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FISH ASSEMBLAGES AT ENGINEERED AND NATURAL CHANNEL STRUCTURES IN THE LOWER MISSOURI RIVER: IMPLICATIONS FOR MODIFIED DIKE STRUCTURES†

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ABSTRACT

Large rivers throughout the world have been modified by using dike structures to divert water flows to deepwater habitats to maintain navigation channels. These modifications have been implicated in the decline in habitat diversity and native fishes. However, dike structures have been modified in the Missouri River USA to increase habitat diversity to aid in the recovery of native fishes. We compared species occupancy and fish community composition at natural sandbars and at notched and un-notched rock dikes along the lower Missouri River to determine if notching dikes increases species diversity or occupancy of native fishes. Fish were collected using gill nets, trammel nets, otter trawls, and mini fyke nets throughout the lower 1212 river km of the Missouri River USA from 2003 to 2006. Few differences in species richness and diversity were evident among engineered dike structures and natural sandbars. Notching a dike structure had no effect on proportional abundance of fluvial dependents, fluvial specialists, and macrohabitat generalists. Occupancy at notched dikes increased for two species but did not differ for 17 other species (81%). Our results suggest that dike structures may provide suitable habitats for fluvial species compared with channel sand bars, but dike notching did not increase abundance or occupancy of most Missouri River fishes. Published in 2011 by John Wiley & Sons, Ltd.

KEY WORDS: Missouri River; dike; notching; fish community; riverine fishes

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INTRODUCTION

Large rivers throughout the world have been modified for anthropogenic uses that have resulted in loss of habitat for native fishes (Sparks, 1995; Poff *et al.*, 1997; Aarts *et al.*, 2004). The Missouri River has undergone substantial modifications since the mid 1900s, 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 that direct current towards the thalweg to maintain a 2.7-m-deep channel for barge traffic. Substantial declines in several native fish populations in the lower Missouri River were attributed to these river modifications (Pflieger and Grace, 1987; Galat *et al.*, 2005). For example, declines in the populations of the federally endangered pallid sturgeon (*Scaphirhynchus albus*), shovelnose sturgeon (*Scaphirhynchus platorynchus*), bigmouth buffalo (*Ictiobus cyprinellus*), plains minnow (*Hybognathus placitus*), western silvery minnow (*Hybognathus argyritis*), sicklefin chub (*Macrhybopsis meeki*), and sturgeon chub (*Macrhybopsis gelida*) were associated with habitat modifications (Pflieger and Grace, 1987; 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 that may shift the fish assemblage towards more habitat generalists and fewer fluvial specialists (species that need flowing water for most of their life; Kinsolving and Bain, 1993; Barko *et al.*, 2004b; Pegg and McClelland, 2004) and negatively affect 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 because of channel modifications (Pflieger and Grace, 1987; Galat *et al.*,

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2005), but similar habitats can be found near engineered (man-made) structures. Dikes are constructed of rock perpendicular to the main current or in an 'L' shape with the long arm oriented downstream (referred to as wing dike and L-dike, respectively) and may be critical for large river fishes because they provide low-velocity shallow water habitats (Jennings, 1979; Brown and Coon, 1994). Fluvial species may use wing dikes because they provide some of the only low-velocity waters remaining in the channelized river or it is the next best physical habitat for their ecological needs (Barko *et al*., 2004a, 2004b).

Many L-dikes and wing dikes in the Missouri River have been 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 to benefit larval and juvenile pallid sturgeon and other native fishes (Quist *et al*., 2004). Estimates by the U.S. Army Corps of Engineers indicate that notching one dike may increase shallow water habitat suitable for native fishes by $4000\,m^2$ per dike (Papanicolaou *et al*., 2011). However, there have been few peer-reviewed publications that report whether modifying dike structures has provided benefits to native fishes (Barko *et al*., 2004b; Papanicolaou *et al*., 2011). The objective of this study was to determine if fish assemblages and species occupancy differed among unnotched and notched L-dikes and wing dikes and natural channel sand bars. We hypothesized 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.

METHODS

Sampling was conducted from 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 kilometre (rkm) 1212 to the confluence of the Mississippi River at St. Louis, Missouri (rkm 0) (Wanner *et al*., 2007; Doyle *et al*., 2008). This portion of the Missouri River is characterized by numerous rock dike structures that direct water into the thalweg to maintain a 2.7-m-deep navigational channel (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). Wing dikes are straight rock structures constructed perpendicular to the main current and located along inside river bends (Jacobson *et al*., 2002). The greatest depths are found near the main channel margins and at scour holes (i.e. deep-water areas created by flowing water) downstream from their tip. Shallow areas form behind the dike and near the shoreline where substrate deposition occurs. Water velocities at wing dikes were 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 that 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 (Jacobson *et al*., 2002). Most L-dikes are located near outside river bends and channel crossovers that utilize the long arm to protect river banks from high water velocities. 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 (Papanicolaou *et al*., 2011). 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 has been notching L- and wing dikes since 2004 to diversify fish habitats (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). In contrast, sand bar habitats represent the most natural habitats remaining in the lower Missouri River. They are dominated by a sand substrate and gradient $<10°$, which differ from engineered dike structures where the gradient ranges from 20° to 40° with more variable substrate composition (Jacobson *et al*., 2002; Laustrup *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) that 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*., 2008). River bends were randomly selected each year (Wanner *et al*., 2007; Doyle *et al*., 2008) and sampled with a suite of gears during the coldwater season (1 October to 30 June when water temperatures were $\leq 13°C$) and the warmwater season (1 July to 31 October).

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Gears deployed during the coldwater season were stationary gill nets, drifted trammel nets, and towed otter trawls; gears deployed during the warmwater season were drifted trammel nets, towed otter trawls, and mini fyke nets. Gill nets were not deployed during the warmwater season to minimize fish mortality. Mini fyke nets replaced gill nets during the warmwater season to sample young of year and juvenile fishes as an index of recruitment. Samples were distributed according to the available habitat at each bend with a minimum of eight samples per gear at five channel structure types (i.e. notched and un-notched L-dikes and wing dikes and channel sand bars).

Gill nets were deployed overnight for 12–24h parallel to the flow and bankline in low-velocity habitats where depths were >1.2m (Doyle *et al*., 2008). A gill net consisted of four 7.6-m sections (2.4m high) made of 3.8-, 5.1-, 7.6-, and 10.2-cmbar multifilament mesh organized in ascending order. One 30.5m length of net deployed overnight was one unit of effort. Trammel nets were drifted a minimum of 75m and a maximum of 300m with the current near the main channel borders of dike structures and sand bars (Doyle *et al*., 2008). Nets were 38.1m long with a 2.4m high centre wall of 2.5-cm multifilament nylon mesh. The outer wall was 1.8m high and made of 20.3cm multifilament nylon mesh on both sides. Catch per unit effort was fish per 100m drifted. Otter trawls were towed a minimum of 75m and a maximum of 300m through pools or banklines where water depths were >1.2m. The trawl net was 4.9m wide, 0.9m high, 7.6m long, with 0.64cm inner bar mesh and 3.8cm outer chafing mesh and towed with 76.2×38.1-cm plywood boards (i.e. trawl doors) to open the net (Doyle *et al*., 2008). Catch per unit effort was fish per 100m trawled. Mini fyke nets were set overnight for 12–24h in low-velocity shallow water (<1.2m) habitats. Small Wisconsin-type fyke nets were made of a 4.5m lead, two rectangular steel frames (1.2×0.6m), 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 (mm) or fork length for sturgeons (*Scaphirhynchus*) spp. 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 if it was a great river species (GRS) based on definitions by Becker (1983), Pflieger (1997), Galat *et al*. (2005), and Thomas *et al*. (2005) (Table I). Fluvial dependent fishes rely on flowing water for part of their life cycle (usually reproduction), fluvial specialists use flowing water for most of their life, and macrohabitat generalists are commonly found both in lentic and lotic systems. Great river species were described as a distinct assemblage 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 analysed 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 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). A two-way analysis of variance (ANOVA) was performed with channel structure and gear type as the main effects to test the null hypothesis that mean richness, diversity, proportional abundance by habitat guild, and proportional abundance of GRS did not differ among channel structures. 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 ($p \leq 0.05$).

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 each season using occupancy models run in program PRESENCE (Hines 2006). Occupancy (ψ) 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 because of 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 to estimate p were accrued from samples taken within the same channel structure classification and bend over the 4-year study period, which is a form of spatial replication (MacKenzie *et al*., 2002, 2006). Species were analysed if they were present in ≥10% of samples within a gear. We used this criterion because the optimal number of replicate surveys necessary to achieve reasonably precise occupancy estimates were not completed for species with low detection probabilities (<0.10; MacKenzie and Royle, 2005).

We used an information theoretic approach to determine which of two candidate models best explained the data. We hypothesized that occupancy may vary by structure type (i.e. L-dike, wing dike, or channel sand bar regardless of notching) and notch type (i.e. un-notched or notched dikes regardless of dike type and channel sand bar). A third model that included all five channel structures (i.e. un-notched and notched L-dikes and wing dikes and channel sand bars) was used as the global model with the most parameters to estimate overdispersion of the data ($\hat{c}$). Akaike Information

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Table I. Missouri River fishes designation as a Great River Species, habitat guild, and the percentage composition for each species caught with four gear types in the Missouri River during the coldwater (1 October to 30 June) and warmwater season (1 July to 31 October; in parenthesis) from 2003 to 2006

Family and name	Great river species	Habitat guild	Percent composition			
			Gill net (n=26045)	Trammel net (n=9300)	Otter trawl (n=41167)	Mini fyke net (n=96154)
Acipenseridae						
Lake sturgeon, *Acipenser fulvescens*	Yes	FD	0.2	(0.2)		
Pallid sturgeon, *Scaphirhynchus albus*	Yes	FS	0.2	0.6 (0.4)	0.1	
Shovelnose sturgeon, *Scaphirhynchus platorynchus*	Yes	FS	65.1	60.3 (60.5)	16.6 (6.0)	
Shovelnose × pallid hybrid, *Scaphirhynchus platorynchus* × *S. albus*	Yes	FS	0.1	0.1 (0.1)		
Polyodontidae						
Paddlefish, *Polyodon spathula*	Yes	FD	0.2		0.8	
Lepisosteidae						
Longnose gar, *Lepisosteus osseus*		FD	2.2	0.9 (1.0)	0.1	(0.1)
Shortnose gar, *Lepisosteus platostomus*	Yes	MG	2.6	0.3 (0.5)	0.1	(0.7)
Hiodontidae						
Goldeye, *Hiodon alosoides*	Yes	FD	9.2	9.3 (5.4)	0.8 (2.2)	
Mooneye, *Hiodon tergisus*	Yes	FD			(0.1)	
Clupeidae						
Skipjack herring, *Alosa chrysochloris*	Yes	FD		0.2 (0.1)		
Gizzard shad, *Dorosoma cepedianum*		MG	1.5	1.2 (0.3)	0.2 (0.4)	(1.2)
Cyprinidae						
Grass carp, *Ctenopharyngodon idella*		FD	0.3	0.7 (0.3)		
Red shiner, *Cyprinella lutrensis*		MG		(0.09)	0.9 (1.5)	(22.7)
Spotfin shiner, *Cyprinella spiloptera*		FS			0.2 (0.1)	(1.5)
Common carp, *Cyprinus carpio*		MG	0.7	0.7 (0.4)	0.3 (0.1)	(0.2)
Plains minnow, *Hybognathus placitus*		FD				(0.1)
Silver carp, *Hypopthalmichthys molitrix*		FD	0.4	0.2	0.1	(0.2)
Speckled chub, *Macrhybopsis aestivalis*	Yes	FS		0.1	12.4 (4.3)	(0.4)
Sturgeon chub, *Macrhybopsis gelida*		FS			1.4 (0.9)	
Sicklefin chub, *Macrhybopsis meeki*		FS			9.4 (3.8)	(0.2)
Silver chub, *Macrhybopsis storeriana*	Yes	MG			5.3 (16.4)	(1.2)
Emerald shiner, *Notropis atherinoides*		MG			1.6 (5.4)	(36.2)
River shiner, *Notropis blennius*	Yes	FS			0.1 (0.8)	(7.4)
Sand shiner, *Notropis stramineus*		FS			0.1 (0.1)	(4.3)
Mimic shiner, *Notropis volucellus*		MG			0.3 (0.1)	(0.2)
Channel shiner, *Notropis subspecies*	Yes	FS			1.2 (0.8)	(0.2)
Bluntnose minnow, *Pimephales notatus*		MG				(0.6)
Fathead minnow, *Pimephales promelas*		MG				(0.6)
Bullhead minnow, *Pimephales vigilas*		MG			0.1 (0.2)	(2.9)
Catostomidae						
River carpsucker, *Carpiodes carpio*		MG	1.5	1.0 (1.5)	0.5 (0.9)	(7.3)
Quillback, *Carpiodes cyprinus*		MG	0.1	0.3 (0.3)		
Blue sucker, *Cycleptus elongatus*	Yes	FS	4.9	13.4 (15.0)	1.3 (1.2)	
Smallmouth buffalo, *Cycleptus elongatus*		MG	0.9	2.4 (2.4)	0.1 (0.1)	(0.1)
Bigmouth buffalo, *Ictiobus cyprinellus*		MG		0.1 (0.1)		
Shorthead redhorse, *Moxostoma macrolepidotum*		FD	0.5	0.1 (0.4)	(0.2)	(0.1)
Ichtaluridae						
Blue catfish, *Ictalurus furcatus*	Yes	FS	5.0	3.1 (6.7)	7.8 (20.2)	(0.1)
Channel catfish, *Ictalurus punctatus*		MG	1.4	3.0 (2.5)	28.2 (23.0)	(1.5)
Stonecat, *Noturus flavus*		FS			0.3	
Flathead catfish, *Pylodictus olivaris*		FD	0.2	0.2 (0.4)	0.4 (0.2)	
Poeciliidae						
Western mosquitofish, *Gambusia affinis*		MG				(0.4)

(*Continues*)

Table I. (Continued)

Family and name	Great river species	Habitat guild	Percent composition			
			Gill net (n=26045)	Trammel net (n=9300)	Otter trawl (n=41167)	Mini fyke net (n=96154)
Percichthyidae						
White bass, *Morone chrysops*		FD	0.1		0.1 (0.7)	(1.6)
Centrarchidae						
Green sunfish, *Lepomis cyanellus*		MG				(0.2)
Orangespotted sunfish, *Lepomis humilis*		MG			(0.1)	(0.8)
Bluegill, *Lepomis macrochirus*		MG			(0.1)	(1.3)
White crappie, *Pomoxis annularis*		MG				(0.2)
Percidae						
Sauger, *Sander canadense*		MG	1.4	0.4 (0.8)	0.3 (0.2)	MG
Walleye, *Sander vitreum*		MG	0.3	(0.1)	0.1	MG
Sciaenidae						
Freshwater drum, *Aplodinotus grunniens*		MG	0.6	0.5 (0.5)	8.7 (9.6)	(4.8)

Values and species less than 0.1% are not reported; n, number of fish collected with each gear; FD, fluvial dependent; FS, fluvial specialist; MG, macrohabitat generalist.

Criterion (AIC) values were adjusted if $\hat{c}$ was >1 (MacKenzie *et al*., 2006). The AIC method encouraged parsimony (i.e. model with the fewest parameters necessary), and models with a delta AIC of less than 2 were considered to have similar support (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 did not overlap.

RESULTS

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, with >150 samples from each gear, season, and habitat. Only 9–89 samples were collected at L-dikes, depending on gear type (Table II). A total of 157875 fish representing 82 species and four hybrids were captured during both seasons. However, only 48 species were collected in at least 0.1% of the samples of at least one gear (Table I). Of the 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 blennius*) (12.7%); and macrohabitat generalists by emerald

Table II. Number of samples collected at five channel structure types 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

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shiner (*Notropis atherinoides*) (34.3%), red shiner (*Cyprinella lutrensis*) (21.0%), and channel catfish (*Ictalurus punctatus*) (11.5%).

Does fish assemblage structure differ among the different channel structures?

Species richness and diversity indices had significant channel structure and gear interactions during the coldwater season ($ps < 0.001$) and marginally significant interactions during the warmwater season ($p = 0.066$ and 0.059). Therefore, individual ANOVA's were performed by gear type to determine differences among channel structures. The null hypothesis that species richness and diversity did not differ among channel structures was not rejected for all gear types and seasons ($ps > 0.07$), except gill nets during the coldwater season ($ps < 0.01$; Figure 1). During the coldwater season, 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. Gill net mean species richness also tended to be higher at L-dikes and lowest in channel sand bars. We did not reject the null hypothesis that species diversity and richness did not differ among channel structures for most gears. Trammel nets generally had the lowest mean species diversity

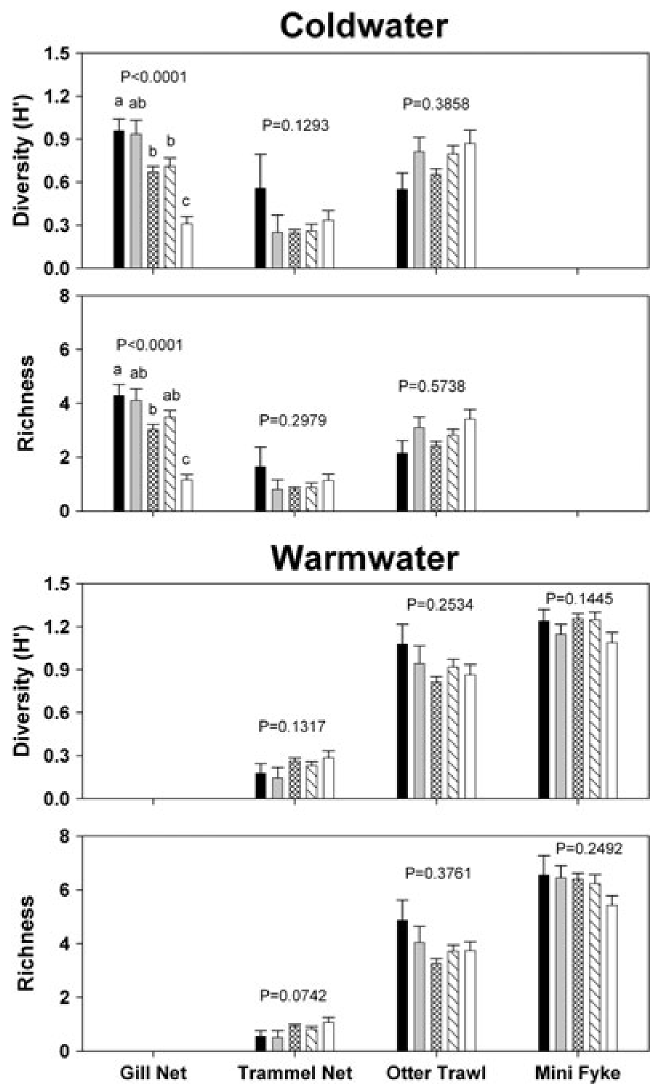

Figure 1. Mean Shannon Weiner fish diversity (H′) and species richness for fish collected in gill nets, trammel nets, otter trawls, and mini fyke nets at un-notched L-dike (black bars), notched L-dike (gray bars), un-notched wing dike (crosshatched bars), notched wing dike (single hatched bars), and channel sand bar (white bars) during the coldwater (1 October to 30 June) and warmwater seasons (1 July to 31 October) in the Missouri River from 2003 to 2006. Error bars represent one standard error

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and richness per sample regardless of season, 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 ($ps < 0.05$) and marginally significant for fluvial

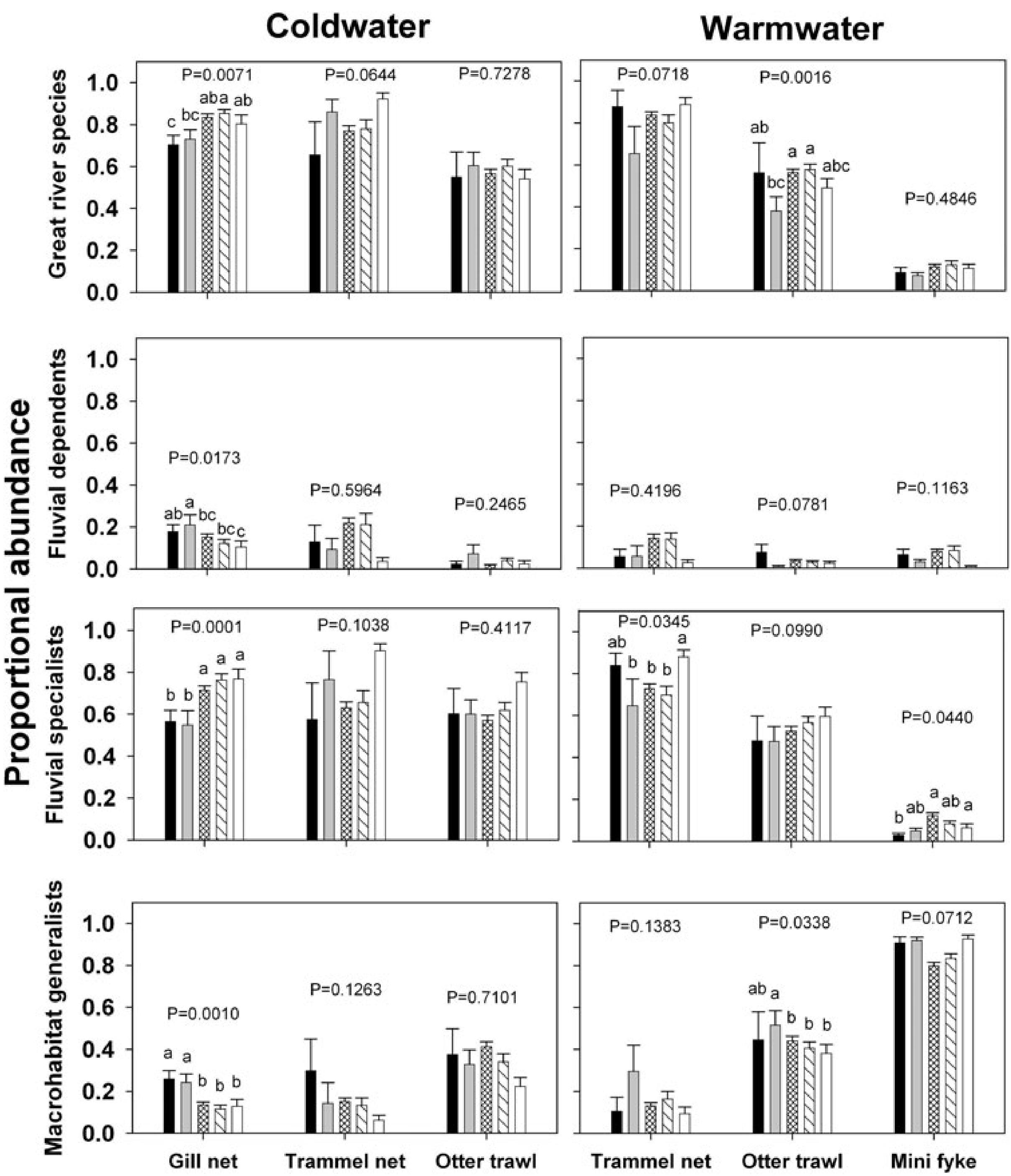

Figure 2. Proportion of fish caught that were classified as great river species (Table I), fluvial dependents, fluvial specialists, and macrohabitat generalists at un-notched L-dike (black bars), notched L-dike (gray bars), un-notched wing dike (crosshatched bars), notched wing dike (single hatched bars), and channel sand bar (white bars) with gill nets, trammel nets, and otter trawls during the coldwater season (1 October to 30 June) and with trammel nets, otter trawls, and mini fyke nets during the warmwater season (1 July to 31 October) in the Missouri River from 2003 to 2006. Error bars are one standard error

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dependents during the warmwater season ($p=0.109$). Fluvial specialists averaged 66.9% of fish collected over all gears in the coldwater season, whereas fluvial dependents and macrohabitat generalists comprised 10.8% and 22.3%, respectively (Figure 2). We rejected the null hypothesis that proportional abundance of each habitat guild did not differ among channel structures only with gill nets in the coldwater season. Gill net samples collected at L-dikes had greater proportional abundance compared with wing dikes and channel sand bars for fluvial dependent and macrohabitat generalists, 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 ($ps>0.05$). During the warmwater season, fluvial dependent species generally comprised a low percentage (<15%) of the total catch (Figure 2). Fluvial specialists accounted for 75.8%, 52.8%, and 7.0% of the total catch in trammel nets, otter trawls, and mini fyke nets, respectively, 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 gear types, but 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

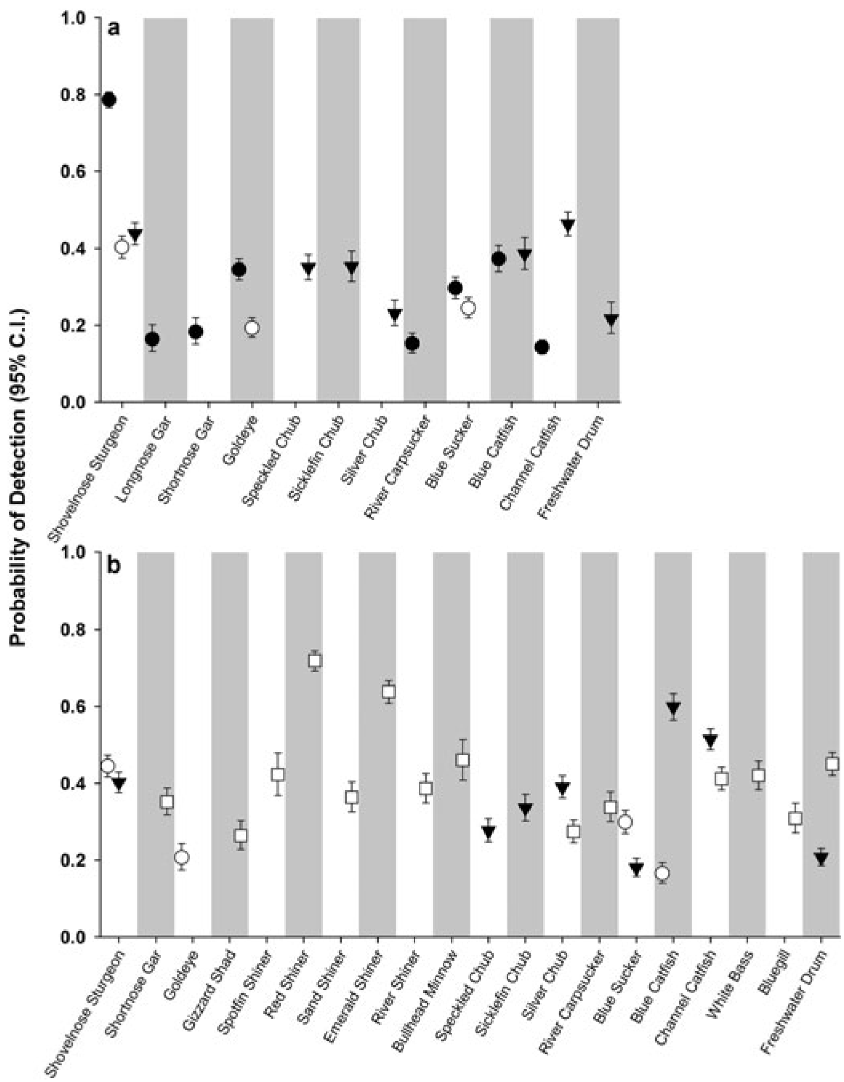

Figure 3. Probability of detecting Missouri River fishes with gill nets (black circles), trammel nets (white circles), otter trawls (black triangles), and mini-fyke nets (white squares) during the coldwater (a; 1 October to 30 June) and warmwater seasons (b; 1 July to 31 October) from 2003 to 2006. Error bars are 95% confidence intervals

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but similar among the other channel structures (p=0.03). There was no evidence of greater proportional abundance at notched dikes compared with un-notched dikes for any habitat guild (Figure 2).

Great river species comprised on average >50% of the total catch for all gears and seasons, except mini fyke nets (Figure 2). Great river species had significant channel structure and gear type interactions during both seasons (ps$<$ 0.05), but proportional abundance 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, and warmwater otter trawls caught the lowest proportion at notched L-dikes (Figure 2). Notched dikes had similar proportional abundance of GRS to un-notched L- and wing dikes for all gears and seasons.

Did the probability of occupancy differ among the different channel structures?

Of the 82 total species captured, 12 and 20 species were present in ≥10% of the samples collected within a gear during the coldwater and warmwater season, respectively.

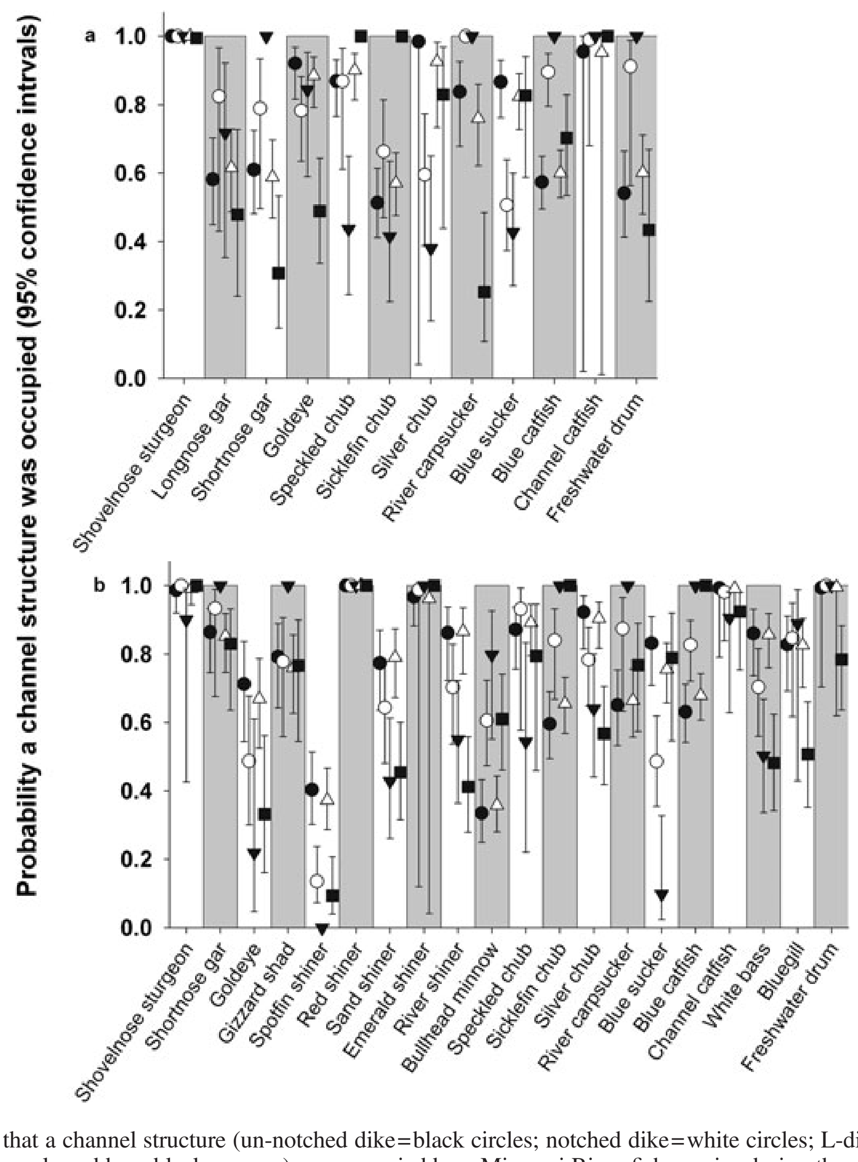

Figure 4. The probability that a channel structure (un-notched dike=black circles; notched dike=white circles; L-dike=black triangles; wing dike=white triangles; channel sand bar=black squares) was occupied by a Missouri River fish species during the coldwater (a; 1 October to 30 June) and warmwater seasons (b; 1 July to 31 October) from 2003 to 2006. Error bars are 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

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Probability of detection generally ranged from 0.15 to 0.60 but was as high as 0.79 for shovelnose sturgeon with gill nets (Figure 3). 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 because of models unable to converge on a solution at the extreme upper or lower probability bounds.

We rejected the hypothesis that notching affected occupancy of most species. Notching affected occupancy of only four species and with variable results (Figure 4). Blue sucker had lower occupancy at notched dikes (0.35 mean lower occupancy), whereas 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 vigila*) had higher occupancy at notched dikes (0.27 higher occupancy) but only during the warmwater season. Dike notching did not significantly affect occupancy for over 80% of the species analysed.

Comparisons of occupancy at dike structures with 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 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

Table III. Occupancy model results from testing the hypothesis that occupancy was affected by structure type and notching

Season and species	$\hat{c}$	Δ(Q)AIC		Model weight		Model likelihood		*K*
		Notching	Structure type	Notching	Structure type	Notching	Structure type	
Coldwater (1 October to 30 June)								
Shovelnose sturgeon	0.0	0.0	0.0	0.50	0.50	1.00	1.00	6
Longnose gar	0.0	0.0	3.2	0.83	0.17	1.00	0.20	4
Shortnose gar	0.0	7.8	0.0	0.02	0.98	0.02	1.00	4
Goldeye	0.0	0.0	3.7	0.86	0.14	1.00	0.16	5
Speckled chub	0.1	13.9	0.0	0.00	1.00	0.00	1.00	4
Sicklefin chub	0.1	0.0	0.7	0.58	0.42	1.00	0.72	4
Silver chub	0.2	2.6	0.0	0.64	0.36	0.27	1.00	5
River carpsucker	0.0	7.7	0.0	0.02	0.98	0.02	1.00	4
Blue sucker	1.5	0.0	2.7	0.79	0.21	1.00	0.26	6
Blue catfish	0.0	11.7	0.0	0.00	1.00	0.00	1.00	5
Channel catfish	0.0	1.1	0.0	0.37	0.63	0.58	1.00	5
Freshwater drum	0.3	0.0	3.3	0.84	0.16	1.00	0.20	4
Warmwater (1 July to 31 October)								
Shovelnose sturgeon	1.0	0.0	0.1	0.52	0.48	1.00	0.93	5
Shortnose gar	0.3	3.8	0.0	0.13	0.87	0.15	1.00	4
Goldeye	8.7	0.1	0.0	0.49	0.51	0.95	1.00	5
Gizzard shad	0.0	2.8	0.0	0.20	0.80	0.25	1.00	4
Red shiner	43.1	0.0	0.0	0.50	0.50	1.00	1.00	5
Spotfin shiner	0.5	15.9	0.0	0.00	1.00	0.00	1.00	4
Speckled chub	0.0	2.4	0.0	0.23	0.77	0.30	1.00	4
Sicklefin chub	0.0	0.0	4.5	0.90	0.10	1.00	0.11	4
Silver chub	3.0	2.6	0.0	0.21	0.79	0.27	1.00	6
Emerald shiner	33.7	0.0	0.0	0.50	0.50	0.99	1.00	5
River shiner	1.6	3.5	0.0	0.15	0.85	0.18	1.00	5
Sand shiner	0.5	8.4	0.0	0.01	0.99	0.02	1.00	4
Bullhead minnow	0.0	7.6	0.0	0.02	0.98	0.02	1.00	4
River carpsucker	0.0	4.0	0.0	0.12	0.88	0.14	1.00	4
Blue sucker	7.4	1.0	0.0	0.37	0.63	0.59	1.00	6
Blue catfish	0.0	1.5	0.0	0.32	0.68	0.47	1.00	5
Channel catfish	0.2	1.3	0.0	0.35	0.65	0.53	1.00	5
White bass	0.7	8.9	0.0	0.01	0.99	0.01	1.00	4
Bluegill	1.6	0.1	0.0	0.48	0.52	0.93	1.00	5
Freshwater drum	0.0	0.0	0.1	0.51	0.49	1.00	0.95	5

Overdispersion correction factor ($\hat{c}$), difference in Akaike Information Criterion (ΔAIC) or quasi AIC (QAIC), model weight, model likelihood, and number of parameters (*K*) are presented for the coldwater and warmwater seasons. Quasi AIC was used as the information criterion when $\hat{c}$ was >1.0.

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parameterized with structure type had greater weight indicating they were the best fit model compared with models with notching (Table III). 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

Our study found that fluvial specialists and dependents comprised 50.9%–77.7% of the total catch from the Lower Missouri River. 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 (Pflieger and Grace, 1987; Galat *et al*., 2005). Regulation of the lower Missouri River through dike structures eliminated the conditions that many fluvial species were adapted. Although 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. Low relative abundance of fluvial species suggests a system may be degraded and moving towards a fish assemblage dominated by tolerant species (Barko *et al*., 2004b; Eitzmann and Paukert, 2010). Our study used similar gears as those of 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 (Kinsolving and Bain, 1993; Pegg and McClelland, 2004; Galat *et al*., 2005).

Our study found few differences in community indices among channel structures. Channel sand bars were 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). Therefore, we hypothesized that fluvial species would associate with channel sand bars more than dike structures, whereas generalist species would associate with dike structures because they simulate both lentic and lotic systems (Madejczyk *et al*., 1998). However, 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). This is similar to other midwestern USA rivers where only slight variations in richness and diversity were found among differing habitat types (Madejczyk *et al*., 1998; White *et al*., 2010). The proportion of fluvial specialists collected at channel sand bars was similar to other dike structures, which did not show that fluvial specialists would be more common in channel sand bars. Natural channel sand bars represent the highest proportion of natural habitat type remaining in the lower Missouri River and might be expected to have a higher percent of fluvial dependents or fluvial specialists relative to man-made dike structures. Some adult fluvial dependent and specialist species were most abundant in wing dikes in the Mississippi River but had no strong habitat associations (Barko *et al*., 2004b), which was similar to our findings.

Dike structures may provide some of the only low-velocity and structural habitat outside of the main channel, but this may vary with discharge (Papanicolaou *et al*., 2011). 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 backwaters may have resulted in declines of 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 they provide nursery habitats once prevalent in the pre-modified Missouri River (Ridenour *et al*., 2009), which was similar to the Kanawha River, West Virginia (Niles and Hartman, 2011). Collectively, these results emphasize the importance of dike structures and the associated low-velocity habitats to maintain fluvial fish populations.

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. We found blue sucker had higher occupancy at wing dikes than L-dikes, probably 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 with the higher velocity waters at main channel border habitats (Barko *et al*., 2004a). Generalist species, such as Centrarchids, may use dikes because they simulate more lentic conditions (Barko *et al*., 2004a; Hartman and Titus, 2010), 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,

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1986; Madejczyk *et al*., 1998; Barko *et al*., 2004a). Therefore, dike structures may provide suitable habitats for both lentic and lotic fishes.

We made no attempts to characterize habitat use by fish size or maturity, which may have confounded our analyses and explain why we found few differences between dikes and sand bars for many species and habitat guilds. Differential habitat use was found for three chub (*Macrhybopsis*) spp. in the lower Missouri River with smaller chubs associated with low-velocity dike structures and chubs >25 mm with channel sand bars (Ridenour *et al*., 2009). 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). Future work may need to consider focusing on habitat use by size class.

Fish community indices and species occupancy were generally similar between un-notched and notched dikes. The purpose of notching dikes was to diversify the physical habitat that may benefit large river obligate fishes. Occupancy at notched dikes differed for only four species: blue sucker and spotfin shiner occupancy was lower than un-notched dikes, whereas blue catfish and bullhead minnow occupancy was higher than un-notched dikes. Papanicolaou *et al*. (2011) found that notching did not increase the amount of shallow water habitat, and our study found little evidence that fish assemblages responded to these modifications. Dike notching has occurred at a large scale since 2004, but it may take a longer period or large flow events for the adjacent physical habitat to adjust (Jacobson *et al*., 2004) in order to elicit a fish community response. Pegg and McClelland (2004) found a considerable response time from the fish community to improved water quality in the Illinois River, which warrants continuation of long-term studies to understand the impacts of notching on the fish assemblage.

Our study suggests that notching dikes does not necessarily increase occupancy of native Missouri River fishes. Mitigation efforts (i.e. dike notching) on the Missouri River have focused on the creation of shallow water habitat (<1.5 m depth and velocities 0–0.6 m/s; U.S. Fish and Wildlife Service, 2000; Papanicolaou *et al*., 2011) because it is widely accepted that survival and growth of young fish is dependent on the availability of these habitats (Scheidegger and Bain, 1995; Freeman *et al*., 2001). Dike notching was one method used to recreate physical habitat conditions most similar to those found prior to river modification. Although few fluvial species showed a positive response to notching, this may be a result of selective habitat use during various life stages not accounted for in this study. We 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 behind dike structures (Ridenour *et al*., 2009). In addition, Papanicolaou *et al*. (2011) found that dike notching did not create the shallow water habitat that was considered suitable for native fishes.

Future channel modification efforts may consider the diverse habitats created by dike structures and the importance they have for native fluvial species. Our findings suggest that the current method of notching dikes may not increase native fish assemblages, probably because notching did not increase shallow water habitats for these fishes (Papanicolaou *et al*., 2011). Altering low-velocity areas through dike notching had variable effects on fluvial species and may not necessarily elicit the response expected from many large river obligate fishes, but this may vary under different flow regimes that we did not study. Future mitigation and restoration efforts may need to determine alternative methods to create suitable habitats needed for native large river fishes.

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