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HABITAT USED BY *MACRHYBOPSIS* CHUBS ASSOCIATED WITH CHANNEL MODIFYING STRUCTURES IN A LARGE REGULATED RIVER: IMPLICATIONS FOR RIVER MODIFICATION†

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ABSTRACT

We examined use of channel modifying structures (CMS; e.g., engineered rock dikes, channel sandbars) and their associated smaller spatial-scale habitats (SSH) on lower Missouri River, USA, by speckled chub (*Macrhybopsis aestivalis*), sicklefin chub (*M. meeki*) and sturgeon chub (*M. gelida*) from June through October, 2006 to identify important habitat characteristics that could aid conservation. We sampled chubs primarily in six CMS types: L-dikes, wing-dikes, kicker dikes, rootless dikes, channel sandbars and bank-lines. Ninety-three per cent of chubs were collected from L-dikes, wing-dikes and channel sandbars. Unidentifiable *Macrhybopsis* chubs (UHY) were less than 35-mm TL, were collected early in the sampling season and were most associated with L-dikes where mean bottom current velocity was slow (0.07 m/s). Chubs large enough to be identified to species were associated with large channel sandbars where mean bottom current velocity was faster (0.34 m/s). Chubs from wing-dikes were more abundant in shallow water (<1.2 m deep) adjacent to bars than in deeper (>1.2 m deep), open-water areas ($p = 0.007$). Month accounted for 54% and CMS with SSH 18% of explained variation in chub species distribution and abundance. Our results demonstrate that CMS in the contemporary lower Missouri River channel provide multiple habitats for multiple life-stages of *Macrhybopsis* chubs (e.g., nursery and post-nursery habitats). L- and wing-dikes may provide surrogate nursery habitats for chubs where in-channel slow-velocity areas were lost after river channelization. Managing CMS to address life history stages and an ecologically appropriate proportion and distribution of dike to channel sandbar habitats may be critical for conservation of native *Macrhybopsis* chubs in lower Missouri River. Published in 2008 by John Wiley & Sons, Ltd.

KEY WORDS: *Macrhybopsis*; channel modifying structure; dike and channel sandbar; regulated river; habitat use; ontogenetic habitat shift

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INTRODUCTION

Populations of native fish species have declined in many large regulated rivers where habitats required to complete life history cycles are degraded (Dynesius and Nilsson, 1994; Sparks, 1995; Ward *et al*., 1999; Humphries *et al*., 2002; Aarts *et al*., 2004; Hirzinger *et al*., 2004). The Missouri River, USA is significantly altered to regulate flows for barge traffic navigation and provide flood protection. Six main-stem dams impede flow in much of the upper two-thirds of the river, and channel modifying structures (CMS; e.g., engineered rock wing-dikes, rock revetments) on the lower one-third straighten and narrow the channel, continuously redirect flow towards the thalweg and inhibit fluvial processes that create and maintain fish habitat (Hesse and Mestl, 1993; Nestler and Sutton, 2000; Galat *et al*., 2005a). Biologists have concurrently observed decline in populations of many native archetypical big-river fish species in lower Missouri River: pallid sturgeon (*Scaphirhynchus albus*) were added to the endangered species list in 1990; flathead chub (*Platygobio gracilis*) were historically among the most common cyprinidae collected in seine hauls, but now are rarely collected and many *Macrhybopsis* chubs have declined since river modification was completed (Cross and Moss, 1987; Galat *et al*., 2005b).

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Essential fish habitat in marine and estuarine environments is defined as 'those waters and substrates necessary to fish for spawning, breeding, feeding or growth to maturity' (US Department of Commerce, 1996). Nursery areas provide refuge from harsh environments and other mortality risks, and are important to recruitment and maintenance of fish populations because early life stages (e.g., larvae and juvenile) represent periods when fishes are vulnerable to mortality (Fuiman and Werner, 2002). Degradation of essential fish habitat was identified as a key threat to biodiversity and fish population sustainability in estuarine environments (Schmitten, 1999). Similarly, research from several freshwater lotic environments suggests that decline of native fishes in regulated rivers may be due to a reduction of suitable spawning areas or flows for adults, or nursery areas for recruitment of young (Gehrke *et al*., 1995; Jurajda, 1995; Humphries and Lake, 2000; Aarts *et al*., 2004). Populations of native riverine fish have shown positive responses to engineered off-channel areas in European rivers where constructed floodplain water bodies were connected to the main channel to restore nursery habitat (Bayley *et al*., 2000; Langler and Smith, 2001). Data on how native fishes in lower Missouri River may similarly utilize CMS, ranging from highly engineered (e.g., rock dikes) to more naturally derived types (e.g., channel sandbars), relative to life-history stage will improve management decisions to support fisheries restoration.

Macrhybopsis chubs are small-bodied fishes whose adults usually do not exceed 130 mm TL (Pflieger, 1997). Four species are present in lower Missouri River: speckled chub (*Macrhybopsis aestivalis*), sicklefin chub (*M. meeki*) and sturgeon chub (*M. gelida*) are obligate riverine species because they require flowing water throughout their life history, and silver chub (*M. storeiana*) was classified as a macrohabitat generalist (Galat *et al*., 2005b). The importance of the four *Macrhybopsis* chubs to the ecology of other native species in lower Missouri River is unknown. However, two of the obligate riverine species, sicklefin chub and sturgeon chub, were found to comprise a high proportion of juvenile pallid sturgeon diets in upper Missouri River (Gerrity *et al*., 2006)—this suggests that obligate *Macrhybopsis* chubs may play a critical role in the survival and persistence of native riverine fishes within the upper and lower river.

Many studies have examined microhabitat use of *Macrhybopsis* chubs relative to proximate environmental factors such as water depth, water velocity, substrate composition and temperature (Kopf, 2003; Everett *et al*., 2004; Welker and Scarnecchia, 2006; Ridenour, 2007). Dieterman and Galat (2004) evaluated the effect of temperature, turbidity, flow and piscivore abundance on sicklefin chub on a larger 'riverscape' scale and found that long free-flowing reaches with natural variation in seasonal flows and turbidity promote conservation of the species. These environmental factors are continuously dynamic and vary with river discharge and season. Channel modifying structures, on the other hand, are an intermediate spatial scale and are static, although the smaller-scale proximate environmental factors associated with each may vary. They are easily classified in the field and do not require specialized equipment to measure or quantify. The U.S. Army Corps of Engineers implements habitat improvement projects for fish on CMS to effect proximate environmental factors on Missouri River (US Army Corps of Engineers, 2006).

Channel modifying structures are numerous on lower Missouri River, and maintain habitats at adjacent smaller spatial scales (Frissell *et al*., 1986; Tonn, 1990; Poff, 1997) by effecting flow velocity and water depth. Engineered rock dikes with their associated smaller spatial-scale habitats (SSH) comprise a majority of lower Missouri River water not located within the thalweg. Channel sandbars that form on the inside of river bends are generally less engineered and less abundant than engineered rock dike structures, yet do influence main-channel morphology and hence habitats available to fishes—they represent the most natural type of CMS at this spatial scale. Other researchers in lower Missouri River have found that obligate riverine chubs use CMS-type habitats (Jennings, 1979; Grady and Milligan, 1998; Reeves, 2006; Ridenour, 2007). Therefore, we examined habitat use of obligate *Macrhybopsis* chubs relative to CMS to guide recovery of obligate small-bodied fishes in regulated rivers and identify important life-history stage habitats for chubs during ontogeny. We had two objectives. First, to determine how *Macrhybopsis* chub species composition, abundance and body length varied among common types of CMS and their SSH in lower Missouri River. We used composition and abundance to assess whether chubs differentially used types of CMS, and body length to identify probable life-history stages (e.g., juvenile) of fishes that may use different types of CMS. Our second objective was to quantify depth, velocity, turbidity and substrate composition to provide a background for how CMS may differ with respect to these proximate environmental factors and potentially use them to help explain biological differences in abundance or body length of chubs among CMS.

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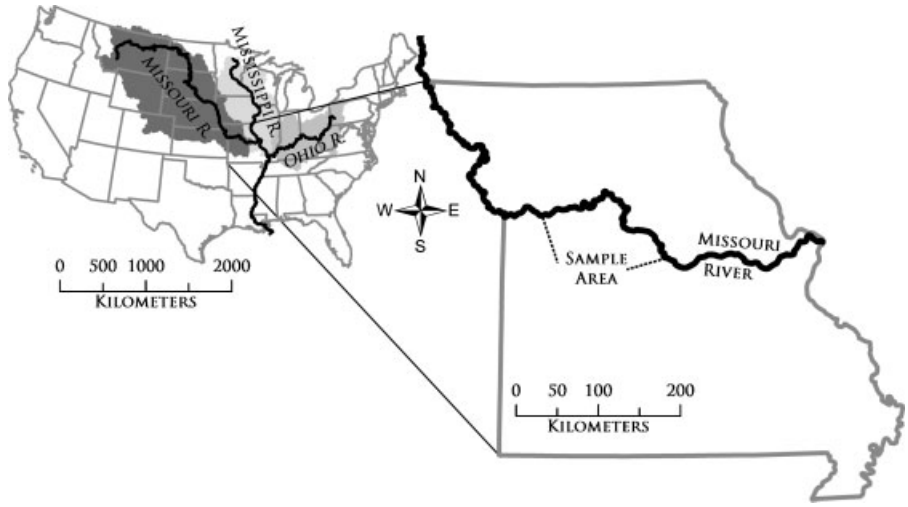

Figure 1. Map showing location of Missouri River basin and lower Missouri River study area

STUDY AREA

Missouri River is the longest named river in North America and drains nearly 1.4 million square kilometres including all or parts of 10 U.S. states and two Canadian provinces (Galat *et al*., 2005a). The named Missouri River begins at the confluence of the Jefferson, Madison and Gallatin Rivers in Montana (river kilometre, RKM, 3 768) and flows southeast to its terminal confluence with Mississippi River near St. Louis, Missouri (RKM 0). Our study area included 10 sites on lower Missouri River within the state of Missouri from RKM 526 downstream to RKM 255 (Figure 1). Maximum, mean and minimum river length of our 10 sites was 6.1, 3.8 and 2.4 km, respectively.

MATERIALS AND METHODS

Data collection

Habitat. We classified habitats at two spatial levels in which the small spatial scale was nested within the large spatial scale according to Drobish (2007); CMS represented the large spatial scale and SSH the small spatial scale (Figure 2). The CMS present were L-dikes ('L' shape), wing-dikes (perpendicular to flow), kicker-dikes (extended revetments parallel to flow), rootless-dikes (not connected to shoreline), channel sandbars (large inside bend sandbars minimally influenced by other structures) and bank-lines (shoreline revetment, mud or sand). Dikes deflect current back towards the thalweg and create low velocity areas downstream of the structure where fine sediments (e.g., silt) settle out of the water. Associated SSH include up to four categories per CMS with an option to classify these as *combined* where sample runs cross multiple SSH that are in close proximity: *bank* (depth <1.2 m adjacent to shoreline but not a connected bar); *bars* (hydraulically deposited sediments where depth <1.2 m, may be connected to shoreline), *open-water* (depth >1.2 m) and *pool* (scour downstream of dike or other obstruction >1.2 m). See Appendix A for complete descriptions of all CMS and SSH.

Depth, velocity, turbidity and substrate composition were measured to examine differences among and within CMS and to assess whether these proximate environmental factors may be useful in explaining habitat use at the CMS spatial scale. Depth was measured (nearest 0.1 m) with sonar (stern trawl) or 2.0 m wading rod (push trawl) depending on trawl type (see below) at the beginning, middle and end of each trawl run. We measured water velocity, turbidity and substrate composition at the midpoint of the run at a target frequency of 25% of trawl runs. We scaled down collection of proximate environmental factors because our primary objective was to examine chub habitat use relative to CMS–SSH and secondarily used proximate environmental measures as baseline to explain patterns in CMS–SSH—we felt the minimum 25% provided adequate data to characterize CMS–SSH types to

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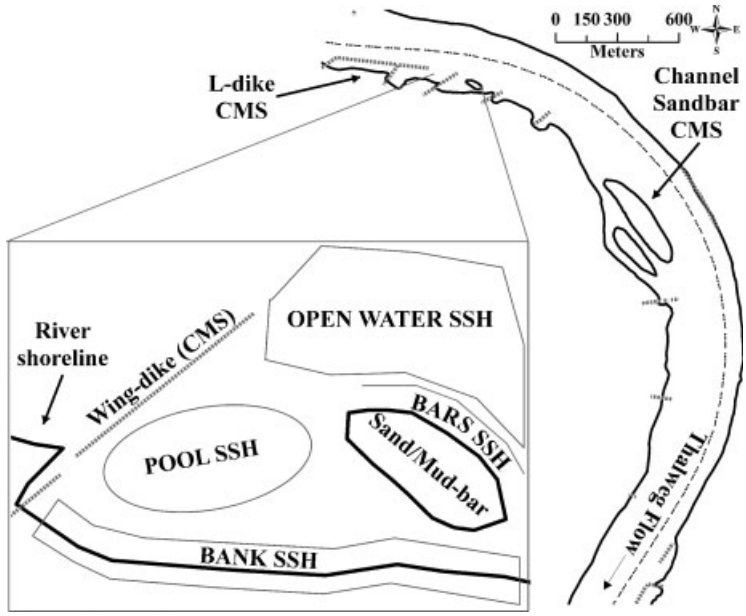

Figure 2. Typical study site reach showing distribution of channel modifying structures (CMS) and associated smaller spatial-scale habitats (SSH) in lower Missouri River. Site is the reach of river shown, CMS are distributed within sites (examples labelled) and SSH are distributed within CMS. See Appendix A for descriptions of CMS and SSH

bridge the gap with existing papers that focused primarily on chub habitat use relative to traditional proximate environmental factors. Velocity was measured (nearest 0.1 m/s) with a Marsh–McBirney Model 2000 electromagnetic flow metre on the river bottom, hereafter *bottom velocity*, and six-tenths (if depth $\leq$1.2 m) or averaged measures from two-tenths and eight-tenths (if depth $>$1.2 m) the distance from the surface, hereafter *mean column velocity*. Turbidity (NTU) was measured with a Hach 2100P turbidimetre. Substrate was collected with a Hesse dredge sampler and proportions of silt ($<$0.063 mm), sand (0.063–2 mm), and gravel (2–64 mm) visually estimated summing to 100%; sample estimates were periodically calibrated against a sieved sample with known substrate proportions to ensure accuracy. Substrate samples were later converted to the geometric mean particle size (D_g) as a measure of central tendency of particle size distribution as: $D_g = \mathrm{D}_1^{\mathrm{w}1} \times \mathrm{D}_2^{\mathrm{w}2} \times \mathrm{D}_3^{\mathrm{w}3}$, where D_i was the median size for a given substrate category (i.e., 0.03 mm for silt; 1.03 mm for sand; and 33 mm for gravel) and w_i was the proportion of the substrate category represented in the sample (McMahon *et al*., 1996; Galat *et al*., 2001).

Fish. Macrhybopsis chubs were collected monthly from CMS–SSH in lower Missouri River during daylight from 6 June to 26 October, 2006. Channel modifying structures were sampled in proportion to their availability within each site. We used a 4 mm mesh otter trawl net (or skate balloon trawl) designed to sample the near-bed fish community (i.e., with minimum lift) deployed either off the stern and pulled behind the boat ($>$1.5 m depth) or off the bow and pushed in front of the boat (0.4–2.0 m depth). The pulled stern trawl had a 4.8 m foot rope (i.e., width), 0.9 m height and 7.6 m bag length—but mean opened fishing width was 2.9 m. We used this ratio as a guide and made crude direct measurements to obtain a 1.75 m opened fishing width for the pushed bow trawl (2.4 m foot rope width, 0.6 m height, and 1.8 m bag length). Trawl runs varied in length relative to trawl type and distance appropriate to sample a given habitat. Our target range for run length was 150–300 m with stern trawls and 25–75 m with pushed bow trawls; minimum lengths to accept trawl runs as valid were 75 m for stern and 15 m for pushed bow trawls.

Data analysis

Chubs were identified to species when possible using Pflieger (1997). Individuals of speckled chub, sturgeon chub and sicklefin chub not identifiable to species were coded as *unidentifiable Macrhybopsis* (UHY) and treated in analyses as a unique species; however, we stress that UHY was simply a group comprising speckled chub, sturgeon chub, and/or sicklefin chub. Silver chubs were not included in analyses because they are not classified as

obligate big-river species. We are reasonably confident that small-size silver chubs ($\leq$15 mm TL) were correctly identified because they have morphological features that noticeably distinguish them from other *Macrhybopsis* species; their morphology differs in the following ways: (1) considerably larger eye relative to head size compared to sturgeon chubs and sicklefin chubs, (2) lack of pigment or markings on side of body and considerably shorter barbels at corners of mouth compared to speckled chubs, (3) considerably shorter pectoral fins compared to sicklefin chubs, (4) and deeper anterior body depth compared to sturgeon chubs and speckled chubs (Pflieger, 1997). We caution that identification of small-size silver chubs to UHY may have occurred in some cases (e.g., when specimens were damaged by the net).

We calculated catch-per-unit-effort (CPUE) to standardize chub abundance relative to trawling effort and make comparisons across trawl types and habitats. Fishing width for each trawl type (see above) was multiplied by length of each trawl run to standardize effort, and divided by the number of individuals from each species collected in the trawl. Therefore, trawl run (as m^2) represented our sample unit and comprised m^2 subunits. We included only sample units that exceeded the minimum distance (m) for each trawl type (see above). We selected these minimum distance criteria because they (1) allowed the net to function as designed for an adequate period of time to provide a representative sample of fishes present at that time and place and eliminating sample units representing the effect of short runs where trawls did not fully open before retrieval, and (2) reduced the likelihood that trawl distance would bias results. The theoretical concept for our second rationale was discussed for ecological studies where 'size of the sample unit' is variable; specifically, bias weighted towards detecting effects predominantly influenced by large sample units when effects by small samples units may actually be present (Connor *et al*., 1997). We assumed once trawls were fully opened, the sample subunit (m^2) was effectively constant and our response variable (i.e., CPUE or body length) would represent true biological effects and not effects of trawl distance. We did not perceive long trawls a bias in the same light as short trawls because once trawls are fully open, the response variable represents standardization against the sample unit. The resulting CPUE represented the number of individuals per species per square metre trawled. Chub species CPUEs were then summed to obtain total chub CPUE for each trawl sample. CPUE was used as the response variable representing chub abundance in subsequent analyses (except analyses of chub body lengths).

Canonical correspondence analysis (CCA) was run in CANOCO 4.5 (ter Braak and Šmilauer, 2002) to explore relationships among chub species and CMS and their associated habitat types. Observed variation in chub species composition was then decomposed with partial canonical correspondence analysis (pCCA; CANOCO 4.5) to determine the effect of CMS and their SSH on chub species composition. Length frequency histograms were examined for differences in the distribution of chub body length by species. One-way analysis of variance (ANOVA) (StatSoft Inc, 2005) was used to separately test for differences in (1) mean total length among chub species to determine if length frequency histograms were significant among species, and (2) mean total length of chubs (species pooled) among CMS–SSH to determine if chubs differently used habitats relative to body length and distinguish probable nursery areas from non-nursery areas. We used multivariate analysis of variance (MANOVA) to test for differences in mean abundance of chub species, water depth, velocity, turbidity and geometric mean of substrate particle size among CMS–SSH. Chub CPUE was log-transformed ($CPUE' = Log10(CPUE + 1)$) to better meet assumptions of normality for multivariate tests; then back transformed (except CCA and pCCA results) to report CPUE means and standard errors below. Other variables were reasonably normally distributed and thus were not transformed. However, both MANOVA (Zar, 1999) and CCA (Palmer, 1993) are robust to skewed distributions and perform reasonably well with non-normal data—thus, we did not expect our results to be highly effected by transformation. Bonferroni's post-hoc test was used to identify differences where ANOVA and MANOVA indicated significance. α probability was set to 0.05 for ANOVA and MANOVA analyses and adjusted for Bonferroni's post-hoc test by dividing 0.05 by the number of classes in ANOVA/MANOVA. Standard errors were reported with means to reflect variability associated with the mean.

RESULTS

We collected 11 872 chubs (excluding silver chub) from seven SSH (i.e., bank, bars, pool, open-water, or the combinations bar and pool, open-water and pool, or bar and open-water) associated with L-dikes, wing-dikes,

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kicker dikes, rootless dikes, channel sandbars or bank-lines using our 4-mm mesh trawls. However, 92% (10 883) of these were collected from bank, bars and open-water SSH associated with L-dikes, wing-dikes and channel sandbar CMS types. Therefore, only these three CMS and three SSH (i.e., 9 CMS–SSH interactions) and the chubs collected there were used for further analysis.

Chub length. Mean total length among all chub species was different ($df = 3$, $F = 1\,711$, $p < 0.01$). A sicklefin chub was the largest chub collected (99 mm, $n = 1$), but sturgeon chubs had the longest mean total length (45.5 ± 0.7 mm). Mean length of speckled chubs was 36.8 ± 0.2 mm, sicklefin chubs was 35.1 ± 0.3 mm and unidentified chubs was 21.3 ± 0.2 mm. Length frequency analysis showed many unidentified chubs (59%) were 15–25 mm TL, and most (90%) were less than 35 mm total length (Figure 3). In contrast, 77% of sturgeon chubs, 63% of speckled chubs and 50% of sicklefin chubs collected were $\geq$35 mm total length. Mean chub length was significant among CMS ($df = 2$, $F = 59.9$, $p < 0.01$). Chubs were shorter (Bonferroni's adjusted significant $p \leq 0.02$) at L-dikes (25.9 ± 1.0 mm) than at wing-dikes (40.0 ± 0.6, $p < 0.001$) or channel sandbars (43.8 ± 0.9, $p < 0.001$), and shorter at wing-dikes than at channel sandbars ($p < 0.002$).

Chub abundance. Unidentified chubs were more abundant (Bonferroni's adjusted significant $p \leq 0.02$) than all three identified chub species ($p < 0.001$; Figure 4A). Abundance of speckled chubs did not differ from sicklefin chubs ($p = 0.153$), but was higher than abundance of sturgeon chubs ($p = 0.007$). There was no difference in abundance of sturgeon chubs and sicklefin chubs ($p = 1.000$).

Chub mean CPUE (#/m^2) was 0.031 ± 0.004 at L-dikes, 0.019 ± 0.003 at wing-dikes and 0.030 ± 0.011 at channel sandbars. Chub mean CPUE within each of these CMS was lower in open-water SSH than at bars or bank (Figure 4B). There was no difference (Bonferroni's adjusted significant $p \leq 0.006$) among bank, bars or open-water

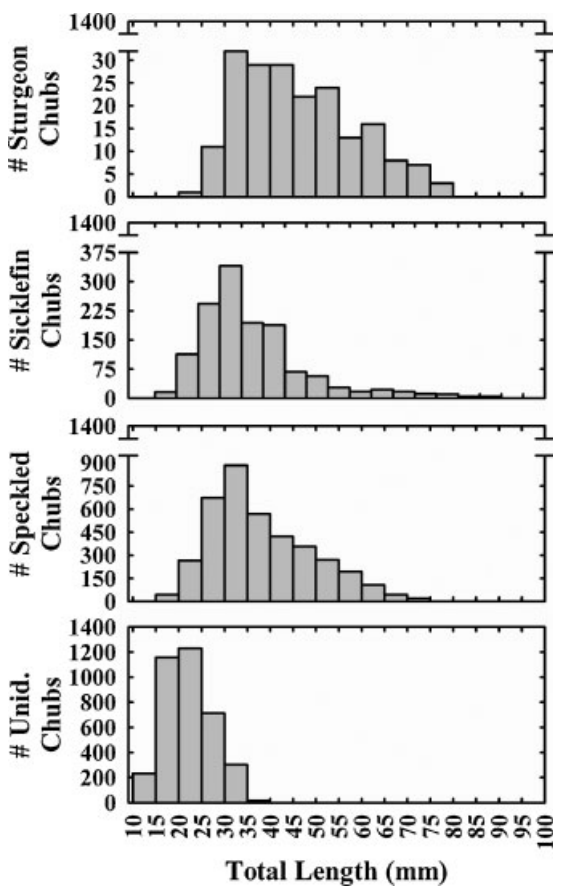

Figure 3. Length frequency histograms for sturgeon chub (*Macrhybopsis gelida*), sicklefin chub (*M. meeki)*, speckled chub (*M. aestivalis*) and unidentifiable chubs collected from channel modifying structures in lower Missouri River, MO between June and October, 2006

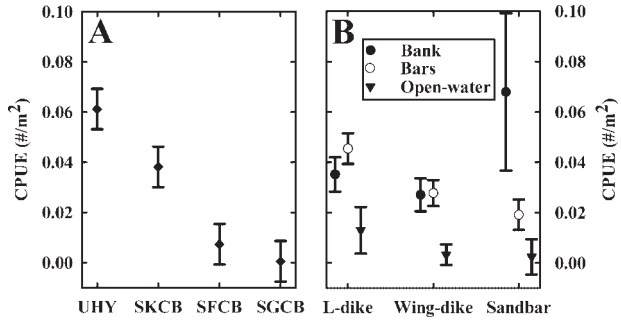

Figure 4. Mean CPUE (± SE) among (A) unidentified *Macrhybopsis* chubs (UHY), speckled chub (SKCB), sicklefin chub (SFCB) and sturgeon chub (SGCB) and (B) channel modifying structures and their associated smaller spatial-scale habitats in lower Missouri River, MO between June and October, 2006. See Table II for results of Bonferroni's post-hoc comparisons for significant differences in window B

habitats among CMS type (Table I). Chub CPUE was higher in bank ($p = 0.002$) and bars ($p < 0.001$) SSH at L-dikes than in open-water SSH at wing-dikes and the difference between bars and open-water SSH at wing-dikes (Figure 4B) was significant at $p = 0.007$.

Physical environmental factors associated with channel modifying structures

Velocity, turbidity and/or substrate composition were measured at the midpoint on 39% ($n = 618$) of trawls at L-dikes, wing-dikes and channel sandbars. Adjusted α for the following results of Bonferroni's post-hoc test was significant at $p \leq 0.006$. There was no significance in depths among bank or bars SSH across CMS ($p > 0.500$; Table II). However, open-water SSH at channel sandbars was deeper than at L-dikes ($p < 0.001$) or wing-dikes ($p < 0.003$). Mean bottom current velocity was at least four times slower at L-dikes (0.08 m/s) than at wing-dikes (0.36 m/s) or channel sandbars (0.34 m/s). Average mean-column current velocities ranged from 0.06 ± 0.04 to 0.17 ± 0.09 m/s at L-dikes, 0.09 ± 0.06 to 0.89 ± 0.04 at wing-dikes and 0.48 ± 0.09 to 0.88 ± 0.07 at channel sandbars. Mean current velocities were at least 1.8 times faster in open-water than bank or bars SSH in all three CMS types included in the analysis (Table II). Velocities of bars SSH at L-dikes were slower than at open-water SSH at wing-dikes ($p < 0.001$) and channel sandbars ($p < 0.001$), but not different from bars or bank ($p \geq 0.446$). Turbidity did not differ among CMS–SSH ($p \geq 0.573$; Table II). L-dikes were dominated by silt substrates and channel sandbars were composed primarily of sand substrates (Table II). Substrates were larger in the open-water

Table I. Matrix of p values from Bonferroni's post-hoc comparisons indicating significant differences ($p \leq 0.006$; italic bold type) in *Macrhybopsis* chub mean CPUE (#/m^2) among channel modifying structures (CMS) and their associated smaller spatial-scale habitats (SSH) in lower Missouri River, MO between June and October, 2006. OPWR is open-water. See Figure 4B to compare means among pairs of CMS and SSH

	L-dike			Wing-dike			Channel sandbar		
	Bank	Bars	OPWR	Bank	Bars	OPWR	Bank	Bars	OPWR
L-dike, Bank									
L-dike, Bars	1.000								
L-dike, OPWR	1.000	0.123							
W-dike, Bank	1.000	1.000	1.000						
W-dike, Bars	1.000	0.984	1.000	1.000					
W-dike, OPWR	***0.002***	***<0.001***	1.000	0.073	0.007				
Sandbar, Bank	1.000	1.000	1.000	1.000	1.000	1.000			
Sandbar, Bars	1.000	0.079	1.000	1.000	1.000	1.000	1.000		
Sandbar, OPWR	0.029	***<0.001***	1.000	0.365	0.129	1.000	1.000	1.000	

Table II. Means, standard errors and results from ANOVA with Bonferroni's post-hoc significance test ($p \leq 0.006$) for physical environmental factors measured from 681 trawl runs collected in habitats associated with channel modifying structures in lower Missouri River, MO between June and October, 2006

Environmental factor	L-dike			Wing-dike			Channel sandbar		
	Bank	Bars	Open-water	Bank	Bars	Open-water	Bank	Bars	Open-water
Depth	1.17	0.78	2.81	1.09	0.81	2.57	0.70	0.73	2.36
	(0.09)	(0.03)	(0.10)	(0.06)	(0.02)	(0.04)	(0.19)	(0.03)	(0.05)
	c	*ab*	*d*	*bc*	*ab*	*d*	*abc*	*a*	*e*
Velocity bottom	0.05	0.04	0.14	0.22	0.17	0.68	0.06	0.36	0.61
	(0.03)	(0.01)	(0.05)	(0.18)	(0.04)	(0.04)	(0.00)	(0.07)	(0.07)
	a	*a*	*abc*	*ab*	*a*	*c*	*abc*	*abc*	*bc*
Mean column	0.06	0.06	0.17	0.09	0.47	0.89	0.25	0.48	0.88
	(0.04)	(0.02)	(0.09)	(0.06)	(0.24)	(0.04)	(0.00)	(0.09)	(0.07)
	a	*a*	*abc*	*a*	*abc*	*c*	*abc*	*ab*	*bc*
Turbidity	51.50	73.13	86.62	160.21	88.06	104.74		54.00	132.55
	(11.67)	(3.95)	(16.82)	(34.62)	(7.55)	(8.94)		(6.04)	(18.16)
	a	*a*	*a*	*a*	*a*	*a*		*a*	*a*
Substrate (D_g)	0.05	0.12	0.41	0.05	0.51	2.28	1.03	2.26	1.10
	(0.02)	(0.04)	(0.28)	(0.01)	(0.10)	(0.43)	(0.00)	(0.77)	(0.08)
	ab	*a*	*abc*	*a*	*ab*	*c*	*abc*	*bc*	*abc*
Silt (%)	92.75	84.52	79.19	89.29	61.93	26.74	0.00	17.11	10.45
	(2.30)	(3.04)	(5.61)	(2.28)	(4.45)	(3.91)	(0.00)	(4.83)	(2.86)
Sand (%)	7.25	14.04	14.83	10.18	34.47	57.43	100.00	70.56	84.74
	(2.30)	(2.95)	(4.40)	(2.27)	(4.27)	(3.76)	(0.00)	(5.42)	(2.93)
Gravel (%)	0.00	1.44	5.98	0.54	3.60	15.83	0.00	12.33	4.81
	(0.00)	(0.82)	(2.60)	(0.21)	(0.95)	(2.23)	(0.00)	(3.29)	(1.10)

Proportions of silt, sand and gravel are reported here but were converted to the geometric mean particle size (D_g) for tests. Standard errors are listed in parentheses below each mean. Letters common among columns within a row are not significant. Blank data indicates no measurements were collected.

SSH of wing-dikes than in bank or bars SSH at L- or wing-dikes ($p < 0.001$), but not different from substrate sizes collected at channel sandbars ($p > 0.447$).

Relationships among chubs and habitats associated with channel modifying structures

The variables used in constrained ordination (CCA) explained 29.8% of the total variation in chub species composition. Month accounted for more than half (pCCA), and depth, trawl type, CMS and SSH for more than a quarter of the explained variation in observed chub species composition (Figure 5). Controlling for the effect of month (pCCA), CMS alone explained 1.8%, and SSH independent of CMS 0.1%, of the total variation. However, the synergistic effect of CMS, SSH and their interactions explained 2.8 times more variation than the additive effects of CMS and SSH. Channel sandbars explained the most variation in chub species composition among CMS, and bank explained the least among SSH (Figure 5).

Bank and bars SSH were more associated with L- and wing-dike CMS than channel sandbar CMS, but open-water SSH were more associated with channel sandbars than L- or wing-dikes (Figure 6). Ninety-nine per cent of the explainable variation (i.e., 29.5% of total variation in chub species composition explained by constraining variables in CCA) was captured by the first two canonical axes. The first canonical axis accounted for 91.1% of the explainable variation in the relationship between chub species and constraining variables (i.e., month, trawl type, depth, CMS and SSH). Month ($r = 0.71$), channel sandbar ($r = 0.30$) and open-water ($r = 0.22$) were most associated with the first canonical axis. High first axis scores relate to species collected during later months (e.g., September and October) in channel sandbar open-water areas. Low first axis scores indicate early months (e.g., June and July), L-dike CMS and bank SSH; unidentified chubs most represented low first axis scores. Depth ($r = 0.19$), open-water ($r = 0.18$) and trawl type ($r = 0.16$) were most associated with the second canonical axis.

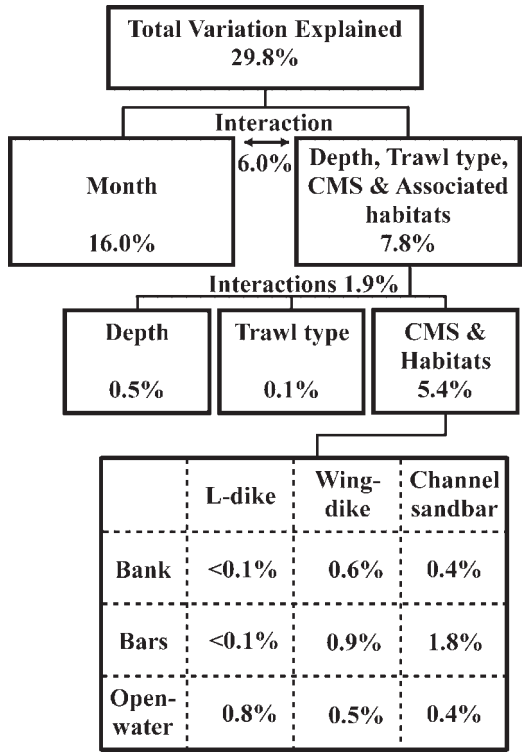

Figure 5. Decomposition of explained variation from partial canonical correspondence analysis (pCCA) observed in Macrhybopsis chub species composition from channel modifying structures (CMS) and their associated smaller spatial-scale habitats in lower Missouri River, MO between June and October, 2006

High second axis scores relate to fishes collected in deeper depths (> 1.2 m) associated with open-water areas using the stern trawl; sturgeon chub most represented high second axis scores.

Unidentified chubs were most associated with L-dike structures and occurred earlier during the sampling season than larger, identifiable chubs. They were present in 25% of trawls at L-dikes, 14% of trawls at wing-dikes but only 7% of trawls at channel sandbars. Sturgeon chubs were collected most in open-water SSH associated with channel sandbars where depth was deeper (mean = 2.36 m) than bars (mean = 0.80 m) or bank (mean = 1.13 m) SSH associated with wing-dikes and L-dikes. They were present in 11% of trawls at channel sandbars, 7% of trawls at wing-dikes and 2% of trawls at L-dikes. Sicklefin chubs were most associated with channel sandbars but were present in similar proportions of trawl runs at channel sandbar (23%), wing-dikes (27%) and L-dikes (24%). Speckled chubs used the shallower (<1.2 m) bank and bars SSH at all three CMS studied. They were present in 41% of trawls at channel sandbars, 37% of trawls at wing-dikes and 25% of trawls at L-dikes.

DISCUSSION

Many large-river fish species perform ontogenetic habitat shifts away from nursery areas where environments are benign during early life stages (Copp and Peňáz, 1988; Copp, 1997; Jurajda, 1999). Our results demonstrate that the smaller *Macrhybposis* chubs used areas associated with L- and wing-dike structures, while chubs that were large enough to be identified to species (approximately 25 mm) were more associated with channel sandbar structures. This differential habitat use of CMS relative to body size suggests that L- and wing-dike structures provide a nursery area to chubs and that channel sandbars provide areas used by chubs during later life stages. Our results show that month accounted for the greatest proportion of explained variation in chub species composition. This is likely due to the influence of unidentified chubs in the analysis and points to the nursery function of CMS

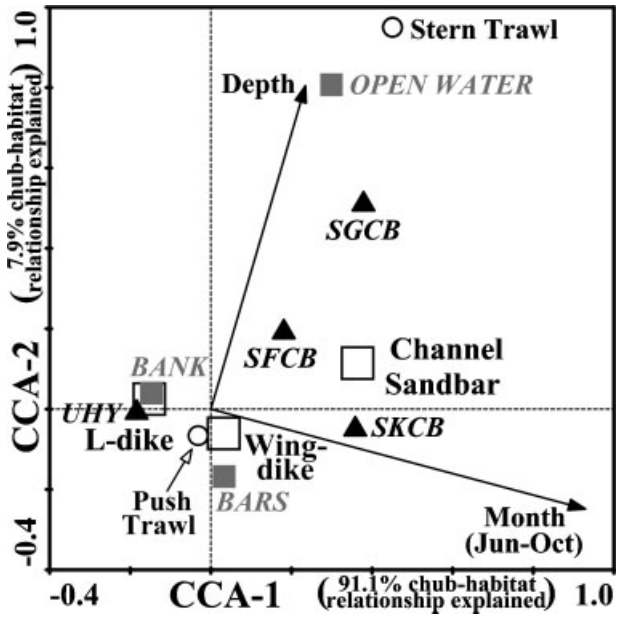

Figure 6. Canonical correspondence analysis (CCA) bio-plot depicting relationships among *Macrhybopsis* chub species (closed triangles), channel modifying structures (open squares) and their associated smaller spatial-scale habitats (closed squares), trawl type (open circles), water depth, and month (vector arrows) in lower Missouri River, MO between June and October, 2006. Species codes: UHY = unidentifiable chub, SKCB = speckled chub, SFCB = sicklefin chub, SGCB = sturgeon chub

they used. Many native fishes in large temperate rivers use elevated spring flows to cue spawning for adults, whose offspring develop during subsequent months (Galat *et al*., 1998). Unidentified chubs dominated the species composition in samples at L-dikes during the period (i.e., June and July) when larvae and juvenile size fishes should be most abundant. Their short length indicated they were probably juveniles, thus, were likely using the shallow, slow velocity areas (i.e., bank and bars) at L-dikes as nursery. Historically, *Macrhybopsis* chubs may have used the widely available shallow, slow velocity areas created from the braided channel of the pre-modified lower Missouri River as nursery. Engineered CMS (i.e., L- and wing-dikes) in the contemporary lower Missouri River channel may facilitate recruitment and function as surrogate for natural nursery habitat. These results confirm what others have reported on habitat use for post-juvenile or post-nursery age chubs; swift flow (*ca*. 0.8 m/s or swifter) in deep areas (*ca*. 2.0 m or deeper; Kopf, 2003; Herzog, 2004; Welker and Scarnecchia, 2006). However, Everett *et al*. (2004) in upper Missouri River and Herzog (2004) in Mississippi River reported that sturgeon chubs most used shallower depths (*ca*. <2.0 m) with swifter currents. Further, our results contribute to the small but growing body of knowledge on habitat use during early life history for *Macrhybopsis* chubs in a large and highly modified river, specifically that early life-stage chubs use a considerably different depth-velocity regime than post-nursery chubs. Below we discuss how management of dike structures as nursery areas may influence chub recruitment to post-nursery age on lower Missouri River in light of the current results.

Implications of macrhybopsis chub habitat use for river management

There are several management implications that emerge from our study. First, L-dikes may be a critical recruitment source area for *Macrhybopsis* chub populations in the contemporary lower Missouri River. Other studies have shown that early life-stage fishes often use the shallow, slow-velocity nursery habitats that are associated with backwaters (Copp, 1992; Garner, 1996; Flore and Keckeis, 1998; Jurajda, 1999; Grift *et al*., 2003; Nunn *et al*., 2007a, b). Barko *et al*. (2004a) suggest that shallow water (< 0.4 m) and slower current velocity habitats associated with wing-dikes promote benthos production and create microhabitats suitable for early life stages of some species in the unimpounded upper Mississippi River. Second, L-dikes do not appear to provide

appropriate areas for larger size chubs (i.e., probable adults) because chubs apparently make a shift away from L-dikes at some point during their ontogeny. Our results support that post-nursery age chubs moved to wing-dikes and channel sandbars where velocities were generally faster and substrates were generally composed of larger diametre particles. Third, it is clear that other factors we did not monitor effect *Macrhybopsis* chub species composition and abundance relative to CMS in lower Missouri River.

The explainable variation in species–environment relationships we report is within a range typically reported in other ecological studies (20–50%; Borcard et al., 1992; Rodríguez and Magnan, 1995; Marchetti and Moyle, 2001; Økland, 2003; Barko *et al*., 2004b). However, it leads us to re-examine our approach to identify other factors that may be important to chub conservation given we cannot test the influence of long-term factors with our single-year dataset. For example, the relative distribution of CMS may influence survival through ontogenetic habitat shift and help identify mechanisms controlling chub year class strength. Organisms respond to spatial scales relevant to their body size where larger body sizes respond to a larger habitat scale (Holling, 1992; O'Neill *et al*., 1997; Ritchie, 1998). Whereas some large-bodied large-river species have been documented travelling more than 100 km during post-larvae transitional periods in their life history (Tyus and Karp, 1990; Knights *et al*., 2002; Vokoun and Rabeni, 2005), we expect *Macrhybopsis* chubs would perform functional movements on a more localized scale. Thus, we hypothesize that the proximity of dikes to channel sandbar structures may be a key factor to survival of chubs during their transition from nursery to post-nursery habitat. If mortality risk (e.g., predation, starvation, wash-out) increases with time spent transitioning between habitats, chubs moving from nursery to adjacent post-nursery patches should be more likely to survive than chubs required to move a longer distance between patches.

Shallow-water habitat for fishes is being created on lower Missouri River using several techniques including breaking up continuous dikes with dike-notches. Dike notches allow river flows to erode accreted sediments and create shallow, slow moving (relative to thalweg) fish habitat downstream of dikes (U.S. Army Corps of Engineers, 2006). L-dikes generally provide greater flow refuge than wing-dikes or channel sandbars because their trailing downstream arm deflects river flows from outside the structure back towards the thalweg and protects the low or no-flow area inside the structure. Dike 'notching' is a common habitat improvement tool implemented on L- and wing-dikes to increase diversity of flows through their SSH. How notching impacts *Macrhybopsis* chubs found behind dikes is not yet well understood. However, our data suggests that the low current velocity associated with L-dikes provides an area used by many juvenile *Macrhybopsis* chubs as nursery. We sampled habitats immediately below many dike structures that represented a range of dike-structure modifications, including both notched and un-notched dikes. Although the current analysis was not intended to examine relationships between types of dike modifications and fish assemblages, our findings raise questions about the merit of using dike notches as a tool to improve native fish habitat on lower Missouri River. If un-notched dikes, particularly L-dikes, provide the slow flow used by early life-stage *Macrhybopsis* chubs, it may not be prudent to notch all dikes for the purpose of fish habitat restoration.

We have documented that L-dike, wing-dike and channel sandbars are the types of CMS most used by *Macrhybopsis* chubs in lower Missouri River. L-dikes, characterized by slow current velocity and small substrate particles, apparently provide nursery to small, probably juvenile age, *Macrhybopsis* chubs. We propose that managing CMS to address life history stages and an ecologically appropriate proportion and distribution of dike to channel sandbar habitats may be critical for conservation of native *Macrhybopsis* chubs in lower Missouri River.

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REFERENCES

Aarts BGW, Van Den Brink FWB, Nienhuis PH. 2004. Habitat loss as the main cause of the slow recovery of fish faunas of regulated rivers in Europe: the transversal floodplain gradient. *River Research and Applications* **20**: 3–23.

Barko VA, Herzog DP, Hrabik RA, Scheibe JS. 2004a. Relationship among fish assemblages and main-channel-border physical habitats in the unimpounded upper Mississippi River. *Transactions of the American Fisheries Society* **133**: 371–384.

Barko VA, Palmer MW, Herzog DP, Ickes BS. 2004b. Influential environmental gradients and spatiotemporal patterns of fish assemblages in the unimpounded upper Mississippi River. *The American Midland Naturalist* **152**: 369–385.

Bayley PB, O'Hara K, Steel R. 2000. Defining and achieving fish habitat rehabilitation in large, low-gradient rivers. In *Management and Ecology of River Fisheries*, Cowx IG (ed). Blackwell Science: Malden, MA; 279–289.

Borcard D, Legendre P, Drapeau P. 1992. Partialling out the spatial component of ecological variation. *Ecology* **73**: 1045–1055.

Connor EF, Hosfield E, Meeter DA, Niu X. 1997. Test for aggregation and size-based sample-unit selection when sample units vary in size. *Ecology* **78**: 1238–1249.

Copp GH. 1992. Comparative microhabitat use of cyprinid larvae and juveniles in a lotic floodplain channel. *Environmental Biology of Fishes* **33**: 181–193.

Copp GH. 1997. Importance of marinas and off-channel water bodies as refuges for young fishes in a regulated lowland river. *Regulated Rivers: Research and Management* **13**: 303–307.

Copp GH, Peňáz M. 1988. Ecology of fish spawning and nursery zones in the floodplain, using a new sampling approach. *Hydrobiologia* **169**: 209–224.

Cross FB, Moss RE. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. In *Community and Evolutionary Ecology of North American Stream Fishes*, Matthews WJ, Heins DC (eds). University of Oklahoma Press: Norman, OK; 155–165.

Dieterman DJ, Galat DL. 2004. Large-scale factors associated with sicklefin chub distribution in the Missouri and lower Yellowstone Rivers. *Transactions of the American Fisheries Society* **133**: 577–587.

Drobish MR. (editor). 2007. *Missouri River Standard Operating Procedures for Sampling and Data Collection*, vol. 1.2. U.S. Army Corps of Engineers: Omaha District, Yankton, South Dakota.

Dynesius M, Nilsson C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* **266**: 753–762.

Everett SR, Scarnecchia DL, Ryckman LF. 2004. Distribution and habitat use of sturgeon chubs (*Macrhybopsis gelida*) and sicklefin chubs (*M. meeki*) in the Missouri and Yellowstone Rivers, North Dakota. *Hydrobiologia* **527**: 183–193.

Flore L, Keckeis H. 1998. The effect of water current on foraging behaviour of the rheophilic cyprinid *Chondrostoma nasus* (L.) during ontogeny: evidence of a trade-off between energetic gain and swimming costs. *Regulated Rivers: Research and Management* **14**: 141–154.

Frissell CA, Liss WJ, Warren CE, Hurley MD. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management* **10**: 199–214.

Fuiman LA, Werner RG. 2002. *Fishery Science: The Unique Contributions of Early Life Stages*. Blackwell Science: Osney Mead, Oxford.

Galat DL, Berry CR, Peters EJ, White RG. 2005a. Missouri river basin. In *Rivers of North America*, Benke AC, Cushing CE (eds). Elsevier Academic Press: San Diego, CA; 427–480.

Galat DL, Berry CR, Gardner WM, Hendrickson JC, Mestl GE, Power GJ, Stone C, Winston MR. 2005b. Spatiotemporal patterns and changes in Missouri River fishes. In *Historical Changes in Fish Assemblages of Large American Rivers*, Rinne JN, Hughes RM, Calamusso R (eds). Symposium 45, American Fisheries Society: Bethesda, MD; 249–291.

Galat DL, Fredrickson LH, Humburg DD, Bataille KJ, Bodie JR, Dohrenwend J, Gelwicks GT, Havel JE, Helmers DL, Hooker JB, Jones JR, Knowlton MF, Kubisiak J, Mazourek J, McCoplin AC, Renken RB, Semlitsch RD. 1998. Flooding to restore connectivity of regulated, large-river wetlands. *Bioscience* **48**: 721–733.

Galat DL, Wildhaber ML, Dieterman DJ. 2001. Spatial patterns of physical habitat, vol. 2. In *Population Structure and Habitat use of Benthic Fishes along the Missouri and Lower Yellowstone Rivers*. U.S. Geological Survey, Cooperative Research Units, University of Missouri: Columbia, MO. https://www.nwd.usace.army.mil/. [20 October 2007].

Garner P. 1996. Microhabitat use and diet of 0+ cyprinid fishes in a lentic, regulated reach of the river Great Ouse, England. *Journal of Fish Biology* **48**: 367–382.

Gehrke PC, Brown P, Schiller CB, Moffatt DB, Bruce AM. 1995. River regulation and fish communities in the Murray-Darling river system, Australia. *Regulated Rivers: Research and Management* **11**: 363–375.

Gerrity PC, Guy CS, Gardner WM. 2006. Juvenile pallid sturgeon are piscivorous: a call for conserving native cyprinids. *Transactions of the American Fisheries Society* **135**: 604–609.

Grady JM, Milligan J. 1998. Status of selected cyprinid species at historic lower Missouri River sampling sites. U.S. Fish and Wildlife Service Report, Columbia Fisheries Resource Office, Columbia, Missouri.

Grift RE, Buijse AD, Van Densen WLT, Machiels MAM, Dranenbarg J, Klein Breteler JGP, Backx JJGM. 2003. Suitable habitats for 0-group fish in rehabilitated floodplains along the lower River Rhine. *River Research and Applications* **19**: 353–374.

Herzog DP. 2004. Capture efficiency and habitat use of sturgeon chub (*Macrhybopsis gelida*) and sicklefin chub (*Macrhybopsis meeki*) in the Mississippi River. *Master's Thesis.* Southeast Missouri State University, Cape Girardeau, Missouri.

Hesse LW, Mestl GE. 1993. An alternative hydrograph for the Missouri River based on the precontrol condition. *North American Journal of Fisheries Management* **13**: 360–366.

Hirzinger V, Keckeis H, Nemeschkal HL, Schiemer F. 2004. The importance of inshore areas for adult fish distribution along a free-flowing section of the Danube, Austria. *River Research and Applications* **20**: 137–149.

Holling CS. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs* **62**: 447–502.

Humphries P, Lake PS. 2000. Fish larvae and the management of regulated rivers. *Regulated Rivers: Research and Management* **16**: 421–432.

Humphries P, Serafini LG, King AJ. 2002. River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47**: 1307–1331.

Jennings DK. 1979. An evaluation of aquatic habitat associated with notched dikes on the Missouri River, Missouri. *Master's Thesis*. University of Missouri, Columbia, Missouri.

Jurajda P. 1995. Effect of channelization and regulation on fish recruitment in a flood plain river. *Regulated Rivers: Research & Management* **10**: 207–215.

Jurajda P. 1999. Comparative nursery habitat use by 0+ fish in a modified lowland river. *Regulated Rivers: Research and Management* **15**: 113–124.

Knights BC, Vallazza JM, Zigler SJ, Dewey MR. 2002. Habitat and movement of lake sturgeon in the upper Mississippi River system, USA. *Transactions of the American Fisheries Society* **131**: 507–522.

Kopf SM. 2003. Habitat Use by Chubs of the Genera Macrhybopsis and Platygobio in the Lower Platte River, Nebraska. *Master's Thesis*. University of Nebraska: Lincoln, NE.

Langler GJ, Smith C. 2001. Effects of habitat enhancement on 0-group fishes in a lowland river. *Regulated Rivers: Research and Management* **17**: 677–686.

Marchetti MP, Moyle PB. 2001. Effects of flow regime on fish assemblages in a regulated California stream. *Ecological Applications* **11**: 530–539.

McMahon TE, Zale AV, Orth DJ. 1996. Aquatic habitat measurements. In *Fisheries Techniques, 2nd edition.* Murphy BR, Willis DW (eds). American Fisheries Society: Bethesda, MD; 83–120.

Nestler J, Sutton VK. 2000. Describing scales of features in river channels using fractal geometry concepts. *Regulated Rivers: Research and Management* **16**: 1–22.

Nunn AD, Harvey JP, Cowx IG. 2007a. Benefits to 0+ fishes of connecting man-made waterbodies to the lower River Trent, England. *River Research and Applications* **23**: 361–376.

Nunn AD, Harvey JP, Cowx IG. 2007b. The food and feeding relationships of larval and 0+ year juvenile fishes in lowland rivers and connected waterbodies. I. Ontogenetic shifts and interspecific diet similarity. *Journal of Fish Biology* **70**: 726–742.

Økland RH. 2003. Partitioning the variation in a plot-by-species data matrix that is related to *n* sets of explanatory variables. *Journal of Vegetation Science* **14**: 693–700.

O'Neill RV, Hunsaker CT, Jones KB, Riitters KH, Wickham JD, Schwartz PM, Goodman IA, Jackson BL, Baillargeon WS. 1997. Monitoring environmental quality at the landscape scale. *BioScience* **47**: 513–519.

Palmer MW. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. *Ecology* **74**: 2215–2230.

Pflieger WL. 1997. *The fishes of Missouri, revised edition*. Missouri Department of Conservation: Jefferson City, MO.

Poff LN. 1997. Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society* **16**: 391–409.

Reeves K. 2006. Use of main channel and shallow-water habitat by larval fishes in the lower Missouri River. *PhD Dissertation*. University of Missouri, Columbia, MO.

Ridenour CJ. 2007. Assemblage structure and shallow-water habitat use by small-bodied fishes and lower Missouri River sandbars. *Master's Thesis*. University of Missouri, Columbia, MO.

Ritchie ME. 1998. Scale-dependant foraging and patch choice in fractal environments. *Evolutionary Ecology* **12**: 309–330.

Rodríguez MA, Magnan P. 1995. Application of multivariate analyses in studies of the organization and structure of fish and invertebrate communities. *Aquatic Sciences* **57**: 199–216.

Schmitten RA. 1999. Essintial fish habitat: opportunities and challenges for the next millennium. In *Fish Habitat: Essential Fish Habitat and Rehabilitation*, Benaka L (ed). Symposium 22, American Fisheries Society: Bethesda, MD; 3–10.

Sparks RE. 1995. Need for ecosystem management of large rivers and their floodplains. *Bioscience* **45**: 168–182.

StatSoft Inc. 2005. *Statistica 7*. StatSoft: Tulsa, OK.

ter Braak CJF, Šmilauer P. 2002. *CANOCO Reference Manual and CanoDraw for Windows Uuser's Guide: Software for Canonical Community Ordination* (version 4.5). Microcomputer Power: Ithaca, New York.

Tonn WM. 1990. Climate change and fish communities: a conceptual framework. *Transactions of the American Fisheries Society* **119**: 337–352.

Tyus HM, Karp CA. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. *The Southwestern Naturalist* **35**: 427–433.

US Army Corps of Engineers. 2006. Missouri River bank stabilization and navigation project, fish and wildlife mitigation project: annual implementation report FY05 & FY06 http://www.nwk.usace.army.mil/projects/mitigation/. [15 October 2007].

US Department of Commerce. 1996. Magnuson-Stevens Fishery Conservation and Management Act as amended through October 11, 1996. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-F/SPO-23 http://www.nmfs.noaa.gov/sfa/magact/. [27 November 2007].

Vokoun JC, Rabeni CF. 2005. Variation in annual movement cycle of flathead catfish within and between two Missouri watersheds. *North American Journal of Fisheries Management* **25**: 563–572.

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

Welker TL, Scarnecchia DL. 2006. River alteration and niche overlap among three native minnows (Cyprinidae) in the Missouri River hydrosystem. *Journal of Fish Biology* **68**: 1530–1550.

Zar JH. 1999. *Biostatistical Analysis*, 4th edition. Prentice-Hall: NJ.

APPENDIX A. DESCRIPTIONS OF CHANNEL MODIFYING STRUCTURES AND ASSOCIATED SMALL SPATIAL-SCALE HABITATS TAKEN FROM DROBISH (2007).

CHANNEL MODIFYING STRUCTURES

L-dike—Dikes shaped like an L with the shorter arm extending to the bank and the longer arm parallel with the current.
Wing-dike—A straight dike that is perpendicular to the main channel current.
Kicker dike—These are ends of revetments that extend into the river channel parallel to the main current allowing pools to form on the back side.
Rootless-dike—Dike where the landward portion of the rock structure is not connected to shore. The dike is separated by water by a distance greater than the length of the dike. Not to be confused with a wing dike with a bank notch where submerged rock (sill) connects the dike to the bank.
Cheveron—A 'V' shaped dike set out in the river channel away from the shoreline that has flow around both sides.
Channel sandbar—Large inside-bend bars. In most cases, local dikes are absent or do not influence the bar to a large degree.
Bankline—Shore that may consist of revetment, mud or sand. May be vegetated or bare. Not a deposited bar. Not associated with other structures (example: bank in close proximity of a dike).
Chute—A large side channel to the main channel. Associated island covered with woody vegetation. Water flowing behind channel sandbars should not be considered a chute.
Highly engineered—Dike which has had extensive engineering to create diverse habitat and will not appropriately fit in the above descriptions.

SMALL SPATIAL-SCALE HABITATS WITHIN CHANNEL MODIFYING STRUCTURES

Pool—Areas immediately downstream from dikes, or other obstructions that have formed a scour greater than 1.2 m in depth.
Bars—Sandbar or shallow bankline at the terrestrial-aquatic interface area of deposited sediment where water depth is less than 1.2 m.
Open-water—Areas with depth greater than 1.2 m, but not a scour.
Natural—Banks that have not been modified to be stabilized. Usually composed of sand, silt or mud, and may include snags (this habitat type is associated with only bankline CMS).
Bank—The actual bank of the river but not a deposited bar.
Combined—Areas where multiple habitat types are in close proximity and more than one is sampled during a trawl run.
Dike—Embedded dike–sand bar interface where water depth is less than 1.2 m. A minimal portion of the dike is exposed and does not create a substantial scour of the bar (this habitat type is associated with only channel sandbar CMS).
Braided—Channel sandbar crossed by multiple small channels of shallow water (this habitat type is associated with only channel sandbar CMS).
Shoal—A dramatic change in depth. A sand ledge or drop off where water depth abruptly changes from 1 to 3 or 4 m (this habitat type is associated with only channel sandbar CMS).

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