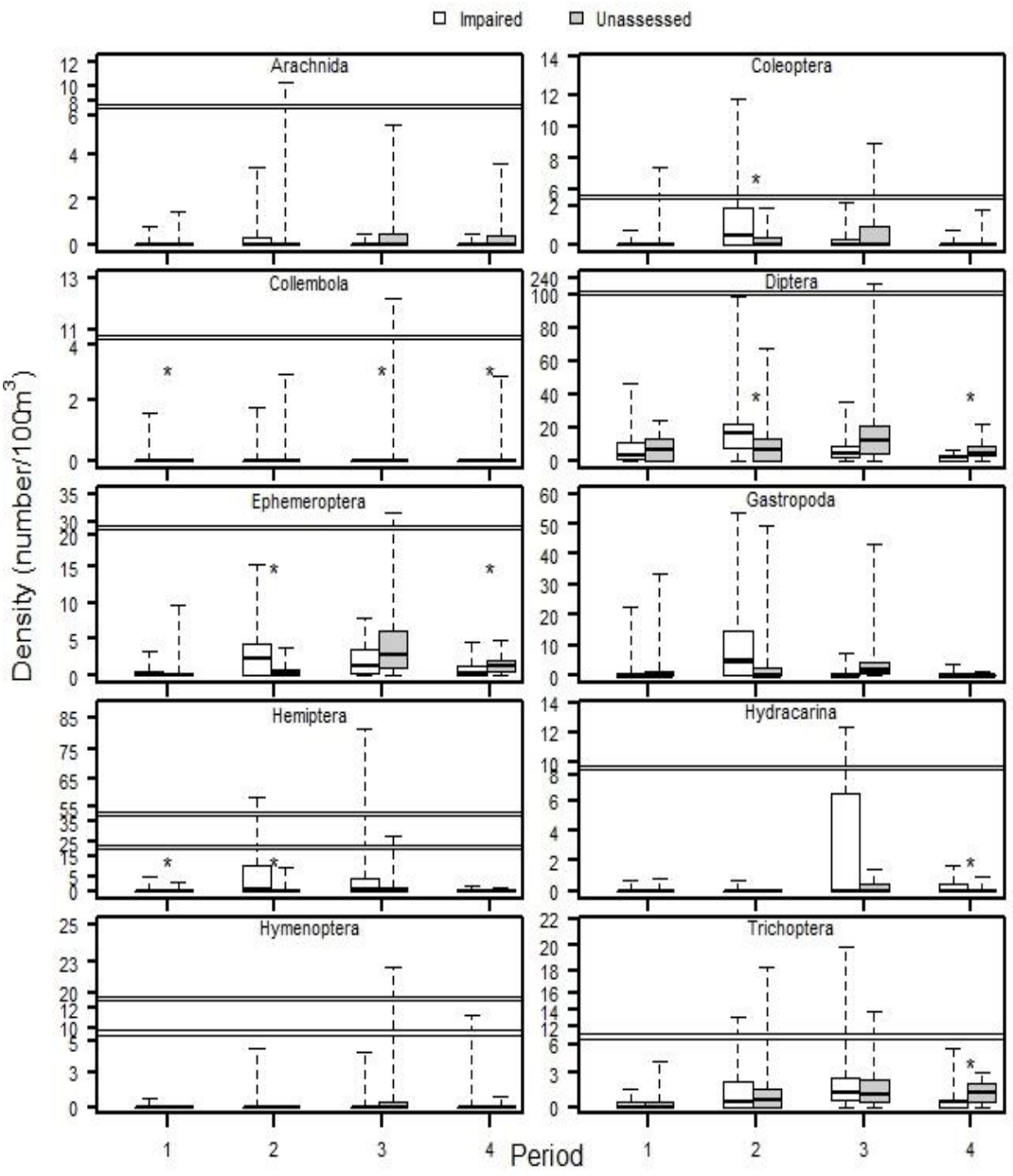

Figure 13. Boxplots of the density (number/100m^3) of the ten dominate orders (>1% of total catch) captured in the Minnesota River during the 2014 and 2015 sampling among the different hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)]. Whiskers extend to the extremes of the data and lines represent the median of the data, and an asterisk (*) denotes significant differences between reach type within that period. Scale of each boxplot is set to appropriate scale for that plot. Comparisons among orders should be made carefully.

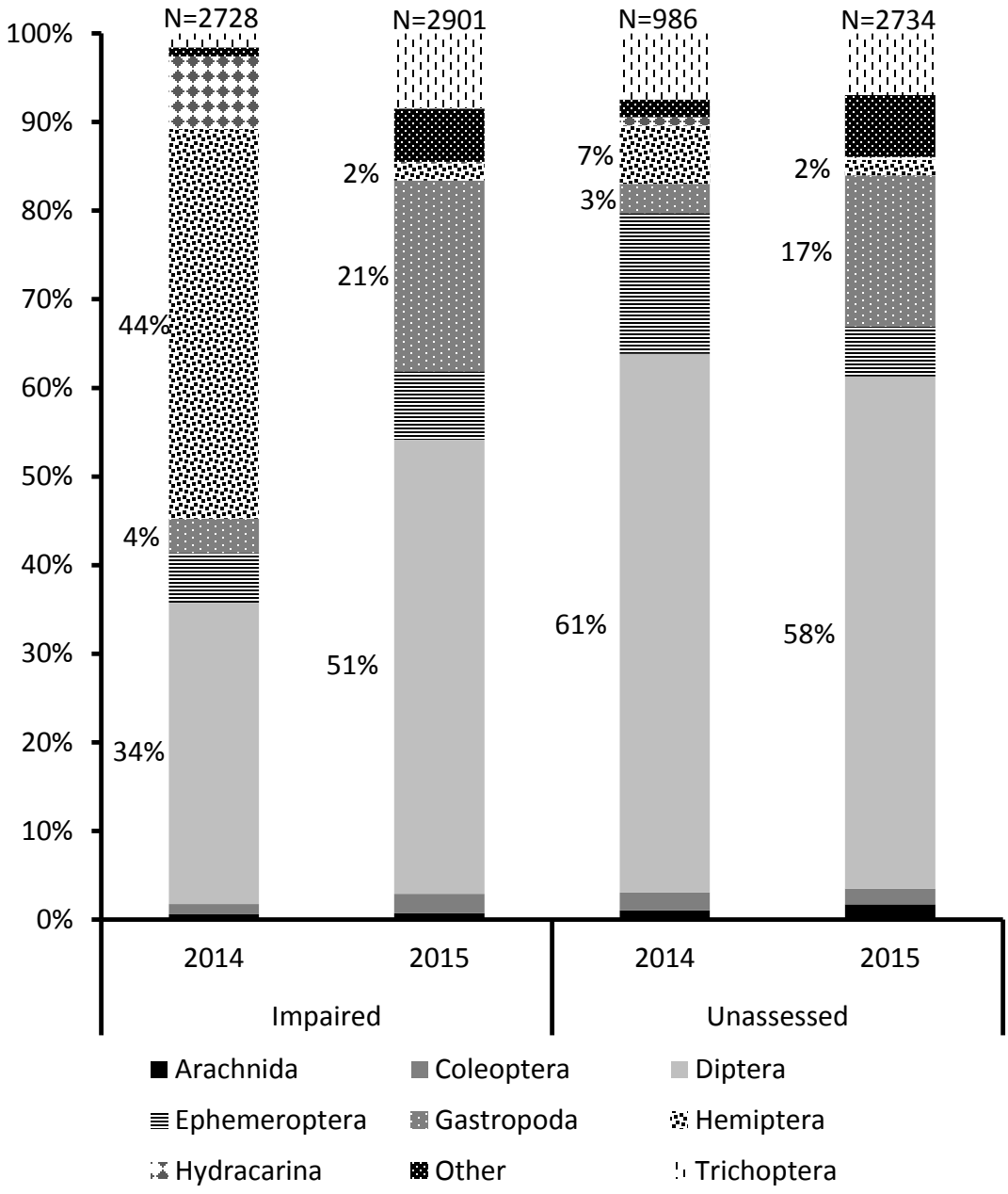

Figure 14. Percent each taxa group represented in the total catch of slednet trawls in the Minnesota River during the 2014- and 2015 field seasons. Other was comprised of taxa groups that numerically made up < 5% of the total catch being Amphipoda, Apidae, Collembola, Diplopoda, Entomobryomorhpa, Formicidae, Hirudinea, Hydra, Hymenoptera, Isopoda, Lepidoptera, Megaloptera, Nematomorphas, Nemertea, Neuroptera, Odonata, Oligochaete and Plecoptera. N is the total number of individual macroinvertebrates captured during that year for that particular reach and the percentages are the taxa groups that represented > 75% of the community.

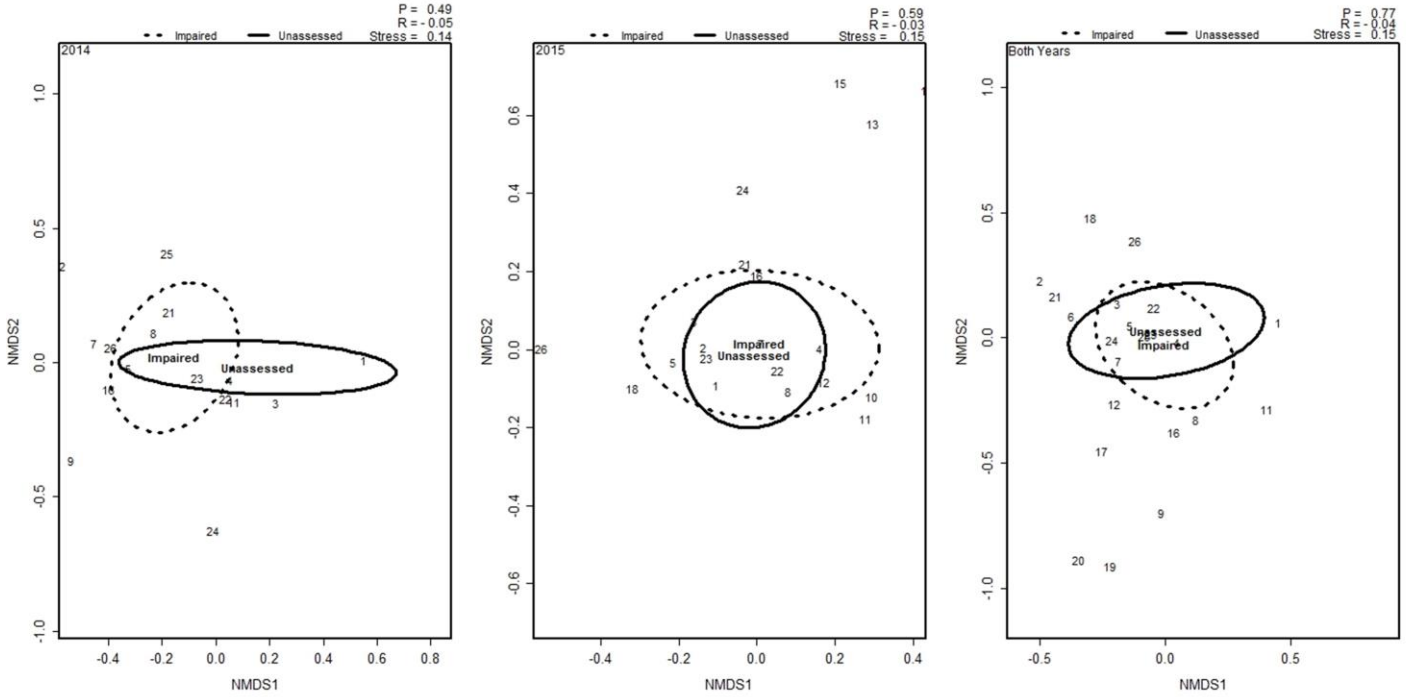

Figure 15. NMDS ordinations plotted with mean densities (number/100m^3) by sample date and orders captured in the Minnesota River during 2014 and 2015 between locations. Ellipses around each reach type denote the 95% confidence interval for that reach type. Text of reach status represents the mean of the ordination plot for the reach type. Each ordination is a separate ordination for only 2014, only 2015 and both years cumulatively. Therefore, comparison among ordinations is not appropriate. Numbers correspond to a particular taxa group: 1: Amphipoda, 2: Apidae, 3: Arachnida, 4: Coleoptera, 5:Collembola, 6: Diplopoda, 7:Diptera, 8:Ephemeroptera, 9: Entomobryomorpha, 10:Formicidae, 11: Gastropoda, 12:Hemiptera, 13: Hirudinea, 14: Hydra, 15:Hydracarina, 16:Hymenoptera, 17:Isopoda, 18:Lepidoptera, 19:Megaloptera, 20:Nematomorpha, 21:Nemertea, 22:Neuroptera, 24:Oligochaeta, 25:Plecoptera, 26: Trichoptera

Period one. –Macroinvertebrate densities differed significantly between reaches in two of the 15 orders sampled during period one (Table 11). Those differences were within Hemiptera (U = 300, df = 2, P = 0.03) and Collembola (U = 300, df = 2, P = 0.02). The unassessed reach's relative Hemiptera density (0.27±0.13) was significantly greater than that of the impaired reach (0.15±0.15; Table 11). While the impaired reach relative Collembola density (0.17±0.07) was significantly greater than that of the unassessed reach (0.00±0.00; Table 11).

Period two.—Macroinvertebrate densities differed significantly in 6 of the 23 orders captured in the SN (Table 12). Those differences were in the Amphipoda (U = 660, df = 2, P = 0.01), Ephemeroptera (U = 548, df = 2, P = 0.01), Coleoptera (U = 539, df = 2, P = 0.01), Diptera (U = 553, df = 2, P = 0.02), Hemiptera (U =534, df =2, P = 0.01) and Nemertea (U =720, df = 2, P = 0.04). The impaired reach's density of Ephemeroptera (2.92±0.53), Coleoptera (1.11±0.30), Diptera (20.13±3.34), Hemiptera (8.10±2.37), and Nemertea (0.08±0.05) were significantly greater than that of the unassessed reach Ephemeroptera (1.27±0.28), Coleoptera (0.33±0.14), Diptera (12.82±2.58), Hemiptera (0.49±0.21), and Nemertea (0.00±0.00; Table 12). However, the unassessed reach relative density of Amphipoda (0.40±0.23) was significantly greater than that of the impaired reach's relative density (0.00±0.00; Table 12).

Period three.—Macroinvertebrates densities between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 were significantly different in one

Table 11. Mean density (number/100m^3) of macroinvertebrates sampled in the impaired (N=30) and unassessed (N=25) reaches of Minnesota River during period one (first ascending limb) of the 2014 and 2015 using the slednet. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches.

Order	**Impaired**	**Unassessed**	***P*-value**
Amphipoda	0.03(0.02)	0.06(0.03)	0.46
Apidae	0.00(0.00)	0.02(0.02)	0.29
Arachnida	0.06(0.03)	0.23(0.09)	0.20
Coleoptera	0.08(0.03)	0.65(0.33)	0.32
Collembola	**0.17(0.07)**	**0.00(0.00)**	**0.02**
Diptera	9.28(2.39)	7.38(1.54)	0.82
Ephemeroptera	0.43(0.16)	0.52(0.03)	0.66
Gastropoda	2.66(1.08)	2.66(1.40)	0.38
Hemiptera	**0.15(0.15)**	**0.27(0.13)**	**0.03**
Hydracarina	0.08(0.03)	0.10(0.05)	0.79
Hymenoptera	0.02(0.02)	0.00(0.00)	0.38
Odonata	0.04(0.02)	0.10(0.05)	0.47
Oligochaeta	0.03(0.03)	0.14(0.07)	0.11
Plecoptera	0.77(0.73)	0.08(0.08)	0.42
Trichoptera	0.22(0.07)	0.59(0.22)	0.37

Table 12. Mean density (number/100m^3) of macroinvertebrates sampled in the impaired (N=40) and unassessed (N=40) reaches of Minnesota River during period two (second ascending limb) of the 2014 and 2015 using the slednet. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches.

Order	Impaired	Unassessed	*P*-value
Amphipoda	**0.00(0.00)**	**0.40(0.23)**	**0.01**
Arachnida	0.40(0.14)	0.57(0.27)	0.88
Coleoptera	**1.11(0.30)**	**0.33(0.14)**	**0.01**
Collembola	0.09(0.05)	0.23(0.10)	0.46
Diptera	**20.13(3.34)**	**12.82(2.58)**	**0.02**
Ephemeroptera	**2.92(0.53)**	**1.27(0.28)**	**0.01**
Entomobryomorpha	0.05(0.03)	0.00(0.00)	0.08
Gastropoda	8.68(1.76)	6.26(1.96)	0.06
Hemiptera	**8.10(2.37)**	**0.49(0.21)**	**0.01**
Hirudinea	0.00(0.00)	0.04(0.02)	0.08
Hydracarina	0.04(0.02)	0.05(0.03)	0.98
Hymenoptera	0.11(0.10)	0.45(0.20)	0.17
Isopoda	0.18(0.12)	0.00(0.00)	0.16
Lepidoptera	0.02(0.02)	0.00(0.00)	0.16
Megaloptera	0.01(0.01)	0.00(0.00)	0.33
Nematomorpha	0.00(0.00)	0.02(0.02)	0.16
Nemertea	0.08(0.05)	0.00(0.00)	0.04
Neuroptera	0.01(0.01)	0.00(0.00)	0.33
Odonata	0.12(0.05)	0.04(0.04)	0.06
Oligochaeta	1.02(0.40)	0.34(0.14)	0.13
Plecoptera	0.10(0.05)	0.08(0.04)	0.77
Trichoptera	1.95(0.51)	1.94(0.60)	0.78

of the 22 orders captured (Table 13). Collembola relative densities were significantly different (U =150, df = 2, P = 0.02). The unassessed reach had a significantly greater relative density (0.97±0.62) compared to the impaired relative density of (0.00±0.00; Table 13).

Period four. –Macroinvertebrate relative densities between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 were significantly different in five of the 18 orders captured (Table 13). Significant differences existed in the relative densities of the Ephemeroptera(*U* = 253, df = 2, *P* = <0.00), Diptera (*U* = 242, df = 2, *P* = <0.00), Trichoptera (*U* = 280, df = 2, *P* = 0.01), Hydracarina (*U* = 339, df = 2, *P* = 0.03), and Collembola (*U* = 375, df = 2, *P* = 0.02) orders. With the unassessed reach's relative densities of Ephemeroptera(1.40±0.21), Diptera (6.24±1.01), Trichoptera (1.24±0.17), and Collembola (0.27±0.14) significantly greater than the impaired reach's Ephemeroptera(0.76±0.23), Diptera (2.66±0.56), Trichoptera (0.83±0.24), and Collembola (0.00±0.00; Table 13). While the impaired reach's relative density of Hydracarina (0.62±0.27) was significantly greater than the unassessed reach's (0.08±0.04; Table 13).

Light traps

Cumulatively in 2014 and 2015, and between both reaches, 2,550 macroinvertebrate were sampled representing fifteen different macroinvertebrate orders with the LTs in the Minnesota River. In 2014, 1,088 macroinvertebrates were captured representing 12 orders while in 2015, 1,462 macroinvertebrates were

Table 13. Mean density (number/100m^3) of macroinvertebrates sampled in the impaired (N=30) and unassessed (N=30) reaches of Minnesota River during period four (steady state) of the 2014 and 2015 using the slednet. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches.

Order	**Impaired**	**Unassessed**	***P*-value**
Amphipoda	0.03(0.02)	0.02(0.02)	0.57
Arachnida	0.06(0.03)	0.30(0.14)	0.12
Coleoptera	0.06(0.03)	0.09(0.05)	0.99
Collembola	**0.00(0.00)**	**0.27(0.14)**	**0.02**
Diplopoda	0.00(0.00)	0.01(0.01)	0.33
Diptera	**2.66(0.56)**	**6.24(1.01)**	**<0.01**
Ephemeroptera	**0.76(0.23)**	**1.40(0.21)**	**<0.01**
Gastropoda	0.22(0.12)	0.09(0.05)	0.29
Hemiptera	0.44(0.37)	0.28(0.08)	0.15
Hydra	0.08(0.08)	0.00(0.00)	0.33
Hydracarina	**0.62(0.27)**	**0.08(0.04)**	**0.03**
Hymenoptera	0.44(0.37)	0.04(0.03)	0.37
Nematomorpha	0.03(0.03)	0.00(0.00)	0.33
Neuroptera	0.01(0.01)	0.00(0.00)	0.33
Odonata	0.01(0.01)	0.04(0.03)	0.54
Oligochaeta	0.04(0.02)	0.00(0.00)	0.08
Plecoptera	0.04(0.02)	0.16(0.10)	0.63
Trichoptera	**0.83(0.24)**	**1.24(0.17)**	**0.01**

captured representing 12 orders. In 2014, 847 macroinvertebrates were capture in the impaired reach compare to 241 captured the unassessed. In 2015, 708 macroinvertebrates were captured impaired reach captured compared to 754 in the unassessed reach.

During 2014, peak macroinvertebrate abundance occurred during period three in both the impaired (Figure 16). However, in 2015, peak macroinvertebrate abundance occurred during period two in both the impaired and unassessed reaches (Figure 16). In the impaired reach during 2015, abundance continued to decline through period four, but the unassessed reach increased (Figure 16).

Cumulatively over both years, all 15 orders sampled with the LTs were represented in both reach types. Of those 15 orders, only 10 had captures greater than 4 individuals (Figure 17) over the two years. Those ten were Amphipoda, Coleoptera, Ephemeroptera, Diptera, Hemiptera, Odonata, Plecoptera, Trichoptera, Entomobryomorpha, and Oligochaete. Of those, the Ephemeroptera, Diptera and Trichoptera comprised the major portion (~95%) of the catch in both the impaired and unassessed reaches (Figure 18).

The NMDS plots from each reach showed weak ties to the reach type and the macroinvertebrate community. Reaches varied slightly along NMDS axis 2 but not as much on the NMDS axis 1 (Figure 19) in 2014, 2015, and both years cumulatively. The

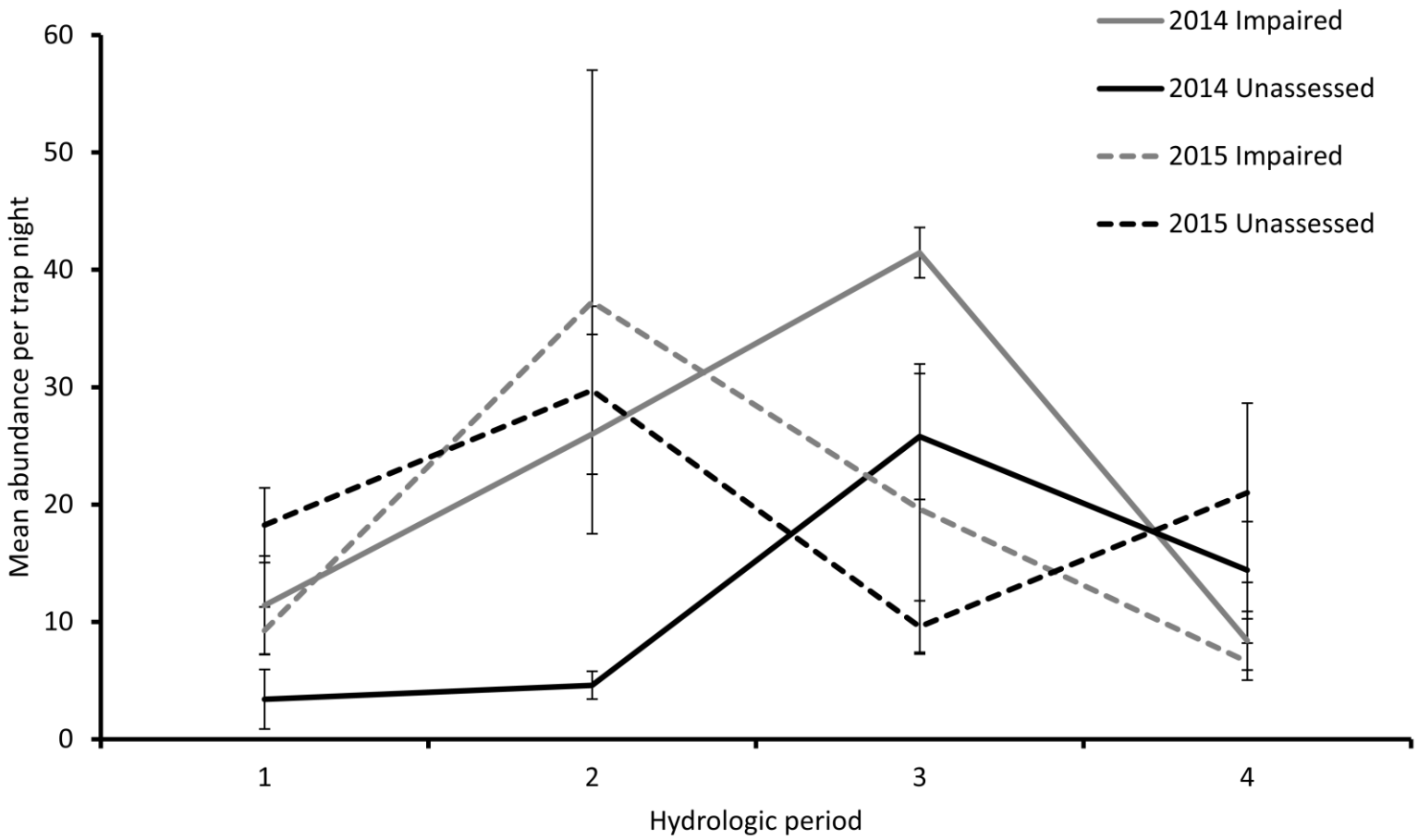

Figure 16. Mean macroinvertebrate abundance (number/trap night) among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015.

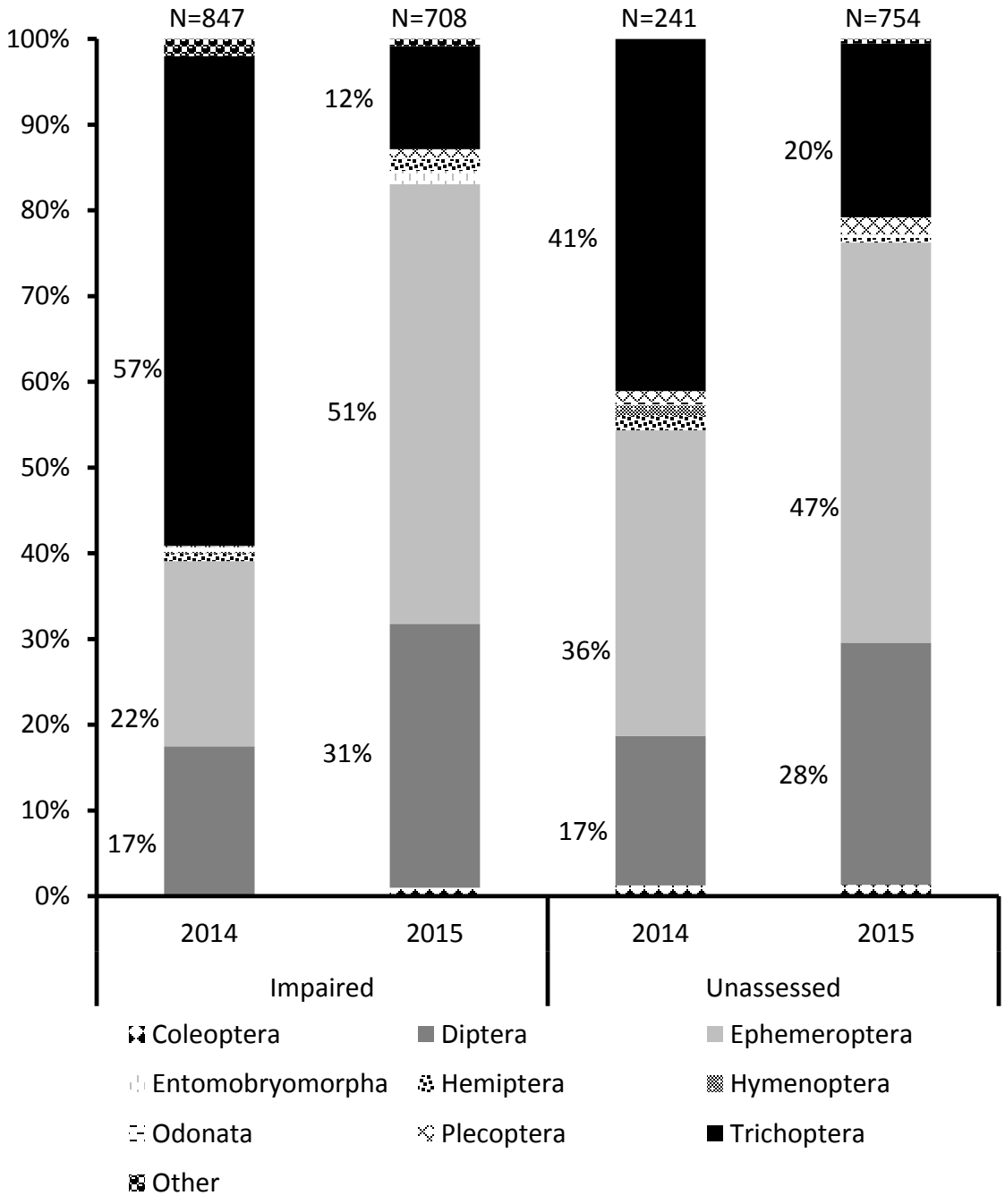

Figure 17. Percent each order of macroinvertebrate represented in the total catch of the light traps in the Minnesota River during the 2014- and 2015 field seasons within the impaired and unassessed reaches. Other was comprised of taxa groups that numerically made up < 1% of the total catch of Amphipoda, Arachnida, Gastropoda, Hydracarina, Nemertea and Oligochaeta. N is the total number of individual macroinvertebrates captured during that year for that particular reach.

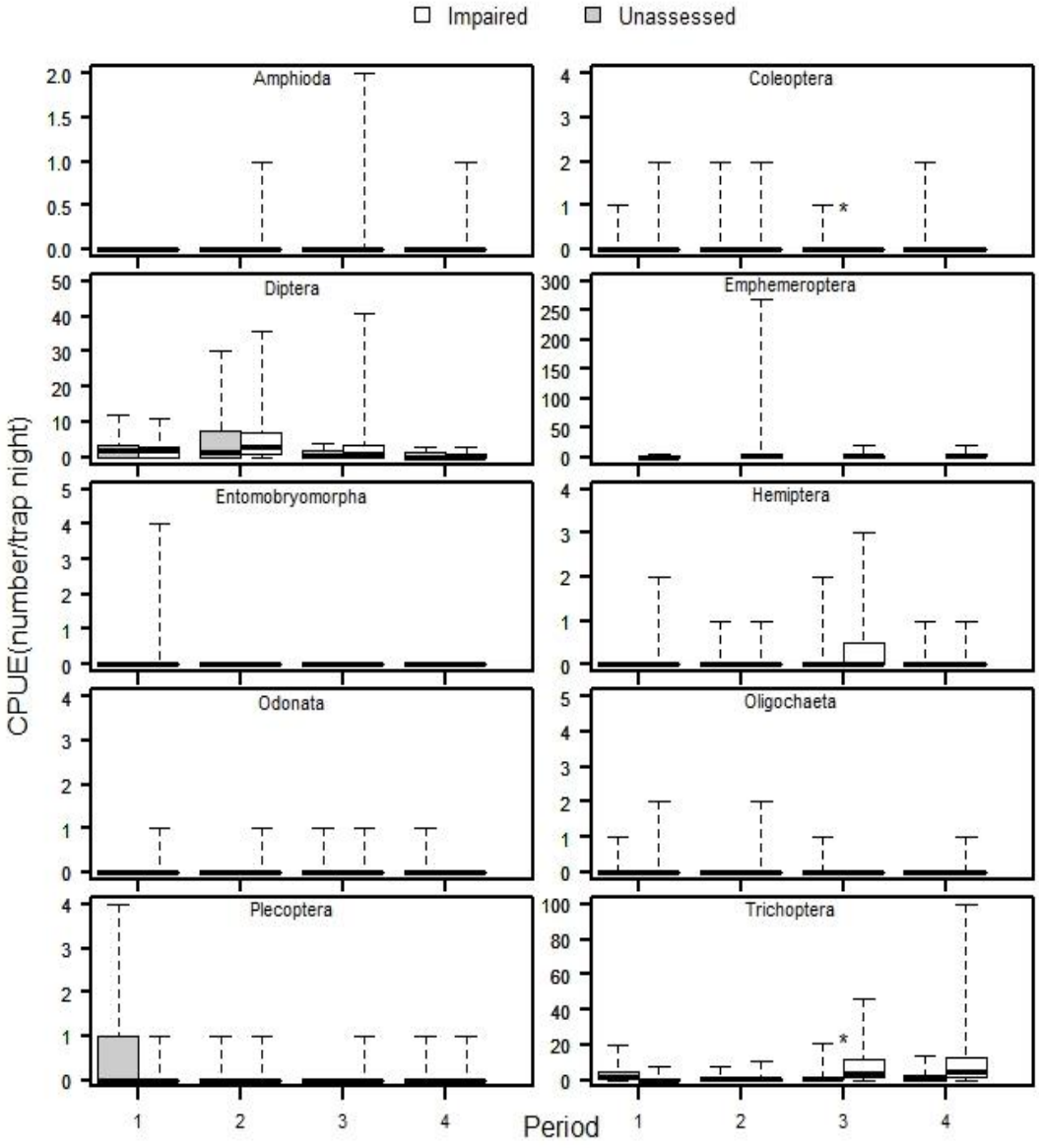

Figure 18. Boxplots of the CPUE (number/trap night) of the ten dominate orders (number of individuals <4) captured in the Minnesota River during the 2014 and 2015 sampling among the different hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)]. Whiskers extend to the extremes of the data and lines represent the median of the data and an asterisk (*) denotes significant differences between reach type within that period. Scale of each boxplot is set to appropriate scale for that plot. Comparisons among orders should be made carefully.

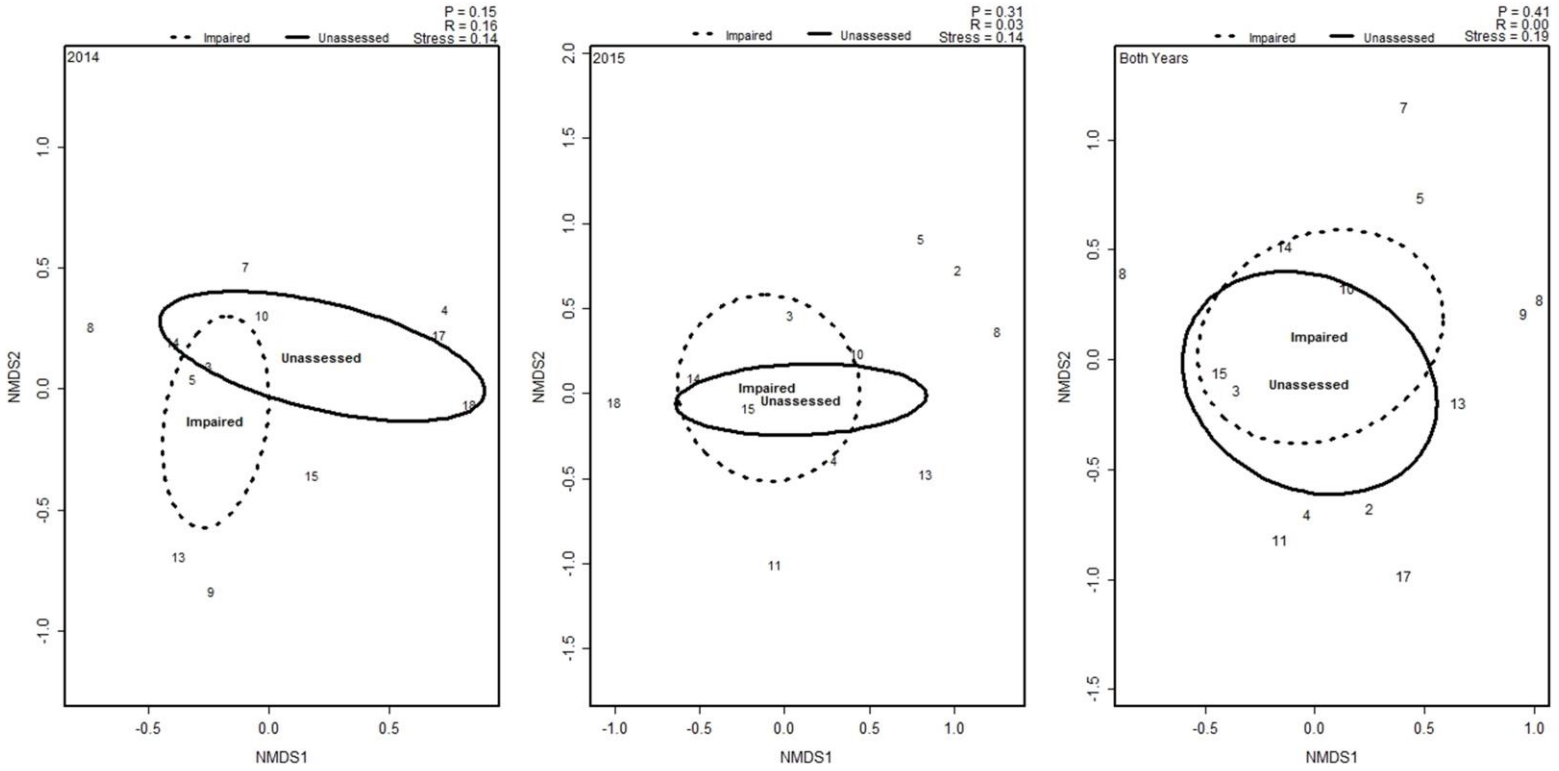

Figure 19. NMDS ordinations plotted with mean CPUE (number/trap night) by sample outing of orders captured in the Minnesota River during 2014 and 2015 between locations. Ellipses around each reach type denote the 95% confidence interval for that reach type. Text of reach status represents the mean of the ordination plot for the reach type. Each ordination is a separate ordination for only 2014, only 2015 and both years cumulatively. Therefore, comparison among ordinations is not appropriate. Numbers correspond to a specific order; 1: Amphipoda, 2: Arachnida, 3: Coleoptera, 4: Diptera, 5: Ephemeroptera, 6: Entomobryomorpha, 7: Gastropoda, 8: Hemiptera, 9: Hydracarina, 10: Hymenoptera, 11: Megaloptera, 12: Nematomorpha, 13: Nemertea, 14: Neuroptera, 15: Odonata, 16: Oligochaeta, 17: Plecoptera, 18: Trichoptera.

95% confidence ellipses nearly completely overlapped indicating similar macroinvertebrate communities being sampled between the impaired and unassessed reaches of the Minnesota River. The ANOSIM results found no differences between the impaired and unassessed reaches in 2014 (R = 0.16, P = 0.15), 2015 (R = 0.03, P = 0.31),and both years combined (R = <0.00, P = 0.40; Figure 19). Due to these similarities in community structure among years, analyses among period used both years cumulatively.

Period one. –Macroinvertebrate catch rates between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 were not significantly different in any of the 11 orders captured in period one with the LTs (Table 14).

Period two. –Macroinvertebrate catch rates between reaches were not significantly different between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 in any of the 13 orders captured in period two with the LTs (Table 15).

Period three. –Macroinvertebrate catch were significantly different between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 in three of the 13 orders during period three (Table 16). Differences existed in Coleoptera (U = 360, df =2, P = 0.05), Trichoptera (U = 249, df = 2, P = 0.02) and Gastropoda (U = 360, df =2, P = 0.05). The unassessed reach captured significantly more Coleoptera (0.10±0.07) and Gastropoda (0.10±0.07) compared to the impaired reach's Coleoptera (0.00±0.00) and Gastropoda (0.00±0.00; Table 16). However, the impaired reach captured

Table 14. Mean CPUE (number/trap night) of macroinvertebrates sampled in the impaired (N=26) and unassessed (N=27) reaches of Minnesota River during period one (first ascending limb) of the 2014 and 2015 using the light trap. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of trap nights collected in each reach type during those two years.

Order	**Impaired**	**Unassessed**	***P*-value**
Coleoptera	0.08(0.08)	0.07(0.05)	0.63
Diptera	4.42(0.56)	2.30(0.65)	0.45
Ephemeroptera	0.58(0.26)	0.44(0.19)	0.72
Entomobryomorpha	0.42(0.22)	0.00(0.00)	0.04
Hemiptera	0.15(0.11)	0.00(0.00)	0.15
Hymenoptera	0.04(0.04)	0.00(0.00)	0.33
Nemertea	0.04(0.04)	0.00(0.00)	0.33
Odonata	0.04(0.04)	0.00(0.00)	0.33
Oligochaeta	0.08(0.08)	0.04(0.04)	0.98
Plecoptera	0.15(0.07)	0.48(0.20)	0.28
Trichoptera	1.04(0.39)	3.07(0.97)	0.08

Table 15. Mean CPUE (number/trap night) of macroinvertebrates sampled in the impaired (N=36) and unassessed (N=39) reaches of Minnesota River during period two (second ascending limb) of the 2014 and 2015 using the light trap. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of trap nights collected in each reach type during those two years.

Order	**Impaired**	**Unassessed**	***P*-value**
Amphipoda	0.05(0.04)	0.00(0.00)	0.14
Arachnida	0.03(0.03)	0.00(0.00)	0.31
Coleoptera	0.16(0.08)	0.18(0.07)	0.64
Diptera	5.16(1.09)	3.90(0.97)	0.12
Ephemeroptera	10.49(7.22)	6.13(2.73)	0.86
Gastropoda	0.03(0.03)	0.00(0.00)	0.31
Hemiptera	0.03(0.03)	0.10(0.06)	0.35
Hymenoptera	0.00(0.00)	0.05(0.03)	0.18
Nemertea	0.03(0.03)	0.00(0.00)	0.13
Odonata	0.03(0.03)	0.03(0.03)	0.97
Oligochaeta	0.08(0.06)	0.00(0.00)	0.14
Plecoptera	0.05(0.04)	0.10(0.05)	0.46
Trichoptera	0.97(0.32)	1.25(0.25)	0.13

Table 16. Mean CPUE (number/trap night) of macroinvertebrates sampled in the impaired (N=20) and unassessed (N=20) reaches of Minnesota River during period three (major descending limb) of the 2014 and 2015 using the light trap. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of trap nights collected in each reach type during those two years.

Order	**Impaired**	**Unassessed**	***P*-value**
Amphipoda	0.18(0.08)	0.00(0.00)	0.11
Coleoptera	**0.00(0.00)**	**0.10(0.07)**	**0.05**
Diptera	2.63(1.05)	0.90(0.31)	0.22
Ephemeroptera	2.95(0.74)	3.65(0.70)	0.08
Gastropoda	**0.00(0.00)**	**0.10(0.07)**	**0.05**
Hemiptera	0.33(0.12)	0.10(0.07)	0.30
Hydracarina	0.08(0.04)	0.00(0.00)	0.22
Hymenoptera	0.00(0.00)	0.05(0.05)	0.17
Nemertea	0.03(0.03)	0.00(0.00)	0.50
Odonata	0.05(0.03)	0.15(0.08)	0.20
Oligochaeta	0.03(0.03)	0.05(0.05)	0.63
Plecoptera	0.03(0.03)	0.00(0.00)	0.50
Trichoptera	**11.73(2.95)**	**3.75(1.22)**	**0.02**

significantly more Trichoptera (11.73±2.95) compared to the unassessed (3.75±1.22; Table 16).

Period four. –Macroinvertebrate catch rates among orders were not significantly different between the two reaches during 2014 and 2015 in any of the seven orders captured during period four with the LTs (Table 17).

Ichthyoplankton

Slednet

Cumulatively, 184 ichthyoplankton were captured with SNs, representing 8 families and 17 genera were sampled between unassessed and impaired reaches of the Minnesota River during 2014-2015. Of those 17 genera, 13 were found in the impaired reach and 13 in the unassessed area (Table 18). In 2014, 38 and 34 ichthyoplankton were captured in the impaired and unassessed reaches, respectively. The impaired reach was represented by 8 genera, while the unassessed reach had 6 genera. In 2015, 50 and 62 ichthyoplankton were captured in the impaired and unassessed reaches of the Minnesota River, respectively. The impaired reach was represented by 9 genera, while the unassessed reach had 13 genera.

Over both years of this study, 9 SN-captured genera were represented by more than one individual in the impaired reach, including *Carpiodes* spp., *Catostomus* sp., *Cyprinella* sp., *Cyprinus* sp., *Ictiobus* spp., *Notropis* spp., *Pimephales* spp., and *Pomoxis* spp. In the unassessed reach, 7 genera had more than one individual, including

Table 17. Mean CPUE (number/trap night) of macroinvertebrates sampled in the impaired (N=30) and unassessed (N=29) reaches of Minnesota River during period four (steady state) of the 2014 and 2015 using the light trap. For each order, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of trap nights collected in each reach type during those two years.

Order	**Impaired**	**Unassessed**	***P*-value**
Coleoptera	0.00(0.00)	0.07(0.07)	0.60
Diptera	0.30(0.21)	0.79(0.19)	0.17
Ephemeroptera	1.10(0.31)	4.21(1.45)	0.11
Hemiptera	0.00(0.00)	0.07(0.05)	0.42
Odonata	0.00(0.00)	0.07(0.05)	0.42
Plecoptera	0.10(0.10)	0.03(0.03)	0.45
Trichoptera	1.80(0.68)	2.17(0.59)	0.95

Table 18. Total individual larvae captured for genera within the impaired and unassessed reaches of Minnesota River with the slednet during 2014 and 2015.

Taxa	Impaired	Unassessed
Acipenseridae		
Scaphirhynchus sp.	1	0
Amiidae		
Amia calva	0	1
Catostomidae		
Carpiodes spp.	27	14
Catostomus sp.	3	1
Ictioubus spp.	7	1
Moxostoma spp.	1	9
Centrarchidae		
Lepomis spp.	0	8
Pomoxis spp.	3	0
Clupeidae		
Dorosoma sp.	1	1
Cyprinidae		
Cyprinella sp.	13	11
Cyprinus sp.	3	4
Hybognathus sp.	0	1
Notropis spp.	20	25
Pimephales spp.	6	19
Percidae		
Etheostoma spp.	2	0
Sander sp.	1	0
Sciaenidae		
Aplodinotus sp.	0	1
Total	**88**	**96**

Carpiodes spp., *Cyprinella* sp., *Cyprinus* sp., *Lepomis* spp., *Moxostoma* spp., *Notropis* spp., and *Pimephales* spp.

Overall, the mean density of ichthyoplankton was <1.0/100m^3 (SE = 0.05), however, detectable variations in density among hydrologic periods and between years were noted (Figure 20). In the impaired reach, relative densities of ichthyoplankton were greatest in period two in 2014, but during 2015, greatest in period 4 with the SN. In the unassessed reach, relative densities of ichthyoplankton were greatest in period three in both 2014 and 2015 with the SN.

Due to that limited ichthyoplankton catch, NMDS ordinations for each year individually were unable ran to reach a convergent solution with an acceptable level of stress. However, mean densities by sample date for both years together did reach a convergent solution with the SN. The NMDS plot for the SN showed weak ties to the reach type and the ichthyoplankton community on the mean relative number of larvae per 100m^3 of water by date. Reaches varied minimally along NMDS axis 2 and NMDS axis 1 (Figure 21). The 95% confidence ellipses nearly completely overlapped, indicating ichthyoplankton communities being sampled between the impaired and unassessed reaches of the Minnesota River were similar. Analysis of similarities results revealed no significant differences between communities in the unassessed and impaired reaches (ANOSIM: R = 0.03; P = 0.29), supporting the contention that the reaches are not

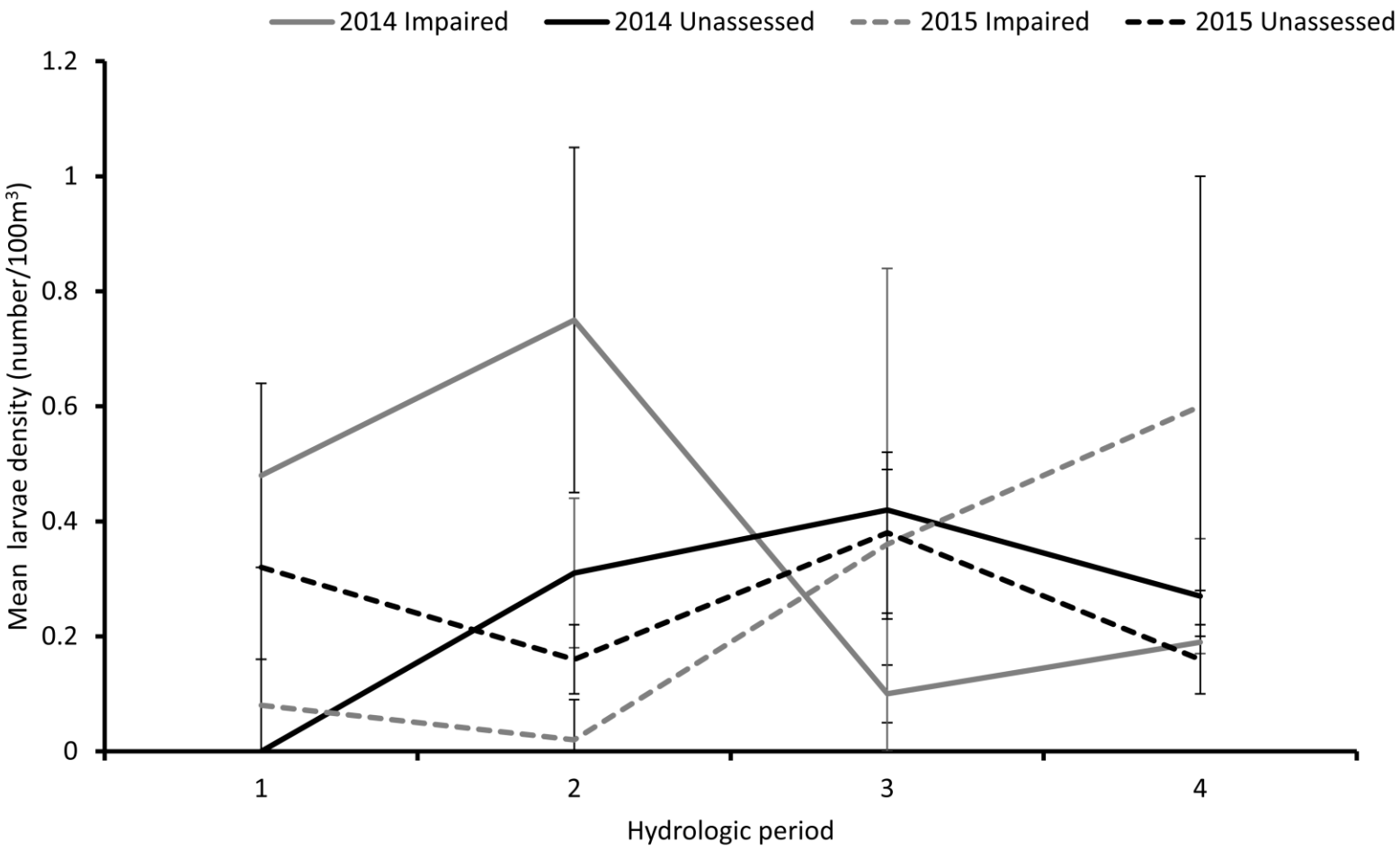

Figure 20. Mean ichthyoplankton density (number/100 m^3) among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015.

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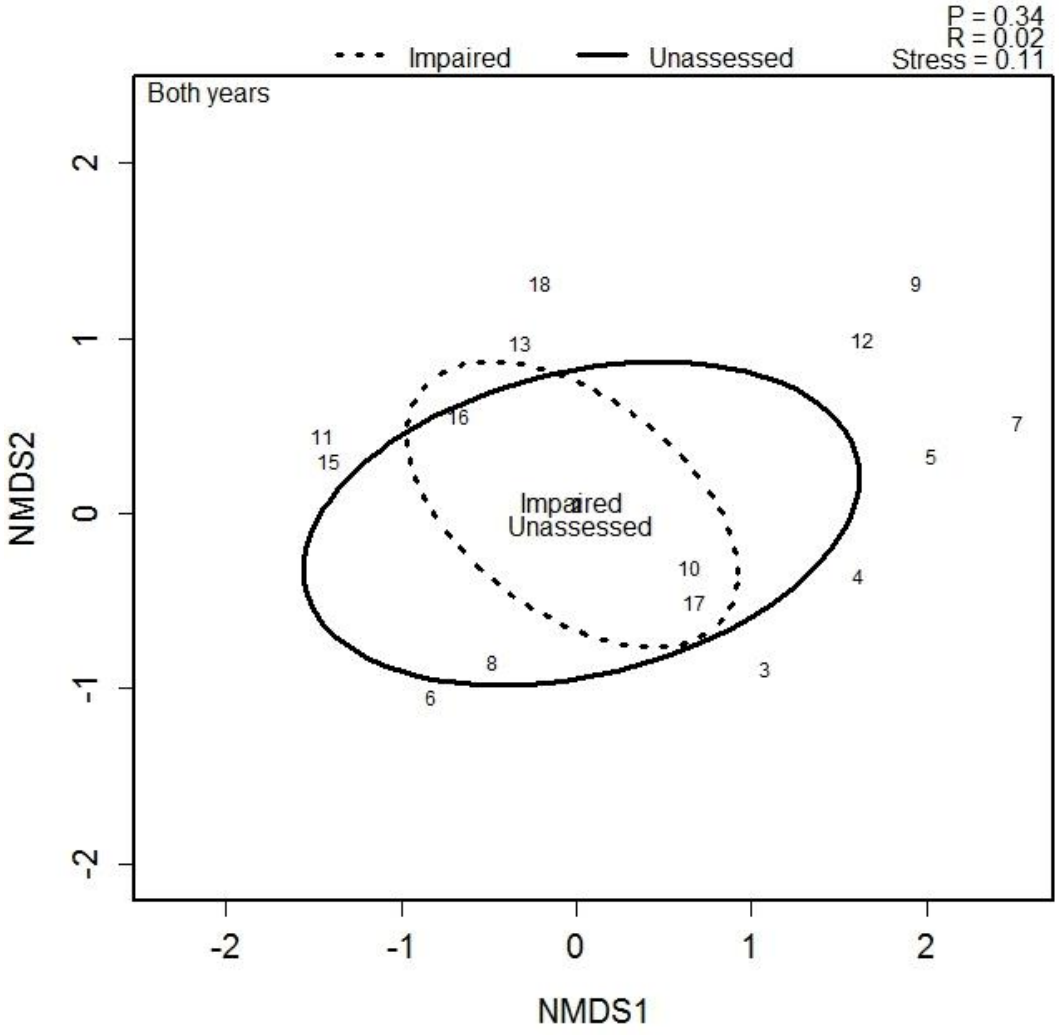

Figure 21. NMDS ordinations plotted with mean CPUE (number/per 100m^3) by sample date and genera of ichthyoplankton captured in the Minnesota River during 2014 and 2015 between locations. Ellipses around each reach type denote the 95% confidence interval for that reach type. Numbers correspond to a specific genera; 1: *Amia* sp, 2: *Aplodinotus* sp., 3: *Carpiodes* spp., 4: *Catostomus* sp. 5: *Cyprinus* sp. 6: *Cyprinus* sp., 7: *Dorosoma* sp., 8: *Etheostoma* sp. 9: Hybognathus sp., 10: *Ictiobus* spp., 11: *Lepomis* spp., 12: *Moxostoma* spp., 13: *Notropis* spp., 14: Percidae spp., 15: *Pimephales* spp., 16: *Pomoxis* spp., 17: *Sander* sp., 18: *Scaphirhynchus* sp.

substantively different. Due to the limited number of larvae captured and the similarities between reaches, analyses within a period used both years cumulatively.

Period one. –Of the four ichthyoplankton genera sampled during period one of 2014 and 2015, only densities of *Carpiodes* spp. differed significantly between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (U = 300, df =2, P = 0.02). The impaired reach had a significantly greater density of *Carpiodes* spp. (0.14±0.06) compared to the unassessed reach (0.00±0.00; Table 19).

Period two. –Of the 12 Ichthyoplankton genera sampled during period two none differed significantly between reaches between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015. Three of the four genera captured in period one were also captured in period two, as well as 8 previously uncaptured genera (Table 20).

Period three. –Of the 11 ichthyoplankton genera densities captured during period three none differed significantly between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (Table 21). However, seven of the ichthyoplankton genera captured had been captured in the early periods, and four new genera were sampled in period three.

Period four. –Of the seven Ichthyoplankton genera captured during period four, only the densities of *Lepomis* spp. differed between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015 (U = 375, df =2, P = 0.02); (Table 22). The

Table 19. Mean density (number/100m^3) of larval genera sampled in the impaired (N=30) and unassessed (N=25) reaches of Minnesota River during period one (first ascending limb) of the 2014 and 2015 using the slednet. For each genera, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of samples collected in each reach during that period

Genera	**Impaired**	**Unassessed**	***P*-value**
***Carpiodes* spp.**	**0.14(0.06)**	**0.00(0.00)**	**0.02**
Cyprinus sp.	0.02(0.02)	0.02(0.02)	0.94
Dorosoma sp.	0.00(0.00)	0.02(0.02)	0.29
Notropis spp.	0.04(0.03)	0.00(0.00)	0.20

Table 20. Mean density (number/100m^3) of larval genera sampled in the impaired (N=40) and unassessed (N=40) reaches of Minnesota River during period two (second ascending limb) of the 2014 and 2015 using the slednet. For each genera, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of samples collected in each reach during that period

Genera	**Impaired**	**Unassessed**	***P*-value**
Carpiodes spp.	0.11(0.04)	0.21(0.09)	0.99
Catostomus sp	0.03(0.02)	0.01(0.01)	0.55
Cyprinus sp.	0.02(0.01)	0.01(0.01)	0.59
Cyprinella sp.	0.00(0.00)	0.03(0.03)	0.33
Etheostoma spp.	0.01(0.01)	0.00(0.00)	0.33
Hybognathus sp.	0.00(0.00)	0.01(0.01)	0.33
Ictiobus spp.	0.07(0.03)	0.01(0.01)	0.16
Moxostoma spp.	0.01(0.01)	0.07(0.03)	0.16
Notropis spp.	0.06(0.03)	0.02(0.01)	0.37
Pimephales spp.	0.00(0.00)	0.05(0.03)	0.08
Sander sp.	0.01(0.01)	0.00(0.00)	0.33
Scaphirhynchus sp.	0.04(0.04)	0.00(0.00)	0.33

Table 21. Mean density (number/100m^3) of larval genera sampled in the impaired (N=20) and unassessed (N=20) reaches of Minnesota River during period three (major descending limb) of the 2014 and 2015 using the slednet. For each genera, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of samples collected in each reach during that period

Genera	**Impaired**	**Unassessed**	***P*-value**
Amia calva	0.00(0.00)	0.05(0.05)	0.34
Aplodinotus sp.	0.00(0.00)	0.02(0.02)	0.34
Carpiodes spp.	0.09(0.04)	0.04(0.04)	0.11
Cyprinus sp.	0.00(0.00)	0.02(0.02)	0.34
Cyprinella sp.	0.04(0.02)	0.02(0.02)	0.57
Dorosoma sp.	0.02(0.02)	0.00(0.00)	0.34
Ictiobus spp.	0.04(0.03)	0.00(0.00)	0.16
Lepomis spp.	0.00(0.00)	0.04(0.03)	0.16
Notropis spp.	0.11(0.07)	0.44(0.20)	0.13
Pimephales spp.	0.03(0.03)	0.15(0.07)	0.17
Pomoxis spp.	0.02(0.02)	0.00(0.00)	0.34

Table 22. Mean density (number/100m^3) of larval genera sampled in the impaired (N=30) and unassessed reaches (N=30) of Minnesota River during period four (steady state) of the 2014 and 2015 using the slednet. For each genera, the mean density, standard error (in parentheses), and statistical results are noted. Bold indicates a significant difference between reaches. N is the number of samples collected in each reach during that period in each reach during that period

Genera	**Impaired**	**Unassessed**	**P-value**
Carpiodes spp.	0.02(0.02)	0.00(0.00)	0.33
Cyprinella sp.	0.24(0.22)	0.14(0.05)	0.10
Etheostoma spp.	0.02(0.02)	0.00(0.00)	0.33
***Lepomis* spp.**	**0.00(0.00)**	**0.11(0.05)**	**0.02**
Notropis spp.	0.15(0.09)	0.09(0.06)	0.27
Pimephales spp.	0.09(0.04)	0.15(0.07)	0.92
Pomoxis spp.	0.03(0.03)	0.00(0.00)	0.33

unassessed reach had significantly greater relative density of *Lepomis* spp. (0.14±0.06) compared to the impaired (0.00±0.00; Table 22).

Light trap

Cumulatively, 29 larvae, representing six genera and four families were captured in the unassessed and impaired reaches of the Minnesota River during 2014-2015. All six genera were found in the impaired reach, but only three were found in the unassessed area (Table 23). Additionally, only three genera were represented by more than one individual in each reach type, including *Cyprinella* sp. in the impaired reach and *Percina* spp. and *Lepomis* spp. in the unassessed reach. In 2014, 28 larvae were captured, 22 from the impaired reach and 6 from the unassessed area, representing six genera. In 2015, only one larvae was captured with LTs in the impaired reach and none were captured in the unassessed reach. Ichthyoplankton LT CPUEs were quite low during all hydrologic periods (Figure 22). The greatest number of ichthyoplankton were capture during periods three and four both years in the impaired reach (Figure 22).

A NMDS plot could not reach a convergent solution with an acceptable level of stress for the LT data due to the low capture of ichthyoplankton. Therefore, only Mann Whitney U tests were used for both years combined to compare reach types within periods.

Periods one to four. –Ichthyoplankton captures did not differ significantly among any genera captured among periods (Table 24). Each period captured genera that were only captured during that period except for period three. *Cyprinella* sp. had the greatest

Table 23. Total individual larvae captured in each genera and percentage of capture the comprised within the impaired and unassessed reaches of Minnesota River [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] using the light traps during 2014 and 2015.

	Impaired		Unassessed	
Taxon	**N**	**%**	**N**	**%**
Catostomidae				
Ictioubus spp.	1.00	3.45	0.00	0.00
Moxostoma spp.	1.00	3.45	0.00	0.00
Centrarchidae				
Lepomis spp.	1.00	3.45	3.00	10.34
Cyprinidae				
Cyprinella sp.	18.00	62.07	0.00	0.00
Percidae				
Etheostoma spp.	1.00	3.45	1.00	3.45
Percina spp.	1.00	3.45	2.00	6.90
Total	**23.00**	**79.31**	**6.00**	**20.69**

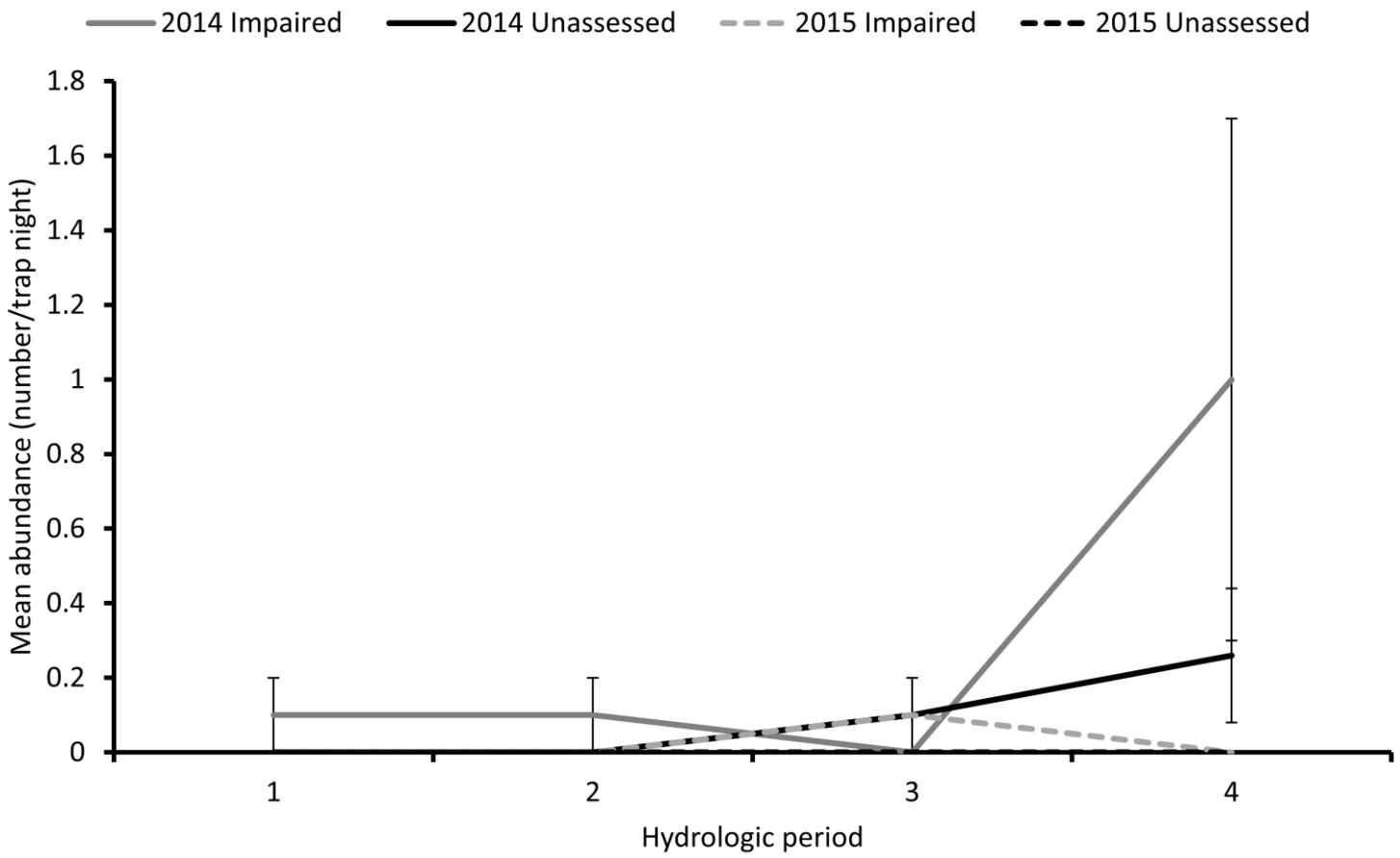

Figure 22. Mean ichthyoplankton abundance (number/trap night) among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] between the impaired and unassessed reaches of the Minnesota River during 2014 and 2015.

Table 24. Mean relative CPUE (number/trap night) of larval genera sampled in the impaired and unassessed reaches of Minnesota River during all four periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)] of the 2014 and 2015 using the light trap. For each period, the amount of effort is noted (italicized).For each genera, the mean density, standard error (in parentheses), and statistical results are noted. N is the number of samples collected in each reach during that period.

Period/Genera	**Impaired**	**Unassessed**	***P*-value**
Period one	*N=26*	*N=27*	
Ictioubus spp.	0.04(0.04)	0.00(0.00)	0.33
Period two	*N=36*	*N=39*	
Moxostoma spp.	0.03(0.03)	0.00(0.00)	0.31
Period three	*N=20*	*N=20*	
Etheostoma spp.	0.00(0.00)	0.05(0.05)	0.34
Lepomis spp.	0.05(0.05)	0.00(0.00)	0.34
Period four	*N=30*	*N=29*	
Cyprinella sp.	0.60(0.47)	0.00(0.00)	0.08
Etheostoma spp.	0.03(0.03)	0.00(0.00)	0.34
Lepomis spp.	0.00(0.00)	0.10(0.10)	0.34
Percidae spp.	0.03(0.03)	0.07(0.07)	0.98

CPUE among all periods and reach type. Period four in the impaired reach captured the greatest *Cyprinella* sp. (0.60±0.47) and may be biologically significant compared to the unassessed reach (0.00±0.00).

Discussion

Lower trophic levels in the impaired and unassessed reaches of the Minnesota River were quite similar. A high degree of overlap among taxa groupings and comparable catches between the reaches suggest that the unassessed reaches are relatively analogous to the reaches deemed impaired. Key variables, particularly hydrology, appear to be playing a substantial role in shaping lower trophic level community composition. Therefore, disruptions in natural hydrographs, and the associated alterations to sedimentation and nutrient dynamics, are contributing to the biological impairments identified in the Minnesota River.

Minnesota River sediment load is particularly high, being 26 times greater than the St. Croix River and four times greater than the Mississippi River (Johnson et al. 2009). Elevated concentrations of suspended sediment and other solids can significantly reduce survival of larval fish, limnetic macroinvertebrates, and larval fish. Striped Bass *Morone saxatilis*, Yellow Perch *Perca flavescens*, and American Shad *Alosa sapidissima* larvae exposed to sediment concentrations ≥ 100 mg l^{-1} for 96-h survival was significantly reduced (Auld and Schubel 1976). High turbidity also causes selective feeding and decreases fecundity and survival of zooplankton (Gasparini and Castel

1999). If significant mortality were happening among taxa groups studied, low densities would be expected with only the most tolerant species dominating the communities.

The impaired and unassessed reaches possessed the majority of same taxa groupings. *Moina* sp., *Pomoxis* spp., *Sander* sp., and *Scaphirhynchus* sp., Lepidoptera, and Nemertea were not found in the unassessed reach. While *Amia calva*, Apidae, *Aplodinotus* sp., *Hybognathus* sp., Diplopoda, Formicidae, and Megaloptera were not found in the impaired reach. However, these taxa were found in low densities and influence on community dynamics was hypothesized as minimal.

Battle et al. (2007) also found minimal differences among macroinvertebrate communities throughout the Mississippi River Basin. They hypothesized that because of similar food (i.e., energy sources) transported from upstream, few barriers preventing long-distance dispersal, and nominal localized habitat differences compared to a lower order stream, could explain similarities. The two reaches observed in the Minnesota River were both within the free-flowing section, thereby making long-distance dispersal possible. In addition, watershed characteristics dominated by row-crop agriculture are present in the watersheds for both reaches. Therefore, one could hypothesize that food, energy sources, and suspended sediment particle size are typically comparable between the two reaches due to the similarity of watershed traits. If the conditions described above are valid, it would also stand to reason that the zooplanktonic communities

would be influenced by largely the same set of parameters and would therefore exhibit similar structure and dynamics.

Communities in both reaches were dominated by a few smaller-statured taxa groupings, including *Bosmina* spp., Cyclopoida copepods, *Chydoridae* spp., *Asplanchna* sp. and *Monstyla* sp.; however, even the most abundant taxa were found in low densities. Smaller-sized taxa have shorter generation times (Pace and Orcutt 1981, Wahl et al. 2008) and are more durable than larger limnetic taxa in the river environment (Zimmermann-Timm et al. 2007). Therefore, the smaller-sized taxa may have been able to withstand the harsh conditions of this turbid riverine system, and had the capacity to take advantage of brief periods of favorable conditions to reproduce. Low numbers of individuals and few taxa groups can be indicators of degradation in permanent Minnesota streams (Niemela and Feist 2000). Because the impaired and unassessed reaches exhibited similar taxa dominance, albeit at very low densities, it is implied that the zooplanktonic community across the entire free-flowing portion of the Minnesota River is likely experiencing the same impairment challenges.

Other factors, however, such as taxonomic resolution may have also played a role in the similarity of results between reaches. Identification of many biota to taxonomic classifications more inclusive than genus species could have caused my assessment to miss finer differences between the impaired and unassessed reaches. Researchers have, however, used similar identification techniques as those used in this

study and still quantify biotic differences between study sites (e.g., Bouchard et al. 2005). It is possible, however, that differences between unassessed and impaired reaches may require lower taxonomic resolution to identify differences.

Sample design may have also been a driver of community composition results. A majority of the sampling efforts, regardless of gear type, occurred in lower-flow areas near the channel bank, as opposed to the higher-flow thalweg of the river. Bank areas typically have lower turbulence and greater water retention (Sluss et al. 2008), increasing the residence times of the individuals. However, limited swimming capabilities of taxa groups investigated during this study, may have decreased their abilities to reach these areas. Increasing sampling effort directly in the drift may help determine if densities found in this study were an artifact of study design or actually indicative of low densities.

Although some experimental design error has come into question above, additional investigation of sediment loading influences on biota within the system, and if reductions would increase survival of the zooplanktonic community is warranted. However, the dynamic nature of the hydrologic regime, regardless of sedimentation, is influencing the zooplanktonic community in the Minnesota River. Hydrologic stage appears to be a driver in community composition within the Minnesota River. Poff et al. (1998) suggested emphasis be placed on high and low flow events that serve as catalysts to ecological function. Recall in this study, zooplanktonic densities and species richness

increased following periods of high flows. Fisher and Willis (2000) noted that high-flow periods within the hydrologic regime allow floodplain wetlands and backwaters to connect with the river channel and experience a flushing event.

Backwater flushing generates a mass export of organic resources, including zooplanktonic biota, from the floodplain into the main channel. The annual pulse of floodplain resources is typically a rejuvenating factor to riverine systems that allows species with rapid generational turnover and good colonizing abilities to reestablish (Fisher 1983). Backwaters have also been found to be substantial production habitats for zooplankton (Fisher 2011), macroinvertebrates (Konrad 2010), and ichthyoplankton (Slipke et al. 2005). Periods of high flow in the Minnesota River appear to be important for lower trophic levels and are likely a crucial component of a functional river system. Therefore, the importance of the natural hydrologic regime should not be understated and efforts to maintain and restore channel-floodplain connections should be a high priority.

Chapter 2: Evaluation of Four Ichthyoplankton Sampling Methods in a Large, Midwestern River

Abstract

Sampling large rivers for fish, particularly ichthyoplankton, can be difficult and sampling gears have inherent biases that must be identified to secure reliable data. The need to improve ichthyoplankton sampling strategies in the Minnesota River is a priority to state management agencies. Therefore, a benthic slednet, light trap equipped with a glow-stick light source, light trap equipped with a LED light source, and a surface slednet were evaluated for efficacy in capturing Ichthyoplankton in a large, Midwestern river. Ichthyoplankton were sampled from 15 May through 15 August in 2015 and 23 April to 15 August in 2015 with four gears noted above in the Minnesota River. During this study, 213 ichthyoplankton were captured. The surface slednet captured the greatest number of larvae (N = 141), most genera (N = 15), most unique genera (N = 6) and had the lowest coefficient of variation of icthyoplankton catch (167). However, each gear sampled a narrow range of genera (Niche breadth: 0.00-0.35) and different components of the ichthyoplankton community (ANOSIM: $R = 0.12$; $P = 0.04$). Results suggest that the selection of ichthyoplankton sampling gears for assessing ichthyoplankton in a Midwestern river need to be objective orientated and sampling designs will often require a multiple gear approach.

Introduction

Examination of fish early life history is often essential for understanding aquatic ecosystems, fish community dynamics, understanding fish species ecology and development of management strategies (Snyder and Muth 2004). For example, ichthyoplankton drift patterns allow inferences of spawning dates, spawning activity, and spawning locations (Braaten et al. 2010). Ichthyoplankton densities can also predict year-class strength as mortality during the larval stage influences recruitment and ultimately stock abundance (Houde 2008, Roseman et al. 2007). Ichthyoplankton have also been used as indicator taxa, establishing their accordance with other biotic and abiotic factors (Kelso et al. 2012). Unfortunately, sampling ichthyoplankton is inherently difficult, time consuming, and expensive (U.S. Fish and Wildlife Service 1992).

Sampling ichthyoplankton can be complicated by their spatial and temporal variability (Chambers and Trippel 1997). Temporally, ichthyoplankton distributions tend to cluster, centered on spawning events (Kelso et al. 2012). Seasonally, ichthyoplankton distributions are dependent on species and ideal abiotic conditions, as spawning events have a wide temporal range, from days to months (Neal et al. 2012). Spatially, ichthyoplankton distributions vary among habitats (King 2004) including the water column (Kelso et al. 2012) depending on the stage of larval development. Later-stage larvae are mobile and tend to reside in different habitats, compared to earlier stages that are less mobile that mostly drift (Reichard et al. 2004). Seasonal and temporal icthyoplankton variability will also occur annually, because of temperature and

hydrology (Kelso et al. 2012). Due to the unpredictability in sampling icthyoplankton, the variety of habitats icthyoplankton inhabitat and specific species tendencies, numerous active and passive sampling gears have been developed, tested, and used across a range of temporal periods and sampling ichthyoplankton (Neal et al. 2012).

Common active methods for sampling ichthyoplankton have included electrofishing, pumping, and trawling. Electrofishing stuns larvae with electricity to facilitate capture and is best suited for sampling shallow, yet structurally complex habitats (King and Crook 2002). Pumping intakes water and suspended organisms delivering the mixture to a filter that allows targeted sampling of specific depths and volumes of water (Nayar et al. 2002). Trawls have been designed with (Tibbs and Galat 1997) or without frames and usually consist of plankton nets that simply filter water and capturing suspended organisms while the gear is pulled or pushed through the water column (Claramunt et al. 2005). Various trawl designs and arrangements (e.g., round, square, single, or paired); have been developed for use in riverine systems (Gallagher and Conner 1983).

Ichthyoplankton net mesh sizes often range from 363 (Neal et al. 2012) to 1,000 µm with mesh size influencing size selectivity of larvae (Iserman et al. 2002). Fisher (1999) and Nickel (2014) used a 500-µm bar-measure mesh surface trawl during an assessment of the Missouri River and Minnesota River and associated backwaters. Trawl tow speed range from <0.5 m/s (Isaacs and Kidd 1953) to an excess of 2.5 m/s (Wiebe

and Benfield 2003). Due to the success of various trawl designs among different conditions, the gear is considered well suited for a variety of habitats and several portions of the water column, from benthic (Carleton and Hamner 2007), to pelagic (Oozeki et al. 2004) and surface (Overton and Rulifson 2007).

Passive methods primarily include drift nets and stationary traps (Neal et al. 2012, Siegwarth and Johnson 1993). Drift nets allow discharge and natural flow of water to pass through a mesh and thereby capture larvae. Drift nets often have similar designs as active trawls, but are held stationary. Stationary traps are typically engineered to capture larvae by taking advantage of their phototaxic nature to attract and then entrap larvae as they emerge from nests, enter the swim up stage, or are otherwise utilizing the habitat (Kelso et al. 2012). Traps have been designed of wooden frames with fiberglass screen bottoms (Gammon 1965), devices similar to traditional minnow traps (Baugh and Pedretti 1986), activity traps (Niles and Hartman 2007), and translucent light traps (LT; Floyd et al. 1984).

Light traps, however, are believed to be one of the gears capable of capturing large numbers of larval fish representing a wide variety of species (Snyder and Meismer 1997). Several different light sources have been used to attract ichthyoplankton to LTs. Light sources used include bright light emitting diodes (LED; Gyekis et al. 2006), white fluorescent light (Miller and Shanks 2005), and chemical light sticks (Kehayias and

Doulka 2007) and have been found to capture similar densities and taxa (Gyekis et al. 2006).

Currently, the MN DNR is interested in developing standardized sampling protocols for sampling ichthyoplankton in the Minnesota River (MN DNR 2013). Understanding the bias each gear possesses, can aid in monitoring protocol development to meet specific objectives, target specific various life history characteristics and species, or secure data in particular habitat (Leis 2000). Ichthyoplankton sampling methods, like all fish sampling methods, capture specific species and sizes more effectively than others and vary in performance among habitats and seasons (Quist et al. 2006). Hickford and Schiel (1999) recommended combination of LTs and plankton nets to obtain a more comprehensive understanding of an ichthyoplankton community. Additionally, Nile and Hartman (2007) recommended using LTs for capturing ichthyoplankton in large rivers.

Based on the literature, Minnesota River characteristics, (i.e., accessibility, size, and morphology), and prior research on the system (e.g., Nickel 2014), an ichthyoplankton sampling strategy was developed that included two different modified trawls (e.g., surface and benthic slednets; SN) and LTs equipped with two different light sources were hypothesized to be potentially effective at capturing a representative sample of ichthyoplankton in the Minnesota River.

The objective of this chapter was to

- evaluate a benthic and surface slednet and light traps equipped with glow-stick and LED light sources SN for sampling ichthyoplankton in the Minnesota River over time and in relation to the hydrologic stage by
  a. comparing ichthyoplankton taxonomic richness among gears over time and in relation to the hydrologic stage,
  b. estimating overlap of ichthyoplankton genera captured among gears, and
  c. estimating ichthyoplankton CPUE over time and in relation to the hydrologic stage among gears.

It was hypothesized that a

- ichthyoplankton catches in the benthic slednet, the light trap with a glow-stick light source, light trap with a LED light source and surface slednet within the Minnesota river, over time and in relation to hydrologic stage will
  a. capture different components of ichthyoplankton community because three are passive gears and one is active,
  b. have minimal overlap of ichthyoplankton captures because three are passive gears and one is active, and
  c. ichthyoplankton CPUE within gears will be similar as gears are sampling the same system.

Methods

Gears

During the 2014 field season, quatrefoil LTs (41.4-cm high x 21.5-cm wide with 2-mm slot openings; Floyd et al. 1984) fitted with one 12-h glow-stick (Figure 23), and a SN were used (Figure 24). The SN was a 500-µm drift net (30-cm tall, 46-cm wide and 1.0-m long with a 1,000-ml dolphin bucket) with a 3.81-cm diameter polyvinyl chloride (PVC) pipe frame (Figure 24). The PVC frame surrounded the net creating a sled similar to the one utilized by Galat et al. (2004) and identical to Nickel (2014). The sled allowed the net to be actively towed, sampling the upper 0.5 m of the water column and slide over obstacles without damaging the net or compromising that sample.

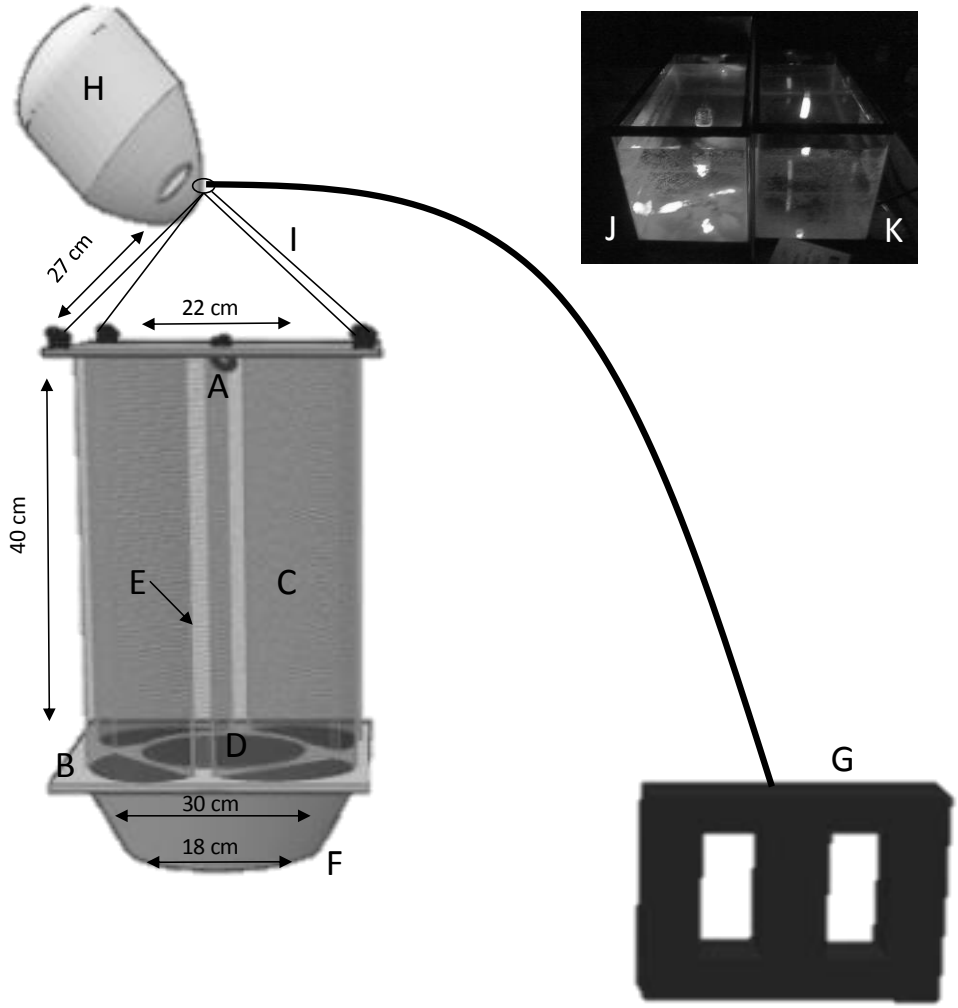

Figure 23. Schematic of light traps used in sampling ichthyoplankton in the Minnesota River during the 2014 and 2015 field seasons. A. Eyebolt (0.64-cm) where light source was attached. B. Plexiglas sheet (0.63-cm thick), 22-cm by 22-cm for top of the trap and 30-cm by 30-cm for the bottom of the trap. C. Half a circle (10-cm outside diameter, 9.53-cm inside diameter) of clear extruded acrylic tube, cemented to the top and bottom Plexiglas plates. D. Hole (12.7-cm) in the center of bottom Plexiglas sheet. E. Entry slot (2-mm width) F. Stainless steel collection pan, systemically drilled with holes (0.63-cm diameter), then covered with mesh (500-µm) and attached to bottom Plexiglas plate with pony spring clamp (1.9-cm) or binder clips (1.9-cm). G. Cinder block anchor (9.1-kg). H. Hard shell buoy. I. Vinyl coated, galvanized cable (0.32-cm thick, 30.48-cm length) attached to eyebolts (0.64-cm) and meeting at nickel plated, single ended snap hook. J. LED light source used in 2015. K. Photochemical light source used in 2014 and 2015.

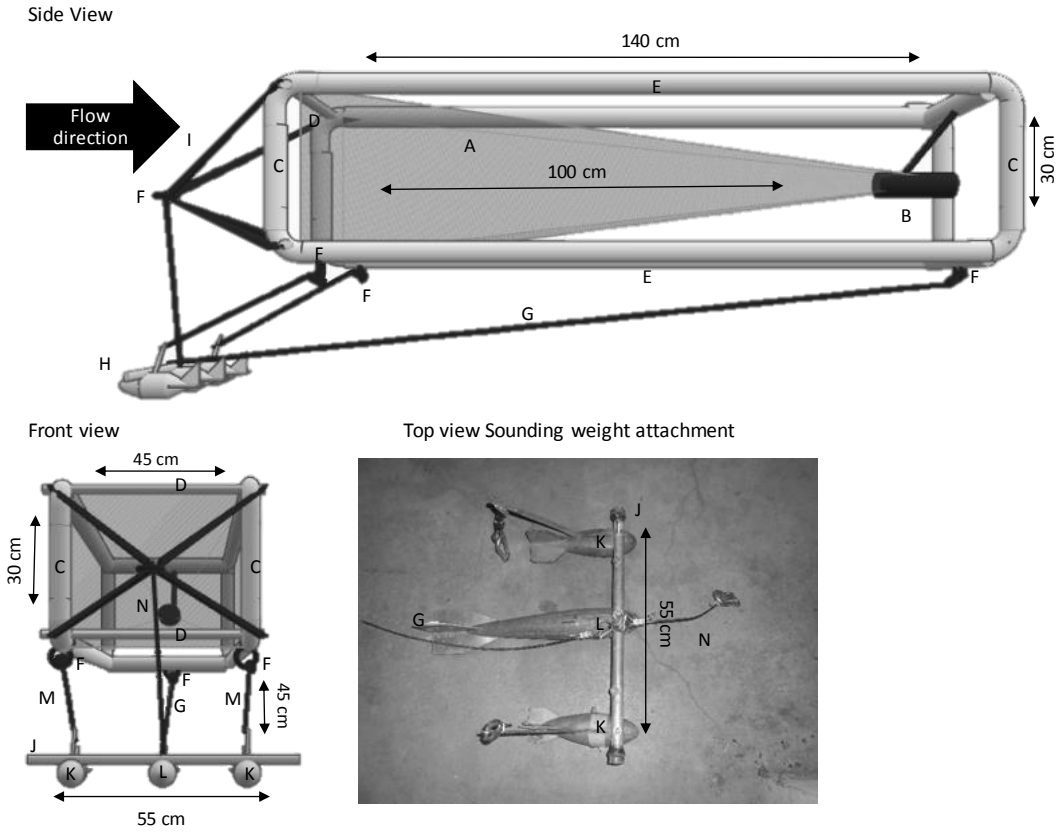

Figure 24. Schematic of the slednet and sounding weight attachment used in sampling ichthyoplankton in the Minnesota River during the 2014 and 2015 field seasons. A. Drift net (30-cm tall, 46-cm wide and 1.0-m long, 500-µm mesh). B. Dolphin bucket (1000-ml with 504-µm stainless steel mesh). C. Vertical PVC supports (3.81-cm diameter, 30-cm length). D. Threaded rod (1.27-cm thick, 50-cm long) horizontal supports. E. Horizontal PVC supports (3.81-cm diameter, 140-cm length). F. Steel rings (3.81-cm) secured to the PVC frame with U clamps (3.81-cm). G. Vinyl coated, galvanized cable connecting sounding weight system to the cod end steel ring. H. Sounding weight attachment attached to F with snap hook carabiners (5-cm). I. Vinyl coated, galvanized cable lead, secured to D by nylock nuts (1.27-cm) and flat washer (1.27-cm) meeting at and attaching to a steel ring for towing. J. Carbon steel tubing (1.3-cm diameter, 55-cm length) K. Sounding weight (6.8-kg) bolted to J. L. Sounding weight (13.6-kg) added during high flows. M. Vinyl coated, galvanized cable directly attached to the sounding height hanger bars and using snap hook carabiners (5-cm) to the mouth end F's. N. Vinyl coated, galvanized cable directly attached to J and using a hook carabiner (5-cm) to the F attached to I.

After reviewing data from the first year of sampling, modifications were made to each gear. In 2015, half of the LTs were fitted with either one 12-h glow-stick and the other half of the LTs were equipped with one green LED light (120-mm x 43-mm LED light with 2 green LED lamps and a Poly Carbonate resin body; Figure 23), which is brighter and longer lasting light source of one

In attempts to sample ichthyoplankton near the river bottom or benthos, a sounding weight system was constructed to allow the SN to fish near the river bottom and essentially function as a benthic larval drift net that passively fished 0.5-m from the river bottom. The sound weight was constructed with a carbon steel bar (1.3-cm diameter, 55-cm length) and 27.2-kg of sounding weights to easily attach to and detach from the SN. Detachment of the sounding weight system allowed the SN to function identically to as it had the previous year, as a surface trawl (surface SN).

Initially, the sounding weight system was constructed with two 6.8-kg sounding weights, bolted to a 1.3-cm diameter, 55-cm long, carbon steel tube. Increased flows during the field season required the addition of another 13.6-kg sounding weight (Figure 24) to maintain SN position in the water column. The sounding weight system, had four vinyl coated, galvanized cables attached through 1.3-cm eyebolts to the carbon steel tube. 5-cm snap hook carabiners allowed the weight to be quickly attached/detached to four 3.81-cm steel rings attached to the SN PVC frame steel rings with 3.81 U clamps.

Ichthyoplankton Collections

Ichthyoplankton were sampled approximately biweekly in the Minnesota River between 15 May 2014 to 15 August 2014 and 23 April 2015 to 15 August 2015. Two reaches were sampled each year based on proximity to MN DNR intensive study sites on the Minnesota River. During 2014, sample reaches were near Franklin (RKM 298) and Savage (RKM 24; Figure 25). In 2015, sample reaches were near Henderson (RKM 105) and New Ulm (RKM 234; Figure 25).

During both years, starting points of 10 sampling transects were systematically arranged on the left downstream bank at 200-m intervals and spanned diagonally upstream across the entire channel to the opposite (right downstream) bank (Figure 25). During the 2014 field season, on the downstream end of each transect, near the bank directly below the water surface in water ≥ 1-m in depth, one LT fitted with one 12-h glow-stick was deployed. Light traps were set between 0800 and 1100 h, let set for approximately 24 h and retrieved the following day. In 2015, either one 12-h photochemical light stick or a 120x43-mm LED light with 2 green LED lamps and a polycarbonate resin body were randomly selected as the light source in each LT on the downstream end among all 10 transects (N=5 for each LT light source per sample date).

Surface SNs were towed upstream parallel to the side of the boat at speeds ~1.6 km/h greater than the discharge of the river, across the entire length of each transect (Figure 25). General Oceanics mechanical flow meter (Model number2030R) was

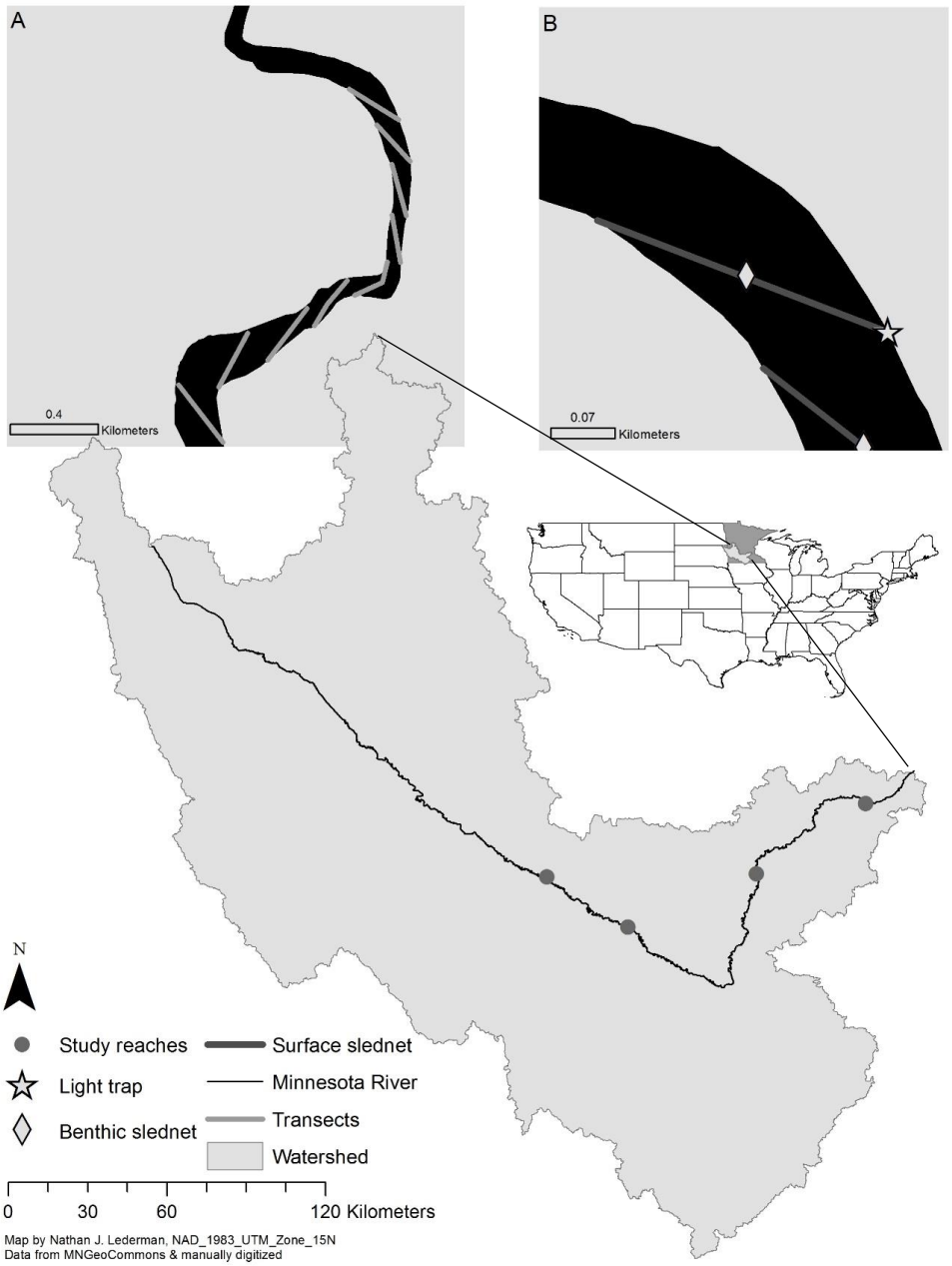

Figure 25. Study reaches from the 2014 and 2015 sampling season on the Minnesota River. **(A)** Generalized distribution of sampling transects within a reach. **(B)** Placement of sampling gears within a single transect. The star represents a light trap, the diamond represents the benthic trawl and line represents the distance of a surface trawl. During the 2014 sampling year only the LT glow-stick and SN surface were used. While in 2015 the light trap light source was either a glow-stick or LED and the slednet method could have been surface or benthic.

suspended in the mouth of the net and used to estimate volume of water sampled in m^3. In 2014, surface SN samples, were collected from the upper 0.5 m of the water column was collected at each transect. During the 2015 field season, SN methods were randomly selected of either benthic or surface (N=5 for each SN method per sample date). If surface SN was selected for a transect, it was deployed identically as in 2014. If, benthic SN was selected, the boat was anchored in the thalweg of that transect. After anchoring, the sounding weight attachment secured to the SN frame and then manually deployed from the side of the boat, sunk to the bottom and left stationary for five minutes. After five minutes had elapsed, the benthic SN was manually retrieved.

Contents collected from LTs and SN gears during both years were fixed and preserved using methodology established by the United States Geological Survey (USGS: J. Larson, United States Geological Services Upper Midwest Environmental Sciences Center, personal communication) and the MN DNR (J. Waters, Minnesota Department of Natural Resources, personal communication). The protocol included immediate fixation of captured biota in 10% buffered formalin. After 24 to 48 h, sample contents were filtered through a 53-µm sieve, rinsed back into the same sample bottle, and preserved with 90% ethyl alcohol. Preserved sample contents were placed in a Pyrex sorting pan and ichthyoplankton separated from detritus, course particulate matter, and other biota and identified under an Olympus SZ61 dissecting microscope. Larval fish identification was to the lowest taxonomic category possible, usually genus.

Identifications were aided using an ichthyoplankton key by Auer (1982) and Fuiman et al. (1983) and Wallus and Simon (1990, 1994, 2003, 2005, 2006, and 2008).

The 2014 ichthyoplankton identifications were verified by Thomas Simon at Indiana State University. Due to aggregation of samples to meet fiscal constraints, percent agreement between expert identification and my identifications could not be determined. However, all families and genera were represented in similar abundances in both the professional and my identifications, with the exception of my identifications of the genera Hiodontidae. Hiodontidae specimens were reanalyzed and adjustments made to their identifications. The 2015 samples were not sent out for expert verification due to budgetary and time constraints.

Gear Analyses

Since species-level identification of ichthyoplankton is not easily and accurately achieved, analyses were completed on genera-level. Data of captured ichthyoplankton were aggregated based on month, similar to Pritt et al. (2015), and prevailing hydrologic regime hydrologic (i.e., first rise, major rise, major descending limb, steady state; Figure 26) similar to Nickel (2014).

Typically, SN data are based on water volume filtered (e.g. number/m^3, number/$100m^3$) and LT data are reported as a unit of time (number/night, number/10mins), creating difficulties for direct comparison of ichthyoplankton catch data among gears. To facilitate comparison among gears, larval densities and genera densities relationships to the volume of water sampled by the SN methods and the

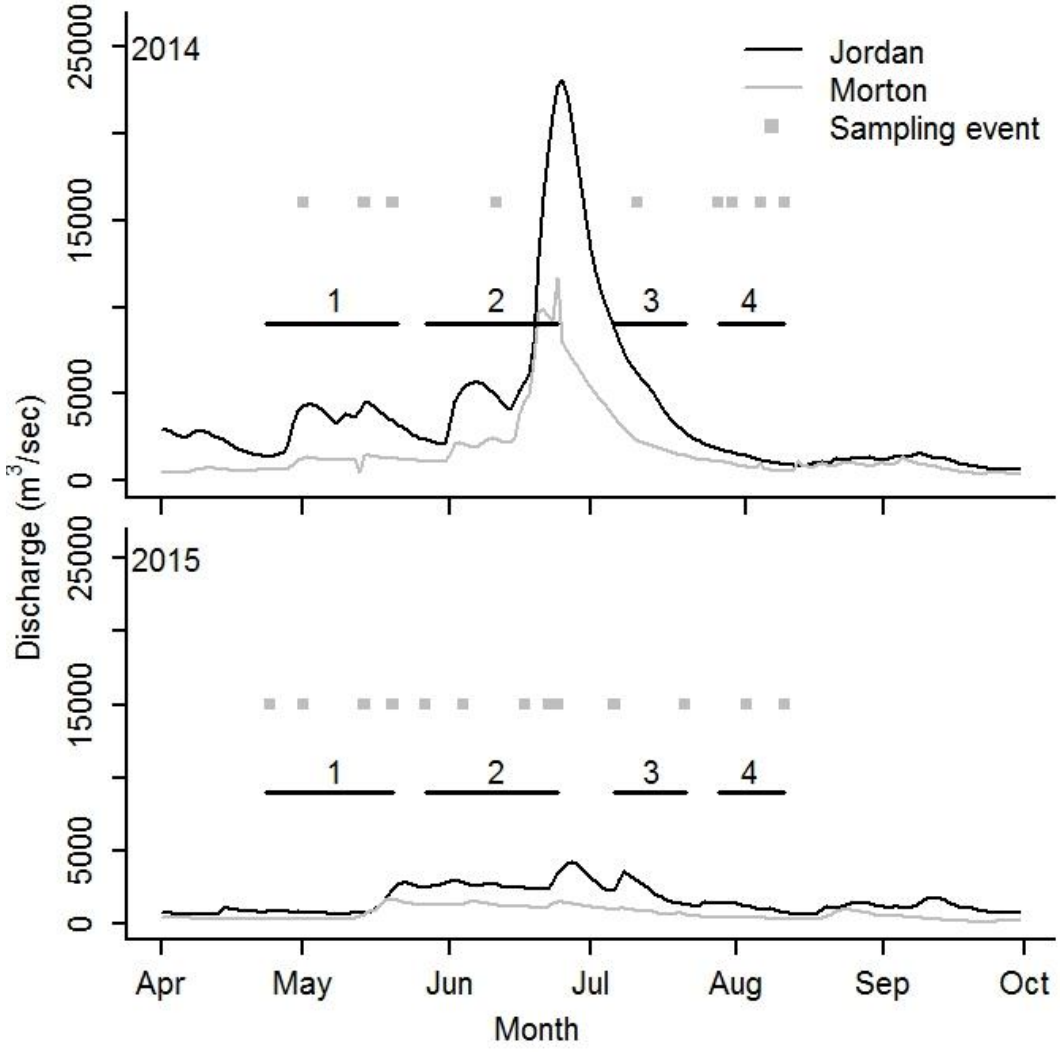

Figure 26. Daily mean flow (converted to m^3/s from ft^3/s values) for the Minnesota River gauging stations near Jordan, MN (USGS 05330000) ; (black line) and near Morton, MN (USGS 0533000) ; (grey line) during the **(top)** 2014 sampling season and **(bottom)** 2015 sampling season. Discrete sampling events throughout each year are represented by grey squares and hydrologic periods denoted by lines extending the entire period, with respective ranking on top.

minutes the LT methods were set for were investigated with regression analyses. No significant relationship between total time set for LT glow-stick and abundance of larvae (r^2 = 0.00, P = 0.69) or genera richness (r^2 = 0.00, P = 0.89) existed. Also, no significant relationship exited between the total time set of LT LED and abundance of larvae (r^2 = 0.00, P = 0.68) or genera richness (r^2 = 0.00, P = 0.68) either. Additionally, no significant relationship between volume of water sampled for benthic SN and relative density of larvae (r^2 = 0.01, P = 0.57), and relative density of genera richness (r^2 = 0.01, P = 0.38) existed. Similarly, no significant relationship was detected between volume of water sampled for surface SN and relative density of larvae (r^2 = 0.01, P = 0.44), or relative density of genera richness (r^2 = 0.01, P = 0.39) as well. Thus, catch was standardized per sample unit of effort (i.e., one benthic SN was equal to one LT fitted with a LED) for the qualitative analyses. This method of standardization was also used by Sluss et al. (2008) in the Ohio River to compare sampling gears for riverine zooplankton.

However, to enable quantitative analyses and future comparisons with these data, ichthyoplankton catches with LT methods were summarized as number/trap night for number of larvae and genera and catches SNs were recorded as number/100m^3 of larvae and genera. Summarizations by number/trap night and number/100m^3 of water were used in the quantitative comparison between gears with similar sampling methods (i.e., LT glow-stick vs LT LED) among months and hydrologic periods.

Qualitative analyses

Catches of ichthyoplankton were summarized as total number of larvae and genera captured in each gear during each month during each of the two years of this study. The percent each gear caught was also calculated.

Species accumulation curves were then plotted for each gear type (i.e., benthic SN, LT glow-stick, LT LED, and surface SN). Species accumulation curves record the rate new species are added to a dataset as a function of cumulative effort and used in assessing total abundance, species evenness and species diversity (McCune and Grace 2002). As more species are sampled, and the more even their abundances within that gear, the more rapidly the curve will rise (Gotelli and Colwell 2011). Curves were generated using the program R software 3.1.2 (R Development Core Team., Vienna, Austria) and the vegan package, using the random method with 100 permutations.

Exploring similarities of ichthyoplankton taxonomic composition among gears, a non-metric multidimensional scaling (NMDS; Kruskal 1964) analysis was performed. The NMDS technique “maps” results in such a way that the distance between gears represents the degree of similarity between their catches (Morris and Ball 2006). Dimensionality was kept below three axes as greater than three axes makes the eyes unable to spot patterns (Bartholomew et al. 2008). Stress was also kept between 0.05-0.25 ensuring that the model created represented a proper fitting model (Kruskal 1964).

Non-metric multidimensional scalings were attempted on the unmodified ichthyoplankton genera captured data, the mean number of each ichthyoplankton

genera captured by date and gear type, and mean number individual ichthyoplankton of each genera by gear type and sampling trip using a Bray-Curtis dissimilarity calculation with the program R software 3.1.2 and the vegan package.

To determine if the benthic SN, LT with the glow-stick, LT with the LED and surface SN captured significantly different portions of the ichthyoplankton community, an analysis of similarities (ANOSIM) was completed. An ANOSIM is a non-parametric randomization procedure that determines if samples within groups are more similar in composition than samples from different groups (Clarke 1988). An *R*-statistic with a range of -1 to 1 and a *P*-value are provided. The *R*-statistic itself is useful for comparative measures of the degree of separation (Clarke 1988). An *R*-statistic close to 1 suggested dissimilarity among gears, while an R-statistic close to 0 suggested a more even distribution among gears. Additionally, to assess the amount of overlap in larval fish catch composition between all gears used in this study, a Schoener's percentage overlap index (Schoener 1970) was used. This index provides a qualitative description of the amount of overlap in genera composition. The Schoener's percentage overlap indices were calculated using the program R 3.1.2, its spaa package, and the Schoener function. Indices were calculated as

$$\mathrm{P_{jk}} = [\sum_{i=1}^{n} (\mathrm{minimum}\ \mathrm{p_{ij}}, \mathrm{p_{ik}})]100,$$

where p_{ij} was the proportion of genera “i" to the total number of “i” larval fish in gear “j” (i.e., surface SN), p_{ik} was the proportion of each genera captured “i” to the total number of larval fish in gear “k” (i.e., benthic SN), n was the total number of genera captured, and P_{jk} was the percentage overlap between gears. Values from 0 to 100 were possible, with 0 suggesting no overlap and 100 indicating complete overlap. Schoener indices are commonly used in diet studies and an overlap value ≥ 60% has been considered biologically significant (Wallace and Ramsay 1983 and Hill et al. 2015). Although diet overlap was not assessed, the ≥ 60% criteria between gears was applied to suggest biological significant overlap in larval fish catches between gears.

The Levins’ measure of niche breadth (Levins 1968) was also calculated for each gear as a measure of the amount of specialization to specific genera or equal use by all genera. Levins’ measures (B) were calculated in the program R software 3.1.2 using the spaa package and the following equation of

$$B = 1/\sum p_{j^2} ,$$

where p_j was the proportion of larvae in genera “i” associated with gear j (e.g., LT LED or surface SN). The value for B can range from 1 to N, where N is the total number of genera captured among all gears combined (N = 19). A score of 1 signifies complete specialization of the gear to capture a single genera and the closer to N, the less specialized the gear is.

Levins' index was then standardized to (B_a) a 0 to 1 scale using the modification suggested by (Hurlbert 1978) to allow for easier biological interpretations. Using the equation

$$B_a = (B - 1/n - 1),$$

in the program R software 3.1.2, where n is the number of total number fish genera captured among all gears (N = 19) B is the Levins' measure and "a" is the particular gear. A B_a value of 0 indicated complete specialization of genera to a gear type, whereas a value of 1 indicated a more equal likelihood of all genera to be capture with that gear type.

Percentage of ichthyoplankton genera captured cumulatively among all gears, and within each gear type were calculated in terms of the adult fish community sampled within the Minnesota River during the last six years of standardized electrofishing (A. Sindt, Minnesota Department of Natural Resources, personal communication; Table 25). The adult community sampled should represent the majority of potential spawning species in the Minnesota River and the genera of ichthyoplankton that should be present. Calculation of percentage of ichthyoplankton genera capture from those genera potentially spawning should determine effectiveness of the sampling gears in terms of sampling the entire ichthyoplankton community.

Table 25. Fish species found in the Minnesota River in the last six years during standardize electrofishing surveys performed by the Minnesota Department of Natural Resources throughout the Minnesota River (Source: A. Sindt, Minnesota Department of Natural Resources, personal communication).

Family	Genus	Common Name
Acipenseridae	*Acipenser*	Lake Sturgeon
	Scaphirhynchus	Shovelnose Sturgeon
Amiidae	*Amia*	Bowfin
Atherinopsidae	*Labidesthes*	Brook Silverside
Catostomidae	*Carpiodes*	Highfin Carpsucker
		Quillback
		River Carpsucker
	Catostomus	White Sucker
	Cycleptus	Blue Sucker
	Hypentelium	Northern Hog Sucker
	Ictiobus	Bigmouth Buffalo
		Black Buffalo
		Smallmouth Buffalo
	Moxostoma	Golden Redhorse
		River Redhorse
		Shorthead Redhorse
		Silver Redhorse
Centrarchidae	*Ambloplites*	Rock Bass
	Lepomis	Bluegill
		Green Sunfish
		Orangespotted Sunfish
		Hybrid Sunfish
	Micropterus	Largemouth Bass
		Smallmouth Bass
	Pomoxis	Black Crappie
		White Crappie
Clupeidae	*Dorosoma*	Gizzard Shad
Cyprinidae	*Campostoma*	Central Stoneroller
	Cyprinella	Spotfin Shiner
	Cyprinus	Common Carp
	Hybognathus	Brassy Minnow
	Luxilus	Common Shiner
	Macrhybopsis	Silver Chub
		Speckled Chub
	Nocomis	Hornyhead Chub
	Notemigonus	Golden Shiner
	Notropis	Channel Shiner
		Emerald Shiner
		Rosyface Shiner
		Sand Shiner
		Spottail Shiner
		Weed Shiner

Table 26 Continued.

Family	Genus	Common Name
Cyprinidae	*Pimephales*	Bluntnose Minnow
		Bullhead Minnow
		Fathead Minnow
	Rhinichthys	Blacknose Dace
Esocidae	*Esox*	Northern Pike
Umbridae	*Umbra*	Central Mudminnow
Gasterosteidae	*Culaea*	Brook Stickleback
Hiodontidae	*Hiodon*	Goldeye
		Mooneye
Ictaluridae	*Ameiurus*	Black Bullhead
		Yellow Bullhead
	Ictalurus	Channel Catfish
	Noturus	Stonecat
		Tadpole Madtom
	Pylodictis	Flathead Catfish
Lepisosteidae	*Lepisosteus*	Longnose Gar
		Shortnose Gar
Moronidae	*Morone*	White Bass
Percidae	*Etheostoma*	Banded Darter
		Fantail Darter
		Iowa Darter
		Johnny Darter
	Perca	Yellow Perch
	Percina	Blackside Darter
		Logperch
		River Darter
		Slenderhead Darter
	Sander	Sauger
		Walleye
		Walleye/Sauger
Petromyzontidae	*Ichthyomyzon*	Silver Lamprey
Polydontidae	*Polyodon*	Paddlefish
Sciaenidae	*Aplodinotus*	Freshwater Drum

Quantitative analyses

Catch data between gears with the same units of effort (i.e., benthic and surface SN and glow-stick and LED LT) were tested for normality with a Shapiro-Wilk tests (program R software 3.1.2) among months and among hydrologic periods. If data were not normally distributed, data were log-transformed [$\log_{10}$ (N+1)] and tested again for normality. If the transformed data still did not meet normality requirements, the un-transformed data were analyzed with appropriate nonparametric tests. For all quantitative comparisons, a *P*-value ≤ 0.05 indicated statistical significance.

The two light trap light source catch data (number of ichthyoplankton and number genera/trap night) were compared with Mann-Whitney U tests (compare two groups; t-test procedure, SigmaPlot 11.0, Systat Software Inc., San Jose, CA). Comparison with the Mann-Whitney U tests occurred within a period and month using both years of data cumulatively to determine if catch rates of the number of ichthyoplankton or number of genera differed. The same procedure noted above was used to compare benthic and surface SN data (number larval fish or number genera/ 100m^3). Within each gear type, a Kruskal-Wallis test (compare many groups; non-parametric procedure, SigmaPlot 11.0) was used to compare catch data among months and hydrologic periods. If Kruskal-Wallis procedures indicated the presence of a significant difference among months or hydrologic periods, a Dunn's Test was conducted to determine in which month or hydrologic period those significant differences existed.

The final analyses performed were calculating the variability and precision for each gear type by determining the coefficient of variation (CV) of the total number of larvae captured and genera richness within each period, month, and cumulatively. Coefficient of variation is used to compare relative dispersion in one type of data to relative dispersion in another type of data, and used as an index of variability for catch per unit effort, allowing comparisons of variability among gear types with differing units of effort (e.g., benthic SN to LT LED). Coefficient of variation was calculated using the following equation

$$\mathrm{CV} = \left(\frac{\mathrm{SD}}{\mathrm{mean}}\right) * 100.$$

Coefficient of variation was then compared among gears, periods and months for normality and heterogeneity with a Shapiro-Wilk and Equal Variance Test (SigmaPlot 11.0). Data passed normality and heterogeneity and a two-way analysis of variance (ANOVA; compare many groups; two-way ANOVA procedure, SigmaPlot 11.0) was ran having month and gear type as the independent variables and CV the dependent. Also, a two-way analysis of variance (ANOVA; compare many groups; two-way ANOVA procedure, SigmaPlot 11.0) was ran having hydrologic period and gear type as the independent variables and CV the dependent determining if mean CV among months or hydrologic periods differed significantly among gear types.

Results

Sample Effort

During this study, the number of samples collected with each gear type ranged from 64 to 100 dependent on the year and gear type (Table 26). Benthic SN sets sampled 633 m^3 to 2,987 m^3 of water and surface SN tows sampled ranged from 1,849 m^3 to 12,882 m^3 of dependent on month or period sampled (Table 27). Light trap glow-stick trap nights ranged from 4 to 49 and LT LED trap nights ranged from 4 to 28 dependent on month or period sampled (Table 27).

Gear Analyses

Qualitative

Cumulatively over both years, 213 larval fishes were captured, representing 8 families and 19 genera (Table 28). Temporally, the number of larvae and genera increased as spring progressed into summer for all gears (Figure 27 and Figure 28). The greatest number of larvae and genera were captured in July with LTs and the surface SN (Figure 27 and Figure 28); however, the benthic SN captured the greatest number of larvae and genera in August 2015. It is worth noting though, that during 2014, no sampling occurred from 4 June to 11 July due to high flood stage flows that raised safety concerns and poor gear performance. Additionally, benthic SN samples were not collected anytime in 2014 due to late addition of gear evaluation or on 20 May 2015 due to equipment failure that resulted from increased flows.

Table 26. Sampling effort in terms of months sampled, number of collection trips, number of samples and units of effort taken using the light trap (LT) glow-stick and LT LED. As well as the benthic slednet (SN) and surface SN during 2014 and 2015 within the Minnesota River.

Measure of effort	Gear	Year	Effort amount
Months			
	LT Glow	2014	4
		2015	5
	LT LED	2014	0
		2015	5
	Surface SN	2014	4
		2015	5
	Benthic SN	2014	0
		2015	5
Collection trips			
	LT Glow	2014	5
		2015	7
	LT LED	2014	0
		2015	7
	Surface SN	2014	5
		2015	7
	Benthic SN	2014	0
		2015	7
Samples collected			
	LT Glow	2014	99
		2015	64
	LT LED	2014	0
		2015	64
	Surface SN	2014	100
		2015	70
	Benthic SN	2014	0
		2015	65
Unit of effort			
	LT Glow	2014	99
	Trap nights	2015	64
	LT LED	2014	0
	Trap nights	2015	64
	Surface SN	2014	22,515
	m^3 of water	2015	19,564
	Benthic SN	2014	0
	m^3 of water	2015	7,928

Table 27. **(Top)** Sampling effort categorized among hydrologic periods [first ascending limb (1), second ascending limb (2), major descending limb (3), steady state (4)] and **(Bottom)** months using the benthic slednet (SN), light trap (LT) glow-stick and LT LED and surface SN in 2014 and 2015 within the Minnesota River. Following each gear, in parentheses type is the unit of effort used.

	Period			
Gear	**1**	**2**	**3**	**4**
Benthic SN (m^3 of water)	2,885	2,987	1,349	1,433
LT glow-stick (trap nights)	37	47	30	49
LT LED (trap nights)	16	28	10	10
Surface SN (m^3 of water)	9,839	12,882	7,860	11,497

	Month				
Gear	**April**	**May**	**June**	**July**	**August**
Benthic SN (m^3 of water)	633	2,161	2,349	1,349	1,433
LT glow-stick (trap nights)	4	48	32	49	30
LT LED (trap nights)	4	15	25	10	10
Surface SN (m^3 of water)	1,849	11,541	9,331	12,498	6,858

Table 28. Total number of larvae, genera and unique genera captured by the benthic slednet (SN), light trap (LT) glow stick, LT LED and surface SN within the Minnesota River during 2014 and 2015. Total in the number of families and number of genera columns are all the different families and genera captured cumulatively with all gears.

Gear	Number of Larvae	Number of families	Number of Genera	Number of Unique Genera
Benthic SN	43	6	8	2
LT glow-stick	28	4	7	1
LT LED	1	1	1	0
Surface SN	141	6	15	6
Total	**213**	**8**	**19**	

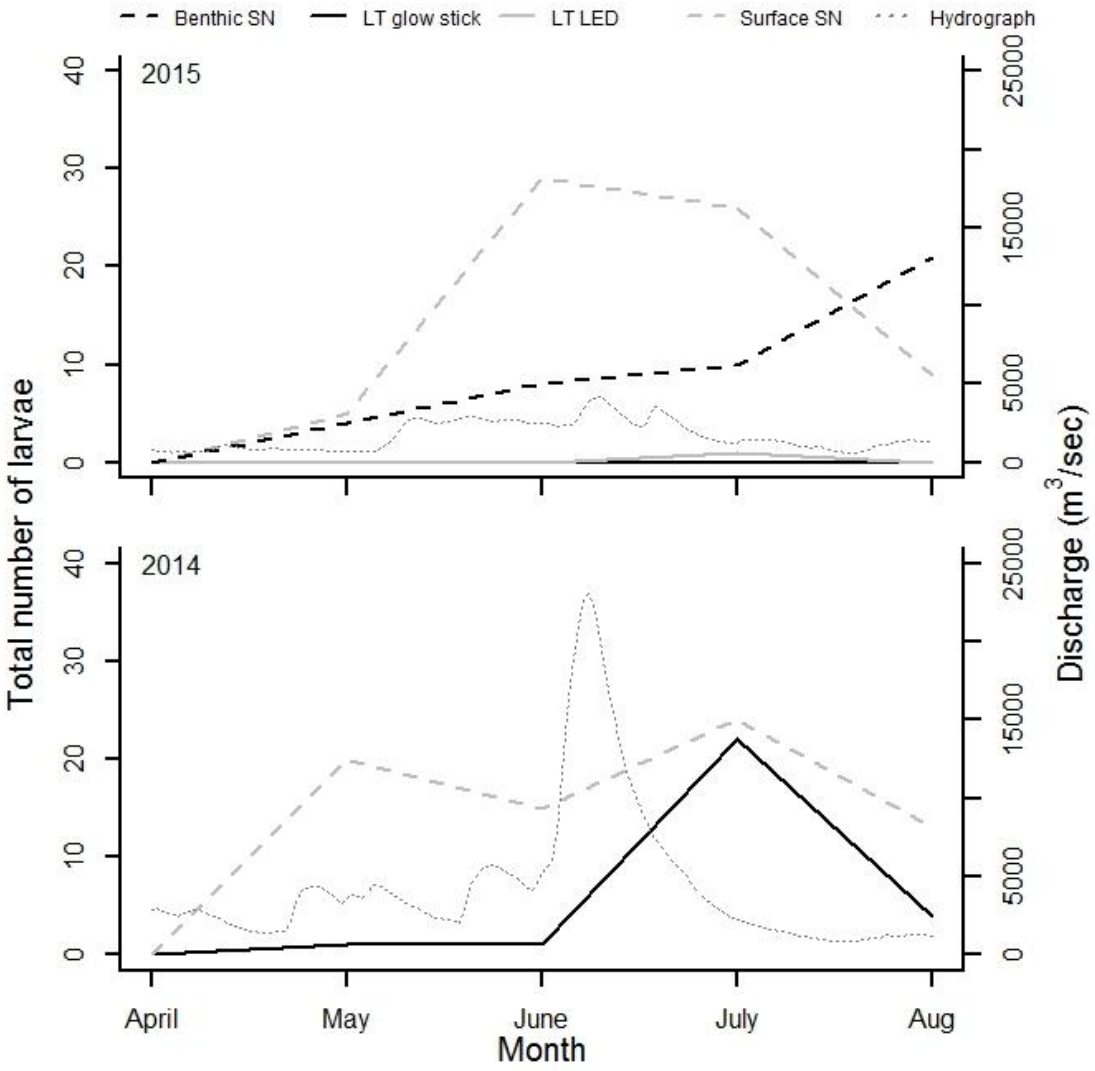

Figure 27. Total number of larvae captured within the Minnesota River in **(bottom)** 2014 and **(top)** 2015 using the benthic slednet, light trap glow stick, light trap LED and surface slednet in relation to discharge (converted to m^3/s from ft^3/s values) from USGS gauging station (USGS 05330000) near Jordan, MN.

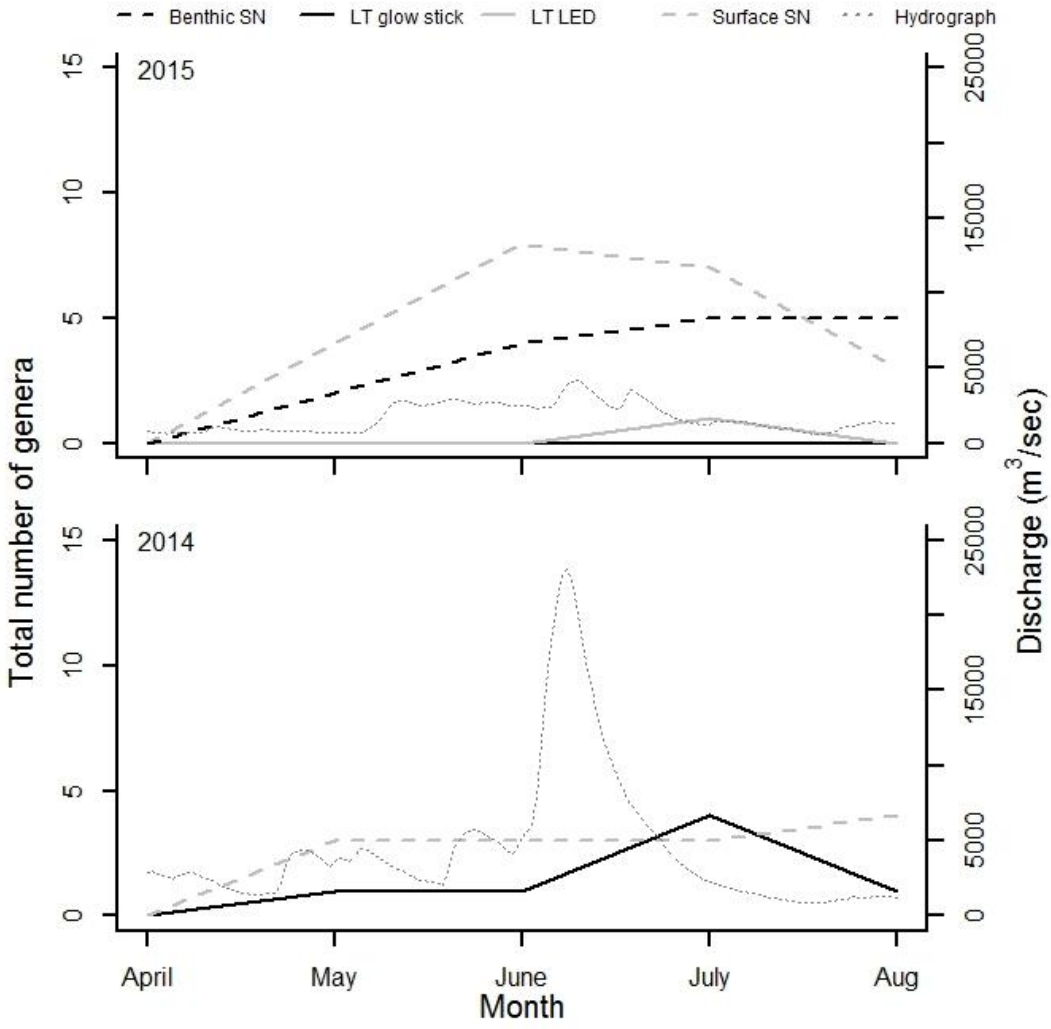

Figure 28. Total number of genera captured within the Minnesota River in **(bottom)** 2014 and **(top)** 2015 using the benthic slednet, light trap (LT) glow stick, LT LED and surface slednet in relation to discharge (converted to m^3/s from ft^3/s values) from USGS gauging station (USGS 05330000) near Jordan, MN.

Genera accumulation rates increased as the number of samples collected increased for each gear type except the LT LED (Figure 29). An accumulation curve for the LT LED could not be produced as only 1 larvae was captured. The LT glow-stick accumulation curve was more level compared to the other gears, adding new genera more slowly as the number of samples collected increased (Figure 29). The surface SN accumulation curve was steeper compared to the LT glow-stick and the benthic SN produced a truncated curve similar in shape to the surface SN (Figure 29). However, none of these gears genera accumulation curves reached an asymptote, suggesting that more sampling effort would likely capture new icthyoplankton genera

Light traps equipped with glow-sticks captured 28 larvae in total (13.3% of all larvae captured) during 2014 and 2015 for a CPUE of 0.17±0.09 larvae/night (Table 29). The larval fish captured with glow-stick LTs represented 4 families and 7 genera (Table 29) with a catch rate of 0.06±0.02 genera per trap night. *Percina* spp. was captured by LT fitted with glow-sticks but not in any other gears (Table 29). The LT equipped with LEDs captured one larvae during this study (<0.0% of all larvae captured) for a CPUE of 0.02±0.02 larvae and genera per trap night (Table 29).

Benthic SN captured 43 larvae in total (20.2% of all larvae) during 2015 for a CPUE of 0.50±0.14 larvae per $100m^3$ of water (Table 29). Ichthyoplankton captured with the benthic SN represented 6 families, 8 genera (Table 29) with a CPUE of 0.34±0.08 genera per $100m^3$ of water. *Amia calva*, and *Scaphirhynchus* sp. were only captured by the benthic SN and not any other gears (Table 29). The surface SN captured 141 larvae

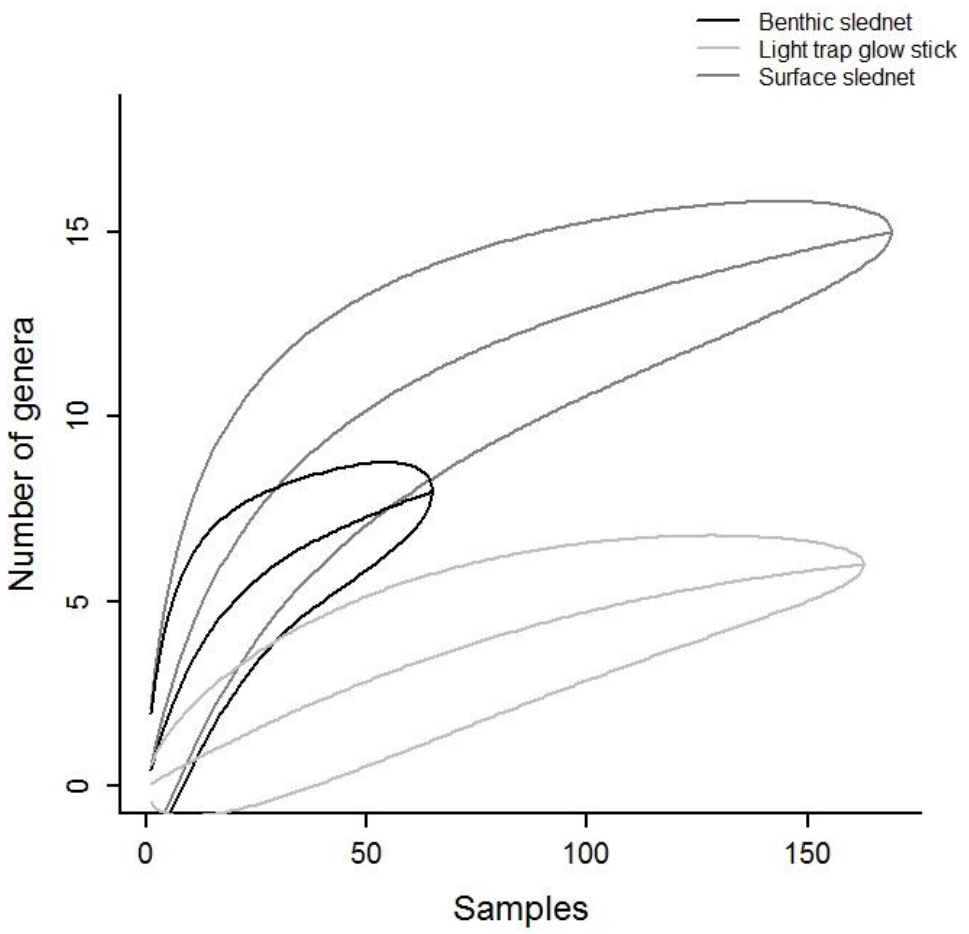

Figure 29. Genera accumulation curves for the benthic slednet, light trap glow-stick and surface slednet in the Minnesota River during 2014 to 2015 at the Franklin, Henderson, New Ulm and Savage sampling locations. The polygon surrounding each accumulation curve represents the confidence interval associated with that curve.

Table 29. Total number of larvae sampled and percent composition captured with light traps glow stick, light trap LED, benthic slednet and surface slednet samples in the Minnesota River during the 2014, and 2015 sampling seasons.

	Benthic		Glow stick		LED		Surface	
Taxon	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Acipenseridae								
Scaphirhynchus sp.	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Amiidae								
Amia calva	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Catostomidae								
Carpiodes spp.	7.0	3.4	1.0	0.5	0.0	0.0	33.0	16.1
Catostomus spp.	0.0	0.0	0.0	0.0	0.0	0.0	4.0	2.0
Ictioubus spp.	3.0	1.5	0.0	0.0	0.0	0.0	5.0	2.4
Moxostoma spp.	0.0	0.0	1.0	0.5	0.0	0.0	10.0	4.9
Centrarchidae								
Lepomis spp.	0.0	0.0	3.0	1.5	1.0	0.5	8.0	3.9
Pomoxis spp.	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.5
Clupeidae								
Dorosoma sp.	1.0	0.5	0.0	0.0	0.0	0.0	1.0	0.5
Cyprinidae								
Cyprinella sp.	3.0	1.5	17.0	8.3	0.0	0.0	22.0	10.7
Cyprinus sp.	2.0	1.0	0.0	0.0	0.0	0.0	6.0	2.9
Hybognathus sp.	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5
Notropis spp.	17.0	8.3	1.0	0.5	0.0	0.0	19.0	9.3
Pimephales spp.	5.0	2.4	0.0	0.0	0.0	0.0	20.0	9.8
Percidae								
Etheostoma spp.	1.0	0.5	2.0	1.0	0.0	0.0	1.0	0.5
Percina sp.	0.0	0.0	3.0	1.5	0.0	0.0	0.0	0.0
Sander sp.	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5
Sciaenidae								
Aplodinotus grunniens	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5

in total (66.2% of all larvae captured) during 2014 and 2015 for a CPUE of 0.33±0.04 larvae per 100m^3 of water. The Ichthyoplankton captured with the surface SN represented 6 families, 15 genera (Table 29) with a catch rate of 0.23±0.03 genera per 100m^3 of water. *Aplodinotus grunniens*, *Catostomus* spp., *Cyprinus* sp., *Hybognathus* sp., *Pomoxis* spp., and *Sander* spp. were only captured by the surface SN and not any other gears (Table 29).

Due to low catches, NMDS could only reach a convergent solution with an acceptable number of axes and stress level for the mean number of individual ichthyoplankton of each genera by gear type and sampling trip. A two-dimensional solution, demonstrating weak ties in ichthyoplankton taxonomic composition was produced (Figure 30). The LT glow-stick and LT LED differed among the first and second NMDS axes to all other gears (Figure 30). While the benthic SN and surface SN were on similar points of the first NMDS axis (Figure 30).

Based off each gears locations on the NMDS plot, the surface SN and benthic SN sampled relatively similar icthyoplankton communities, while the glow-stick and LED sampled relatively different icthyoplankton communities compared to the other gears used in this study. Keep in mind that a NMDS depicts the dissimilarity of samples with closer objects being more similar, or associated. It should be noted thought, that the LED only captured one larvae during this study. The ANOSIM also found significant

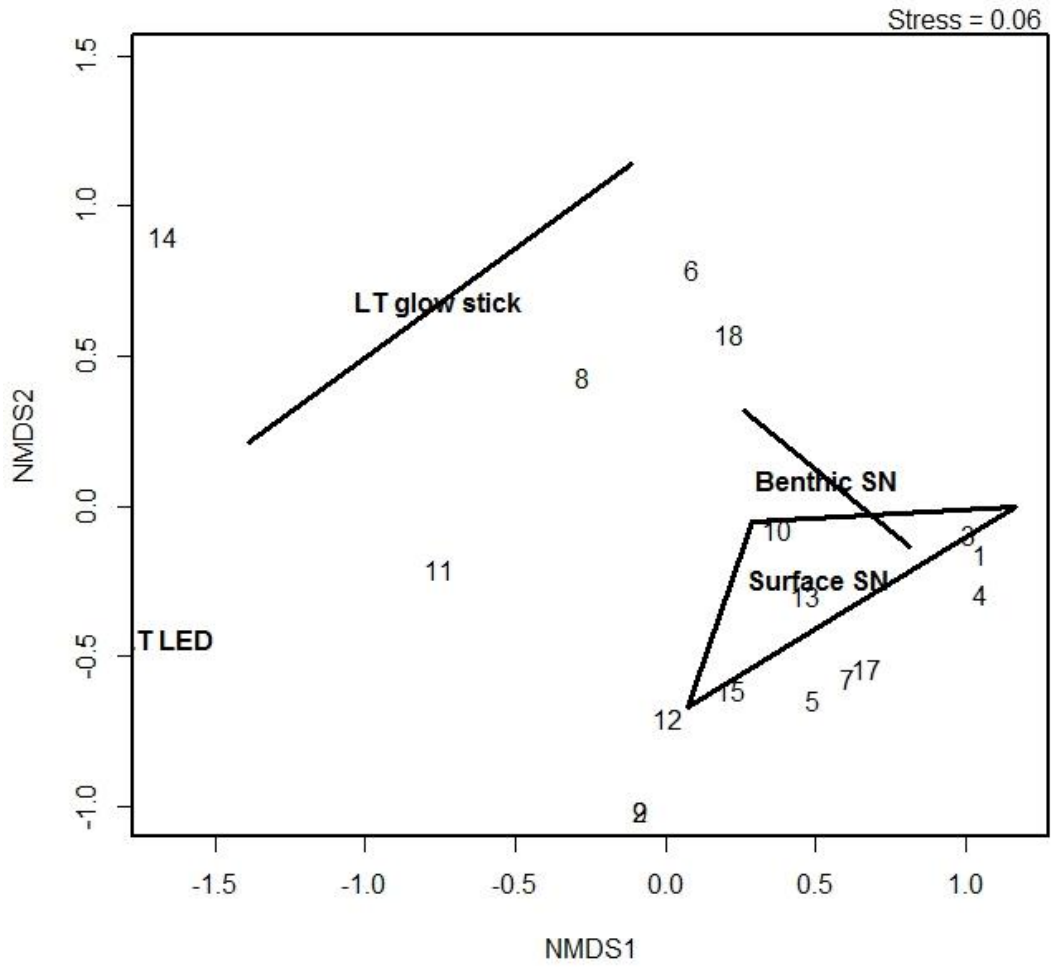

Figure 30. Non-metric multidimensional scaling of ichthyoplankton communities captured with benthic slednet, light trap glow stick, light trap LED, and surface slednet using mean number of larval per genera by sampling location (Franklin, Henderson, New Ulm, and Savage) and gear type during the 2014 and 2015 sampling season in the Minnesota River. Hulls around each gear type encircle all taxa captured with that gear in. The numbers represent genera with 1: *Amia calva*, 2: *Aplodinotus grunniens*, 3: *Carpiodes* spp., 4: *Catostomus* spp., 5: *Cyprinus* sp. 6: *Cyprinella* sp. 7: *Dorosoma* sp. 8: *Etheostoma* spp., 9: *Hybognathus* sp., 10: *Ictiobus* spp. 11: *Lepomis* spp., 12: *Moxostoma* spp. 13: *Notropis* spp., 14: *Percidae* sp. 15: *Pimephales* spp. 16: *Pomoxis* spp., 17: *Sander* sp., 18: *Scaphirhynchus* sp.

dissimilarities among larval composition based on the gears (ANOSIM: $R = 0.12$; $P = 0.04$).

Investigating genera more associated with each gear during this study using the NMDS, the surface SN was more associated with higher catch rates of Shiners *Notropis* spp., Redhorses *Moxostoma* spp., Carp *Cyprinus* sp., *Sander* spp., *Pimephales* spp. and Suckers *Catostomus* spp. (Figure 30). The benthic SN was more associated with higher catches of Buffalo *Ictiobus* spp. (Figure 30). Both the benthic SN and surface SN were associated with the Carpsucker *Carpiodes* spp. equally (Figure 30). *Cyprinella* sp., *Etheostoma* spp., and *Percina* sp. were more associated with the LT glow-stick. However, no taxa appeared to be more associated with LT LED (Figure 30). Additionally, no single gear seemed to be strongly associated with catches of *Lepomis* spp. (Figure 30).

Using Schoener's percentage overlap index, significant biological overlap (≥ 60%) in genera captured existed between benthic SN and surface SN (Table 30). Non-significant overlap was detected in the remaining gear comparison and no overlap existed between the LT LED and benthic SN (Table 30). Exploring the range of genera captured among gears utilizing niche widths, gears widths ranged from 1.00 to 7.32 with the LT LED being completely specialization (1.0) and surface SN capturing nearly half of the total genera captured (7.32;Table 30). Placing those values into a more biologically

Table 30. Niche width, breadth (Levin's index) and overlap (Schoener's index) in ichthyoplankton captures by the benthic slednet (SN), light trap (LT) glow-stick, LT LED and surface SN in the Minnesota River during 2014 and 2015.

Gear Type	**Niche width**	**Niche breadth**
LT Glow	2.65	0.09
LT LED	1.00	0.00
Benthic SN	4.63	0.20
Surface SN	7.32	0.35
Overlap Comparison		**Niche overlap index**
Benthic vs Surface		61.20
Benthic vs Glow stick		22.50
Benthic vs LED		0.00
Glow stick vs LED		10.30
Glow stick vs Surface		35.80
LED vs Surface		5.90

interpretable term, the LT LED's standardized breadth indice was 0 and the surface SN breadth score was 0.35 (Table 30).

Of the 17 families and 45 genera sampled with standardize electrofishing surveys of the Minnesota River, gears used in this study cumulatively captured 47% (8 of 17) of the families and 42% (19 of 45) genera. The benthic SN and surface SN captured the greatest percentage of families, capturing 35% (6 of 17), followed by the LT glow-stick, capturing 24% (4 of 17), and the LT LED, capturing only 5% (1 of 17). The surface SN also captured the greatest percentages of genera, capturing 33% (15 of 45), followed by the benthic SN, capturing 22% (10 of 45), the LT glow-stick, capturing 15% (7 of 45) and finally the LT LED, capturing 2% (1 of 45).

Quantitative

Among hydrologic periods and months, no significant differences existed for either LT light source in terms of number of ichthyoplankton or number of ichthyoplankton genera per trap night (Figure 31). Additionally, between LT light sources within each hydrologic period and month, no significant differences existed for number of ichthyoplankton or number of ichthyoplankton genera per trap night (Figure 31). No significant differences were detected among months for density of larvae or relative genus richness per $100m^3$ of water (Figure 32). Significant differences were, however, detected among hydrologic periods for the density of larvae within the benthic SN (Kruskal-Wallis: $H = 8.39$, df = 3, $P = 0.04$) and surface SN (Kruskal-Wallis: $H = 12.84$, df = 3, $P = 0.01$). The benthic SN Dunn's Test among hydrologic periods revealed no

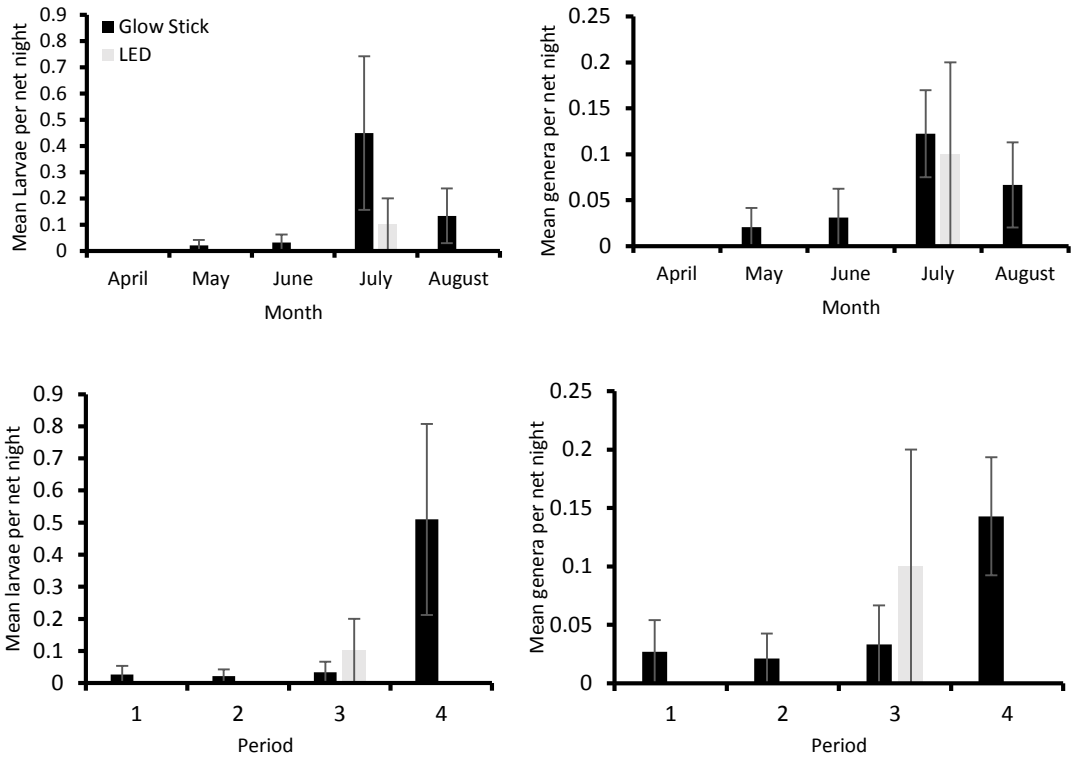

Figure 31. Mean number (number/trap night) of larvae and genera capture by the light trap glow stick and LED among months and hydrologic periods during the 2014 and 2015 sampling seasons on the Minnesota River. No significant differences were found between light source type with in periods and months or among periods and months within a light source.

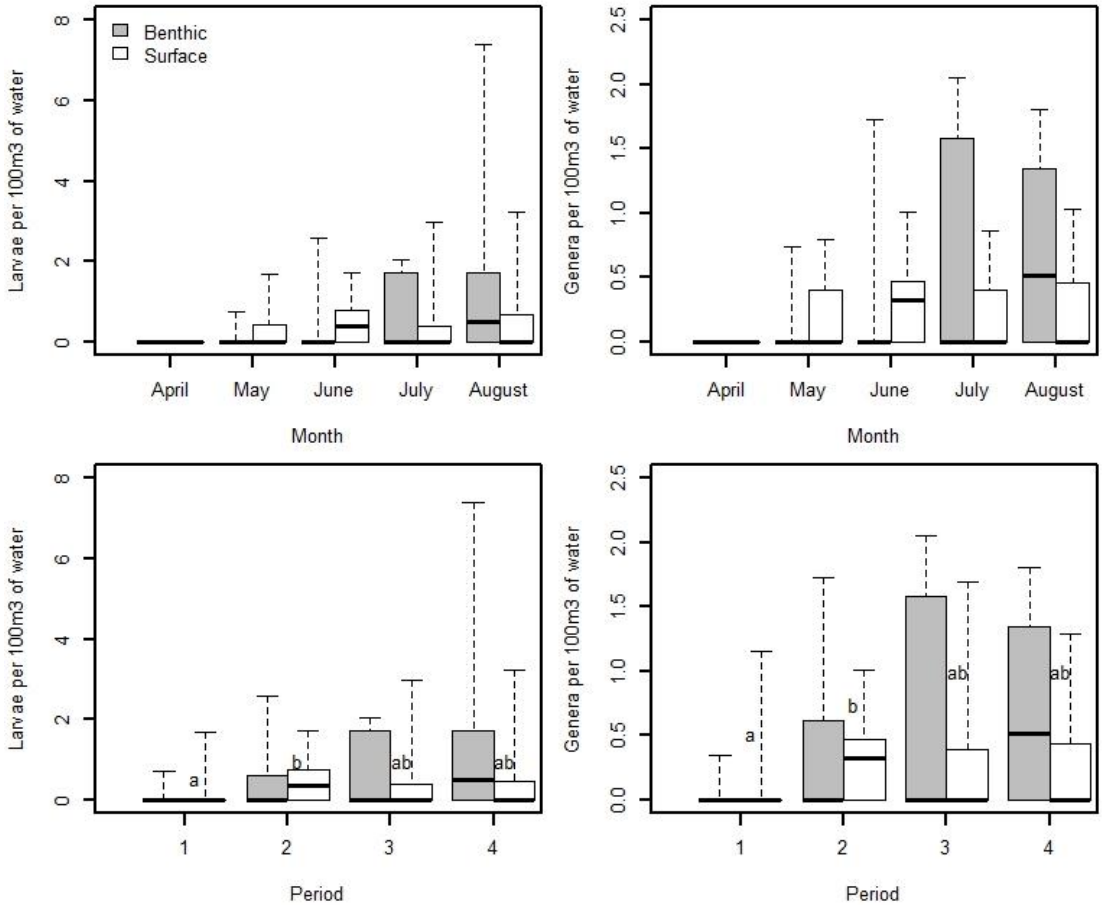

Figure 32. Density (number/100m^3) of larval fishes and genera among sampling months and hydrologic periods [first ascending limb (1), second ascending limb(2), major descending limb (3), steady state (4)] during the 2014 and 2015 sampling seasons on the Minnesota River with either the benthic or surface slednet. Whiskers extend to the extremes of the data and lines represent the median. Letters denote significant difference based on Kruskal-Wallis and Dunn's post-hoc test. No letter or the same letter signifies no significant difference among months and periods or between gear within one month and hydrologic period.

significant differences in the denstiy of larvae (Figure 32). However, the surface SN Dunn's Test among hydrologic periods indicated that period two captured signifcantly greater densities of larvae and genera compared to period one (Figure 32).

The LT LED had the highest overall CV (800) and the surface SN had the lowest CV (167; Table 31). Coefficient of variations were not significantly different for the number of larvae among months (ANOVA: $F = 2.94$; df = 4; $P = 0.06$) or periods (ANOVA: $F = 0.88$; df = 3; $P = 0.49$) within each gear. Additionally, CV for the number of genera captured were not significantly different among months (ANOVA: $F = 2.16$; df = 4; $P = 0.14$) or periods (ANOVA: $F = 1.49$; df = 3; $P = 0.28$) within each gear.

Significant differences did, however, exist among gears in the CV for the number of larvae captured (ANOVA: $F = 12.353$; df = 3; $P = <0.00$) and number of genera captured (ANOVA: $F = 8.268$; df = 3; $P = 0.01$) among gears among periods. A Tukey test revealed that the LT glow-stick (563±59) had a significantly greater CV for the number of larvae captured compared to the LT LED (79±79), benthic SN (216±58), and surface SN [(180±28); (Figure 33)]. A Tukey test also revealed the LT glow-stick (522±96) had a significantly higher CV for the number of genera captured compared to LT LED (79±79), benthic SN (203±63), and surface SN [(162±30; (Figure 33)].

Additionally, significant differences exist among gears among gears during months in the CV for the number of larvae captured (ANOVA: $F = 7.72$; df = 3; $P = <0.01$)

Table 31. Coefficient of variances for the number of larvae (number/trap night), density of larvae (number/100m^3 of water), number of genera (number/trap night) ;[italicized] and density of genera (number/100m^3 of water) ; [italicized] among months, hydrologic period [first ascending limb (1), second ascending limb(2), major descending limb (3), steady state (4)] and overall during the 2014 and 2015 sampling of the Minnesota River at four locations (Franklin, Henderson, New Ulm, Savage). A coefficient of variance of 0 means no larvae were captured during that month or period with that gear.

	Month				
Gear	**April**	**May**	**June**	**July**	**August**
LT Glow (Trap night)	0	693	566	457	429
	0	*693*	*566*	*270*	*381*
LT LED (Trap night)	0	0	0	316	0
	0	*0*	*0*	*316*	*0*
Benthic SN (100m^3 of water)	0	208	197	130	157
	0	*217*	*196*	*132*	*107*
Surface SN (100m^3 of water)	0	186	101	191	173
	0	*182*	*93*	*159*	*147*

	Period				
Gear	**1**	**2**	**3**	**4**	**Overall**
LT Glow (Trap night)	608	686	548	408	677
	608	*686*	*548*	*247*	*392*
LT LED (Trap night)	0	0	316	0	800
	0	*0*	*316*	*0*	*800*
Benthic SN (100m^3 of water)	387	193	130	1570	222
	387	*187*	*132*	*107*	*177*
Surface SN (100m^3 of water)	245	108	189	179	167
	246	*98*	*158*	*149*	*148*

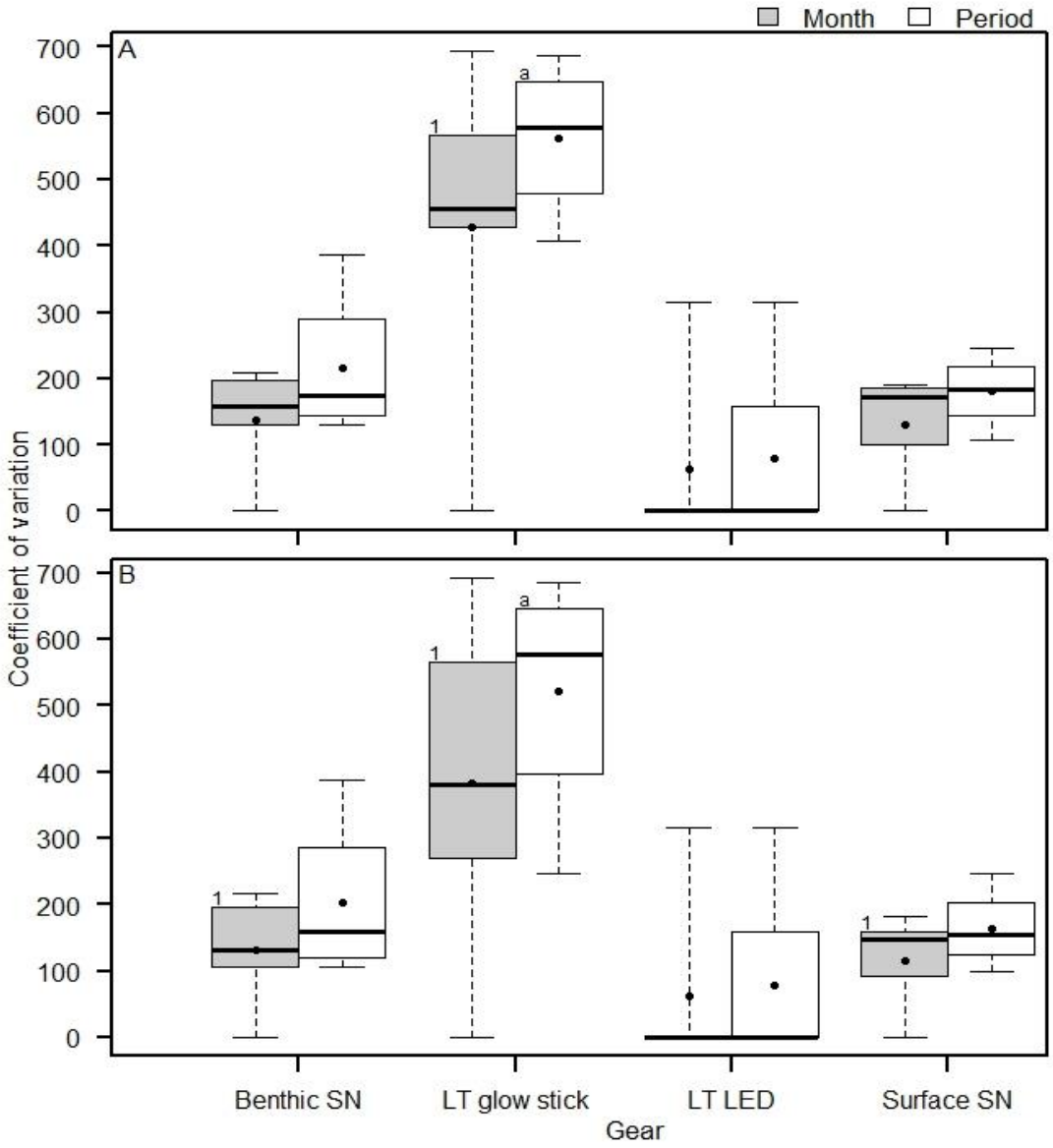

Figure 33. Coefficient of variations during 2014 and 2015 sampling of the Minnesota River cumulatively among all four locations (Franklin, Henderson, New Ulm, Savage) for **(A)** abundance and densities of larvae and **(B)** genera among months and periods within a single gear among periods [first ascending limb (1), second ascending limb(2), major descending limb (3), steady state (4)] and among months. Whiskers extend to the extremes of the data, lines represent the median, and dots represent the means of the data. Letters A-D signifies significant difference among gears for periods, same or no lowercase letter signifies no significant difference. Numbers 1-4 signifies significant difference among gears for months, same or no number signifies no significant difference.

and number of genera captured (ANOVA: $F = 4.98$; df = 3; $P = 0.02$). A Tukey test revealed that the LT glow-stick (563±59) had a significantly greater CV for the number of larvae captured among months compared to the LT LED (79±79), benthic SN (216±58), and surface SN (180±28) among periods (Figure 33). A Tukey test also revealed that the LT glow-stick (522±96) had a significantly greater CV for the number of genera capturedamong months compared to the LT LED (79±79), but not to the benthic SN (203±63) or the surface SN [(163±30); (Figure 33)].

Discussion

The four gears evaluated in this study, collectively captured a limited number of larvae. The results could be interpreted a couple of different ways, including 1) that the gears were ineffective at capturing ichthyoplankton or 2) icthyoplankton densities in the main channel of the Minnesota River were low during the sampling periods. Overall, ichthyoplankton abundance and genera richness increased from April into July, with the catch from surface SNs showing the highest taxonomic richness. The surface SNs also appeared to be the gear of choice by capturing the greatest number of larvae, the most number of unique genera, and having the lowest overall CV for the number of ichthyoplankton and genera captured.

The benthic SN also demonstrated potential, as it captured the second greatest number of larvae, genera, and unique genera. The LT with glow-stick light sources also captured some larvae, but did not appear to be effective in the prevailing conditions. The LT LED captured only a single ichthyoplankton, but also had the least amount of

effort. Overall, CV for both the number of larvae and number of genera captured were significantly lower in benthic SN and surface SN compared to the LT glow-stick. Low catch rates during this study with LTs may suggest that this is not an effective gear for sampling ichthyoplankton in flowing waters of a turbid river. The icthyoplankton gears should be further evaluated in a wider range of habitat types and conditions.

Temporally, benthic SN and surface SN captured more genera and individual larvae compared to both LT methods during the earlier months. However, during 2014, the LT glow-stick sets caught nearly as many individual larvae as the surface SN in July. During July, larvae from early spawning species would be more developed and mobile. Most larvae lose vulnerability to towed gears after they have grown large enough to actively avoid nets (Sammons and Bettoli 1998) and LTs tend to be more effective as icthyoplankton increase mobility, as is typically seen during late post-larvae and early juvenile larvae stages (D'Alessandro et al. 2007). Given the potential for active avoidance and phototaxic attractions, sampling with LTs in June, July, and August may benefit data collections by capturing those larvae not being sampled with a SN.

The SN gears captured larvae during all hydrologic periods, except the first ascending limb, however, no larvae were captured during this period in any of the gears. The LT methods captured the most icthyoplankton during period 4, the steady-flow stage. During stable and low flows, larvae would be more apt to have the ability to swim toward a light source. Whereas, in higher flows during periods two and three, it was

likely very difficult for icthyoplankton to actively swim to the LTs. Early stage icthyoplankton possess limited swimming capabilities. Lindquist and Shaw (2005) found increasing current speeds negatively affected LT catches of icthyoplankton and juvenile fishes. During high flows, icthyoplankton get caught up in the drift, and therefore would SN methods would likely be the better option.

The genera accumulation curves for icthyoplankton captured in LT equipped with glow-sticks had the shallowest curve, indicating that it captured the fewest genera and abundance was concentrated in few genera. The surface SN, however, had a steeper genera accumulation curve, indicating it sampled the greatest number of genera and the distribution was more even over a greater number of genera. The benthic SN had a steeper curve than the LT glow-stick but shallower than the surface SN, indicating that the benthic SN sampled more genera than the LT glow-stick but fewer than the surface SN. However, the distributions of individuals among the genera were similar between the surface and benthic SN.

Light traps are an increasingly utilized sampling tool along riverbanks (Niles and Hartman 2007). However, previous studies from different systems show conflicting results when comparing the number of individuals and genera capture between nets and LTs. Hickford and Schiel (1999) found that plankton nets captured more individual icthyoplankton and taxa compared to LT in inshore temperate waters. Whereas, Neal et al. (2012) found LTs captured more individual icthyoplankton and taxa compared to

plankton nets. This study did not support the Minnesota River research of Nickel (2014) who demonstrated that LTs captured more larvae, but the SN captured more genera in the Minnesota River. There are many factors that cause gear effectiveness to vary, and it appears to be system dependent. In this study, the SN methods captured a greater number of individuals and more taxa groupings. Using a SN method could allow one to get a better idea of the wider range of species of fish that are spawning, as it captures a greater number of genera, while LTs may be more effective at targeting specific taxa groups (e.g., *Percina* spp.) when the gear can be set in suitable flow conditions.

Icthyoplankton taxa composition captured among all gears was similar to a previous study from the Minnesota River and, representative of a large navigable and channelized rivers, such as the Kanawha, Ohio, and Missouri rivers. Nickel (2014) found *Percina* spp. and Spotfin Shiner *Cyprinella siploptera* to be captured more in the LT than the SN. Similar results were found in this study, suggesting that *Percina* spp. and Spotfin Shiner can be sampled more effectively with LTs compared to SN methods in riverine habitats. In contrast, Nickel (2014) and this study found that *Carpiodes* spp. were sampled more often with the SN than LT, meaning that if *Carpiodes* spp. were the target taxa, a SN method would be the better choice.

Although direct evidence is limited, the impacts of turbidity levels need to be considered when choosing an ichthyoplankton sampling method for a Midwestern river. During this study, light traps slowed water velocity, allowing sediment to drop out of

suspension, accumulating in the trap pans. High turbidity has been found to negatively affect LTs effective sampling radii (Lindquist and Shaw 2005). Prior research by Niles and Hartman (2007) reported being able to visually see larvae behavioral responses next to their LTs. Snyder and Meismer (1997) also reported being able to see the glow of their LTs from 15 m away with a glow-stick light source. We were unable to observe any light emitting from the light traps due to water clarity that was frequently <10 cm.

Increasing the brightness of a LT light source should increase the effective range and elicit greater phototactic response from ichthyoplankton and juvenile fishes. Bulkowski and Meade (1983) found that walleye larvae preferred the most intense light in LTs and increased the distance from which larvae could be attracted in a turbid system. However, during 2015 when LED light sources were used, fewer larvae were caught than in 2014 when only light sticks were used. Snyder and Meismer (1997) suggested that light intensities can be too bright as well, and actually repel larvae. Given the high turbidity in the Minnesota River that drastically reduces water clarity, light inhibition is much more likely to be the problem, which helps explain why LT glow-stick did not catch any larvae in 2015 as well.

Slednet methods were also affected by the turbidity, as high amounts of sand, sediment, and other detritus accumulated in the gear. As a towed net, such as the slednets use in this study, becomes inundated, the filtration rate slow because of a diminishing ratio between porosity and decreasing filtering area (Vannucci 1968). A

decreased filtering capacity would increase net avoidance and decrease larval catches (Iserman et al. 2002). Sampling with a SN, either as a function of distance (active gear movement) or set time (passive gear in the drift) will need additional consideration under highly turbid conditions. As turbidity levels increase, sampling designs may need to be adjusted to include shorter tow distances and reduced deployment times.

Coefficient of variation was high for all gears, but particularly LTs. Demonstrating the gear had limited precision and high variability among samples. Low CV and high catch rates are important characteristics to try and achieve when selecting an ichthyoplankton sampling gear (Rozas and Minello 1997); however, none of the gears evaluated in this study meet that criteria. Ichthyoplankton have a tendency to be spatially and temporally clustered (Kelso et al. 2012) and highly variable catches among replicate samples is common (Hilden and Urho 1988). The CV during this study was similar to what Niles and Hartman (2007) found in the Kanawha River when using LTs and a benthic SN and may not be as concerning as first thought.

Nevertheless, due to genera specialization of these gears, the variety of habitats present in a river, and the high CV, a multiple gear approach will be warranted in the Minnesota River. Multiple-gear approaches are commonly employed in sampling ichthyoplankton (Kwak and Peterson 2007) and this study lends further support to the approach. No single gear in this study demonstrated clear superiority to the others. Additionally, the niche breadth indicated that each gear was sampling relatively distinct

portions of the larval fish community, limited to only a few specific genera. Bonar et al. (2009) noted that gears have inherent biases and Poesch (2014) noted that using multiple gears can reduce overall variability introduced by using an individual gear.

Additional gears, speeds, and habitats should be considered for further evaluation. Structurally complex regions (e.g., finger dike and zipper dike) of the Kanawha River, provided conditions were LTs captured 9,221 larvae and benthic SNs 395 larvae (Niles and Hartman 2009). Reeves (2006) found larval fish densities were greatest near sandbar edges in the lower Missouri river. Therefore, targeting these structurally complex regions with different gears in a Midwestern river, such as log jams, riffle areas, and sandbars may provide better relative abundance, species composition, and even spatial-temporal data regarding ichthyoplankton communities.

Management implications

Ichthyoplankton sampling efforts within the Minnesota River and other turbid systems appear to need to be objective oriented due to low densities and high variability. If interested in determining when and where a specific genus is spawning, a thorough review of life history should be performed and sampling efforts should focus on those habitats initially with gears that can easily sample that habitat in hopes of limiting variability. For example, if researchers or managers were interested in understanding *Carpiodes* spp. or *Ictiobus* spp. ichthyoplankton densities within the Minnesota River in order to establish a commercial harvest quota, a sampling protocol using a surface and benthic SN method would provide a truer estimate compared with a

sampling protocol using LT methods. If however, researchers and managers are interested in understanding the entire ichthyoplankton community, such as studies looking at species distributions or community dynamics, a multiple gear approached is suggested utilizing SN and LT with glow-sticks methods as well as experimentation with other gears. Single gear approaches are particularly susceptible to erroneous results due to inherent biases (Jackson and Harvey 1997). That multiple gear approach needs to encompass a diverse range of habitats and span a broad time spectrum of which larvae will likely be present allowing managers and fisheries biologists to reduce biases and variability.

Additionally, alternative ichthyoplankton sampling gears and protocols should be explored for their use in a large, Midwestern river. A multitude of variables could have been the reasoning why such few larvae were captured with the gears during this study. However, testing additional ichthyoplankton sampling gears and sampling protocols should help determine if the low CPUEs were due to inefficiencies of the gears selected or indicative of low ichthyoplankton abundances, within the Minnesota River.

Chapter 3: Operational costs of Four Different Ichthyoplankton Sampling Gears for use in a Long-Term Minnesota River Monitoring Program

Abstract

Well-designed long-term monitoring programs provide critical data on the status, trends, or even evaluations of a system. However, most long-term monitoring programs can fail because conclusions are not ecologically relevant, do not secure statistically credible data, or fail to be cost effective. Therefore, cost of gear operations need to be consider. Here a benthic slednet, light trap with a glow-stick light source, light trap with a LED light source, and a surface slednet were evaluated for cost effectiveness in a long-term monitoring program that includes ichthyoplankton sampling. Initial gear investment, was greatest for the slednet method. However, little differences were found in the mean cost per sample among the four gears (<$1.00). Expenses did incur in different areas of the budget. Majority of expenses for the slednet methods came from labor in the laboratory, compared to light trap methods expenses coming from labor in the field. Economically, it appears that any method would be cost effective and pairing two or more together in a multiple gear approach would have little impact on total operations of the long-term monitoring program.

Introduction

Ecologists and natural resources managers have long acknowledged the importance of long-term monitoring data (Lindenmayer and Likens 2009). Well-designed long-term monitoring programs provide information, that can be been used to assess impacts of climate change, provide baseline descriptions, evaluate responses of a system to management interventions, or even help understand threats to biodiversity (Lindenmayer et al. 2012).

The success of a long-term monitoring program, however, depends on its ability to provide ecologically relevant conclusions and statistically credible data while being cost effective (Hinds 1984). Meaning, long-term benefits from data collected must justify the cost of the program (Caughlan and Oakley 2001). However, because we do not pay or trade most of the services provided by nature, putting an economic value to that data collected is difficult (Sukhdev 2011).

One can, however, evaluate the economic cost of running a long term-monitoring program and evaluate the statistical creditability of collected data. Particularly, in the early stages of development, by investigating cost effectiveness of each variable in a long-term monitoring program (Heathcote 2009). Within a long-term monitoring program, 60 to 69% of the whole budget is spent on data collection (Burk 2005).

Costs associated with data collection include the cost of and maintenance of sampling gears, labor expenses in operating those gears and any additional materials that are needed to collect and interpret that sample (Caughlan and Oakley 2001). A cost analysis between of those expenses gives decision-makers a way to compare program elements allowing for the minimization of dollar cost and maximized output level to a fixed budgetary constraint (Loomis and Walsh, 1997).

The MN DNR is in the process of developing a long-term monitoring program for the Minnesota River that includes standardized sampling for larval fish. Therefore, the cost effectiveness of gears used in sampling ichthyoplankton should be assessed. Ultimately, this cost effectiveness evaluation can be compared to opportunity costs allowing for the thorough evaluation of that portion of the monitoring program (Caughlan and Oakley 2001). The objective of this chapter was to assess, quantify, and describe the economic viability of a benthic SN, LT glow-stick, LT LED and surface SN per sample effort for use in a long-term monitoring program. It is hypothesized that the LT LED and LT glow-stick will cost more per sampling effort compared to the benthic and surface SN as two trips are required for each sample efforts.

Methods

To assess the economic viability of the gears in this study, the cost for one SN that could function as a surface SN or benthic SN and the cost of a single LT with either a glow-stick light source or LED light source were calculated. Additionally, the mean costs

per sample effort among gear types were determined. This will allow managers to understand initial cost required to implement these gears into and the costs of regular monitoring with those gears in a long-term monitoring program.

Totals from the manufactures costs of the custom ordered (WILDCO) net and all materials required to build the frame and the sounding weight system were determined. Initial cost of a LT was determined by totaling the cost of all materials required in constructing a LT. The cost of light sources of glow-stick and LED were also recorded. These totals are noted in the results, but not included in the determination of sampling effort costs, as cost will vary depending on the number of samples collected with each gear type. With the LED cost decreasing and the glow-stick increasing in total cost.

Sampling occurred approximately biweekly from 23 April 2015 to 11 August 2015, using a benthic SN, a LT with a glow-stick light source, a LT with a LED light source and a surface SN with in the Minnesota River. Benthic SN and surface SN samples were collected with only one outing. While LT samples were let set overnight requiring two outings. It was estimated that each outing took four hours to get to the sampling location, collect the samples, and arrive back to the MN DNR office. This was used in the determination of some of the labor expenses. Each outing also assumed the need for two employees for the operational safety in a riverine system.

To assess cost per sample, labor expense and operational expense were determined. Labor expense was the cost of personnel to collect, sort and identify larvae from samples. Operational expenses were expenses incurred to collect a sample excluding labor (i.e., fixative and preservative cost).

Labor expenses also included processing time per sample. Processing time was determined by noting the start and end time during sorting of a sample and calculating the number of minutes it took for processing of the 2015 samples. Mean sorting time per sample was than calculated by summing the total amount of time processing within each gear type and dividing it by the total number of samples for that gear.

Labor expenses assumed a technician cost of 19.47/h. This is the average between the minimum and maximum hourly wage from the State of Minnesota Salary Plan (State of Minnesota Salary Plan 2013). It was felt to be a good representative of the actual cost of a technician, as all technicians currently working would not be at the lowest or highest pay grade, but would be most likely the ones completing the majority of the efforts.

Additionally, the cost for expert identification was included in labor expenses. Identification of ichthyoplankton is notoriously difficult (Pritt et al. 2015) taking tremendous amount of time to understand how to identify solely off morphological characters. Therefore, it was felt that using the amount of time spent by a non-professional would be inappropriate, but some cost needed to be included in that

analysis. The cost of identification, assumed the cost of US$50/sample for identification (Thomas Simon, Indiana University, unpublished data). Thomas Simon is the expert ichthyoplankton identifier, used previously by the MN DNR (J. Waters Minnesota Department of Natural Resources, personal communication).

Operational costs of each gear included the mean cost of fixatives and preservative per sample for each gear. During sampling transfer from formalin to ethyl alcohol, the amount of formalin was measured to the nearest milliliter (ml). Formalin amount was measured with a 2,000 ml polypropylene graduated cylinder. Amount of perseverative was not recorded, but assumed identical to fixative amount. Mean ml of fixative and preservative used per sample were calculated by summing the amount of ml of fixative used within each gear type and dividing it by the total number of samples for that gear. That mean was than multiplied by the market cost of $1.08 and $3.25 for formalin and ethyl alcohol per liter respectively (March 2015) obtaining mean cost of fixative and preservative by gear. Total mean cost per sample unit was then determined by adding average labor expenses per sample and average operational expenses per sample.

Results

The production of a LT and a SN with the benthic and surface capabilities were $53.68 and $2,316.33, (Table 32) respectively. Light source costs for the LT were $0.35

Table 32. Cost of materials to make a construct a light trap that can use both a glow-stick or LED light source and a slednet that functions as both a surface and benthic trawl.(OD=outside diameter ID=inside diameter).

Gear/Material	Cost
Light Trap	
0.220 acrylic	$8.83
4" ODx3.75ID acrylic tube	$24.99
Collection pan w/mesh	$5.28
Nuts and bolts	$7.20
Cable	$1.21
Buoy	$4.99
Cinder block anchor	$1.18
Total	**$53.68**
Slednet	
Custom 500-µm net	$299.00
Dolphin adapter	$79.00
Dolphin bucket 1000ml	$119.00
Shipping	$49.70
PVC frame	$132.00
Sounding weight frame	$12.63
Sounding weights	$1,625.00
Total	**$2,316.33**

for a single use glow-stick and $24.99 for multiple use LED, that could be used 780 h continuously, without battery replacement.

Processing time of a sample was lower for the LT (19±1 minutes) compared to SN (77±3 minutes). Within each gear and its modifications the average minutes (mins) of time processing were similar (LT glow-stick 19±1 mins, LT LED 16±2 mins, SN Benthic 75±6 mins, SN surface 78±3 mins ;Figure 34). Average cost for processing a sample from a LT glow-stick ($6.17) and LT LED ($5.19) was lower than the benthic SN ($24.33) and surface SN ($25.31; Table 33). Estimated labor cost for sample collection was higher for the LT ($31.15) compared to the SN methods ($15.58).

The LT used less fixative per sample (328±8 ml) compared to the SN (997±41 ml). Within the LT, similar fixative volumes were used between the glow-stick (324±11ml) and LED (331±12 ml; Figure 35). While the surface SN used slightly more fixative per sample (1008±54 ml) compared to the benthic SN (985±62 ml; Figure 35). Average cost of $0.35 and $1.08 for fixative and $1.06 and $3.24 for preservative was lower for a LT sample compared to a SN sample respectively (Table 33). Light trap glow-stick and LT LED costs were the same for fixative ($0.35) and similar for preservative ($1.06 and $1.08; Table 13). The benthic SN and surface SN also had similar cost for fixative and preservative ($1.07 and $1.09 for fixative and $3.20 and $3.28 for preservative; Table 33).

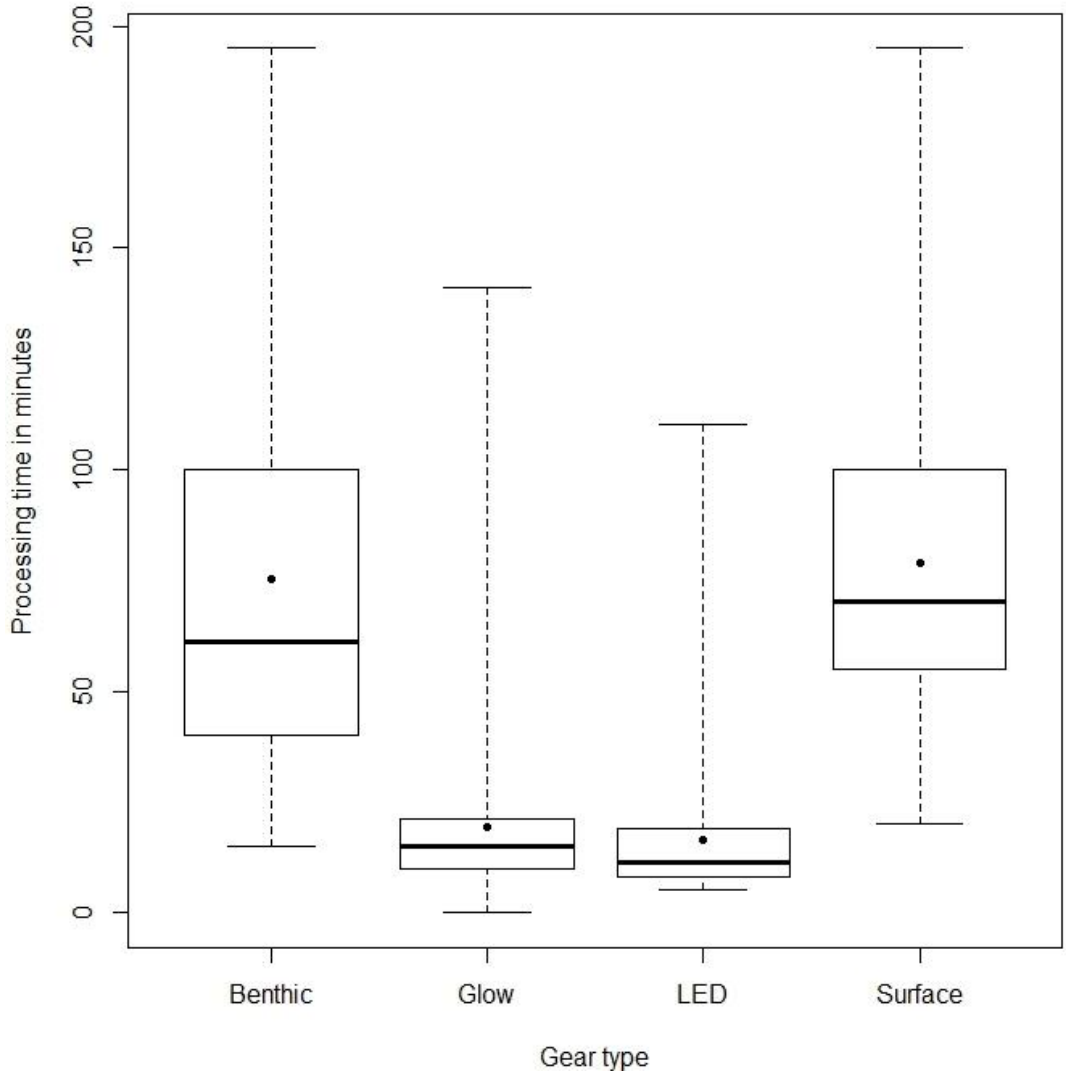

Figure 34. Processing time of a sample collected with a benthic slednet, light traps, glow-stick (Glow) and LED and the surface slednet in minutes during the 2015 sampling on the Minnesota. Whiskers extend to the extremes of the data, lines represent the median of the data and dots represent the means.

Table 33. Average cost of sample collection, processing, fixing, preserving, identification and total cost per sample among the benthic slednet (SN) light trap (LT) glow-stick, LT LED and surface SN used in the Minnesota River during the 2015 sampling season.

	Gear			
Cost expenditure	**Benthic SN**	**LT glow-stick**	**LT LED**	**Surface SN**
Collection	$15.58	$31.15	$31.15	$15.58
Processing	$24.33	$5.19	$6.17	$25.31
Fixative	$1.07	$0.35	$0.35	$1.09
Expert ID	$50.00	$50.00	$50.00	$50.00
Preservative	$3.20	$1.08	$1.06	$3.28
Total Cost	**$94.18**	**$87.77**	**$88.73**	**$95.26**

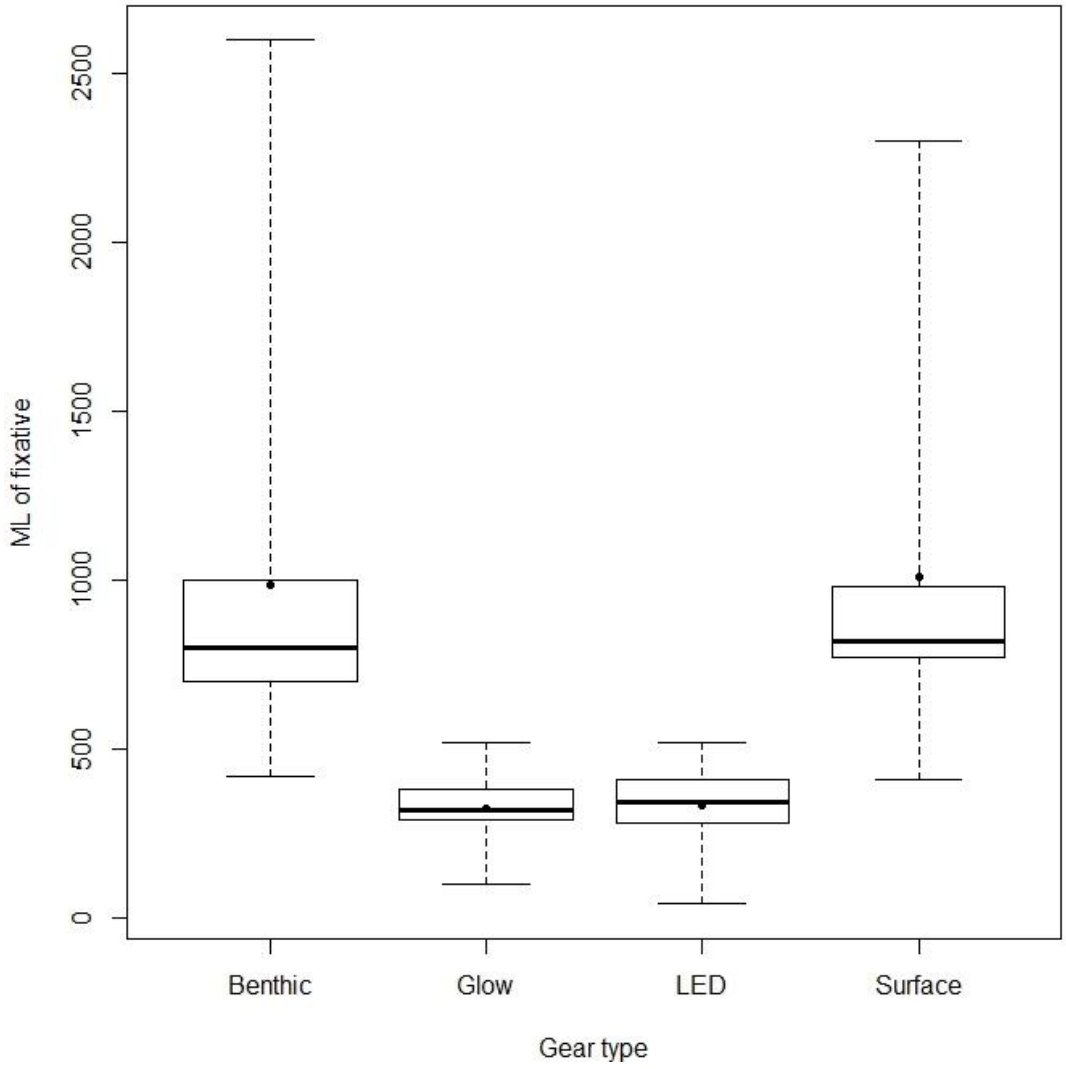

Figure 35. Milliliters of fixative used by the light trap glow stick (Glow), LED and the slednet surface and benthic ichthyoplankton sampling gear during the 2015 sampling on the Minnesota. Whiskers extend to the extremes of the ml used, lines represent the median of ml and the dots represent the means.

Average operational and labor expense per sample for the 2015 sampling season within the Minnesota River were similar. The LT average cost was $88.25 per sample, while the SN average cost was $94.72 per sample. Within a gear type (e.g., LT glow-stick and LT LED) very little difference existed (~$1.00; Table 33).

Discussion

Managing bodies of the natural resources have begun to support monitoring ichthyoplankton and provided new opportunities to obtain extensive data sets on this life stage. However, sampling ichthyoplankton is inherently difficult, time consuming and expensive (U.S. Fish and Wildlife Service 1992). The cost analyses in this study took data from one year of ichthyoplankton sampling of the Minnesota River, quantified initial investment and cost of operations of those gears to evaluate the cost effectiveness of four ichthyoplankton sampling gears.

If one were to start an ichthyoplankton monitoring program, initial investment of SN would be higher compared to a LT. However, rarely is a single LT deployed for use in a sampling design. Increasing the initial number of LTs to the number traps in this study (N=10), initial investment would have been $536.50. Additionally, modification could be made to the SN sounding weight system, reducing initial cost. The sounding weight system made up 70% of the total cost of the SN. Substitute sounding weights for more inexpensive weights, (i.e., downrigger weights) initial cost could be around $811.30. The weight system would than only make up 15% of the total cost of the net, reducing the

initial cost by 65%, and decrease initial difference between the two gears to $274. That is less than the labor expenses for collecting light trap samples.

However, initial startup cost, makes up a minor portion to monitoring and further considerations need to be taken. Sixty to seventy percent of a budget for a long term monitoring is spent on data collection (Burk 2005) placing more emphasis and importance on the operational cost of each gear during monitoring. Mean cost per sample differences among gear types were minimal (<10%). Nevertheless, on average, the surface SN cost most per sample, followed by the benthic SN, the LT glow-stick and the LT LED.

The majority (>50%) of the operational expense for all gears came from the cost of expert identification for all gears. Training individuals to become proficient at ichthyoplankton identification initially may be more costly than having an expert identify the samples. But, once proficient, should reduce the overall cost of the long-term monitoring program, by reducing total cost for identification.

Of the remaining costs, excluding cost of expert identification, expenses were inquired differently between the SN and LT. Light trap labor expenses for collecting a sample was double that of the SN. As in this study LT samples required two trips, were SN samples required only one. However, the SN labor processing a sample, fixing, and preserving a sample require nearly three times that of a LT sample.

Changing the sampling protocol, to limit LT sampling time to one day, allowing samples to be collected with a single trip, would minimize field labor cost for the LT inquired in the field making it more economical. However, this potentially could negatively affect an already low catch rate of larval fish. Additionally, shortening filtration time or tow distance of the SN would reduce the amount of water filtered and should theoretically reduce labor cost for processing sample and cost in fixing and preserving as less material would be sampled. However, again this could negatively affect catch rates of larvae. The reduced catch in larvae would decrease the ecological merit and statistical power of the data collected from those gears, increasing the likelihood that the monitoring may not meet its goals and objectives leading to failure.

With initial cost of gear making up a small portion of budget for a long term monitoring program and the similar operational costs among the gears during this study, it would appear negligible economic impacts over the life of a monitoring program would occur if one gear instead of the other were used. Schwanke and Hubert (2004) suggested that a combination of gears be utilized when creating a monitoring program. Hickford and Schiel (1999) made the recommendation for using LT and plankton nets when investigating the genera and density that were captured only. Economically, this appears to be a good pairing as well. As long as the same number of samples are collected whether one or multiple gears are used. The use of multiple gears has been found to remove some of the biases and overall variability (Poesch 2014)

creating a stronger and more ecologically relevant dataset. Multiple gears should provide managers a more ecologically relevant dataset that is statistically credible.

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Appendices

Appendix A. Mean crustaceous zooplankton (standard error in parentheses) community characteristics and abundances (number/liter) for taxa captured with the Wisconsin vertical trawl from the Minnesota River in 2014 and 2015 and among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)]. Reach type is noted in each table. Asterisk (*) indicated taxa present but sampled in mean densities <0.01 individuals per liter.

Impaired

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=100	n=140	n=30	n=40	n=20	n=30
Mean Total abundance	0.93(0.09)	0.24(0.04)	0.63(0.14)	0.23(0.04)	1.03(0.18)	0.47(0.06)
Mean total taxa richness	6.22(0.29)	2.63(0.22)	3.81(0.53)	3.50(0.34)	6.6(0.66)	3.73(0.33)
Bosmina. sp.	0.05(0.01)	0.01(0.01)	0.04(0.02)	0.02(0.01)	0.05(0.01)	0.03(0.01)
Calanoida	0.03(0.01)	0.01(0.01)	0.03(0.01)	0.01(0.01)	0.03(0.01)	0.00(0.00)*
Ceriodaphnia.sp.	0.03(0.02)	0.01(0.01)	0.06(0.03)	0.00(0.00)*	0.01(0.01)	0.01(0.01)
Chydoridae	0.03(0.01)	0.02(0.01)	0.03(0.01)	0.03(0.01)	0.03(0.01)	0.00(0.00)*
Cyclopoida	0.58(0.06)	0.05(0.01)	0.26(0.08)	0.08(0.02)	0.62(0.13)	0.31(0.06)
Daphnia spp.	0.06(0.01)	0.02(0.01)	0.08(0.02)	0.02(0.01)	0.04(0.01)	0.01(0.01)
Diaphanosoma.sp.	0.03(0.01)	0.00(0.00)*	0.03(0.01)	0.00(0.00)*	0.03(0.01)	0.00(0.00)*
Moina. sp.	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)*	0.00(0.00)
Copepoda nauplii	0.05(0.01)	0.04(0.01)	0.06(0.01)	0.04(0.02)	0.09(0.02)	0.02(0.01)
Ostracoda	0.05(0.01)	0.07(0.01)	0.05(0.01)	0.06(0.01)	0.11(0.02)	0.06(0.02)
Pontoporeia sp.	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Sida crystallina	0.00(0.00)*	0.00(0.00)*	0.00(0.00)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*
Simocephalus. sp.	0.02(0.01)	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.02(0.01)

Appendix A Continued.

Unassessed

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=100	n=140	n=30	n=40	n=20	n=30
Mean Total abundance	1.07(0.33)	0.27(0.03)	1.44(0.53)	0.29(0.03)	0.53(0.21)	0.26(0.05)
Mean total taxa richness	3.35(0.25)	2.71(0.19)	2.76(0.39)	2.98(0.21)	3.63(0.37)	2.76(0.30)
Bosmina sp.	0.05(0.02)	0.02(0.01)	0.07(0.03)	0.01(0.01)	0.01(0.01)	0.03(0.02)
Calanoida	0.04(0.01)	0.01(0.01)	0.05(0.02)	0.02(0.01)	0.02(0.01)	0.01(0.01)
Ceriodaphnia. sp.	0.01(0.01)	0.00(0.00)*	0.01(0.01)	0.00(0.00)*	0.01(0.01)	0.00(0.00)*
Chydoridae	0.02(0.01)	0.01(0.01)	0.00(0.00)*	0.01(0.01)	0.04(0.2)	0.02(0.01)
Cyclopoida	0.80(0.28)	0.07(0.02)	1.11(0.44)	0.13(0.03)	0.31(0.22)	0.04(0.01)
Daphnia spp.	0.01(0.01)	0.01(0.01)	0.01(0.01)	0.00(0.00)*	0.01(0.01)	0.00(0.00)*
Diaphanosoma sp.	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*	0.00(0.00)
Moina. sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Copepoda nauplii	0.09(0.03)	0.02(0.01)	0.09(0.04)	0.04(0.01)	0.02(0.02)	0.04(0.01)
Ostracoda	0.04(0.02)	0.14(0.02)	0.09(0.03)	0.08(0.01)	0.11(0.02)	0.12(0.03)
Pontoporeia sp.	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)*
Sida crystallina	0.01(0.01)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*	0.00(0.00)	0.00(0.00)*
Simocephalus sp.	0.00(0.00)*	0.00(0.00)*	0.00(0.00)	0.00(0.00)*	0.01(0.01)	0.00(0.00)*

Appendix B. Mean rotifer (standard error in parentheses) community characteristics and abundances for taxa captured (number/liter) with the Wisconsin vertical trawl from the Minnesota River in 2014 and 2015 and among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)]. Reach type is noted in each table. Asterisk (*) indicated taxa present but sampled in mean densities <0.01 individuals per liter

Impaired

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=100	n=140	n=30	n=40	n=20	n=30
Mean Total abundance	0.95(0.40)	0.20(0.03)	0.12(0.03)	0.08(0.02)	2.61(0.88)	0.07(0.02)
Mean total taxa richness	1.14(0.17)	2.55(0.23)	1.33(0.28)	1.98(0.31)	3.55(0.34)	1.4(0.21)
Anuraeopsis sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)
Ascomorpha sp.	0.76(0.33)	0.01(0.01)	0.03(0.01)	0.01(0.01)	2.02(0.76)	0.03(0.01)
Asplanchna sp.	0.00(0.00)	0.00(0.00)	0.04(0.02)	0.02(0.01)	0.07(0.03)	0.02(0.01)
Collotheca sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.01(0.01)	0.01(0.01)	0.00(0.00)*
Conochilus sp.	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.01(0.010	0.01(0.01)	0.00(0.00)*
Filinia sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)
Gastropus sp.	0.00(0.00)*	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.00(0.00)*
Hydra	0.00(0.00)*	0.01(0.01)	0.01(0.01)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*
Hydracarina	0.03(0.02)	0.00(0.00)*	0.01(0.01)	0.00(0.00)	0.05(0.04)	0.00(0.00)*
Keratella sp.	0.02(0.02)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*	0.05(0.05)	0.00(0.00)*
Lecane sp.	0.00(0.00)*	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)*
Monstyla sp.	0.11(0.06)	0.01(0.01)	0.01(0.01)	0.01(0.01)	0.27(0.14)	0.00(0.00)*
Notholca sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)*	0.00(0.00)*	0.01(0.01)	0.00(0.00)*
Synchaeta sp.	0.02(0.01)	0.00(0.00)*	0.00(0.00)	0.01(0.01)	0.05(0.04)	0.01(0.01)
Trichocerca sp.	0.02(0.02)	0.00(0.00)	0.01(0.01)	0.00(0.00)*	0.06(0.05)	0.00(0.00)*

Appendix B continued.

Unassessed

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=100	n=140	n=30	n=40	n=20	n=30
Mean Total abundance	0.08(0.04)	0.11(0.01)	0.08(0.05)	0.11(0.02)	0.08(0.02)	0.11(0.03)
Mean total taxa richness	0.96(0.16)	2.04(0.21)	0.59(0.14)	2.23(0.28)	1.84(0.41)	1.57(0.26)
Anuraeopsis sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Ascomorpha sp.	0.01(0.01)	0.07(0.02)	0.01(0.01)	0.02(0.01)	0.01(0.01)	0.03(0.01)
Asplanchna sp.	0.00(0.00)	0.06(0.01)	0.00(0.00)*	0.02(0.01)	0.01(0.01)	0.02(0.01)
Collotheca sp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*
Conochilus sp.	0.00(0.00)*	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.02(0.01)	0.01(0.01)
Filinia sp.	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Gastropus sp.	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.00(0.00)*	0.00(0.00)
Hydra	0.01(0.01)	0.00(0.00)*	0.00(0.00)*	0.02(0.01)	0.00(0.00)	0.00(0.00)*
Hydracarina	0.01(0.01)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)	0.01(0.01)	0.00(0.00)*
Keratella sp.	0.00(0.00)*	0.00(0.00)*	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)
Lecane sp.	0.04(0.03)	0.01(0.01)	0.06(0.06)	0.00(0.00)	0.01(0.01)	0.00(0.00)*
Monstyla sp.	0.01(0.01)	0.01(0.01)	0.00(0.00)*	0.01(0.01)	0.00(0.00)*	0.01(0.01)*
Notholca sp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)*	0.01(0.01)	0.00(0.00)
Synchaeta sp.	0.00(0.00)*	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.00(0.00)*	0.02(0.01)
Trichocerca sp.	0.00(0.00)*	0.01(0.01)	0.00(0.00)	0.00(0.00)*	0.00(0.00)*	0.00(0.00)*

Appendix C. Mean macroinvertebrate (standard error in parentheses) community characteristics and abundances for taxa captured from the Minnesota River in 2014 and 2015 and among hydrologic periods [first ascending limb (period one), second ascending limb (period two), major descending limb (period three), steady state (period four)]. Gear specification, and reach type are noted in each table. Asterisk (*) indicated taxa present but sampled in mean relative densities per $100m^3$ <0.01 individuals for the slednet or <0.01 individuals per trap night.

Slednet
Impaired

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=70	n=30	n=40	n=20	n=30
Mean total relative abundance	22.97(4.58)	27.19(4.19)	14.00(3.70)	45.17(6.77)	23.81(5.38)	5.54(1.31)
Total taxa richness	4.06(0.38)	4.75(0.322)	2.66(0.35)	5.65(0.45)	5.1(0.47)	3.85(0.47)
Amphipoda	0.09(0.03)	0.00(0.00)*	0.03(0.02)	0.00(0.00)	0.16(0.07)	0.03(0.02)
Apidae	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Arachnida	0.14(0.07)	0.20(0.07)	0.06(0.03)	0.40(0.14)	0.07(0.03)	0.06(0.03)
Coleoptera	0.26(0.09)	0.59(0.17)	0.08(0.03)	1.11(0.30)	0.28(0.12)	0.06(0.03)
Collembola	0.00(0.00)	0.12(0.04)	0.17(0.07)	0.09(0.05)	0.00(0.00)	0.00(0.00)
Diplopoda	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Diptera	7.78(1.52)	13.87(2.23)	9.28(2.39)	20.13(3.34)	9.81(2.60)	2.66(0.56)
Ephemeroptera	1.28(0.29)	2.09(0.33)	0.43(0.16)	2.92(0.53)	2.91(0.49)	0.76(0.23)
Entomobryomorpha	0.05(0.03)	0.00(0.00)	0.00(0.00)	0.05(0.03)	0.02(0.02)	0.00(0.00)
Formicidae	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.00(0.00)	0.01(0.01)	0.00(0.00)
Gastropoda	0.89(0.46)	5.82(1.13)	2.66(1.08)	8.68(1.76)	0.91(0.37)	0.22(0.12)
Hemiptera	10.05(2.61)	0.52(0.19)	0.15(0.15)	8.10(2.37)	9.56(4.78)	0.44(0.37)
Hirudinea	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Hydra	0.00(0.00)	0.05(0.03)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.08(0.08)
Hydracarina	1.88(0.47)	0.05(0.02)	0.08(0.03)	0.04(0.02)	3.75(0.97)	0.62(0.27)
Hymenoptera	0.03(0.02)	0.33(0.17)	0.02(0.02)	0.11(0.10)	0.30(0.19)	0.44(0.37)
Isopoda	0.00(0.00)	0.10(0.07)	0.00(0.00)	0.18(0.12)	0.00(0.00)	0.00(0.00)
Lepidoptera	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.00(0.00)
Megaloptera	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Nematomorpha	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.03(0.03)
Nemertea	0.00(0.00)	0.05(0.03)	0.00(0.00)	0.08(0.05)	0.00(0.00)	0.00(0.00)
Neuroptera	0.02(0.01)	0.00(0.00)	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.01(0.01)
Odonata	0.06(0.03)	0.05(0.03)	0.04(0.02)	0.12(0.05)	0.03(0.02)	0.01(0.01)
Oligochaeta	0.02(0.01)	0.62(0.24)	0.03(0.03)	1.02(0.40)	0.06(0.05)	0.04(0.02)
Plecoptera	0.05(0.02)	0.42(0.32)	0.77(0.73)	0.10(0.05)	0.15(0.07)	0.04(0.02)
Trichoptera	0.36(0.08)	2.29(0.45)	0.22(0.07)	1.95(0.51)	3.45(1.12)	0.83(0.24)

Appendix C Continued.

Slednet
Unassessed

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=65	n=15	n=40	n=20	n=30
Mean total relative abundance	14.06(6.94)	30.30(4.81)	12.81(3.41)	19.38(5.22)	48.75(13.64)	10.27(1.24)
Total taxa richness	2.98(0.40)	5.66(0.29)	3.16(0.59)	3.63(0.51)	6.77(0.47)	4.20(0.32)
Amphipoda	0.03(0.03)	0.27(0.15)	0.06(0.03)	0.40(0.23)	0.07(0.07)	0.02(0.02)
Apidae	0.00(0.00)	0.01(0.01)	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Arachnida	0.14(0.07)	0.52(0.17)	0.23(0.09)	0.57(0.27)	0.17(0.06)	0.30(0.14)
Coleoptera	0.28(0.17)	0.54(0.16)	0.65(0.33)	0.33(0.14)	0.82(0.43)	0.09(0.05)
Collembola	0.00(0.00)	0.56(0.21)	0.00(0.00)	0.23(0.10)	0.97(0.62)	0.27(0.14)
Diplopoda	0.00(0.00)	0.02(0.01)	0.00(0.00)	0.00(0.00)	0.04(0.04)	0.01(0.01)
Diptera	8.54(4.94)	17.49(3.65)	7.38(1.54)	12.82(2.58)	33.96(15.73)	6.24(1.01)
Ephemeroptera	2.23(0.70)	1.71(0.31)	0.52(0.03)	1.27(0.28)	5.83(1.62)	1.40(0.21)
Entomobryomorpha	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.03(0.03)	0.00(0.00)
Formicidae	0.00(0.00)	0.03(0.03)	0.00(0.00)	0.00(0.00)	0.09(0.09)	0.00(0.00)
Gastropoda	0.46(0.24)	5.16(1.32)	2.66(1.40)	6.26(1.96)	1.94(0.58)	0.09(0.05)
Hemiptera	0.93(0.58)	0.53(0.14)	0.27(0.13)	0.49(0.21)	2.30(1.41)	0.28(0.08)
Hirudinea	0.00(0.00)	0.03(0.02)	0.00(0.00)	0.04(0.02)	0.00(0.00)	0.00(0.00)
Hydra	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Hydracarina	0.13(0.04)	0.09(0.03)	0.10(0.05)	0.05(0.03)	0.27(0.08)	0.08(0.04)
Hymenoptera	0.03(0.03)	0.62(0.36)	0.00(0.00)	0.45(0.20)	1.13(1.11)	0.04(0.03)
Isopoda	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.04(0.04)	0.00(0.00)
Lepidoptera	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.02(0.02)	0.00(0.00)
Megaloptera	0.05(0.05)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.14(0.14)	0.00(0.00)
Nematomorpha	0.00(0.00)	0.03(0.01)	0.00(0.00)	0.02(0.02)	0.04(0.04)	0.00(0.00)
Nemertea	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Neuroptera	0.04(0.03)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.09(0.07)	0.00(0.00)
Odonata	0.02(0.01)	0.10(0.04)	0.10(0.05)	0.04(0.04)	0.10(0.07)	0.04(0.03)
Oligochaeta	0.02(0.01)	0.38(0.15)	0.14(0.07)	0.34(0.14)	0.43(0.38)	0.00(0.00)
Plecoptera	0.09(0.06)	0.10(0.04)	0.08(0.08)	0.08(0.04)	0.06(0.05)	0.16(0.10)
Trichoptera	1.05(0.27)	2.10(0.43)	0.59(0.22)	1.94(0.60)	2.98(0.88)	1.24(0.17)

Appendix C Continued.

Light trap
Impaired

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=65	n=26	n=36	n=20	n=30
Total abundance	16.18(2.84)	11.24(4.38)	5.04(0.99)	17.11(7.26)	18(3.61)	3.30(0.79)
Total taxa richness	2.6(0.22)	2.09(0.15)	1.92(0.25)	2.38(0.24)	2.7(0.22)	1.6(0.27)
Amphipoda	0.12(0.05)	0.05(0.04)	0.00(0.00)	0.05(0.04)	0.18(0.08)	0.00(0.00)
Arachnida	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.03(0.03)	0.00(0.00)	0.00(0.00)
Coleoptera	0.02(0.02)	0.11(0.06)	0.08(0.08)	0.16(0.08)	0.00(0.00)	0.00(0.00)
Diptera	2.88(0.78)	3.46(0.76)	4.42(0.56)	5.16(1.09)	2.63(1.05)	0.30(0.21)
Ephemeroptera	3.38(0.63)	5.76(4.26)	0.58(0.26)	10.49(7.22)	2.95(0.74)	1.10(0.31)
Entomobryomorpha	0.00(0.00)	0.17(0.09)	0.42(0.22)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Gastropoda	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.03(0.03)	0.00(0.00)	0.00(0.00)
Hemiptera	0.16(0.08)	0.16(0.07)	0.15(0.11)	0.03(0.03)	0.33(0.12)	0.00(0.00)
Hydracarina	0.06(0.03)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.08(0.04)	0.00(0.00)
Hymenoptera	0.02(0.02)	0.00(0.00)	0.04(0.04)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Nemertea	0.06(0.03)	0.00(0.00)	0.04(0.04)	0.03(0.03)	0.03(0.03)	0.00(0.00)
Odonata	0.06(0.03)	0.02(0.02)	0.04(0.04)	0.03(0.03)	0.05(0.03)	0.00(0.00)
Oligochaeta	0.1(0.06)	0.02(0.02)	0.08(0.08)	0.08(0.06)	0.03(0.03)	0.00(0.00)
Plecoptera	0.02(0.02)	0.11(0.04)	0.15(0.07)	0.05(0.04)	0.03(0.03)	0.10(0.10)
Trichoptera	9.3(2.46)	1.35(0.26)	1.04(0.39)	0.97(0.32)	11.73(2.95)	1.80(0.68)

Appendix C Continued.

Light trap
Unassessed

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=66	n=27	n=39	n=20	n=29
Total abundance	14.06(6.94)	11.25(1.79)	6.37(1.30)	11.73(2.82)	8.85(1.69)	7.41(1.56)
Total taxa richness	1.82(0.17)	2.63(0.14)	1.74(0.26)	2.58(0.20)	2.6(0.23)	3.57(0.24)
Amphipoda	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Arachnida	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Coleoptera	0.06(0.05)	0.15(0.05)	0.07(0.05)	0.18(0.07)	0.10(0.07)	0.07(0.07)
Diptera	0.92(0.29)	3.18(0.62)	2.30(0.65)	3.90(0.97)	0.90(0.31)	0.79(0.19)
Ephemeroptera	2.04(0.37)	5.25(1.74)	0.44(0.19)	6.13(2.73)	3.65(0.70)	4.21(1.45)
Entomobryomorpha	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Gastropoda	0.00(0.00)	0.03(0.02)	0.00(0.00)	0.00(0.00)	0.10(0.07)	0.00(0.00)
Hemiptera	0.08(0.04)	0.06(0.040	0.00(0.00)	0.10(0.06)	0.10(0.07)	0.07(0.05)
Hydracarina	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Hymenoptera	0.06(0.03)	0.00(0.00)	0.00(0.00)	0.05(0.03)	0.05(0.05)	0.00(0.00)
Nemertea	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Odonata	0.06(0.03)	0.04(0.03)	0.00(0.00)	0.03(0.03)	0.15(0.08)	0.00(0.00)
Oligochaeta	0.00(0.00)	0.03(0.02)	0.04(0.04)	0.00(0.00)	0.05(0.05)	0.07(0.05)
Plecoptera	0.06(0.03)	0.22(0.08)	0.48(0.20)	0.10(0.05)	0.00(0.00)	0.03(0.03)
Trichoptera	2.41(0.63)	2.28(0.42)	3.07(0.97)	1.25(0.25)	3.75(1.22)	2.17(0.59)

Appendix D. Mean ichthyoplankton (standard error in parentheses) community characteristics and abundances for taxa captured from the Minnesota River in 2014 and 2015. Gear specification, and reach type are noted in each table. Asterisk (*) indicated taxa present but sampled in mean densities <0.01 individuals per liter.

Slednet

Impaired

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=70	n=30	n=40	n=20	n=30
Mean relative abundance	0.32(0.06)	0.39(0.12)	0.20(0.08)	0.35(0.07)	0.34(0.12)	0.55(0.27)
Total taxa richness	0.58(0.10)	0.49(0.09)	0.30(0.11)	0.60(0.11)	0.75(0.19)	0.50(0.15)
Amia calva	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Aplodinotus sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Carpiodes spp.	0.16(0.05)	0.04(0.02)	0.14(0.06)	0.11(0.04)	0.09(0.04)	0.02(0.02)
Catostomus sp.	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.03(0.02)	0.00(0.00)	0.00(0.00)
Cyprinella sp.	0.01(0.01)	0.10(0.10)	0.00(0.00)	0.02(0.01)	0.04(0.02)	0.24(0.22)
Cyprinus sp.	0.03(0.01)	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Dorosoma sp.	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.02(0.02)	0.00(0.00)
Etheostoma spp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.02(0.02)
Hybognathus sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Ictiobus spp.	0.00(0.00)	0.05(0.02)	0.00(0.00)	0.07(0.03)	0.04(0.03)	0.00(0.00)
Lepomis spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Moxostoma spp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Notropis spp.	0.04(0.02)	0.11(0.05)	0.04(0.03)	0.06(0.03)	0.11(0.07)	0.15(0.09)
Percina spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Pimephales spp.	0.02(0.01)	0.04(0.02)	0.00(0.00)	0.00(0.00)	0.03(0.03)	0.09(0.04)
Pomoxis spp.	0.03(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.02(0.02)	0.03(0.03)
Sander sp.	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Scaphirhynchus sp.	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.04(0.04)	0.00(0.00)	0.00(0.00)

Appendix D Continued.

Slednet

Unassessed

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=65	n=30	n=40	n=20	n=30
Total mean relative abundance	0.39(0.12)	0.49(0.10)	0.03(0.03)	0.43(0.10)	0.78(0.26)	0.49(0.12)
Total taxa richness	0.36(0.08)	0.63(0.12)	0.08(0.08)	0.53(0.10)	0.90(0.32)	0.60(0.12)
Amia calva	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.05(0.05)	0.00(0.00)
Aplodinotus sp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.02(0.02)	0.00(0.00)
Carpiodes spp.	0.07(0.04)	0.08(0.04)	0.00(0.00)	0.21(0.09)	0.04(0.04)	0.00(0.00)
Catostomus sp.	0.00(0.00)	0.00(0.00)*	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Cyprinella sp.	0.05(0.03)	0.05(0.03)	0.00(0.00)	0.01(0.01)	0.02(0.02)	0.14(0.05)
Cyprinus sp.	0.00(0.00)	0.02(0.01)	0.02(0.02)	0.03(0.03)	0.02(0.02)	0.00(0.00)
Dorosoma sp.	0.00(0.00)	0.01(0.01)	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Etheostoma spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Hybognathus sp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Ictiobus spp.	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.01(0.01)	0.00(0.00)	0.00(0.00)
Lepomis spp.	0.06(0.03)	0.01(0.01)	0.00(0.00)	0.00(0.00)	0.04(0.03)	0.11(0.05)
Moxostoma spp.	0.01(0.01)	0.04(0.02)	0.00(0.00)	0.07(0.03)	0.00(0.00)	0.00(0.00)
Notropis spp.	0.09(0.07)	0.12(0.04)	0.00(0.00)	0.02(0.01)	0.44(0.20)	0.09(0.06)
Percina spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Pimephales spp.	0.04(0.03)	0.11(0.04)	0.00(0.00)	0.00(0.00)	0.15(0.07)	0.15(0.07)
Pomoxis spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.05(0.03)	0.00(0.00)	0.00(0.00)
Sander sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Scaphirhynchus sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)

Appendix D Continued.

Light Trap

Impaired

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=65	n=26	n=36	n=20	n=30
Mean abundance	0.44(0.29)	0.02(0.02)	0.04(0.04)	0.03(0.03)	0.05(0.05)	0.66(0.47)
Total taxa richness	0.14(0.05)	0.02(0.02)	0.03(0.03)	0.03(0.03)	0.05(0.05)	0.16(0.07)
Cyprinellus sp.	0.36(0.29)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.60(0.47)
Etheostoma spp.	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.03(0.03)
Ictiobus spp.	0.02(0.02)	0.00(0.00)	0.04(0.04)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Lepomis spp.	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.05(0.05)	0.00(0.00)
Moxostoma spp.	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.03(0.03)	0.00(0.00)	0.00(0.00)
Percina spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.03(0.03)

Appendix D Continued.

Light Trap

Unassessed

	Year		Survey Period			
	2014	2015	1	2	3	4
Variable/Taxon	n=50	n=66	n=27	n=39	n=20	n=29
Mean abundance	0.12(0.08)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.05(0.05)	0.17(0.12)
Total taxa richness	0.06(0.03)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.05(0.05)	0.07(0.05)
Cyprinellus sp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Etheostoma spp.	0.02(0.02)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.05(0.05)	0.00(0.00)
Ictioubus spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Lepomis spp.	0.06(0.06)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.10(0.10)
Moxostoma spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Percina spp.	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.07(0.07)