

LARGE RIVER FISH COMMUNITY SAMPLING STRATEGIES AND FISH  
ASSOCIATIONS TO ENGINEERED AND NATURAL RIVER CHANNEL STRUCTURES

by

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## Abstract

I evaluated sampling strategies and the effects of dike structure modifications in the lower Missouri River to better develop sampling and mitigation strategies to protect and enhance native river fishes. Sampling occurred in the lower 1,212 km of the Missouri River during October-June (coldwater season) and June-October (warmwater season) with stationary gill nets (GN), drifted trammel nets (TN), towed otter trawls (OT), and mini fyke nets (MF) from 2003-2006. We compared probabilities of detection ( $p$ ), variability (coefficient of variation; CV) in catch per unit effort, and lengths for 25 species. Over 80% of adult large-bodied fishes were collected in GN during coldwater, >90% of chub spp. (*Macrhybopsis*) were collected in OT, and >90% of nine small-bodied and juvenile fishes were collected in MF. Trammel nets never had the highest  $p$  during coldwater, but had the highest or equally high  $p$  for 85% of adult large-bodied fishes during warmwater. Mean CV was lowest with GN for adult large-bodied fishes; chub spp. had the lowest CV in OT. Mean lengths were typically greater in GN and TN. Large river monitoring programs might best achieve the highest  $p$ , lowest variability, and widest size range of fishes by employing GN and OT during coldwater and TN, OT, and MF during warmwater sampling periods. We also compared fish community composition and the probability an un-notched and notched dike structure and channel sand bar (referred to as channel structures) was occupied by various fish species. Few differences in species richness and diversity were evident among channel structures. Notching a dike structure had no effect on proportional abundance for any habitat guild. Catch per unit effort (CPUE) was greater at notched dikes for only three (lake sturgeon *Acipenser fulvescens*, paddlefish *Polyodon spathula*, and shovelnose sturgeon *Scaphirhynchus platorynchus*) of 12 great river species. Occupancy at notched dikes increased for blue catfish *Ictalurus furcatus* and decreased for blue sucker

*Cycleptus elongatus*, but did not differ for 17 (81%) other species. No distinct increase in occupancy at natural channel sand bars compared to engineered dike structures was evident. Mean CPUE was higher in dike structures than channel sand bars for four great river species (goldeye *Hiodon alosoides*, lake sturgeon, paddlefish, and shortnose gar *Lepisosteus platostomus*), but did not differ for ten. Our results suggest dike structures may provide necessary habitats for many fluvial species when compared to channel sand bars, but notching did not increase abundance or occupancy of most native Missouri River fishes.

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## **Preface**

This thesis is my own personal work, but was written in third person and formatted for submission to the peer-reviewed journals *Canadian Journal of Fisheries and Aquatic Sciences* (Chapter 1) and *Transactions of the American Fisheries Society* (Chapter 2).

# CHAPTER 1

## **Detectability and sampling variability in four gears used to collect fishes in the Missouri River: implications for large river monitoring programs**

### **ABSTRACT**

We compared probabilities of detection ( $p$ ), variability (coefficient of variation; CV) in catch per unit effort, and lengths for 25 species collected with stationary gill nets (GN), drifted trammel nets (TN), otter trawls (OT), and mini-fyke nets (MF) during October-June (coldwater) and July-October (warmwater) in the Missouri River to refine large river sampling protocols. Over 80% of adult large-bodied fishes were collected in GN during coldwater, >90% of chub spp. (*Macrhybopsis*) were collected in OT, and >90% of nine small-bodied and juvenile fishes were collected in MF. Trammel nets never had the highest  $p$  during coldwater, but had the highest or equally high  $p$  for 85% of adult large-bodied fishes during warmwater. Mean CV was lowest with GN for adult large-bodied fishes; chub spp. had the lowest CV in OT. Mean lengths were typically greater in GN and TN. Large river monitoring programs might best achieve the highest  $p$ , lowest variability, and widest size range of fishes by employing GN and OT during coldwater and TN, OT, and MF during warmwater sampling periods.

## INTRODUCTION

Large-scale monitoring programs are commonly employed to determine the status or trends in abundance of populations or communities (Yoccoz et al. 2001). However, monitoring programs often may not be able to achieve these objectives due to inadequate sampling design, methods, or unachievable sample size requirements (Lubinski et al. 2001; Paukert 2004; Doyle et al. *In press*). If substantial funding and effort is directed towards sampling and data collection, it is critical to use the most appropriate methods that allow for efficient sampling and robust statistical inferences for the species of interest (MacKenzie et al. 2006).

Appropriate gear selection is a fundamental element for an effective monitoring program because of inherent bias towards species, size of fish, and even gear efficiency in different habitats (Quist et al. 2006). Sampling with gears that have lower species detection probabilities may result in misallocation of effort, and ultimately lead to inadequate statistical inference for hypotheses developed from monitoring programs (Paukert 2004; Noble et al. 2007).

Additionally, sampling methods need to be robust to sample a variety of habitats and conditions. Accounting for the variability in capture of fishes by gear type, habitat, season, and other factors, is often ineffectively accounted for in long term monitoring programs (Yoccoz et al. 2001). However, addressing these variables can lead to more precise and efficient evaluations of ecological observations (Ickes and Burkhardt 2002).

Minimizing variability in sampling indices is a critical component to an effective monitoring program. Consistency within sampling procedures, gear type, habitat deployment and sampling conditions can help minimize the spatial and temporal variation in sampling indices (Peterson and Rabeni 1995; Noble et al. 2007). Standardizing methods to minimize the sample variation is a critical link for detecting temporal and spatial trends in abundance using

catch per unit effort (CPUE) indices (Casselman et al. 1990; Willis and Murphy 1996; Hubert and Fabrizio 2007).

Monitoring programs on large rivers often rely on CPUE indices, which assume a proportional relationship between the number of fish caught and density (Ricker 1975). However, use of CPUE indices requires consistent sampling techniques, which may be difficult to achieve in large rivers because of unsafe sampling conditions, continuously changing environmental conditions, and the large spatial extent of rivers (Sheehan and Rasmussen 1999; Lapointe et al. 2006). Variability in sampling can be amplified by various biotic and abiotic factors (e.g., fish resource use, movement, river stage fluctuations), which may limit the utility of CPUE. To capture the full range of biotic and abiotic factors that contribute to diverse fish communities in large rivers, sampling should occur with a variety of gear types (Casselman et al. 1990; Lapointe et al. 2006). However, the use of multiple gear types may make it difficult to assess population status or trends in abundance due to differences in size-related vulnerability and bias with each gear (Beamesderfer and Rieman 1988).

Monitoring programs on the Missouri River USA use seven different gears to sample the fish community to determine long-term trends in abundance of native river fishes and how these trends relate to management actions (Quist et al. 2004). Because of the variable conditions of the Missouri River and low catches of rare and endangered species, detecting trends in abundance or responses to management actions is limited by low statistical power (Sustainable Ecosystems Institute 2004). Operating under an adaptive management framework, review of the sampling methods is important to ensure the program's goals and objectives can be met. Refinements to sampling protocols can then be made as the sampling program develops and new information becomes available (Lubinski et al. 2001; Ickes and Burkhardt 2002). Therefore, the objective of

this study was to determine the probabilities of detection, sampling variability, and length distributions of each fish species caught in gill nets, trammel nets, otter trawls, and mini fyke nets to effectively sample Missouri River fish communities. The goal was to identify the most appropriate suite of sampling gears to collect a common fish assemblage so the monitoring program can focus efforts on methods that best meet long-term objectives.

## METHODS

*Data Collection.*—Sampling was conducted as part of a long-term monitoring program according to procedures established by a panel of representatives from various state and federal agencies involved with the federally endangered pallid sturgeon (*Scaphirhynchus albus*) population monitoring and assessment program on the Missouri River (Drobish 2008). The study area includes the lower 1 212 river km (rkm) of the Missouri River from the Lower Ponca Bend at Sioux City, Iowa, USA to the confluence of the Mississippi River (rkm 0) at St. Louis, Missouri, USA (Figure 1.1). This area is completely channelized with rock dike structures to maintain a 2.7 m navigational channel (National Research Council 2002; Galat et al. 2005). Dikes are static engineered rock structures that continuously direct current towards the thalweg, but also provide low-velocity habitats immediately downstream. Water flows in the lower Missouri River is partially controlled through Gavins Point Dam at Yankton, South Dakota, USA (rkm 1 305), which has reduced hydraulic diversity and been replaced by a more constant discharge for navigation (Hesse and Mestl 1993). Annual water discharge can vary greatly on the Missouri River, but the hydrograph is characterized by peaks in discharge around March and June (Hesse and Mestl 1993).

Sample sites were chosen by dividing the river into bends ( $n = 346$ , mean 3.5 rkm per bend), which were randomly selected and sampled with a suite of gears during two seasons each year (Drobish 2008; Wanner et al. 2007). A river bend was defined as a curvature in the river where it changed direction (Armantrout 1998) and was the distance from thalweg crossover to thalweg crossover (Doyle et al. *In press*). The coldwater sampling season occurred from 1 October to 30 June when water temperatures were  $\leq 12.8^{\circ}\text{C}$  to minimize sturgeon spp. (*Scaphirhynchus*) mortality. Gears deployed during this season were stationary gill nets, drifted trammel nets, and towed otter trawls. The warmwater season occurred from 1 July to 31 October and sampling was conducted with drifted trammel nets, towed otter trawls, and mini fyke nets. All fishes collected were counted and measured (mm) for total length (TL) or fork length (FL) in the case of sturgeon spp.

Sampling gears were deployed proportionally according to suitable habitats within each bend (Drobish 2008; Wanner et al. 2007). A minimum of eight samples were taken with each gear to provide a consistent level of effort among bends. The specific deployment site was categorized as either a pool, bar, or open water as defined by Ridenour et al. (2008; collectively referred to as habitat hereafter). Pools were defined as the area immediately downstream from a dike or other obstruction that formed a scour hole  $>1.2$  m deep. Bars were the terrestrial/aquatic interface area associated with a sand bar or shallow bankline where sediments deposit and water is  $<1.2$  m deep. Open water was considered the area  $>1.2$  m and not associated with a dike or the scour hole.

Gill nets were set overnight for 12-24 h during the coldwater season when water temperatures were  $<12.8^{\circ}\text{C}$  to minimize fish mortality (Doyle et al. *In press*). Gill nets were set parallel to the flow and bankline primarily in pool and open water habitats. A gill net panel (30.5

m long and 2.4 m high) consisted of four 7.6 m horizontal sections made of 3.8-, 5.1-, 7.6-, and 10.2-cm bar multi-filament mesh organized in ascending order. One 30.5 m net set overnight was considered one unit of effort.

Trammel nets were drifted with the current downstream for a minimum distance of 75 m with a target drift of 300 m primarily in open water habitats (Doyle et al. *In press*). Nets were 38.1 m long with a 2.4 m center wall of 2.5 cm multi-filament nylon mesh and a 1.8 m outer wall of 20.3 cm multi-filament nylon mesh on both sides. Trammel nets were fished during both seasons and catch per unit effort was summarized per 100 m drifted.

Otter trawls were 4.9 m wide, 0.9 m high, 7.6 m long, with 0.64 cm inner bar mesh and 3.8 cm outer chafing mesh (Doyle et al. *In press*). The opening of the trawl net was maintained by outward forces generated by water pressure and bottom friction against 76.2- by 38.1-cm plywood boards (trawl doors) as it was towed. Trawls were towed just faster than the current for a minimum of 75 m and target of 300 m. Samples were collected primarily in open water habitats during both seasons. Catch per unit effort was summarized per 100 m towed.

Mini fyke nets were set in shallow, low-velocity habitats (Hubert 1996). Small Wisconsin-type fyke nets consisted of a 4.5 m lead, two rectangular steel frames, and two circular hoops. The netting is 3.2 mm ace type nylon mesh, coated with green latex net dip. The two rectangular frames were 1.2 m wide and 0.6 m high. Mini fyke nets were set along the shoreline for 12-24 h during the warmwater season in primarily bar habitats. One overnight set was considered one unit of effort.

*Data Analyses.*—All analyses of fish captures were conducted by season because all gears were not used during both seasons. Fish species were considered rare and removed from further analysis if they contributed <1% of the total catch in each of all four gear types. The



pallid sturgeon was a rare species but was included in the analyses because of interest as a federally endangered species. Large-bodied fishes were those species which generally exceed a total length >200 mm and were divided into adults (A) and juveniles (J) (based on length at maturity) because susceptibility to capture may be influenced by size and life history traits (Hamley 1975; Kjelson and Johnson 1978; Argent and Kimmel 2005). Length at maturity classifications were based on Becker (1983), Robison and Buchanan (1988), Keenlyne and Jenkins (1993), Jenkins and Burkhead (1994), and Pflieger (1997). Species generally <200 mm total length were considered small-bodied species and not separated into maturity classes. This procedure resulted in 14 large-bodied species (divided into adult and juvenile fishes) and 11 small-bodied species for all analyses (Table 1.1).

Occupancy modeling in program PRESENCE (Hines 2006) was used to estimate probabilities of detection ( $p$ ), occupancy ( $\psi$ ), colonization ( $\gamma$ ), and extinction ( $\epsilon$ ) for each species, maturity class, and season. Our primary interest was  $p$ , the probability that a species will be detected at a site given it is present, rather than  $\psi$ ,  $\gamma$  or  $\epsilon$ . Parameters  $\psi$ ,  $\gamma$ , and  $\epsilon$  represent the probability that a species is present at a site, the probability an unoccupied site at year  $y$  becomes occupied at year  $y+1$ , and the probability an occupied site at year  $y$  becomes unoccupied at year  $y+1$ , respectively (MacKenzie et al. 2002, 2003). A site was considered one bend because sampling effort was allocated by bend. Sites were assumed to be closed spatially and temporally to changes in occupancy because sampling periods were generally <2 days and detection of a species was independent among bends. Samples within a site were compiled into a string of 1's and 0's to indicate detection or non-detection of the species, respectively, and referred to as an encounter history (MacKenzie et al. 2006). Encounter histories were created for each site and gear for parameter estimation. Sites where the species was detected at least once were known to

be occupied, but sites where it was never detected could either be occupied (where the species was not detected) or truly unoccupied. Probabilities of detection were estimated from encounter histories over all sites using a maximum likelihood function (MacKenzie et al. 2002) and parameter estimates of  $\psi$ ,  $\gamma$ , and  $\epsilon$  account for variable detection probabilities by gear type.

Multi-season models were used because sampling was conducted over a four-year period. Two models were run for each species' group: 1) the first model included sampling gear type as a covariate for  $p$ , and 2) the second model varied by sampling gear type and habitat. The second model was run to determine if habitat influenced detection probabilities. Since  $p$  was the primary parameter of interest,  $\psi$ ,  $\gamma$ , and  $\epsilon$  were run as constants to minimize model variation associated with parameters not of interest (MacKenzie et al. 2002). Gears or habitats where an individual species was never collected were omitted because the species must be detected at least once within a stratum to estimate  $p$ . Akaike Information Criterion (AIC) was used to rank models to determine if accounting for variable detection probabilities among habitats and gears resulted in a better fit model. Models were considered parsimonious if the difference between AIC values was  $\leq 2$  (Burnham and Anderson 2002).

Coefficient of variation (CV, Zar 1999) was used as an index of variability for CPUE to make comparisons among gear types. Coefficient of variation of CPUE was calculated by season, gear type, and habitat for each species and maturity class to determine if there were differences among these variables. Analysis of covariance (ANCOVA) performed in SAS 9.1 (SAS Institute Inc. 2002) was used to determine if mean CV differed ( $\alpha \leq 0.10$ ) among gear types for each species using habitat as a covariable. A Dunn-Šidák correction was used to control for the experimentwise error rate and lower the probability of making a type I error ( $\alpha'$ ) because comparisons were made for each species separately (Sokal and Rohlf 1995). Spearman

rank correlation analyses of  $p$  on CV of CPUE were conducted by season and gear type to determine the relationship between detection probabilities and variability in CPUE.

Length distributions were analyzed by species, gear type, and season to determine differences in size structure. Multiple analysis of variance (MANOVA) was used to determine if mean length among any species differed by gear type for each season separately ( $\alpha = 0.10$ ). If the MANOVA was significant, analysis of variance (ANOVA) was then used to determine if mean length for each species differed among gear types. Gears represented by  $\leq 20$  individuals of a species were excluded from length frequency analyses (Paukert et al. 2002).

## RESULTS

*Species Sampled.*—A total of 227 different bends were sampled over four years (range: 73-157 bends per year). Each gear type was fished primarily in one or two habitats. However, over 50 samples were deployed in each season, gear, and habitat, except with trammel nets in pool habitats during each season, and with mini fyke nets in open water during the warmwater season (Table 1.2). Gill nets had 1 008 samples in pools and 746 in open water during the coldwater season. Otter trawls and trammel nets were primarily fished in open water habitats and mini fyke nets in bar habitats.

There were a total of 181 783 fish collected comprising 25 species, which did not include rare species except the pallid sturgeon (Table 1.3). Some species were collected primarily by one gear type. For example, red shiner (*Cyprinella lutrensis*) were only collected in two gear types, but 21 723 fish (97%) were in mini fyke nets. Over 80% of all adult sauger (*Sander canadense*), blue catfish (*Ictalurus furcatus*), longnose gar (*Lepisosteus osseus*), goldeye (*Hiodon alosoides*), gizzard shad (*Dorosoma cepedianum*), and white bass (*Morone chrysops*)

were collected in gill nets. Gill nets also collected 74% of all adult pallid sturgeon. Trammel nets never collected >50% of the total catch for any species. Otter trawls collected >90% of all sicklefin chub (*Macrhybopsis meeki*), sturgeon chub (*Macrhybopsis gelida*), and speckled chub (*Macrhybopsis aestivalis*) during both seasons combined, and >80% of all juvenile blue catfish and channel catfish (*Ictalurus punctatus*). Over 90% of all juvenile river carpsucker (*Carpionodes carpio*), juvenile gizzard shad, bullhead minnow (*Pimephales vigilas*), bluegill (*Lepomis macrochirus*), emerald shiner (*Notropis atherinoides*), red shiner, river shiner (*Notropis blennius*), spotfin shiner (*Cyprinella spiloptera*), and sand shiner (*Notropis stramineus*) collected were in mini fyke nets.

*Occupancy Modeling.*—Occupancy models used to estimate probabilities of detection during the coldwater season had lower AIC values using gear and habitat covariables for 32 of 36 species except juvenile and adult pallid sturgeon, suggesting that gear and habitat were important factors influencing detection probabilities (Table 1.4). Models used for pallid sturgeon during the coldwater period were slightly different than the other models because of errors calculating extinction probabilities caused by very low catches. Therefore, these models held occupancy and colonization as constants while extinction was calculated as the complement of colonization (e.g., 1-probability of colonization), which resulted in one less estimated parameter and alleviated computational issues. Models with only gear type as the covariable for  $p$  ( $\psi$ ,  $\gamma$ , and  $\epsilon$  held constant) had equal parsimony for juvenile gizzard shad and sauger, and were the best fit model for juvenile and adult pallid sturgeon during the coldwater season. Thirty two of 38 models in the warmwater season had the best fit model (or equally best fit) using gear type and habitat as covariables for  $p$ . Gear type as the only covariable was the best fit model for adult channel catfish, adult shortnose gar (*Lepisosteus platostomus*), juvenile blue sucker (*Cycleptus*

*elongatus*), juvenile smallmouth buffalo (*Ictiobus bubalus*), juvenile goldeye, and river shiner.

In general, both gear type and habitat strongly affected detection probabilities of Missouri River fishes.

Estimates of probabilities of detection for large-bodied fishes were generally lower than 0.50, but were as high as 0.73 for adult shovelnose sturgeon (*Scaphirhynchus platyrhynchus*) in gill nets (Figure 1.2). All adult and three juvenile (shovelnose sturgeon, longnose gar, and goldeye) large-bodied fishes in the coldwater season had 2.6 times greater mean  $p$  in gill nets (mean = 0.23, range: 0.02-0.73) than trammel nets (mean = 0.09, range: 0.0-0.34). Otter trawls had 3.7 times greater mean  $p$  (mean = 0.13, range: 0.0-0.46) than trammel nets (mean = 0.04, range: 0.0-0.26) for the other juvenile large-bodied fishes, but four of these species had overlapping 95% confidence intervals to indicate similar probabilities. Trammel nets never had the single highest detection probability for any species during the coldwater season.

Probabilities of detection for adult large-bodied fishes during the warmwater season were highest for five species with trammel nets (1.9 times greater mean  $p$  than otter trawl; shovelnose sturgeon, blue sucker, smallmouth buffalo, longnose gar, and goldeye), similar for six species (pallid sturgeon, sauger, channel catfish, freshwater drum (*Aplodinotus grunniens*), river carpsucker, and gizzard shad) with trammel nets and otter trawls, and highest for two species (shortnose gar and white bass) with mini fyke nets. Mini fyke nets had the highest  $p$  for 7 of the 14 juvenile large-bodied fishes (0.22 mean difference in  $p$  to next highest gear; freshwater drum, river carpsucker, smallmouth buffalo, longnose gar, shortnose gar, gizzard shad, and white bass), but was similar with otter trawl for juvenile sauger. Otter trawls had the greatest  $p$  for juvenile blue catfish, channel catfish, goldeye (0.16 mean difference in  $p$  to next highest gear), but were

similar to trammel nets for pallid sturgeon, shovelnose sturgeon, and blue sucker, based on overlapping 95% confidence intervals.

Small-bodied fishes had the highest  $p$  with otter trawls (mean = 0.21, range: 0.09-0.41) during the coldwater season as it was the only small mesh gear deployed (Figure 1.3). During the warmwater season, seven small-bodied fishes had the greatest  $p$  with mini fyke nets (7.5 times greater mean  $p$  than otter trawl), while sicklefin chub, speckled chub, and sturgeon chub had greater  $p$  with otter trawls (4.8 times greater mean  $p$  than mini fyke net). Silver chub (*Macrhybopsis storeriana*) had similar  $p$  with mini fyke ( $p = 0.34$ ) and otter trawl ( $p = 0.39$ ).

*Variability in CPUE.*—Mean CV differed by gear type for five species in the coldwater season and eight species in the warmwater season (Dunn-Šidák correction for coldwater season:  $\alpha' \leq 0.0036$  and warmwater season:  $\alpha' \leq 0.0028$ ; Table 1.5). However, 12 and 24 out of 39 species groups during the coldwater and warmwater seasons, respectively, were significant ( $\alpha \leq 0.10$ ) prior to the correction. Mean CV of adult large-bodied fishes during the coldwater season was the lowest or equally as low with gill nets (gill net mean = 467, range: 150-952) compared to trammel nets (1.5 times greater mean CV) and otter trawls (2.8 times greater mean CV). Juvenile channel catfish had the lowest CV with otter trawls (CV = 276), freshwater drum with gill nets and otter trawls (mean CV = 632), and juvenile goldeye with gill nets and trammel nets (mean CV = 360). There were no other significant differences in mean CV among gear types for juvenile large-bodied fishes in the coldwater season. Small-bodied fishes collected with otter trawls had CV's >1 000 except the four chubs spp. (*Macrhybopsis*) and red shiner. Gill nets and trammel nets rarely collected small-bodied fishes resulting in high (>3 000) CVs.

Coefficient of variation for adult large-bodied fishes during the warmwater season was the lowest with trammel nets for smallmouth buffalo (CV = 335), but equally as low for other

adult species in trammel nets compared to otter trawls and mini fyke nets (lower mean CV difference of 363 in trammel nets compared to similar gears). Adult white bass were only caught with mini fyke nets (CV = 1 950). Trammel nets and otter trawls had similar CVs for five juvenile large-bodied species (pallid sturgeon, shovelnose sturgeon, blue sucker, blue catfish, and goldeye) which averaged 3.3 times lower compared to mini fyke nets. Coefficient of variation was lower with mini fyke nets (mean = 868, range: 239-1 579) and otter trawls (mean = 570, range: 301-814) than trammel nets for juvenile channel catfish, freshwater drum, and river carpsucker (mean CV difference = 622). All other juvenile large-bodied fishes (sauger, smallmouth buffalo, longnose gar, and gizzard shad) had similar CV's among gear types except shortnose gar (CV = 1 473) and white bass (CV = 296) which was lowest with mini fyke nets. Small-bodied fishes had the lowest CV's with either mini fyke nets or the otter trawls and rarely caught with trammel nets. Chubs spp. had 3.4 times lower mean CV in otter trawls (mean = 403, range: 352-475) compared to mini fyke nets (mean = 1 352, range: 672-2 253), while the remainder of species had 2.1 times lower CV with mini fyke nets (mean = 621, range: 304-963; otter trawl mean = 1 333, range: 997-1 903). For those species with CV differences, the lowest or equally as low CV always corresponded to the gear type with the highest  $p$ . Additionally, Spearman rank correlation coefficients indicated that CV of CPUE was significantly related to  $p$  ( $p < 0.01$ ) among all seasons and gear types (mean  $r = -0.83$ ; range: -0.61 to -0.95). Therefore, sampling gears that had the highest variability in CPUE also had the lowest detection probabilities.

*Size Structure.*—Mean lengths were significantly different among species by gear type for each season (MANOVA;  $p < 0.0001$ ). Mean lengths differed for all species (ANOVA;  $p < 0.05$ ) collected in at least two different gears except longnose gar ( $p = 0.66$ ) during the coldwater

season (Table 1.6). In general, large-bodied species collected during the coldwater season had greater length with gill nets and trammel nets, while otter trawls captured smaller sized fishes (Table 1.6; Figure 1.4). Species length distributions overlapped between gill nets and trammel nets for all 12 species caught in both gears, with gill nets having the highest 90<sup>th</sup> percentile in all species except freshwater drum, river carpsucker, and smallmouth buffalo. Trammel nets were the only large-mesh net fished during the warmwater season and caught the largest fishes, although the otter trawl had overlapping length distributions for pallid sturgeon, shovelnose sturgeon, and blue sucker. Mini fyke nets fished during the warmwater season had the smallest length distribution for the large-bodied fishes and generally overlapped with the otter trawl. Small-bodied fishes were rarely collected with gill nets or trammel nets, meaning otter trawls or mini fyke nets were the only viable gear to sample these fishes (Figure 1.5). While all small-bodied species had significantly different mean lengths between otter trawls and mini fyke nets, box plots indicated little difference because the mean length in one gear was within the 90<sup>th</sup> percentile of the other gear for all species except silver chub. However, otter trawls collected larger chubs spp. with a greater range of lengths than mini fyke nets.

## **DISCUSSION**

Several gear types fished during two seasons were necessary to sample fishes of the Missouri River. Otter trawls and mini fyke nets sampled all small-bodied fishes and numerous juvenile large-bodied fishes with higher detection probabilities and lower CVs than gill nets or trammel nets, which were most effective for adult large-bodied fishes. Gear effectiveness was likely related to mesh size and the type of habitat fished. A similar otter trawl to ours used by Herzog et al. (2005) in the upper Mississippi River increased species detection and catch rates of



small bodied and larval fishes with a small mesh size ( $<5$  mm) when compared to a 19 mm mesh trawl. Although we did not test the effect of mesh size on size of fish caught in otter trawls, we collected a range of fish sizes included small bodied fishes  $<200$  mm, which was similar to Herzog et al. (2005). Mesh size in gill nets is highly selective where mean length increases with mesh size and few fish are caught whose lengths differ from the optimum for a given mesh size (Hamley 1975; Paukert and Fisher 1999). The smallest mesh size used in gill nets was 3.8 cm bar mesh and in trammel nets 2.5 cm bar mesh, which is unlikely to entangle small bodied fishes. Additionally, limitations in habitat deployment also affect the susceptibility of a species to capture based on its ecological needs and preferences. For example, gill nets set in deep waters ( $\geq 1.2$  m) with little current or trammel nets drifted in open waters are less likely to capture littoral species because they may not encounter these gears (Hayes et al. 1996; Hubert 1996).

We used the probability of detection as a means to evaluate gear efficiency because estimating catchability (i.e., the portion of a population removed with a single unit of effort) in an open large-river system is often not feasible. To our knowledge, there are no published studies on catchability of fish in open, large river systems. We suggest that detection probabilities are a useful alternative to catchability to evaluate efficiency because high probabilities of detection represent a greater likelihood of catching a species. Detection can be a function of abundance where increases in the number of animals available for capture will increase the probability of detecting that species (MacKenzie et al. 2006). We found that the probability of detection was  $<0.50$  for most species, which was similar to catchability coefficients in other studies. For example, catchability of yellow perch in an otter trawl was  $<0.40$  (Nielson 1983), brown trout and rainbow trout with electrofishing was 0.22 and 0.56, respectively (Speas et al. 2004), and walleye with fyke nets in a north temperate lake was  $<0.02$

(Newby et al. 2000). The high negative correlations between  $p$  and variability of relative abundance indices (CPUE) also indicates the utility of evaluating gear efficiency by probability of detection because gears with high  $p$  also have lower variability in CPUE.

Otter trawls and mini fyke nets collected different small-bodied and juvenile large-bodied fish assemblages when fished during the same season, likely because they were fished in different habitats (e.g., otter trawls in deep snag free waters and mini fyke nets in shallow, low-velocity habitats). Otter trawls had the highest probability of detection and lowest CV for main channel species such as chub spp. and juvenile catfish spp. (*Ictalurus*), blue sucker, goldeye, and sturgeon spp. (Galat et al. 2005; Ridenour et al. 2008). Conversely, mini fyke nets deployed near bar habitats had the highest probability of detection for generalists and some fluvial specialist species (e.g., river shiner, spotfin shiner, sand shiner; Galat et al. 2005). Generalists and fluvial specialists with the highest probabilities of detection in mini fyke nets include all small-bodied fishes, except chub spp., and juvenile sauger, freshwater drum, river carpsucker, smallmouth buffalo, gar spp. (*Lepisosteus*), gizzard shad, and white bass (Galat et al. 2005). A primary difference in habitats sampled by otter trawls and mini fyke nets was water velocity (i.e., swift open waters and low-velocity sand bars, respectively), which was a main gradient influencing age 0 and adult fish assemblages (Barko et al. 2004b). Barko et al. (2004a) found that some minnow species' use of low-velocity and faster current areas was dependent on life stage and varied by species. Sampling with otter trawls and mini fyke nets is necessary to provide inference toward the entire community of small-bodied and juvenile large-bodied fishes because of gear and species related habitat bias.

All small-bodied fishes caught in otter trawls and mini fyke nets had different mean lengths between gears, but these differences were likely not biologically relevant as length

distribution means and 90<sup>th</sup> percentiles overlapped for most species. For example, sand shiner had mean lengths of 41 mm and 38 mm in otter trawls and mini fyke nets, respectively, which were significantly different, but the 10<sup>th</sup> and 90<sup>th</sup> percentiles of lengths were similar. The greatest difference among lengths was for chub spp. where mean length in otter trawls was greater than the 90<sup>th</sup> percentiles for mini fyke nets. Ridenour et al. (2008) found small chubs associated with low-velocity areas near dike structures, but larger (>25 mm) chubs associated with channel sand bars where water velocities were higher. Our results support Ridenour et al. (2008) because mini fyke nets sampled low-velocity areas and caught smaller chubs, while otter trawls sampled higher velocity areas and caught larger chubs.

Accounting for habitat and seasonal gear bias is important for effective monitoring of many species due to changes in vulnerability (Willis and Murphy 1996; Hubert and Fabrizio 2007). In our study, probability of detection models that incorporated habitat often resulted in better fit models. However, accounting for habitat in sampling variability (CV) of CPUE was rarely significant, suggesting some habitats have higher detection probabilities than others but similar sampling variability. Monitoring programs should direct sampling effort to gears and seasons when target species are most vulnerable (i.e., highest probability of detection) (Willis and Murphy 1996; Hubert and Fabrizio 2007; Noble et al. 2007). Gill nets may be effective during over winter periods as some adult fishes congregate near deep water areas of the river (e.g., Hesse and Newcomb 1982; Doyle et al. *In press*). Trammel nets were important for assessing large river fish communities during the warmwater season because they were the only gear that sampled large-bodied fishes, although gill nets were more efficient for the same species during the coldwater season. Accounting for habitat and seasonal gear bias can appropriately

distribute sampling effort to adequately quantify the temporal and spatial dynamics of a population (Peterson and Rabeni 1995).

Gill nets had higher probabilities of detection and lower CVs for adult and juvenile large-bodied fishes when compared with trammel nets during the coldwater season. Passive gears, such as gill nets, capture mobile species that utilize a variety of habitat types (Weaver et al. 1993), and may be effective during early season spawning migrations, where active gears, such as trammel nets, are generally better at capturing sedentary species (Lapointe et al. 2006). Gill nets with graded mesh were shown to capture a majority of the expected total fish community encompassing several feeding and habitat guilds (Tejerina-Garro and Merona 2001; Argent and Kimmel 2005). Although gill nets can efficiently sample fish populations, mortality increases with increasing water temperatures (Hopkins and Cech 1992). We observed limited mortality in gill net samples when water temperatures were  $<12.8^{\circ}\text{C}$ , but sampling with this gear ceased at warmer temperatures. Gill nets were the most effective gear during the coldwater season to assess the population status and detect abundance trends for large-bodied fishes because of high  $p$  and low CV.

Trammel nets fished during the coldwater season appear to be redundant with gill nets and otter trawls. Trammel nets never had the single highest detection probability or the single lowest CV for any juvenile or adult large bodied fish. All common species collected in trammel nets were also collected in gill nets or otter trawls. In addition, length distributions of fish collected in gill nets and trammel nets were similar, despite significant (but subtle) differences in mean length for most species. Redirecting effort into gill nets and otter trawls that have higher detection probabilities and lower CV of large-bodied fishes may improve sampling efficiency and increase the sample size necessary for adequate power to detect trends (Paukert 2004).

Focused efforts using gill nets may be more efficient than sampling with both gill nets and trammel nets during the coldwater season. However, eliminating trammel net sampling will reduce inference about fish populations utilizing the open water habitats sampled by trammel nets.

Few small (<200 mm TL or FL for sturgeons) pallid sturgeon, shovelnose sturgeon, blue sucker, and shortnose gar were sampled with any of the four gears, which was also evident for blue suckers in other large rivers (Eitzmann et al. 2007). Failure to collect juvenile long lived fishes is problematic because inability to detect changes in recruitment can slow the understanding of ecological responses to management actions or environmental factors (Doyle et al. *In press*). The otter trawl indicated the greatest potential for collection of these and other small benthic fishes in large rivers (Herzog et al. 2005; Braaten and Fuller 2007; Doyle et al. *In press*), but these age-0 to juvenile fishes were not fully vulnerable with our current trawl design and/or mesh size. Identifying other gears that can capture these juvenile fishes is warranted and important for understanding recruitment dynamics (Maceina and Pereira 2007), particularly with rare fishes such as sturgeons (Paragamian and Hansen 2008).

Refinements to the sampling protocol of a large scale monitoring program working under an adaptive management framework are critical to ensure that the goals and objectives can be met. High sampling variability and limited sample sizes on large rivers restrict the ability to determine the status or trends of a community or single species due to low statistical power. Allocation of sampling effort towards the most efficient gears or habitats with the highest detection probabilities can minimize the variance in fish collections and lead to a more effective monitoring program (Peterson and Rabeni 1995). On the Lower Missouri River the gear type with the highest detection probability also had the lowest or equally as low CV in all instances,

which further substantiates our results. Assessing population status and detecting abundance trends for a community of fishes may be best achieved using gill nets and otter trawls during coldwater periods, and trammel nets, otter trawls, and mini fyke nets during warmwater periods. Reallocating effort from coldwater trammel nets to gill nets or otter trawls can increase sample sizes, reduce gear related bias associated with multiple gear sampling, and may lead to a more efficient sampling protocol to detect long-term trends in fish abundance and responses to management actions.

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## Figure Captions

### **Figure**

- 1.1: Drainage basin of the Missouri River and the study area highlighted from the Lower Ponca Bend at Sioux City, Iowa (rkm 1 212), to the confluence of the Mississippi River (rkm 0) at St. Louis, Missouri.
- 1.2: Probability of detection ( $p$ ) by gear type for large-bodied fishes during the coldwater (1 October to 30 June) and warmwater (1 July to 31 October) seasons from 2003-2006 in the Lower Missouri River (rkm 0-1 212). Adult (A) and juvenile (J) fishes were determine by length at maturity.
- 1.3: Probability of detection ( $p$ ) by gear type for small-bodied fishes during the coldwater (1 October to 30 June) and warmwater (1 July to 31 October) seasons from 2003-2006 in the Lower Missouri River (rkm 0-1 212).
- 1.4: Box plots representing the 10<sup>th</sup> percentile, lower quartile, median, upper quartile, and 90<sup>th</sup> percentile of length (mm) distributions for large-bodied fishes caught in three gear types during the coldwater (1 October to 30 June) and warmwater (1 July to 31 October) seasons.
- 1.5: Box plots representing the 10<sup>th</sup> percentile, lower quartile, median, upper quartile, and 90<sup>th</sup> percentile of length (mm) distributions for small-bodied fishes caught in three gear types during the coldwater (1 October to 30 June) and warmwater (1 July to 31 October) seasons.

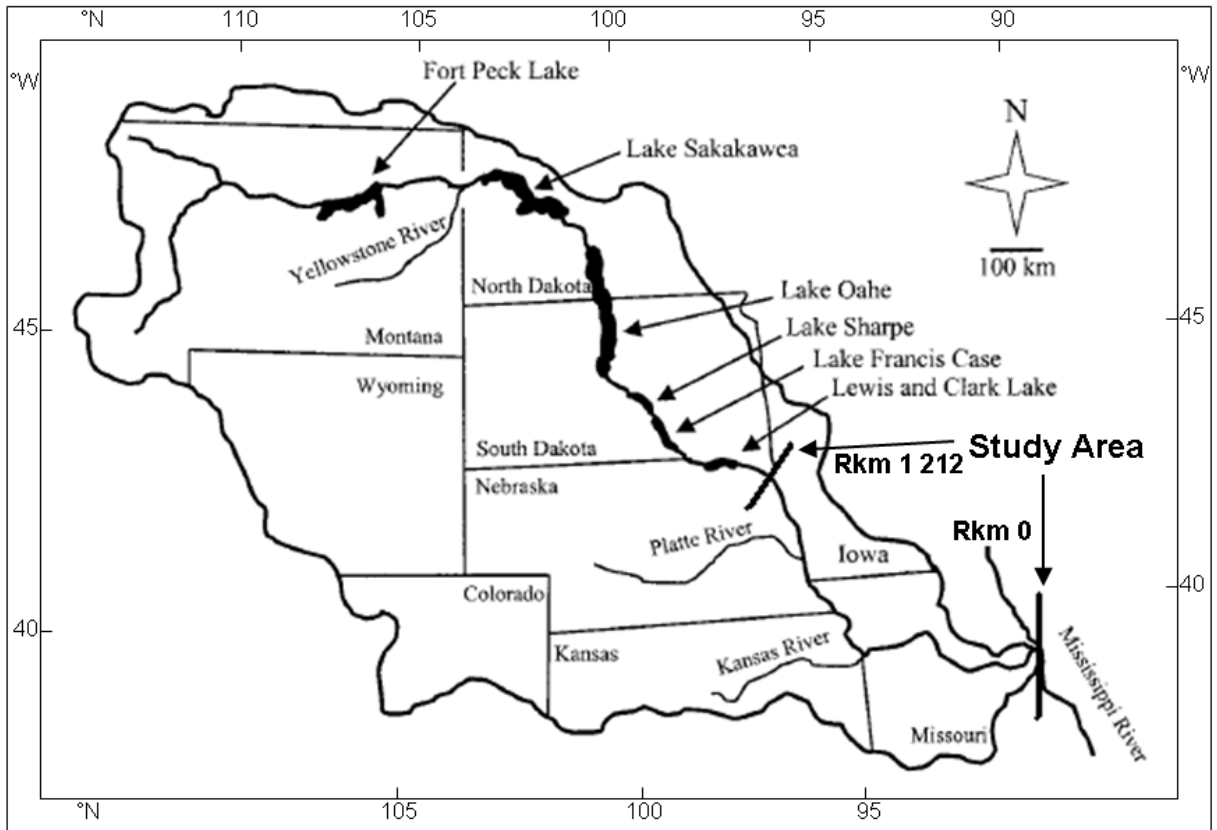


Figure 1.1

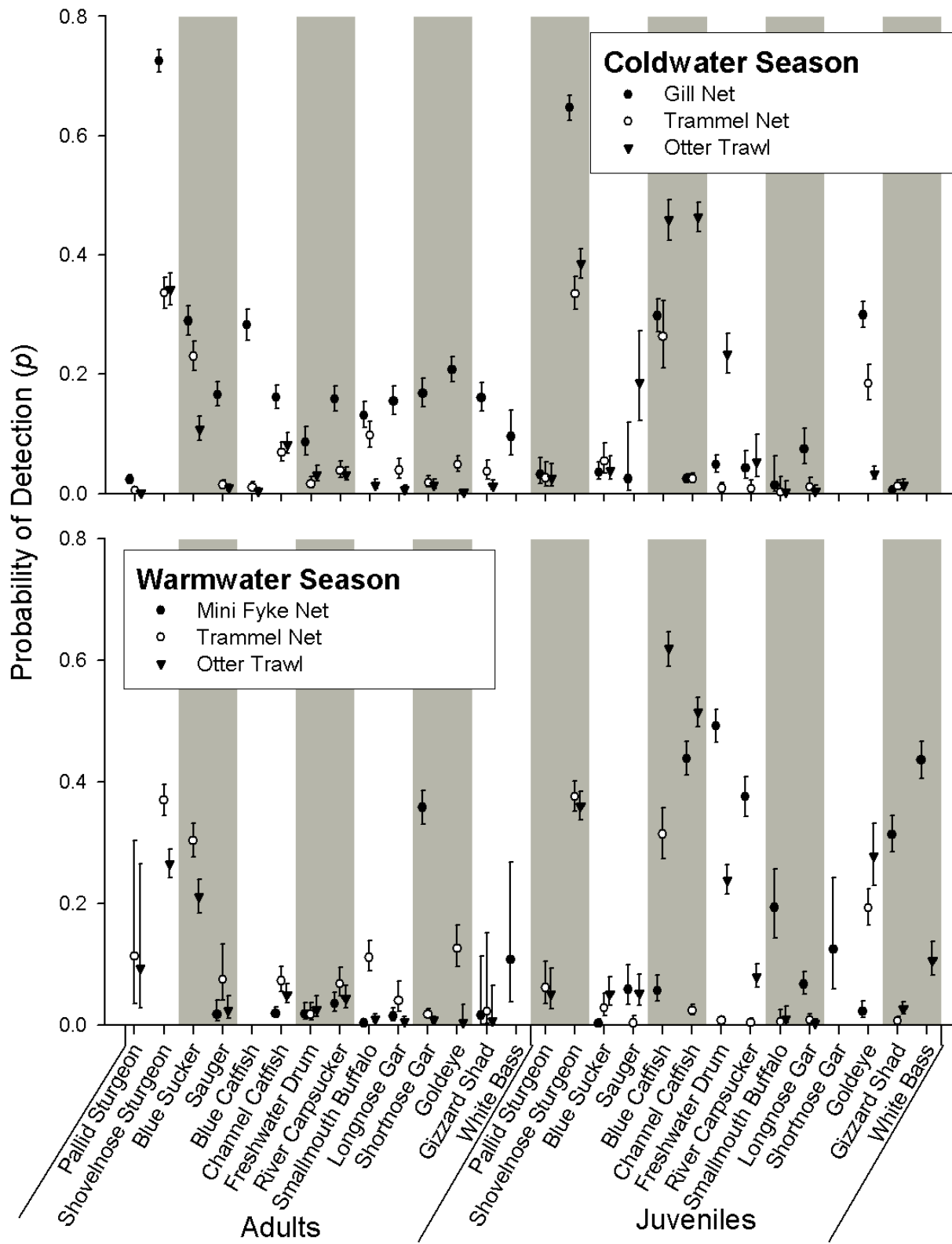


Figure 1.2



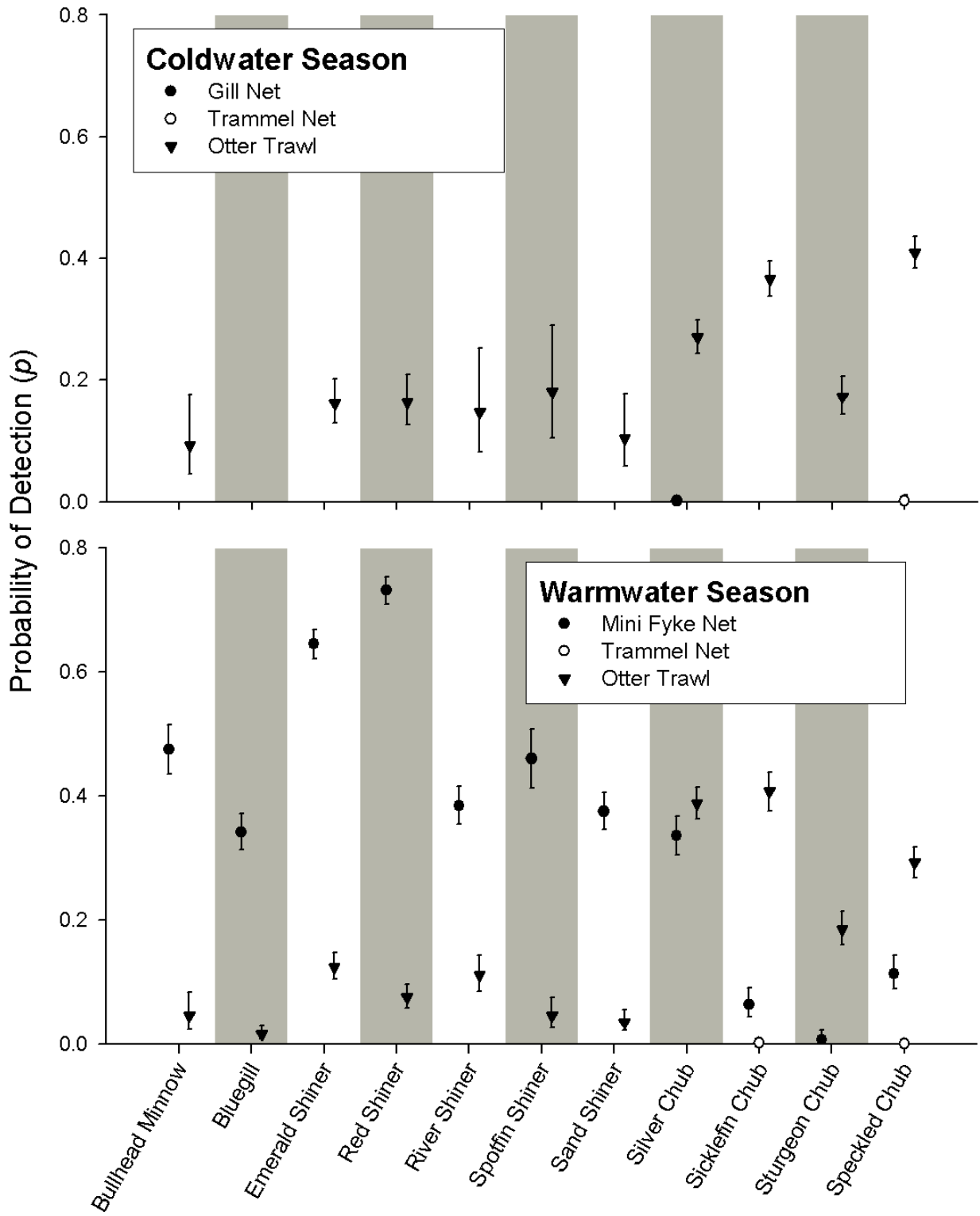


Figure 1.3

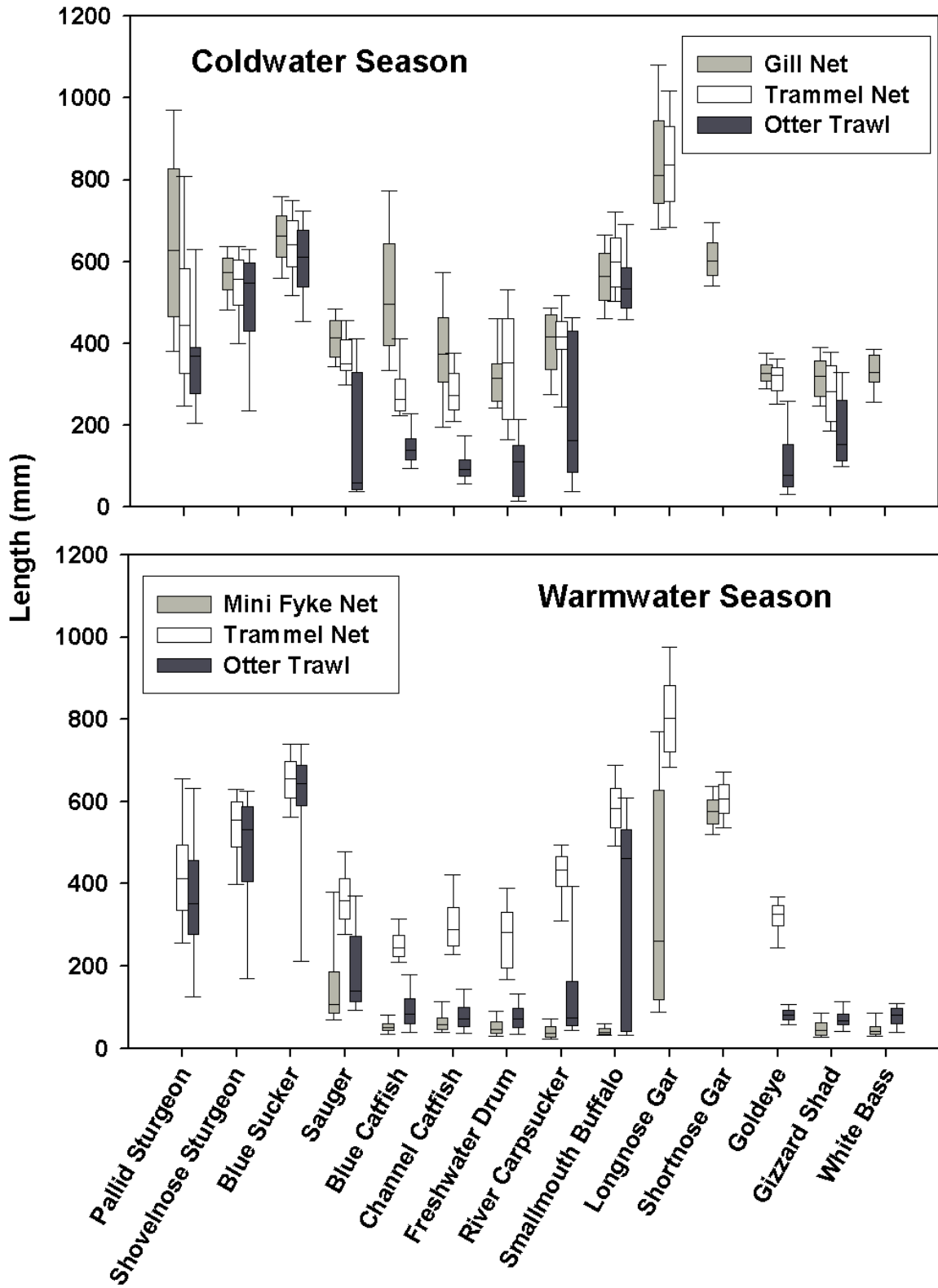


Figure 1.4

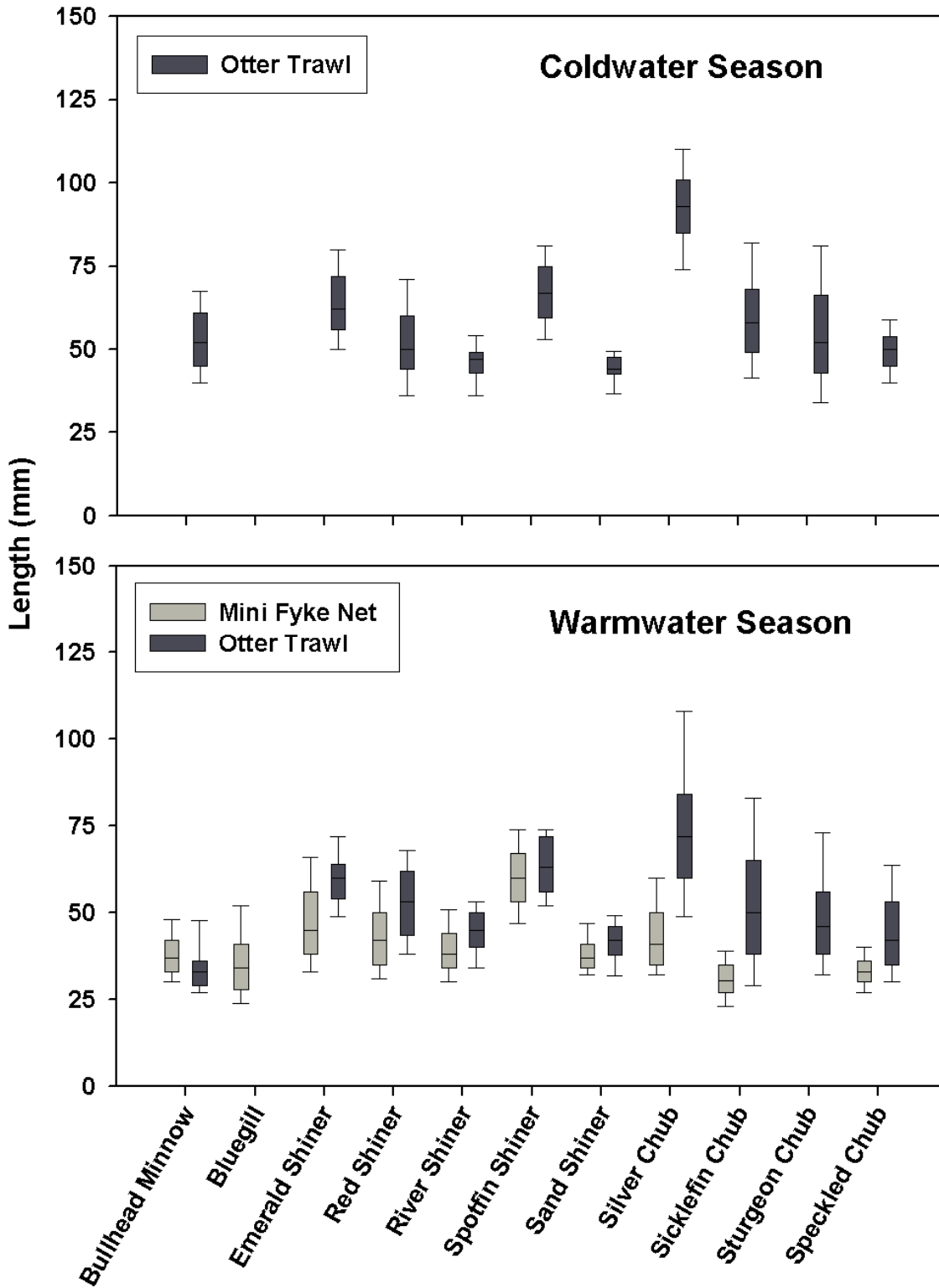


Figure 1.5

Table 1.1. Fish species included in all analyses with the maturity length (mm; total length (TL) or fork length (FL)) used to separate adult large-bodied fish from juveniles in the Missouri River (rkm 0-1 212) during 2003-2006.

Common name	Scientific name	Species code	Length (mm) at maturity	Reference
Large-bodied fishes				
Pallid sturgeon	<i>Scaphirhynchus albus</i>	PDSG	≥550 FL	Keenlyne and Jenkins 1993; Pflieger 1997
Shovelnose sturgeon	<i>Scaphirhynchus platyrhynchus</i>	SNSG	≥550 FL	Pflieger 1997
Blue sucker	<i>Cycleptus elongatus</i>	BUSK	≥500 TL	Pflieger 1997
Sauger	<i>Sander canadense</i>	SGER	≥250 TL	Becker 1983; Jenkins and Burkhead 1994
Blue catfish	<i>Ictalurus furcatus</i>	BLCF	≥500 TL	Pflieger 1997
Channel catfish	<i>Ictalurus punctatus</i>	CNCF	≥250 TL	Pflieger 1997
Freshwater drum	<i>Aplodinotus grunniens</i>	FWDM	≥275 TL	Becker 1983; Pflieger 1997
River carpsucker	<i>Carpionodes carpio</i>	RVCS	≥275 TL	Pflieger 1997
Smallmouth buffalo	<i>Ictiobus bubalus</i>	SMBF	≥400 TL	Robison and Buchanan 1988; Pflieger 1997
Longnose gar	<i>Lepisosteus osseus</i>	LNGR	≥700 TL	Pflieger 1997
Shortnose gar	<i>Lepisosteus platostomus</i>	SNGR	≥375 TL	Pflieger 1997
Goldeye	<i>Hiodon alosoides</i>	GDEY	≥350 TL	Pflieger 1997
Gizzard shad	<i>Dorosoma cepedianum</i>	GZSD	≥200 TL	Pflieger 1997; Jenkins and Burkhead 1994
White bass	<i>Morone chrysops</i>	WTBS	≥225 TL	Pflieger 1997; Jenkins and Burkhead 1994
Small-bodied fishes				
Bullhead minnow	<i>Pimephales vigilas</i>	BHMW		
Bluegill	<i>Lepomis macrochirus</i>	BLGL		
Emerald shiner	<i>Notropis atherinoides</i>	ERSN		
Red shiner	<i>Cyprinella lutrensis</i>	RDSN		
River shiner	<i>Notropis blennioides</i>	RVSN		
Spotfin shiner	<i>Cyprinella spiloptera</i>	SFSN		
Sand shiner	<i>Notropis stramineus</i>	SNSN		
Silver chub	<i>Macrhybopsis storeriana</i>	SVCB		
Sicklefin chub	<i>Macrhybopsis meeki</i>	SFCB		
Sturgeon chub	<i>Macrhybopsis gelida</i>	SGCB		
Speckled chub	<i>Macrhybopsis aestivalis</i>	SKCB		

Table 1.2. Number of samples in each habitat by season and gear type in the Missouri River (rkm 0-1 212) during 2003-2006.

Season and gear	Pool	Bar	Open water	Total
Coldwater (1 October to 30 June)				
Gill net	1 008	184	746	1 938
Trammel net	9	239	1 208	1 456
Otter trawl	106	287	1 099	1 492
Warmwater (1 July to 31 October)				
Trammel net	6	232	1 285	1 523
Otter trawl	66	225	1 388	1 679
Mini fyke net	121	1 143	32	1 296

Table 1.3. Total number of individuals and the percent of total catch (in parentheses) by gear type for each species in the Missouri River (rkm 0-1 212) during 2003-2006. Four letter species codes are listed in Table 1.1.

Species	Coldwater season (1 October to 30 June)			Warmwater season (1 July to 31 October)			Total
	Gill net <i>n</i> =1 938	Trammel net <i>n</i> =1 456	Otter trawl <i>n</i> =1 492	Trammel net <i>n</i> =1 523	Otter trawl <i>n</i> =1 679	Mini fyke <i>n</i> =1 296	
<b>Large-bodied fishes</b>							
<i>Adults</i>							
PDSG	42 (0.1)	8 (0.2)	1 (0.0)	3 (0.1)	3 (0.0)		57
SNSG	14 659 (45.9)	1 714 (34.6)	1 098 (8.2)	2 015 (34.1)	906 (2.8)	5 (0.0)	20 397
BUSK	1 268 (4.0)	594 (12.0)	161 (1.2)	819 (13.9)	328 (1.0)		3 170
SGER	407 (1.3)	22 (0.4)	13 (0.1)	38 (0.6)	14 (0.0)	8 (0.0)	502
BLCF	712 (2.2)	8 (0.2)	3 (0.0)	1 (0.0)	2 (0.0)	1 (0.0)	727
CNCF	429 (1.3)	124 (2.5)	118 (0.9)	125 (2.1)	85 (0.3)	21 (0.0)	902
FWDM	137 (0.4)	15 (0.3)	29 (0.2)	16 (0.3)	31 (0.1)	14 (0.0)	242
RVCS	465 (1.5)	46 (0.9)	46 (0.3)	70 (1.2)	47 (0.1)	29 (0.0)	703
SMBF	270 (0.8)	124 (2.5)	16 (0.1)	140 (2.4)	12 (0.0)	4 (0.0)	566
LNGR	645 (2.0)	32 (0.6)	2 (0.0)	47 (0.8)	6 (0.0)	13 (0.0)	745
SNGR	869 (2.7)	18 (0.4)	14 (0.1)	25 (0.4)	9 (0.0)	732 (0.8)	1 667
GDEY	656 (2.1)	77 (1.6)	4 (0.0)	67 (1.1)	1 (0.0)		805
GZSD	433 (1.4)	45 (0.9)	8 (0.1)	8 (0.1)	3 (0.0)	5 (0.0)	502
WTBS	27 (0.1)					4 (0.0)	31
<i>Juveniles</i>							
PDSG	24 (0.1)	18 (0.4)	16 (0.1)	16 (0.3)	13 (0.0)		87
SNSG	7 694 (24.1)	1 449 (29.3)	1 180 (8.8)	1 822 (30.9)	1 180 (3.6)	3 (0.0)	13 328
BUSK	38 (0.1)	44 (0.9)	27 (0.2)	24 (0.4)	51 (0.2)	2 (0.0)	186
SGER	2 (0.0)		32 (0.2)	2 (0.0)	38 (0.1)	36 (0.0)	110
BLCF	745 (2.3)	145 (2.9)	1 130 (8.4)	362 (6.1)	6 837 (21.0)	113 (0.1)	9 332
CNCF	70 (0.2)	56 (1.1)	3 745 (27.9)	44 (0.7)	6 950 (21.3)	1 505 (1.6)	12 370
FWDM	73 (0.2)	9 (0.2)	1 095 (8.2)	14 (0.2)	3 710 (11.4)	5 056 (5.4)	9 957
RVCS	53 (0.2)	5 (0.1)	61 (0.5)	4 (0.1)	271 (0.8)	6 805 (7.3)	7 199
SMBF	16 (0.1)	1 (0.0)		2 (0.0)	19 (0.1)	208 (0.2)	246
LNGR	111(0.3)	5 (0.1)	1 (0.0)	8 (0.1)	3 (0.0)	49 (0.1)	177
SNGR	2 (0.0)					5 (0.0)	7
GDEY	2 073 (6.5)	373 (7.5)	73 (0.5)	213 (3.6)	718 (2.2)	13 (0.0)	3 463
GZSD	5 (0.0)	12 (0.2)	16 (0.1)	6 (0.1)	101 (0.3)	1 618 (1.7)	1 758
WTBS		2 (0.0)	8 (0.1)		229 (0.7)	1 839 (2.0)	2 078
<b>Small-bodied fishes</b>							
BHMW			52 (0.4)		125 (0.4)	2 034 (2.2)	2 211
BLGL	1 (0.0)				12 (0.0)	1 197 (1.3)	1 210
ERSN			226 (1.7)		1 716 (5.3)	33 550 (36.1)	35 492
RDSN			129 (1.0)		430 (1.3)	21 723 (23.4)	22 282
RVSN			18 (0.1)		445 (1.4)	7 723 (8.3)	8 186
SFSN			27 (0.2)		39 (0.1)	1 424 (1.5)	1 490
SNSN			43 (0.3)		37 (0.1)	5 027 (5.4)	5 107
SVCB	1 (0.0)		754 (5.6)		5 270 (16.2)	1 605 (1.7)	7 630
SFCB			1 165 (8.7)	10 (0.2)	1 345 (4.1)	209 (0.2)	2 729
SGCB			173 (1.3)		292 (0.9)	2 (0.0)	467
SKCB		6 (0.1)	1 922 (14.3)	1 (0.0)	1 349 (4.1)	387 (0.4)	3 665
Total	31 927	4 952	13 406	5 902	32 627	92 969	181 783

Table 1.4.  $\Delta$ AIC values and number of parameters ( $K$ ) for occupancy models used to determine model support for probability of detection ( $p$ ) by gear type or gear and habitat. Bolded values represent best fit model(s) and species codes are in Table 1.1.

Model ( $p$ ) Species	Coldwater (1 October to 30 June)				Warmwater (1 July to 31 October)			
	Gear		Gear/Habitat		Gear		Gear/Habitat	
	$\Delta$ AIC	$K$	$\Delta$ AIC	$K$	$\Delta$ AIC	$K$	$\Delta$ AIC	$K$
Large-bodied fishes								
<i>Adults</i>								
PDSG	<b>0.0*</b>	<b>5</b>	4.9*	8	<b>0.0</b>	<b>5</b>	<b>0.7</b>	<b>8</b>
SNSG	180.5	6	<b>0.0</b>	<b>9</b>	73.6	5	<b>0.0</b>	<b>8</b>
BUSK	20.7	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>5</b>	<b>1.1</b>	<b>8</b>
SGER	31.6	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	<b>1.0</b>	<b>9</b>
BLCF	47.6	6	<b>0.0</b>	<b>9</b>				
CNCF	65.2	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	5.4	9
FWDM	26.8	6	<b>0.0</b>	<b>9</b>	9.0	6	<b>0.0</b>	<b>9</b>
RVCS	78.3	5	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	<b>1.3</b>	<b>9</b>
SMBF	59.2	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	<b>0.3</b>	<b>9</b>
LNGR	9.5	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	<b>1.2</b>	<b>9</b>
SNGR	53.4	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	5.1	9
GDEY	50.8	6	<b>0.0</b>	<b>9</b>	38.0	5	<b>0.0</b>	<b>8</b>
GZSD	14.3	6	<b>0.0</b>	<b>9</b>	<b>0.6</b>	<b>6</b>	<b>0.0</b>	<b>9</b>
WTBS	13.1	4	<b>0.0</b>	<b>7</b>	7.2	4	<b>0.0</b>	<b>7</b>
<i>Juveniles</i>								
PDSG	<b>0.0*</b>	<b>5</b>	5.9	9	8.9	5	<b>0.0</b>	<b>8</b>
SNSG	93.9	6	<b>0.0</b>	<b>9</b>	120.3	5	<b>0.0</b>	<b>8</b>
BUSK	3.7	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	5.3	9
SGER	<b>0.0</b>	<b>5</b>	<b>0.8</b>	<b>8</b>	<b>0.0</b>	<b>6</b>	<b>0.7</b>	<b>9</b>
BLCF	69.9	6	<b>0.0</b>	<b>9</b>	42.4	6	<b>0.0</b>	<b>9</b>
CNCF	11.8	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	<b>1.1</b>	<b>9</b>
FWDM	38.2	6	<b>0.0</b>	<b>9</b>	18.5	6	<b>0.0</b>	<b>9</b>
RVCS	9.2	6	<b>0.0</b>	<b>9</b>	23.6	6	<b>0.0</b>	<b>9</b>
SMBF	5.1	6	<b>0.0</b>	<b>8</b>	<b>0.0</b>	<b>6</b>	3.8	9
LNGR	5.4	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	<b>0.5</b>	<b>8</b>
SNGR					447.4	4	<b>0.0</b>	<b>7</b>
GDEY	79.0	6	<b>0.0</b>	<b>9</b>	<b>0.0</b>	<b>6</b>	3.5	9
GZSD	<b>0.0</b>	<b>6</b>	<b>1.9</b>	<b>9</b>	8.4	6	<b>0.0</b>	<b>9</b>
WTBS					8.5	5	<b>0.0</b>	<b>8</b>
Small-bodied fishes								
BHMW	14.0	4	<b>0.0</b>	<b>7</b>	13.9	5	<b>0.0</b>	<b>8</b>
BLGL					34.9	5	<b>0.0</b>	<b>8</b>
ERSN	17.8	4	<b>0.0</b>	<b>7</b>	15.4	5	<b>0.0</b>	<b>8</b>
RDSN	18.0	4	<b>0.0</b>	<b>7</b>	42.6	5	<b>0.0</b>	<b>8</b>
RVSN	11.0	4	<b>0.0</b>	<b>7</b>	<b>0.0</b>	<b>5</b>	5.6	8
SFSN	5.5	4	<b>0.0</b>	<b>5</b>	21.4	5	<b>0.0</b>	<b>8</b>
SNSN	27.3	4	<b>0.0</b>	<b>7</b>	30.3	5	<b>0.0</b>	<b>8</b>
SVCB	3.3	5	<b>0.0</b>	<b>8</b>	13.8	5	<b>0.0</b>	<b>8</b>
SFCB	56.7	4	<b>0.0</b>	<b>7</b>	10.1	6	<b>0.0</b>	<b>9</b>
SGCB	14.1	4	<b>0.0</b>	<b>7</b>	31.8	5	<b>0.0</b>	<b>8</b>
SKCB	81.9	5	<b>0.0</b>	<b>8</b>	6.0	6	<b>0.0</b>	<b>9</b>

\* model run with occupancy and colonization as constants, and extinction as the complement of colonization (e.g., 1-probability of colonization), which resulted in one less estimated parameter.

Table 1.5. Mean coefficient of variation (CV) of catch per unit effort for three gears during two seasons. Analysis of covariance (ANCOVA) was used to determine if mean CV differed by gear type for each season with habitat as a covariate. Four letter species codes are listed in Table 1.1.

Species	Coldwater season (1 October to 30 June)						Warmwater season (1 July to 31 October)					
	Gill net	Trammel	Otter	F	df	p-value	Mini	Trammel	Otter	F	df	p-value
<b>Large-bodied fishes</b>												
<i>Adults</i>												
PDSG	635 <sup>a</sup>	1 370 <sup>b</sup>	3 005 <sup>c</sup>	100.0	2,4	<0.001*			2 374	0.4	1,1	0.650
SNSG	150	235	225	2.9	2,8	0.116	2 064 <sup>b</sup>	257 <sup>a</sup>	378 <sup>a</sup>	107.8	2,5	<0.001
BUSK	291 <sup>a</sup>	260 <sup>a</sup>	427 <sup>b</sup>	5.2	2,8	0.036 <sup>†</sup>		243	353	5.3	1,5	0.070 <sup>†</sup>
SGER	274 <sup>a</sup>	774 <sup>b</sup>	1 061 <sup>b</sup>	9.7	2,6	0.013 <sup>†</sup>	1 349 <sup>b</sup>	581 <sup>a</sup>	1 157 <sup>ab</sup>	16.9	2,3	0.023 <sup>†</sup>
BLCF	326 <sup>a</sup>	1 228 <sup>b</sup>	2 282 <sup>c</sup>	46.8	2,5	<0.001	3 904	3 333	2 839			
CNCF	622	392	445	0.5	2,7	0.639	759 <sup>b</sup>	475 <sup>a</sup>	576 <sup>ab</sup>	4.3	2,8	0.055 <sup>†</sup>
FWDM	491	930	767	1.7	2,6	0.268	915	991	863	0.3	2,4	0.741
RVCS	366	660	716	2.3	2,8	0.165	701	601	659	0.8	2,6	0.508
SMBF	403 <sup>a</sup>	344 <sup>a</sup>	1 154 <sup>b</sup>	10.6	2,8	0.006 <sup>†</sup>	1 950 <sup>b</sup>	335 <sup>a</sup>	1 244 <sup>b</sup>	9.4	2,3	0.051 <sup>†</sup>
LNGR	592	648	1 756	1.9	2,6	0.227	1 003 <sup>ab</sup>	680 <sup>a</sup>	1 784 <sup>b</sup>	3.7	2,6	0.088 <sup>†</sup>
SNGR	636	853	1 230	1.3	2,7	0.330	193 <sup>a</sup>	672 <sup>ab</sup>	1 244 <sup>b</sup>	3.9	2,7	0.072 <sup>†</sup>
GDEY	320 <sup>a</sup>	880 <sup>b</sup>	2 508 <sup>c</sup>	60.0	2,4	0.001		452	3 960			
GZSD	481 <sup>a</sup>	669 <sup>ab</sup>	1 207 <sup>b</sup>	6.6	2,7	0.024 <sup>†</sup>	1 591	1 338	2 420	1.3	2,4	0.378
WTBS	952						1 950					
<i>Juveniles</i>												
PDSG	843	811	1 022	0.6	2,6	0.577		899	1 252	3.2	1,2	0.216*
SNSG	160	213	181	1.6	2,8	0.269	2 909 <sup>b</sup>	237 <sup>a</sup>	201 <sup>a</sup>	558.5	2,5	<0.001
BUSK	697	661	758	1.0	2,7	0.431	2 760 <sup>b</sup>	785 <sup>a</sup>	648 <sup>a</sup>	152.7	2,3	0.001
SGER	3 123		888	2.0	1,1	0.395	749	2 386	749	3.3	2,3	0.175
BLCF	336	407	289	0.5	2,7	0.614	1 110 <sup>b</sup>	285 <sup>a</sup>	436 <sup>a</sup>	51.0	2,7	<0.001
CNCF	839 <sup>b</sup>	722 <sup>b</sup>	276 <sup>a</sup>	6.5	2,7	0.025 <sup>†</sup>	239 <sup>a</sup>	800 <sup>b</sup>	301 <sup>a</sup>	56.8	2,6	<0.001
FWDM	664 <sup>ab</sup>	1 247 <sup>b</sup>	600 <sup>a</sup>	7.0	2,7	0.022 <sup>†</sup>	787 <sup>a</sup>	1 433 <sup>b</sup>	596 <sup>a</sup>	5.8	2,7	0.032 <sup>†</sup>
RVCS	853	1 668	1 134	0.9	2,7	0.442	1 579 <sup>a</sup>	1 792 <sup>b</sup>	814 <sup>a</sup>	4.2	2,6	0.073 <sup>†</sup>
SMBF	1 843	3 212	3 764		2,0		1 297	2 356	2 785	5.2	2,3	0.095 <sup>†</sup>
LNGR	728	1 659	2 663	2.7	2,4	0.182	577	1 292	2 337	1.7	2,3	0.325
SNGR	3 123						1 473					
GDEY	296 <sup>a</sup>	424 <sup>a</sup>	1 190 <sup>b</sup>	19.7	2,7	0.001	1 140 <sup>b</sup>	307 <sup>a</sup>	892 <sup>ab</sup>	4.9	2,7	0.046 <sup>†</sup>
GZSD	1 801	1 029	1 546	1.9	2,5	0.240	577	1 300	2 224	1.5	2,7	0.291
WTBS		2 290	1 296				296 <sup>a</sup>		1 017 <sup>b</sup>	44.1	1,4	0.003
<b>Small-bodied fishes</b>												
BHMW			2 002				470		1 903	3.6	1,5	0.118
BLGL	4 418		3 764				394 <sup>a</sup>		1 597 <sup>b</sup>	46.7	1,4	0.002
ERSN			1 006				770		997	1.8	1,5	0.239
RDSN			837				304 <sup>a</sup>		1 222 <sup>b</sup>	8.6	1,5	0.033 <sup>†</sup>
RVSN			1 484				963		1 140	5.1	1,5	0.073
SFSN			1 342				828 <sup>a</sup>		1 284 <sup>b</sup>	15.0	1,3	0.030 <sup>†</sup>
SNSN			1 374			*	617 <sup>a</sup>		1 185 <sup>b</sup>	13.4	1,4	0.022 <sup>†</sup>
SVCB	4 418		384 <sup>a</sup>	8 805.2	1,2	<0.001*	672		395	0.1	1,5	0.806
SFCB			299				1 773 <sup>ab</sup>	2 423 <sup>b</sup>	475 <sup>a</sup>	6.6	2,5	0.040 <sup>†</sup>
SGCB			649				2 253 <sup>b</sup>		391 <sup>a</sup>	65.2	1,3	0.004 <sup>†</sup>
SKCB		3 212 <sup>b</sup>	324 <sup>a</sup>	160.3	1,2	0.006 <sup>†</sup>	704 <sup>b</sup>	3 333 <sup>c</sup>	352 <sup>a</sup>	98.1	2,5	<0.001

\* the ANCOVA habitat covariable was significant.

<sup>†</sup> the Dunn-Šidák correction was not significant (coldwater season:  $\alpha' \leq 0.0036$  and warmwater season:  $\alpha' \leq 0.0028$ ) but was significant with pairwise ANCOVA ( $\alpha \leq 0.10$ ).



Table 1.6. Mean length of Missouri River fishes by season and gear type collected at rkm 0-1 212 during 2003-2006. Analysis of variance (ANOVA) was used to determine if mean length differed among gear types. Species codes are listed in Table 1.1.

Species	Coldwater season (1 October to 30 June)						Warmwater season (1 July to 31 October)					
	Gill net	Trammel net	Otter trawl	<i>F</i>	<i>df</i>	<i>p</i> -value	Mini fyke	Trammel net	Otter trawl	<i>F</i>	<i>df</i>	<i>p</i> -value
Large-bodied fishes												
PDSG	656 <sup>c</sup>	480 <sup>b</sup>	368 <sup>a</sup>	19.8	2,123	<0.001		430				
SNSG	565 <sup>c</sup>	536 <sup>b</sup>	495 <sup>a</sup>	1 085.1	2,31 000	<0.001		533 <sup>b</sup>	472 <sup>a</sup>	335.8	1,6 276	<0.001
BUSK	660 <sup>c</sup>	635 <sup>b</sup>	593 <sup>a</sup>	58.1	2,2 268	<0.001		649 <sup>b</sup>	594 <sup>a</sup>	58.5	1,1 238	<0.001
SGER	414 <sup>c</sup>	367 <sup>b</sup>	175 <sup>a</sup>	238.1	2,531	<0.001	162 <sup>a</sup>	371 <sup>b</sup>	193 <sup>a</sup>	49.0	2,142	<0.001
BLCF	530 <sup>c</sup>	296 <sup>b</sup>	148 <sup>a</sup>	2 684.2	2,3 172	<0.001	58 <sup>a</sup>	257 <sup>c</sup>	98 <sup>b</sup>	1 399.0	2,5 341	<0.001
CNCF	385 <sup>c</sup>	284 <sup>b</sup>	105 <sup>a</sup>	3 598.9	2,4 552	<0.001	71 <sup>a</sup>	307 <sup>c</sup>	84 <sup>b</sup>	1 651.6	2,7 144	<0.001
FWDM	326 <sup>b</sup>	337 <sup>b</sup>	109 <sup>a</sup>	579.1	2,1 042	<0.001	57 <sup>a</sup>	279 <sup>c</sup>	82 <sup>b</sup>	549.5	2,5 482	<0.001
RVCS	400 <sup>b</sup>	407 <sup>b</sup>	239 <sup>a</sup>	126.4	2,743	<0.001	50 <sup>a</sup>	416 <sup>c</sup>	135 <sup>b</sup>	1 096.4	2,2 086	<0.001
SMBF	561 <sup>a</sup>	603 <sup>b</sup>	547 <sup>a</sup>	10.8	2,477	<0.001	53 <sup>a</sup>	584 <sup>c</sup>	325 <sup>b</sup>	1 298.7	2,342	<0.001
LNGR	850	840		0.2	1,847	0.661	367 <sup>a</sup>	810 <sup>b</sup>		126.1	1,136	<0.001
SNGR	610						576 <sup>a</sup>	606 <sup>b</sup>		7.4	1,882	0.007
GDEY	329 <sup>c</sup>	312 <sup>b</sup>	116 <sup>a</sup>	1 556.6	2,3 672	<0.001		318 <sup>b</sup>	84 <sup>a</sup>	6 987.2	1,845	<0.001
GZSD	318 <sup>c</sup>	280 <sup>b</sup>	187 <sup>a</sup>	70.0	2,627	<0.001	51 <sup>a</sup>		76 <sup>b</sup>	119.9	1,1 922	<0.001
WTBS	339						50 <sup>a</sup>		78 <sup>b</sup>	219.7	1,2 269	<0.001
Small-bodied fishes												
BHMW			53					38 <sup>b</sup>	34 <sup>a</sup>	27.0	1,1 979	<0.001
BLGL								38				
ERSN			63			<0.001		47 <sup>a</sup>	60 <sup>b</sup>	875.4	1,12 000	<0.001
RDSN			52					44 <sup>a</sup>	53 <sup>b</sup>	184.4	1,12 000	<0.001
RVSN			46					39 <sup>a</sup>	44 <sup>b</sup>	112.6	1,3 361	<0.001
SFSN			67					60 <sup>a</sup>	64 <sup>b</sup>	4.1	1,1 215	0.044
SNSN			44					38 <sup>a</sup>	41 <sup>b</sup>	9.2	1,3 072	0.003
SVCB			93					44 <sup>a</sup>	74 <sup>b</sup>	2 206.9	1,5 060	<0.001
SFCB			60					31 <sup>a</sup>	53 <sup>b</sup>	141.6	1,1 397	<0.001
SGCB			55						49			
SKCB			50					34 <sup>a</sup>	44 <sup>b</sup>	208.1	1,1 539	<0.001

## CHAPTER 2

### **Fish associations with engineered and natural channel structures in a large river: implications for modified dike structures**

#### ABSTRACT

We compared fish community composition and the probability a channel structure was occupied by 21 riverine species at un-notched and notched rock dike structures and channel sand bars (referred to as channel structures) to evaluate habitat use of Missouri River fishes and if mitigation activities have increased abundance or occupancy of these fishes. Fish were collected using gill nets, trammel nets, otter trawls, and mini fyke nets throughout the lower 1,212 river km of the Missouri River from 2003-2006. Few differences in species richness and diversity were evident among channel structures. Notching a dike structure had no effect on proportional abundance for any habitat guild (fluvial dependents, fluvial specialists, and macrohabitat generalists). Catch per unit effort (CPUE) was greater at notched dikes for only three (lake sturgeon *Acipenser fulvescens*, paddlefish *Polyodon spathula*, and shovelnose sturgeon *Scaphirhynchus platyrhynchus*) of 12 great river species. Occupancy at notched dikes increased for blue catfish *Ictalurus furcatus* and decreased for blue sucker *Cycleptus elongatus*, but did not differ for 17 (81%) other species. No distinct increase in occupancy at natural channel sand bars compared to engineered dike structures was evident. Mean CPUE was higher in dike structures than channel sand bars for four great river species (goldeye *Hiodon alosoides*, lake sturgeon, paddlefish, and shortnose gar *Lepisosteus platostomus*), but did not differ for ten. Our results suggest dike structures may provide necessary habitats for many fluvial species when compared to channel sand bars, but notching did not increase abundance or occupancy of most native Missouri River fishes.

## INTRODUCTION

Large rivers throughout the world have been modified for anthropogenic uses which have resulted in loss of habitat for native fishes (Funk and Robinson 1974; Dynesius and Nilsson 1994; Sparks 1995; Poff et al. 1997; Osmundson et al. 2002; Minckley et al. 2003; Aarts et al. 2004). The Missouri River has undergone substantial modifications since the mid 1900s for flood control through impoundments and channelizing for navigation on the lower one-third of the river, which has reduced turbidity, sediment transport, flow variability, and main channel habitat complexity (Hesse and Mestl 1993; Galat et al. 2005). A primary modification is river control structures (e.g., rock dike structures and revetments) in the channelized Missouri River to continuously direct current towards the thalweg to maintain a 2.7 m channel for barge traffic.

Substantial declines in several native fish populations were observed in the lower Missouri River and were attributed to river modifications (Pflieger and Grace 1987; Galat et al. 2005). For example, populations of the federally endangered pallid sturgeon *Scaphirhynchus albus*, shovelnose sturgeon *Scaphirhynchus platyrhynchus*, bigmouth buffalo *Ictiobus cyprinellus*, plains minnow *Hybognathus placitus*, western silvery minnow *Hybognathus argyritis*, sicklefin chub *Macrhybopsis meeki*, and sturgeon chub *Macrhybopsis gelida* declined due to habitat modifications that affected spawning, growth, recruitment, and survival (Pflieger and Grace 1987; Dryer and Sandvol 1993; U.S. Fish and Wildlife Service 2000; National Research Council 2002; U.S. Fish and Wildlife Service 2003; Barko et al. 2004a; Galat et al. 2005). Fishes that decreased in abundance were those with specialized feeding requirements, adapted to turbid waters, or species common in low-velocity backwaters (Pflieger and Grace 1987). River modifications have altered natural habitats which may shift the fish assemblage towards more tolerant species (e.g., generalists) than fluvial species that relate to flowing water (Kinsolving

and Bain 1993; Barko et al. 2004b; Pegg and McClelland 2004) and negatively affected native species (Pflieger and Grace 1987; Gehrke et al. 1995; Galat et al. 2005).

Many natural habitats (e.g., sand bars and islands) of the lower Missouri River have been eliminated due to channel modifications (Pflieger and Grace 1987; Galat et al. 2005), but relatively similar habitats can be found near human-created structures. Dikes are constructed of rock perpendicular to the main current or in an “L” shape with the long arm pointed downstream (referred to as wing dike and L-dike, respectively) and may be critical for large river fishes during spawning, larval, and juvenile stages because they create low-velocity shallow water habitats (Brown and Coon 1994). Fluvial species may use wing dikes because they provide some of the only low-velocity waters remaining in the channelized region or it is the next best physical habitat for their ecological needs (Barko et al. 2004a,b). Most river control structures lack the habitat diversity compared to unregulated rivers, but still may be important for determining fish assemblage structure (Madejczyk et al. 1998).

L-dikes and wing dikes in the Missouri River were modified by removing a section of rock (referred to as notching) to allow water to flow behind the structure to diversify backwater habitats and create side channels (Jacobson et al. 2004). The rationale of these modifications was to provide increased flow through shallow water habitats that might benefit larval and juvenile pallid sturgeon and other native fishes (Quist et al. 2004). However, there have been few evaluations to determine if modifying dike structures has provided benefits to the native fish community (Barko et al. 2004b).

The objective of this study was to determine if fish assemblages differ among un-notched and notched L-dikes and wing dikes and natural channel sand bars. We predicted that channel sand bars would have higher abundance and diversity of large river obligate species than

engineered dike structures, but notched dike structures would have greater abundance than unmodified structures because the goal of habitat modifications was to increase habitat diversity that would benefit large river obligate fishes. Evaluating habitat use by fish at dike structures and channel sand bars will improve conservation efforts by focusing habitat restoration practices towards modifications that provide suitable habitats for large river fishes.

## METHODS

*Study Area and Habitat Descriptions.*—Sampling was conducted during 2003 to 2006 as part of a long term fish community monitoring program on the Missouri River from the Lower Ponca Bend, Sioux City, Iowa, at river kilometer (rkm) 1,212 to the confluence of the Mississippi River at St. Louis, Missouri (rkm 0) (Drobish 2008; Wanner et al. 2007; Doyle et al., in press). This portion of the Missouri River is referred to as the channelized lower region and characterized by numerous rock dike structures that force water into the thalweg to maintain a 2.7 m navigational channel (National Research Council 2002; Galat et al. 2005). Up to 10 structures per rkm protect both banks throughout the lower Missouri River (U.S. Army Corps of Engineers 1991).

Dike habitat was defined as the area extending downstream of the dike to the next dike or a distance of 250 m, whichever was shorter, and extending from the bank to 50 m into the navigational channel (Jacobson et al. 2002). We used engineered dike structure habitat descriptions from Jacobson et al. (2002) to characterize the physical habitat associated with each structure. Wing dikes are straight rock structures constructed perpendicular to the main current and most commonly located along inside river bends. Greatest depths are found nearer the main channel margins and at scour holes downstream from their tip. Shallow areas form behind the

dike and near the shoreline where substrate deposition occurs. Water velocities around wing dikes can be highly variable in magnitude and direction because of complex eddying. Substrate associated with wing dikes typically consists of mud, sand, coarse sand, rippled sand, and gravel, but is highly influenced by velocity and discharge which varies throughout the structure.

L-dikes are shaped like an “L” with the short arm extending to the bank and the long arm parallel to the main current pointing downriver. L-dikes are more common on outside bend habitats and prevent water from scouring the outside bank. The area within the L-dike typically has lower current velocities resulting in fine sediment deposition. A clear substrate boundary occurs around L-dikes with mud dominating the area within the structure and sand, coarse sand, and rippled sand outside near the main channel. All physical habitat characteristics associated with an engineered dike structure can be influenced by discharge and flood events and change quickly. On a broad temporal scale, the physical habitat characteristics are resilient because dike structures are static features (Jacobson et al. 2002).

The U.S. Army Corps of Engineers (USACE) has been notching L-dikes and wing dikes since 2004 to allow water to flow behind them to diversify the habitat for fish (Jacobson et al. 2004). Habitat changes associated with the notch in a dike include small scours, increased flow velocities, and substantial replacement of mud with sand sediments within the structure (Jacobson et al. 2004).

Sand bar habitats represent the most natural habitats remaining in the lower Missouri River. They are dominated by a sand substrate and gradient  $<10^\circ$  on the inside of river bends, which differ from engineered dike structures where the gradient ranges from  $20-40^\circ$  with more variable substrate composition (Jacobson et al. 2002; Lastrup et al. 2007). Channel sand bars

were also more susceptible to alteration by even moderate flows than dike structures (Jacobson et al. 2002).

*Data Collection.*—Sample sites were chosen by dividing the river into bends ( $n = 346$ , mean 3.5 rkm per bend) which was defined as a curvature in the river where it changes direction (Armantrout 1998) and was the length from thalweg crossover to thalweg crossover (Doyle et al., in press). River bends were randomly selected each year (Drobish 2008; Wanner et al. 2007; Doyle et al., in press) to be sampled with a suite of gears during two seasons; the coldwater sampling season occurred from 1 October to 30 June when water temperatures were  $\leq 12.8^{\circ}\text{C}$  and the warmwater season from 1 July to 31 October. Gears deployed during the coldwater season were stationary gill nets, drifted trammel nets, and towed otter trawls, whereas drifted trammel nets, towed otter trawls, and mini fyke nets were used during the warmwater season. Gill nets were not deployed during the warmwater season to minimize fish mortality. Samples were distributed proportionally according to the available habitat at each bend and a minimum of eight samples were taken per gear at five channel structures (i.e., notched and un-notched L-dikes and wing dikes and channel sand bars).

Gill nets were deployed overnight for 12-24 h parallel to the flow and bankline in low-velocity habitat where depths were generally  $>1.2$  m (Doyle et al., in press). A gill net consisted of four 7.6 m sections (2.4 m high) made of 3.8-, 5.1-, 7.6-, and 10.2-cm bar multi-filament mesh organized in ascending order. One 30.5 m length of net deployed overnight was one unit of effort.

Trammel nets were drifted a minimum of 75 m and a maximum of 300 m with the current in open-water habitats near the main channel borders of dike structures and sand bars (Doyle et al., in press). Nets were 38.1 m long with a 2.4 m high center wall of 2.5 cm multi-filament

nylon mesh. The outer wall was 1.8 m high and made of 20.3 cm multi-filament nylon mesh on both sides. Catch per unit effort (CPUE) was fish per 100 m drifted.

Otter trawls were towed a minimum of 75 m and a maximum of 300 m through pools or banklines where water depths were >1.2 m. The trawl net was 4.9 m wide, 0.9 m high, 7.6 m long, with 0.64 cm inner bar mesh and 3.8 cm outer chafing mesh and towed with 76.2- by 38.1-cm plywood boards (i.e., trawl doors) to open the net (Doyle et al., in press). Catch per unit effort was fish per 100 m.

Mini fyke nets were set overnight for 12-24 h in low-velocity shallow water (<1.2 m) habitats. Small Wisconsin-type fyke nets were made of a 4.5 m lead, two rectangular steel frames (1.2 m by 0.6 m), and two circular hoops. The netting was a 3.2 mm ace type nylon mesh and coated with green latex net dip. One overnight deployment was one unit of effort.

All fish collected were enumerated and measured for total length (TL; mm) or fork length (FL) in the case of sturgeons spp. (*Scaphirhynchus*) and eye-fork length for paddlefish *Polyodon spathula*. Each species was assigned to a habitat guild (i.e., fluvial dependent, fluvial specialist, or macrohabitat generalist), and also if it was a great river species (GRS; Becker 1983; Pflieger 1997; Galat et al. 2005; Thomas et al. 2005; Table 2.1). Fluvial dependent fishes depend on flowing water for part of their life and commonly for reproduction, fluvial specialists use flowing water habitats for most of their life, and macrohabitat generalists are commonly found in lentic and lotic systems. Great river species were described as a distinct assemblage of fish found in the Missouri and Mississippi Rivers that relate to strong continuous flows, high turbidity, and unstable sand substrates (Pflieger 1971).

*Data Analyses.*—Differences in fish assemblages among channel structures were analyzed using species richness, Shannon's Diversity Index ( $H'$ ; referred to as diversity; Kwak



and Peterson 2007), proportional abundance by habitat guild, and proportional abundance of GRS. Community indices were calculated per sample and means were summarized for each channel structure at the bend level by gear type and season. Analyses were conducted by gear type because of gear bias and all gears were not fished during both seasons (Schloesser 2008). To test for differences in mean richness, diversity, proportional abundance by habitat guild, and proportional abundance of GRS among channel structures, a two way analysis of variance (ANOVA) was performed with channel structure and gear type as the main effects. If the channel structure and gear type interaction was significant, individual ANOVA's were performed for each gear type to determine differences between channel structures ( $P \leq 0.05$ ).

Great river species were further analyzed to determine if catch per unit effort differed among individual channel structures, structure type (i.e., L-dike, wing dike, or channel sand bar regardless of notching), and notching of dikes (regardless of dike type). One gear type during one season was selected for analysis of each species and was based on the greatest overall CPUE among all channel structures. We used this criterion because of low (<0.1% of total catch) catches in some gear types and seasons (Table 2.1). An ANOVA was used to test if mean CPUE differed among all channel structures ( $P \leq 0.05$ ) for each species. Linear contrasts were used to determine if structure type and notching affected CPUE ( $P \leq 0.05$ ; Zar 1999). Statistical analyses were performed using SAS 9.1 (SAS Institute 2002).

The probability that an un-notched dike, notched dike, L-dike, wing dike, and channel sand bar was occupied was estimated for each species during the coldwater and warmwater season using occupancy models run in Program PRESENCE (Hines 2006). Occupancy ( $\psi$ ) was defined as the probability that a site was occupied by a particular species (MacKenzie et al. 2002). We defined a site as one of the five channel structures located within a bend. Sites where

the species was detected were known to be occupied, but failure to detect the species does not necessarily indicate a true absence due to imperfect detection probabilities (MacKenzie et al. 2006). Therefore, the probability of detection ( $p$ ) was estimated by gear type to account for failing to detect a species at a site and to reduce gear-related bias in collections. Replicate surveys necessary to estimate  $p$  were accrued from samples taken within the same channel structure classification and bend over the four year study period, which is a form of spatial replication (MacKenzie et al. 2002; MacKenzie et al. 2006). Species were analyzed if they were present in  $\geq 10\%$  of samples within a gear. We used this conservative criterion because the optimal number of replicate surveys necessary for reasonable occupancy estimates were not completed given the low detection probabilities ( $< 0.10$ ) observed for most species (MacKenzie and Royle 2005).

Three models were run where occupancy varied by 1) channel structure and served as the global model (i.e., most parameters), 2) notch type (i.e., un-notched or notched dikes regardless of dike type), and 3) structure type (i.e., L-dike, wing dike, or channel sand bar regardless of notching). Overdispersion of the data ( $\hat{c}$ ) was estimated from the global model and AIC values were adjusted if  $\hat{c}$  was  $> 1$  (MacKenzie et al. 2006). Model weights were calculated to determine the probability that notching or structure type was the best fit model. Occupancy estimates were considered different between un-notched and notched dikes as well as L-dikes, wing dikes, and channel sand bars if the 95% confidence intervals (CI's) did not overlap.

## RESULTS

*Species Sampled.*—A total of 113 and 115 bends were sampled with at least eight deployments of each gear during the coldwater and warmwater season, respectively. Wing dikes

were the most common structure sampled, but there were >90 samples with each gear and season at un-notched and notched wing dikes and channel sand bars, whereas 9-89 samples were collected at L-dikes, depending on gear type (Table 2.2). A total of 157,875 fish representing 82 species and four hybrids were captured during both seasons. Of the 82 species captured, 22.5%, 24.7%, and 52.8% were classified as fluvial dependents, fluvial specialists, and macrohabitat generalists, respectively. Habitat guilds were dominated by two or three species: fluvial dependents by goldeye *Hiodon alosoides* (47.2%) and white bass *Morone chrysops* (22.5%), fluvial specialists by shovelnose sturgeon (45.6%), blue catfish *Ictalurus furcatus* (14.7%), and river shiner *Notropis blennioides* (12.7%), and macrohabitat generalists by emerald shiner *Notropis atherinoides* (34.3%), red shiner *Cyprinella lutrensis* (21.0%), and channel catfish *Ictalurus punctatus* (11.5%).

*Community Associations to Channel Structures.*—Richness and diversity indices had significant channel structure and gear interactions during the coldwater season ( $P_s < 0.001$ ) and marginally significant interactions during the warmwater season ( $P = 0.066$  and  $0.059$  for diversity and richness, respectively). For consistency, individual ANOVA's were performed for each gear type to determine differences among channel structures. Species richness and diversity indices were similar among channel structures for all gear types and seasons ( $P_s > 0.07$ ), except gill nets during the coldwater season ( $P_s < 0.01$ ; Figure 2.1). Gill net samples at L-dikes, regardless of notching, had the highest species diversity (mean  $H' = 0.95$ ), whereas wing dikes (mean  $H' = 0.69$ ) and channel sand bars (mean  $H' = 0.31$ ) had lower diversity. Mean species richness using gill nets also tended to be higher at L-dikes and lowest in channel sand bars. Diversity and richness did not differ among channel structures for most gears. Trammel nets

generally had the lowest mean species diversity and richness per sample, whereas mini fyke nets had the highest mean species diversity and richness.

Proportional abundance by habitat guild had significant interactions between gear type and channel structure for each season ( $P_s < 0.05$ ), and marginally significant for fluvial dependents during the warmwater season ( $P = 0.109$ ). We present individual ANOVAs for all gear types for consistency. During the coldwater season, fluvial specialists averaged 66.9% of fish collected over all gears, whereas fluvial dependents and macrohabitat generalists comprised 10.8% and 22.3%, respectively (Figure 2.2). Proportional abundance of each habitat guild differed among channel structures only with gill nets in the coldwater season. L-dikes had greater proportional abundance compared to wing dikes and channel sand bars for fluvial dependent and macrohabitat generalist species, whereas wing dikes and channel sand bars had greater proportional abundance than L-dikes for fluvial specialists. Notching did not affect proportional abundance for any habitat guild ( $P_s < 0.05$ ). During the warmwater season, fluvial dependent species generally comprised a low percentage (<15%) of the total catch in any gear type (Figure 2.3). Fluvial specialists accounted for 75.8%, 52.8%, and 7.0% of the total catch in trammel nets, otter trawls, and mini fyke nets, whereas macrohabitat generalists accounted for 15.8%, 43.8%, and 87.7%, respectively. Fluvial dependents proportional abundance was similar among all channel structures for all three gear types. Fluvial specialists proportional abundance differed among channel structures with two gears; trammel nets had the greatest proportion in channel sand bars and un-notched L-dikes ( $P = 0.03$ ), but mini fyke nets had the lowest proportion (0.03) at un-notched L-dikes ( $P = 0.04$ ). Macrohabitat generalists proportional abundance in otter trawls was greatest at notched L-dikes, but similar among the other channel

structures ( $P = 0.03$ ). There was no evidence of greater proportional abundance at notched dikes compared to un-notched dikes for and habitat guild (Figures 2.2 and 2.3).

*Great River Species Associations to Channel Structures.*—Species classified as GRS comprised on average >50% of the total catch for all gears and seasons, except mini fyke nets where 10.1% of fish collected were GRS (Figure 2.2 and 2.3). Great river species had significant channel structure and gear type interactions during both seasons ( $P_s < 0.05$ ), but proportional abundances among channel structures differed only in gill nets during the coldwater season ( $P < 0.01$ ), and warmwater season otter trawls ( $P < 0.01$ ). Gill nets collected a greater proportion of GRS at wing dikes and channel sand bars in the coldwater season (Figure 2.2), and warmwater otter trawls caught the lowest proportion at notched L-dikes, while other channel structures were similar to each other (Figure 2.3). Notched dikes had similar proportional abundance of GRS to un-notched L- and wing dikes for all gears and seasons.

Catch per unit effort of great river species was calculated using coldwater season gill nets for goldeye, lake sturgeon *Acipenser fulvescens*, pallid sturgeon, shortnose gar *Lepisosteus platostomus*, and shovelnose sturgeon; trammel nets for skipjack herring *Alosa chrysochloris*; and otter trawls for paddlefish and speckled chub *Macrhybopsis aestivalis*. Warmwater season trammel nets were used for blue sucker *Cycleptus elongatus*; otter trawls for blue catfish, channel shiner *Notropis wickliffi*, mooneye *Hiodon tergisus*, and silver chub *Macrhybopsis storeriana*; and mini fyke nets for river shiner. Mean CPUE differed among channel structures for lake sturgeon, paddlefish, shortnose gar, blue catfish, and shovelnose sturgeon ( $P_s < 0.05$ ; Figure 2.4). L-dikes had the greatest CPUE for goldeye, lake sturgeon, paddlefish, and shortnose gar, and channel sand bars had the lowest for those species except paddlefish. Notched dikes had greater CPUE compared to un-notched dikes for lake sturgeon, paddlefish, and shovelnose

sturgeon, but lower CPUE for shortnose gar. Nine out of fourteen GRS had no differences in CPUE between structure types or whether a dike was notched.

*Occupancy Modeling.*—Of the 82 total species captured, 12 and 20 species were present in  $\geq 10\%$  of the samples collected within a gear during the coldwater and warmwater season, respectively, and 11 of those species were analyzed using occupancy models during both seasons. Probability of detection generally ranged from 0.15-0.60, but was as high as 0.79 for shovelnose sturgeon with gill nets (Figure 2.5). All species had probabilities of detection  $> 0.10$ . Nineteen of the 32 total species' analyses conducted during both seasons had at least one occupancy estimate at 0 or 1, meaning standard errors could not be estimated for those channel structures. This was due to models unable to converge on a solution at the extreme upper or lower probability bounds.

Notching affected occupancy of only four species and with variable results (Figure 2.6). Blue sucker had lower occupancy at notched dikes (0.35 mean lower occupancy) while blue catfish had higher occupancy (0.26 mean higher occupancy) during both seasons. Spotfin shiner *Cyprinella spiloptera* had higher occupancy at un-notched dikes (0.27 higher occupancy) whereas bullhead minnow *Pimephales vigilas* had higher occupancy at notched dikes (0.27 higher occupancy), but only during the warmwater season. This was the only evidence that notching significantly affected occupancy of any species, except where occupancy was near 0 or 1 and 95% CI's could not be estimated. Dike notching did not significantly affect occupancy for over 80% of the species analyzed and the estimates for these species were variable in the direction of change with no discernable patterns among species. However, the increase or decrease in occupancy point estimates was consistent between species that were sampled during both seasons.

Comparisons of occupancy at dike structures to channel sand bars were highly variable among species, but L-dikes or wing dikes had higher occupancy than channel sand bars for 42% and 50% of species during the coldwater and warmwater seasons, respectively. Channel sand bars had the single highest occupancy estimate for only speckled chub and sicklefin chub during the coldwater season, but equally as high occupancy as dikes for the remaining 42% and 50% of species during the coldwater and warmwater seasons, respectively. Models parameterized by structure type had greater weight indicating they were the best fit model compared to models with notching. Model weights averaged 0.45 (range: 0.00-0.86) for notching and 0.55 (range: 0.14-1.00) for structure type during the coldwater season, and 0.30 (range: 0.00-0.90) and 0.70 (range: 0.10-1.00) during the warmwater season, respectively. Greater model weights for structure type support that accounting for dike type was more important than notching.

## **DISCUSSION**

Fluvial dependent and specialist species were more abundant under natural river conditions where disturbance such as frequent flooding and shifting sand substrates constantly changed channel morphology (Funk and Robinson 1974; Pflieger and Grace 1987; Galat et al. 2005). Regulation of the lower Missouri River through impoundments and permanent dike structures, mostly eliminated the unstable conditions to which many fluvial species were adapted. However, our study found that fluvial species still comprised 77.7% of the total catch during the coldwater season and 50.9% during the warmwater season. While over half of the species listed were classified as macrohabitat generalists, they accounted for only 22.3% of the total catch during the coldwater season, but 49.1% during the warmwater season. Macrohabitat generalists comprised 87.7% of the total catch in mini fyke nets, whereas no other gear collected

>50% macrohabitat generalists. In the upper Mississippi River, low relative abundance of fluvial species indicated this system may be degraded and moving towards a fish assemblage dominated by tolerant species (Barko et al. 2004b). Our study used a similar suite of gears as Barko et al. (2004b), but the Missouri River exhibited greater proportional abundance of fluvial species than macrohabitat generalists. High proportional abundance of fluvial species is important, because generalist species can tolerate a greater range of conditions than fluvial specialists and are efficient competitors that can eliminate specialized species and reduce richness and diversity under stable conditions (Connell 1978; Kingsolving and Bain 1993; Pegg and McClellan 2004; Galat et al. 2005).

Channel sand bars represented the most natural habitat remaining in the lower Missouri River, but dike structures appear to provide suitable habitats for many fluvial species (Madejczyk et al. 1998). We expected fluvial species to associate with channel sand bars more than dike structures, while generalist species would associate with dike structures because they simulate both lentic and lotic systems. Overall, few differences were found in community indices of richness, diversity, and percent habitat guild among channel structures. Species richness and diversity did not differ among channel structures, except with gill nets, which may be a function of lower efficiency in the shallow waters near sand bars (Schloesser 2008). In the upper Mississippi River, only slight variations in richness and diversity were found among differing habitat types (Madejczyk et al. 1998). The proportion of fluvial specialists caught at channel sand bars was similar to other dike structures, which did not support our expectation that fluvial specialists would be more common in channel sand bars. Channel sand bars represent the most natural habitat type remaining, but dike structures had an equally high percent of fluvial dependents or fluvial specialists as channel sand bars. Some adult fluvial dependent and



specialist species were most abundant in wing dike areas of the upper Mississippi River, but had no strong habitat associations (Barko et al. 2004b), which matches our findings.

Dike structures provide some of the only low-velocity and structural habitat outside of the main channel. Dike scour holes and their associated low-velocity habitats resemble habitats found near sand bars and islands that are important for species adapted to low-velocity habitats (Sandheinrich and Atchison 1986). The loss of low-velocity backwater areas was implicated in the decline of many native species (Pflieger and Grace 1987; Brown and Coon 1994; Barko et al. 2004b), and may explain why fluvial specialists had equally high proportional abundance at dike structures as channel sand bars. Fluvial species such as paddlefish may utilize dike structures for their low-velocity scour pool habitats (Southall and Hubert 1984) and L-dikes were suspected to be important for larval fishes because the trailing arm of the dike provides low-velocity nursery habitats once prevalent in the pre-modified Missouri River (Ridenour et al. 2008). Collectively, these results emphasize the importance of dike structures and the low-velocity habitats associated with them to maintain native fish populations.

Additional studies have emphasized the importance of dike structures for structuring fish assemblages. Generalist species, such as Centrarchids, may use dikes because they simulate more lentic conditions (Barko et al. 2004a), whereas areas of swift current, such as near wing dike tips, may be important for adult fluvial species such as blue sucker, flathead catfish *Pylodictus olivaris*, and sauger *Sander canadense* (Sandheinrich and Atchison 1986; Madejczyk et al. 1998; Barko et al. 2004a). We found blue sucker had higher CPUE and occupancy at wing dikes than L-dikes, likely because they prefer areas of deep swift current with rock substrates (Pflieger 1997; Eitzmann et al. 2007). Species richness was consistently greater in wing dike habitat for adult and age-0 fishes in the upper Mississippi River, when compared to the higher

velocity waters at main channel border habitats (Barko et al. 2004a). The diverse conditions found near dike structures provide the habitats necessary to support a broad fish assemblage and further emphasize their importance in the channelized Missouri River.

Habitat preference may be based on body size or maturity for many species. Differential habitat use was found for three chub spp. (*Macrhybopsis*) based on body size in the lower Missouri River, where smaller chubs associated with low-velocity dike structures and chubs >25 mm associated with channel sand bars (Ridenour et al. 2008). Additionally, emerald shiners, channel shiners, and threadfin shad *Dorosoma petenense* shifted habitat use from age-0 to adults in the upper Mississippi River (Barko et al. 2004a). While we made no attempts to characterize habitat use by fish size or maturity, this may confound our analyses and explain why we found few differences between dikes and sand bars for many species and habitat guilds.

The purpose of notching dikes was to diversify the physical habitat at dike structures which may benefit large river obligate fishes. Jacobson et al. (2004) found that notching increased velocity and depth, but our study found little evidence that fish assemblages responded as expected to these modifications. Fish community indices were similar between un-notched and notched dikes, and most species did not differ in CPUE or occupancy. Those species that differed between notching were variable. For example, notched dikes had higher CPUE of lake sturgeon, paddlefish, and shovelnose sturgeon, but lower for the macrohabitat generalist shortnose gar. Additionally, occupancy at notched dikes differed for four species: blue sucker and spotfin shiner decreased while blue catfish and bullhead minnow increased. Greater CPUE of shovelnose sturgeon at notched dikes is an important finding because they were one species that experienced significant declines in abundance, were the most dominant species collected in gill nets and trammel nets, and are sympatric with the endangered pallid sturgeon (Pflieger and

Grace 1987; Keenlyne 1997; Bramblett and White 2001; Quist et al. 2002). Difficulties in detecting age-0 fishes with the gears we used may hinder our understanding of the effects notching has on the recruitment of long-lived fishes, such as shovelnose sturgeon (Doyle et al., in press). Dike notching has occurred at a large scale since 2004, but it may take a longer time period or large flow events for the adjacent physical habitat to adjust (Jacobson et al. 2004) in order to elicit a response from the fish community. Pegg and McClelland (2004) found a considerable response time from the fish community to improved water quality conditions in the Illinois River, which warrants continuation of long-term studies to understand the impacts of notching on the fish assemblage.

Mitigation efforts (i.e., dike notching) on the Missouri River have focused on the creation of shallow water habitat (SWH; depths 0-1.5 m and velocities 0-0.6 m/s; U.S. Fish and Wildlife Service 2000) because it is widely accepted that survival and growth of young fish is dependent on the availability of shallow low-velocity waters (Scheidegger and Bain 1995; Freeman et al. 2001). Dike notching was one method used to recreate physical habitat conditions most similar to those found pre-modifications. While few fluvial species showed a positive response to notching, this may be a result of selective habitat use during various portions of their life stage that were not accounted for in this study. This study did not focus on young fishes, but it has been questioned whether dike notching is beneficial for larval fishes that depend on low-velocity habitats primarily found behind dike structures (Ridenour et al. 2008). Nonetheless, our study suggests that notching dikes does not necessarily increase abundance or occupancy of native Missouri River fishes.

Future channel modification efforts must consider the diverse habitats created by dike structures and the importance they have for native fluvial species during various portions of their

life. Our findings and others in channelized rivers support the concept that dike structures are important for providing the low-velocity habitats lost with river modifications. Altering low-velocity areas through dike notching had variable effects on fluvial species and may not elicit the positive response expected from many large river obligate fishes. Understanding how large river fish assemblages associate with dike structures and channel sand bars and how modifying these structures impacts the fish community is essential for the successful conservation of declining native fish populations.

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## Figure Captions

### Figure

- 2.1: Mean Shannon Weiner fish diversity ( $H'$ ) and species richness for fish collected in gill nets, trammel nets, otter trawls, and mini fyke nets at five channel structures (un-notched L-dike, notched L-dike, un-notched wing dike, notched wing dike, and channel sand bar) during the coldwater (1 October to 30 June) and warmwater seasons (1 July to 31 October) in the channelized Missouri River from 2003-2006. Error bars represent one standard error.
- 2.2: Proportion of fish caught that were classified as great river species (see Table 2.1) and by habitat guild at five channel structures with gill nets, trammel nets, and otter trawls during the coldwater season (1 October to 30 June) in the channelized Missouri River from 2003-2006. Error bars represent one standard error.
- 2.3: Proportion of fish caught that were classified as great river species (see Table 2.1) and by habitat guild at five channel structures with trammel nets, otter trawls, and mini fyke nets during the warmwater season (1 July to 31 October) in the channelized Missouri River from 2003-2006. Error bars represent one standard error.
- 2.4: Catch per unit effort (CPUE) of great river species at five channel structures in the channelized Missouri River from 2003-2006. Catch per unit effort was represented by the gear and season with the highest overall CPUE. Coldwater season (1 October to 30 June) gill nets were used for goldeye, lake sturgeon, pallid sturgeon, shortnose gar, and shovelnose sturgeon; trammel nets for skipjack herring; and otter trawls for paddlefish and speckled chub. Warmwater season (1 July to 31 October) trammel nets were used for blue sucker; otter trawls for blue catfish, channel shiner, mooneye, and silver chub; and mini fyke nets for river shiner. Linear contrasts listed in parenthesis indicate if structure type (i.e., L-dike, wing dike, or channel sand bar) and notching of a dike affected CPUE. Error bars represent one standard error.
- 2.5: Probability of detecting Missouri River fishes with four gear types during the coldwater (1 October to 30 June) and warmwater seasons (1 July to 31 October) from 2003-2006. Error bars represent 95% confidence intervals. Shovelnose St. = shovelnose sturgeon.
- 2.6: The probability that a channel structure was occupied by a Missouri River fish species during the coldwater (1 October to 30 June) and warmwater seasons (1 July to 31 October) from 2003-2006. Error bars represent 95% confidence intervals. Occupancy estimates near 1 or 0 had no confidence intervals because models were unable to converge on a solution, but the actual proportion of all sites occupied was near or at the upper or lower probability bounds. Shovelnose St. = shovelnose sturgeon.

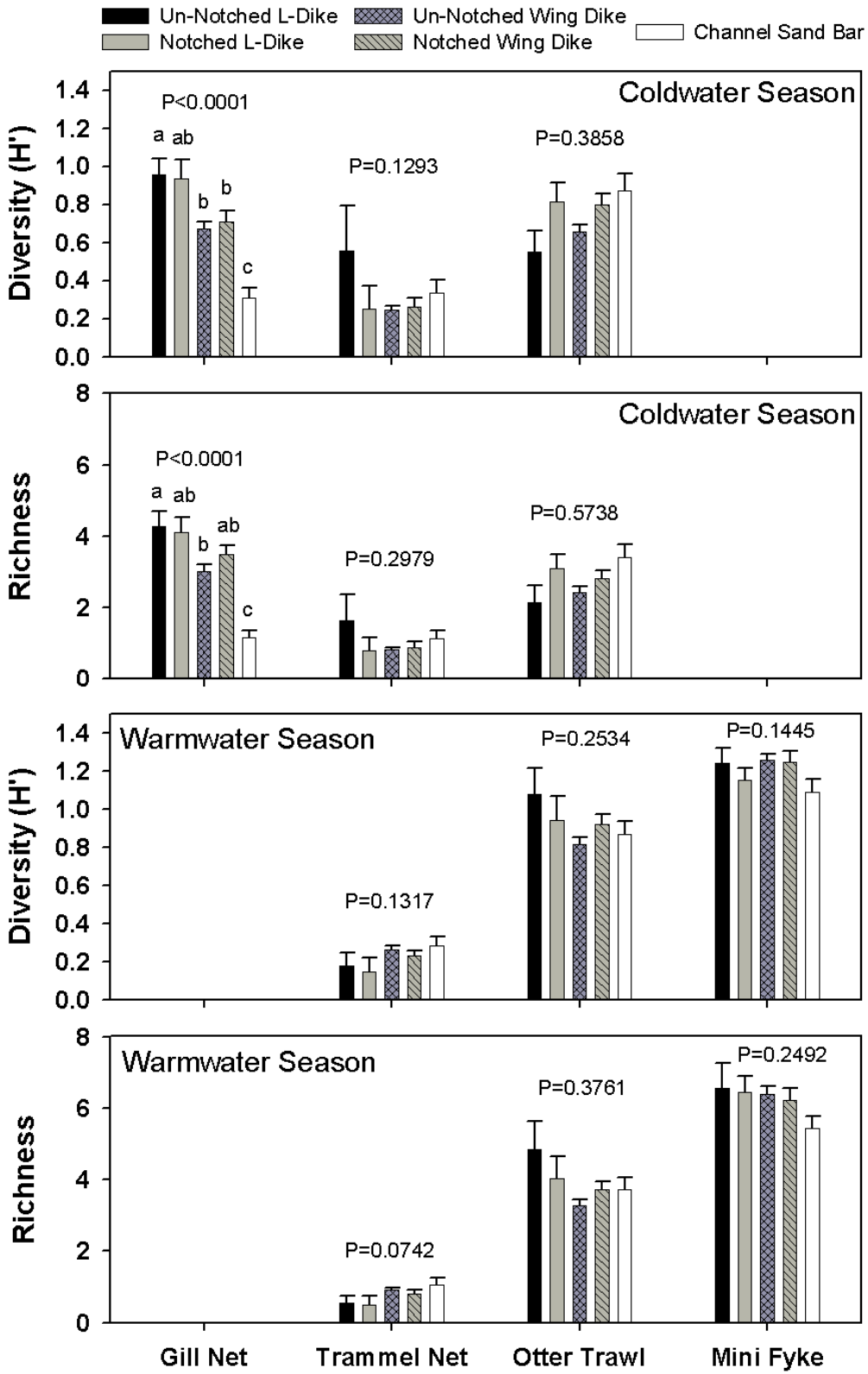


Figure 2.1

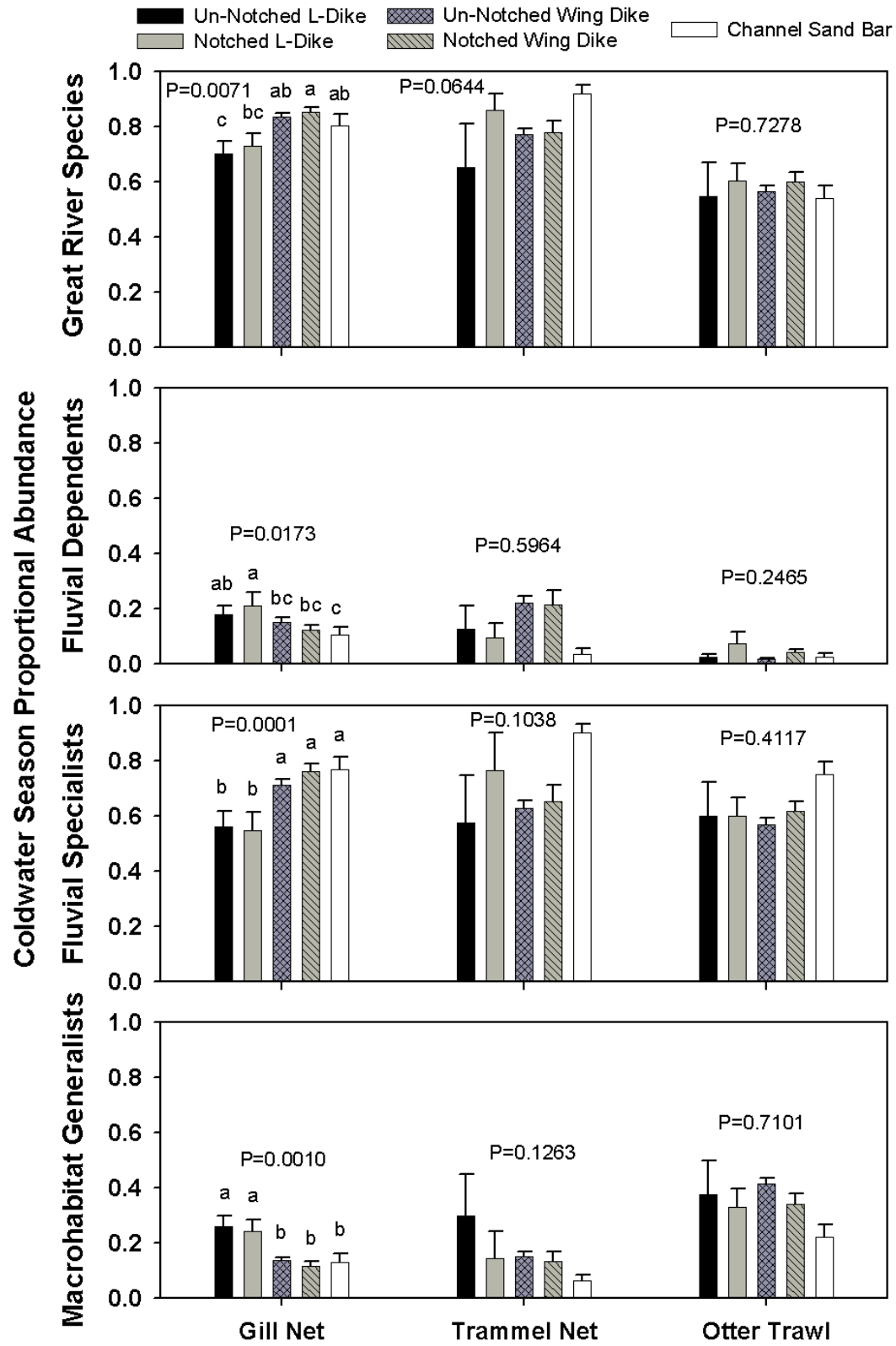


Figure 2.2

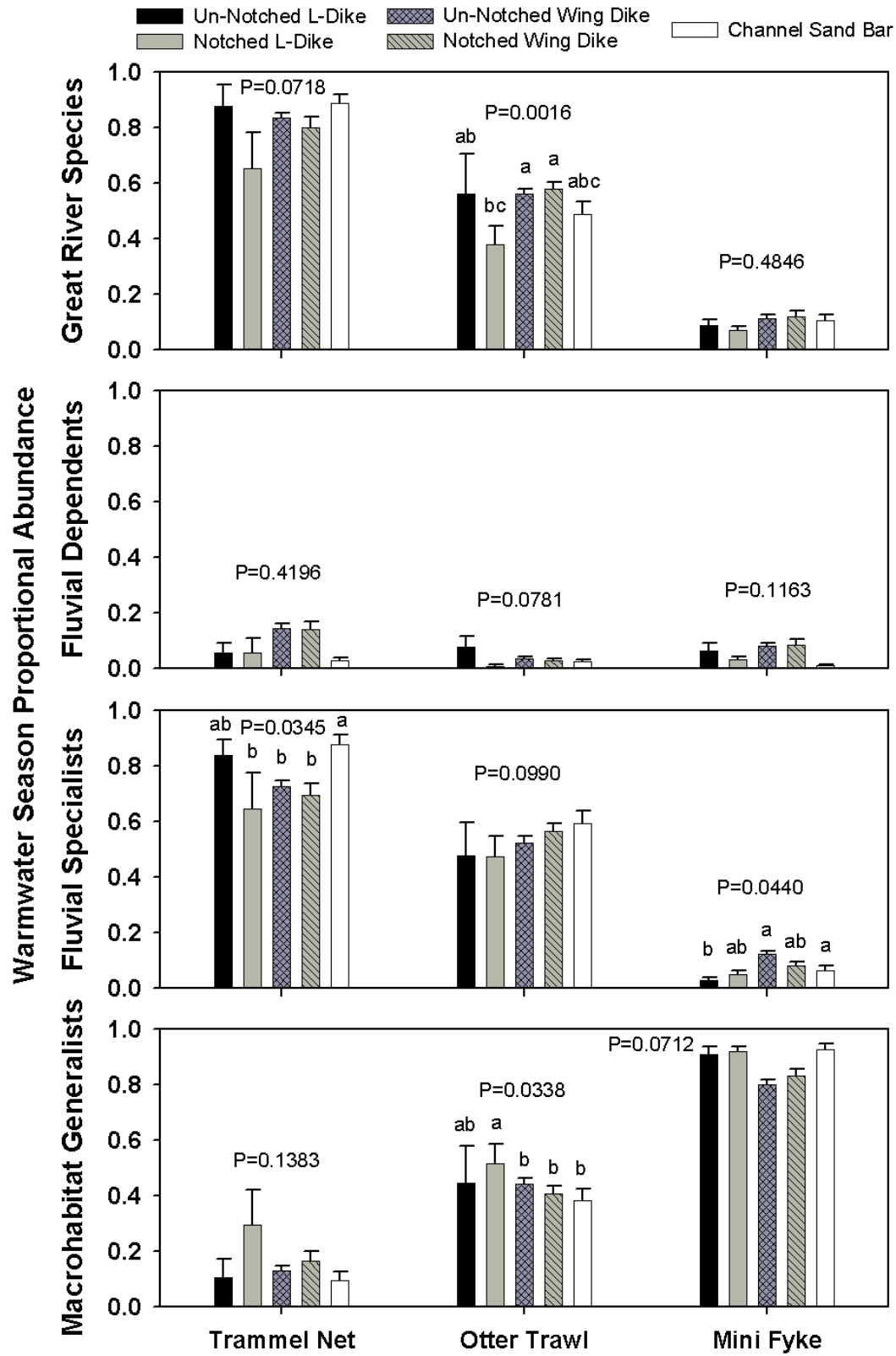


Figure 2.3

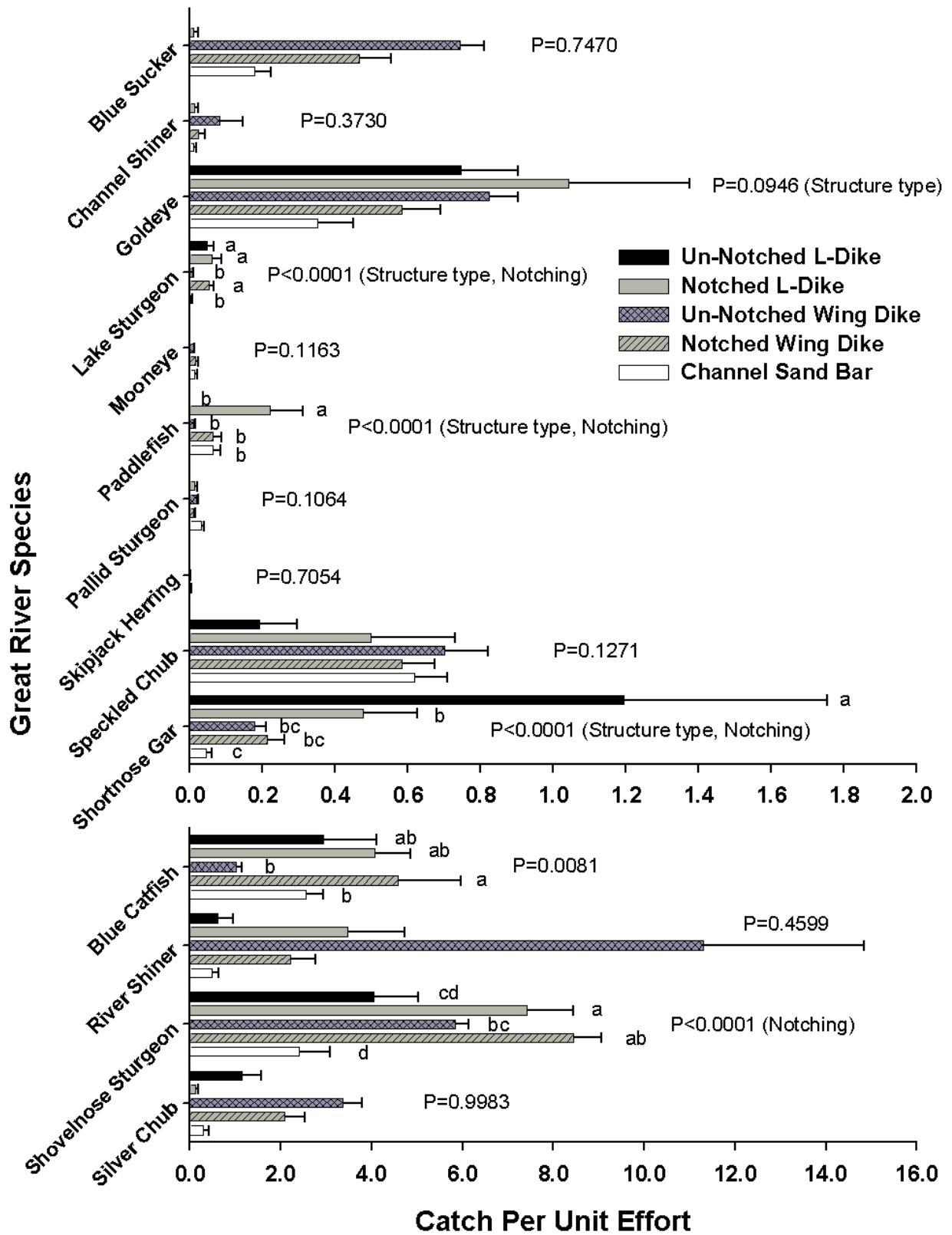


Figure 2.4



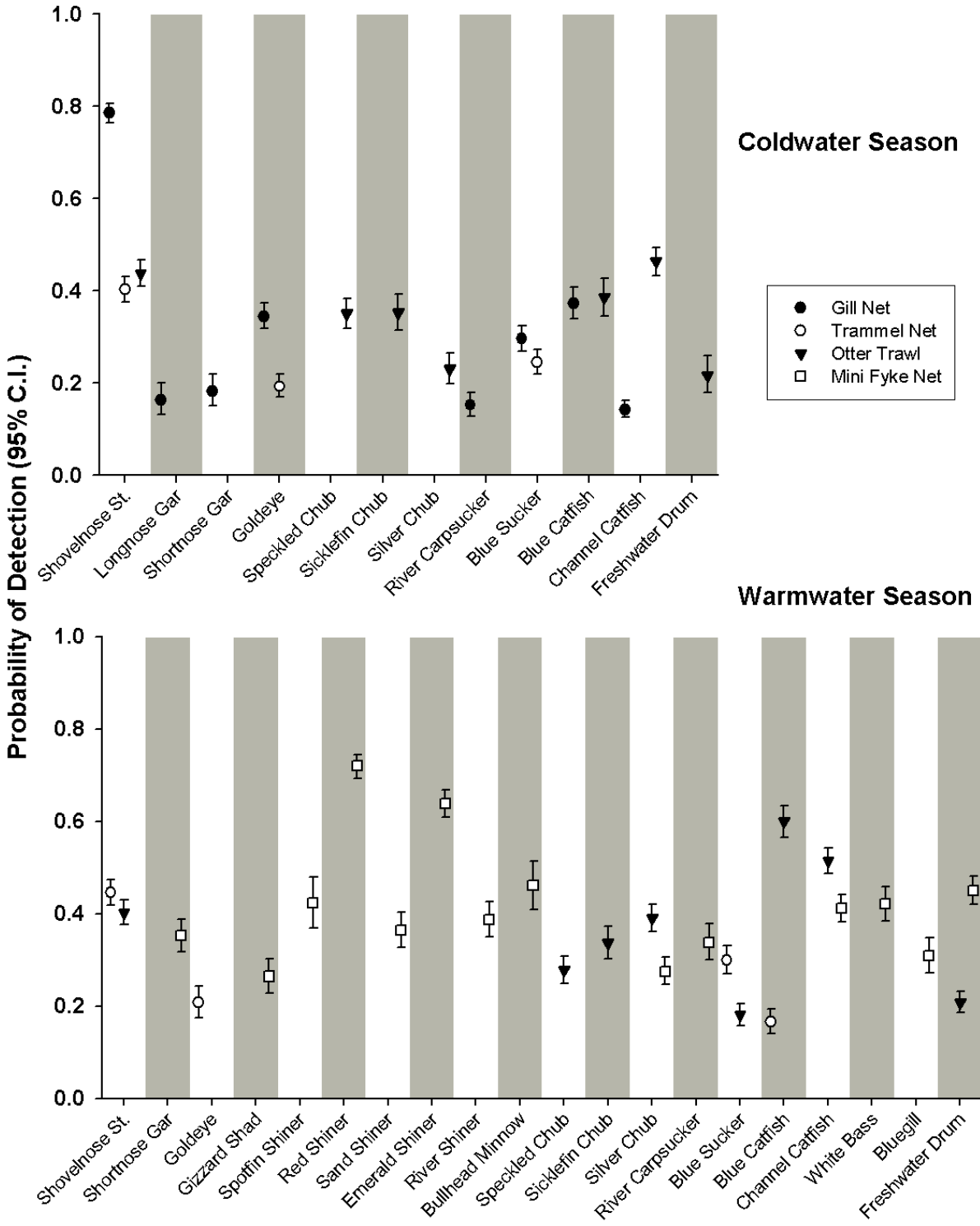


Figure 2.5

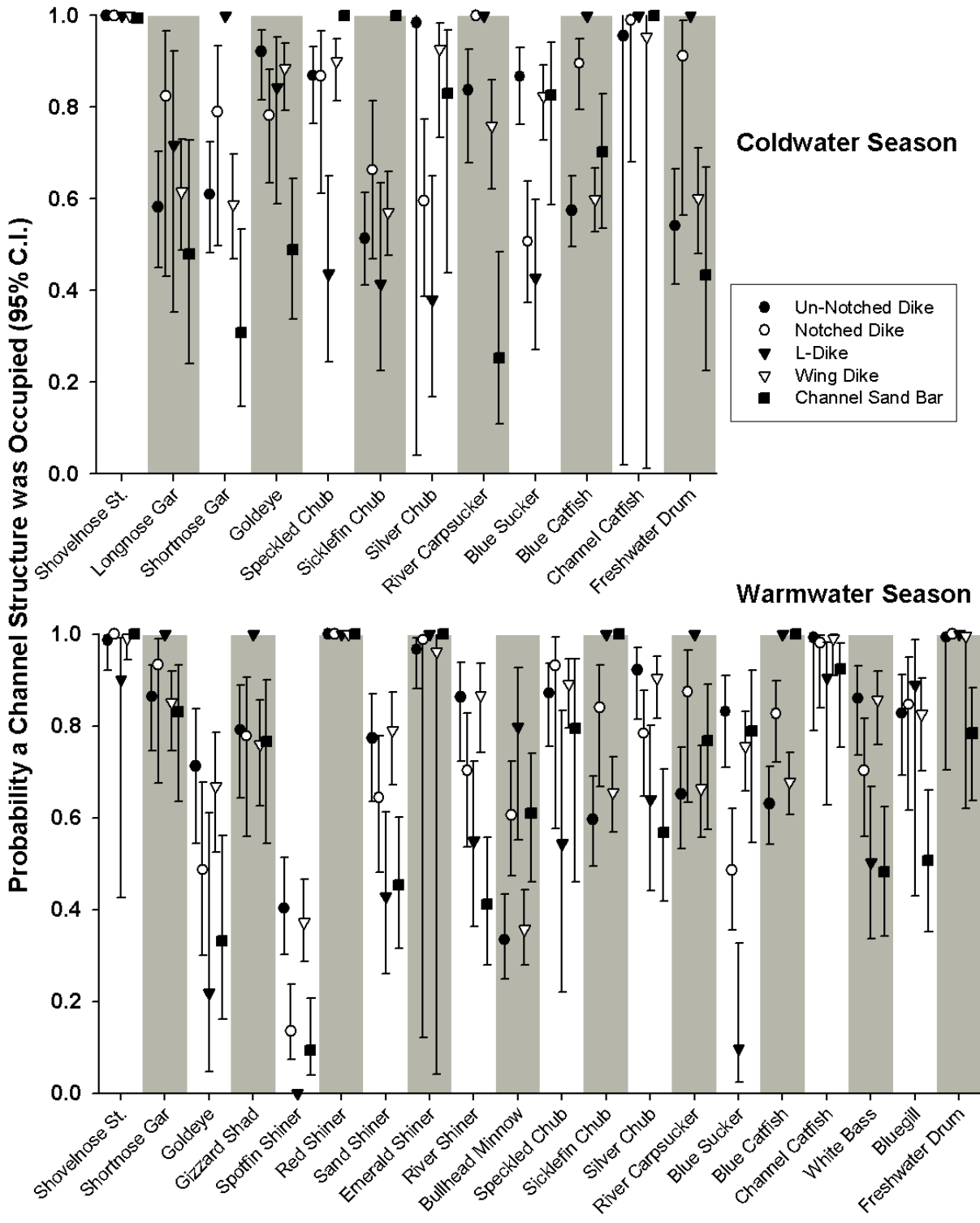


Figure 2.6

Table 2.1. Missouri River fishes and their status as a great river species (X) and habitat guild (FD=fluvial dependent, FS=fluvial specialist, MG=macrohabitat generalist). Percent composition for each species caught with four gear types in the channelized Missouri River during the coldwater season (1 October to 30 June) and warmwater season (1 July to 31 October; listed in parenthesis) from 2003-2006. There were a total of 26,045, 4,614, 4,686, 13,387, 27,780, and 96,154 fish caught in gill nets, coldwater trammel nets, warmwater trammel nets, coldwater otter trawls, warmwater otter trawls, and mini fyke nets, respectively.

Family and common name	Scientific name	Great river species	Habitat guild	Percent composition					
				Gill net	Trammel net	Otter trawl	Mini fyke net		
Acipenseridae									
Lake sturgeon	<i>Acipenser fulvescens</i>	X	FD	0.2	<0.0	(0.2)	<0.0	(<0.0)	(<0.0)
Pallid sturgeon	<i>Scaphirhynchus albus</i>	X	FS	0.2	0.6	(0.4)	0.1	(<0.0)	(<0.0)
Shovelnose sturgeon	<i>Scaphirhynchus platyrhynchus</i>	X	FS	65.1	60.3	(60.5)	16.6	(6.0)	(<0.0)
Shovelnose x Pallid Hybrid	<i>Scaphirhynchus platyrhynchus x S. albus</i>	X	FS	0.1	0.1	(0.1)	<0.0	(<0.0)	(<0.0)
Polyodontidae									
Paddlefish	<i>Polyodon spathula</i>	X	FD	0.2	<0.0	(<0.0)	0.8	(<0.0)	(<0.0)
Lepisosteidae									
Longnose gar	<i>Lepisosteus osseus</i>		FD	2.2	0.9	(1.0)	0.1	(<0.0)	(0.1)
Shortnose gar	<i>Lepisosteus platostomus</i>	X	MG	2.6	0.3	(0.5)	0.1	(<0.0)	(0.7)
Hiodontidae									
Goldeye	<i>Hiodon alosoides</i>	X	FD	9.2	9.3	(5.4)	0.8	(2.2)	(<0.0)
Mooneye	<i>Hiodon tergisus</i>	X	FD	<0.0	<0.0	(<0.0)	<0.0	(0.1)	(<0.0)
Clupeidae									
Skipjack herring	<i>Alosa chrysochloris</i>	X	FD	<0.0	0.2	(0.1)	<0.0	(<0.0)	(<0.0)
Gizzard shad	<i>Dorosoma cepedianum</i>		MG	1.5	1.2	(0.3)	0.2	(0.4)	(1.2)
Cyprinidae									
Central stoneroller	<i>Campostoma anomalum</i>		FS	-	-	(<0.0)	-	(<0.0)	(<0.0)
Largescale stoneroller	<i>Campostoma oligolepis</i>		FS	-	-	(<0.0)	-	(<0.0)	(<0.0)
Goldfish	<i>Carassius auratus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Grass carp	<i>Ctenopharyngodon idella</i>		FD	0.3	0.7	(0.3)	<0.0	(<0.0)	(<0.0)
Red shiner	<i>Cyprinella lutrensis</i>		MG	<0.0	<0.0	(<0.0)	0.9	(1.5)	(22.7)
Spotfin shiner	<i>Cyprinella spiloptera</i>		FS	<0.0	<0.0	(<0.0)	0.2	(0.1)	(1.5)
Common carp	<i>Cyprinus carpio</i>		MG	0.7	0.7	(0.4)	0.3	(0.1)	(0.2)
Plains minnow	<i>Hybognathus placitus</i>		FD	-	-	(<0.0)	-	(<0.0)	(0.1)
Silver carp	<i>Hypophthalmichthys molitrix</i>		FD	0.4	0.2	(<0.0)	0.1	(<0.0)	(0.2)
Redfin Shiner	<i>Lythrurus umbratilis</i>		FS	-	-	(<0.0)	-	(<0.0)	(<0.0)
Speckled chub	<i>Macrhybopsis aestivalis</i>	X	FS	<0.0	0.1	(<0.0)	12.4	(4.3)	(0.4)
Sturgeon chub	<i>Macrhybopsis gelida</i>		FS	<0.0	<0.0	(<0.0)	1.4	(0.9)	(<0.0)

Table 2.1. Continued.

Family and common name	Scientific name	Great river species	Habitat guild	Percent composition					
				Gill net	Trammel net	Otter trawl	Mini fyke net		
Cyprinidae									
Sicklefin chub	<i>Macrhybopsis meeki</i>		FS	<0.0	<0.0	(<0.0)	9.4	(3.8)	(0.2)
Silver chub	<i>Macrhybopsis storeriana</i>	X	MG	<0.0	<0.0	(<0.0)	5.3	(16.4)	(1.2)
Hornyhead chub	<i>Nocomis biguttatus</i>		FD	-	-	(<0.0)	-	(<0.0)	(<0.0)
Golden shiner	<i>Notemigonus crysoleucas</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Emerald shiner	<i>Notropis atherinoides</i>		MG	<0.0	<0.0	(<0.0)	1.6	(5.4)	(36.2)
River shiner	<i>Notropis blennioides</i>	X	FS	<0.0	<0.0	(<0.0)	0.1	(0.8)	(7.4)
Bigmouth shiner	<i>Notropis dorsalis</i>		FS	-	-	(<0.0)	-	(<0.0)	(<0.0)
Spottail shiner	<i>Notropis hudsonius</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Sand shiner	<i>Notropis stramineus</i>		FS	<0.0	<0.0	(<0.0)	0.1	(0.1)	(4.3)
Mimic shiner	<i>Notropis volucellus</i>		MG	<0.0	<0.0	(<0.0)	0.3	(0.1)	(0.2)
Channel Shiner	<i>Notropis subspecies</i>	X	FS	<0.0	<0.0	(<0.0)	1.2	(0.8)	(0.2)
Suckermouth minnow	<i>Phenacobius mirabilis</i>		FS	-	-	(<0.0)	-	(<0.0)	(<0.0)
Bluntnose minnow	<i>Pimephales notatus</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(0.6)
Fathead minnow	<i>Pimephales promelas</i>		MG	-	-	(<0.0)	-	(<0.0)	(0.6)
Bullhead minnow	<i>Pimephales vigilans</i>		MG	<0.0	<0.0	(<0.0)	0.1	(0.2)	(2.9)
Flathead chub	<i>Platygobio gracilis</i>		FS	-	-	(<0.0)	-	(<0.0)	(<0.0)
Longnose dace	<i>Rhinichthys cataractae</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Creek chub	<i>Semotilus atromaculatus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Catostomidae									
River carpsucker	<i>Carpionodes carpio</i>		MG	1.5	1.0	(1.5)	0.5	(0.9)	(7.3)
Quillback	<i>Carpionodes cyprinus</i>		MG	0.1	0.3	(0.3)	<0.0	(<0.0)	(<0.0)
Highfin carpsucker	<i>Carpionodes velifer</i>		FS	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
White sucker	<i>Catostomus commersoni</i>		FD	0.1	<0.0	(-)	<0.0	(-)	(-)
Blue sucker	<i>Cycleptus elongatus</i>	X	FS	4.9	13.4	(15.0)	1.3	(1.2)	(<0.0)
Smallmouth buffalo	<i>Ictiobus bubalus</i>		MG	0.9	2.4	(2.4)	0.1	(0.1)	(0.1)
Bigmouth buffalo	<i>Ictiobus cyprinellus</i>		MG	<0.0	0.1	(0.1)	<0.0	(<0.0)	(<0.0)
Black buffalo	<i>Ictiobus niger</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Spotted sucker	<i>Minytrema melanops</i>		MG	<0.0	<0.0	(-)	<0.0	(-)	(-)
River redhorse	<i>Moxostoma carinatum</i>		FD	<0.0	<0.0	(-)	<0.0	(-)	(-)
Golden redhorse	<i>Moxostoma erythrurum</i>		FD	<0.0	<0.0	(-)	<0.0	(-)	(-)
Shorthead redhorse	<i>Moxostoma macrolepidotum</i>		FD	0.5	0.1	(0.4)	<0.0	(0.2)	(0.1)
Ictaluridae									
Black bullhead	<i>Ameiurus melas</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Yellow bullhead	<i>Ameiurus natalis</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Blue catfish	<i>Ictalurus furcatus</i>	X	FS	5.0	3.1	(6.7)	7.8	(20.2)	(0.1)
Channel catfish	<i>Ictalurus punctatus</i>		MG	1.4	3.0	(2.5)	28.2	(23)	(1.5)

Table 2.1. Continued.

Family and common name	Scientific name	Great river species	Habitat guild	Percent composition					
				Gill net	Trammel net	Otter trawl	Mini fyke net		
Ictaluridae									
Stonecat	<i>Noturus flavus</i>		FS	<0.0	<0.0	(<0.0)	0.3	(<0.0)	(<0.0)
Tadpole madtom	<i>Noturus gyrinus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Flathead catfish	<i>Pylodictus olivaris</i>		FD	0.2	0.2	(0.4)	0.4	(0.2)	(<0.0)
Fundulidae									
Northern studfish	<i>Fundulus catenatus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Blackstripe topminnow	<i>Fundulus notatus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Plains killifish	<i>Fundulus zebrinus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Poeciliidae									
Western mosquitofish	<i>Gambusia affinis</i>		MG	-	-	(<0.0)	-	(<0.0)	(0.4)
Atherinidae									
Brook silverside	<i>Labidesthes sicculus</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Osmeridae									
Rainbow smelt	<i>Osmerus mordax</i>		FD	-	-	(<0.0)	-	(<0.0)	(<0.0)
Percichthyidae									
White perch	<i>Morone americana</i>		FD	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
White bass	<i>Morone chrysops</i>		FD	0.1	<0.0	(<0.0)	0.1	(0.7)	(1.6)
Striped bass x White bass	<i>Morone saxatilis X M. chrysops</i>		FD	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Centrarchidae									
Green sunfish	<i>Lepomis cyanellus</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(0.2)
Green sunfish x Bluegill	<i>Lepomis cyanellus x L. macrochirus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Orangespotted sunfish	<i>Lepomis humilis</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(0.1)	(0.8)
Bluegill	<i>Lepomis macrochirus</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(0.1)	(1.3)
Longear sunfish	<i>Lepomis megalotis</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Smallmouth bass	<i>Micropterus dolomieu</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Spotted bass	<i>Micropterus punctulatus</i>		MG	-	-	(<0.0)	-	(<0.0)	(<0.0)
Largemouth bass	<i>Micropterus salmoides</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
White crappie	<i>Pomoxis annularis</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(0.2)
Black crappie	<i>Pomoxis nigromaculatus</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Percidae									
Johnny darter	<i>Etheostoma nigrum</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Logperch	<i>Percina caprodes</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Sauger	<i>Sander canadense</i>		MG	1.4	0.4	(0.8)	0.3	(0.2)	(<0.0)
Sauger x Walleye	<i>Sander canadense x S. vitreum</i>		MG	<0.0	<0.0	(<0.0)	<0.0	(<0.0)	(<0.0)
Walleye	<i>Sander vitreum</i>		MG	0.3	0.1	(<0.0)	0.1	(<0.0)	(<0.0)
Sciaenidae									
Freshwater drum	<i>Aplodinotus grunniens</i>		MG	0.6	0.5	(0.5)	8.7	(9.6)	(4.8)

Table 2.2. Number of samples taken at five channel structures with four gear types during the coldwater and warmwater season in the lower Missouri River 2003-2006.

Season and gear	L-dike		Wing dike		Channel sand bar
	Un-notched	Notched	Un-notched	Notched	
Coldwater (1 October to 30 June)					
Gill net	87	83	965	211	137
Trammel net	9	15	821	158	90
Otter trawl	36	58	727	170	90
Warmwater (1 July to 31 October)					
Trammel net	19	29	765	250	112
Otter trawl	11	45	887	251	102
Mini fyke	38	89	561	190	143