RIVER RESEARCH AND APPLICATIONS

River. Res. Applic. (2008)

Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/rra.1089

LONGITUDINAL PATTERNS IN FLATHEAD CATFISH RELATIVE ABUNDANCE AND LENGTH AT AGE WITHIN A LARGE RIVER: EFFECTS OF AN URBAN GRADIENT[‡]

CRAIG P. PAUKERT[a*] and ANDREW S. MAKINSTER[b†]

[a] *US Geological Survey, Kansas Cooperative Fish and Wildlife Research Unit, Division of Biology, Kansas State University, Manhattan, KS 66506, USA*

[b] *Kansas Cooperative Fish and Wildlife Research Unit, Division of Biology, Kansas State University, Manhattan, KS 66506, USA*

ABSTRACT

We investigated the spatial variation of flathead catfish (*Pylodictis olivaris*) relative abundance and growth in the 274 km long Kansas River to determine if population dynamics of catfish are related to urbanization. Electrofishing was conducted at 462 random sites throughout the river in summer, 2005–2006 to collect fish. Relative abundance of age 1 fish ($\leq$200 mm), subadult (>200–400 mm) and adult fish (>400 mm) ranged from 0.34 to 14.67 fish h^{-1}, mean length at age 1 was 165 (range: 128–195) mm total length (TL) and mean length at age 3 was 376 mm TL (range: 293–419 mm TL). The proportion of land use within 200 m of the river edge was between 0 and 0.54 urban. River reaches with high relative abundance of age 1 flathead catfish had high relative abundance of subadult and adult catfish. River reaches with fast flathead catfish growth to age 1 had fast growth to age 3. High urban land use and riprap in the riparian area were evident in river reaches near the heavily populated Kansas City and Topeka, Kansas, USA. Reaches with increased number of log jams and islands had decreased riparian agriculture. Areas of low urbanization had faster flathead catfish growth ($r = 0.67$, $p = 0.005$). Relative abundance of flathead catfish was higher in more agricultural areas ($r = -0.57$, $p = 0.02$). Changes in land use in riverine environments may alter population dynamics of a fish species within a river. Spatial differences in population dynamics need to be considered when evaluating riverine fish populations. Published in 2008 by John Wiley & Sons Ltd.

KEY WORDS: flathead catfish; river; growth; abundance

Received 20 August 2007; Revised 15 October 2007; Accepted 22 October 2007

INTRODUCTION

Rivers in the US and throughout the world have been altered by anthropogenic activities such as increased agriculture and urbanization, instream dredging and channelization, and rivers in the Missouri River Basin, USA are no exception. Agriculture is a dominant land use in the Missouri River Basin (Galat *et al*., 2005), which has been linked to poor habitat quality, sedimentation, pollution and reduced biotic integrity (Karr, 1981; Wang *et al*., 1997; Allan, 2004). Streams in watersheds with increased agriculture typically have lower indices of biotic integrity and species richness (Roth *et al*., 1996; Wang *et al*., 1997; Lammert and Allan, 1999; Wang *et al*., 2003). Agriculturally dominated streams can have increased sedimentation, water temperature and nutrient enrichment that alter the fish assemblage to more tolerant species (Allan, 2004).

Urbanization (e.g. cleared areas of impervious surfaces, roads, buildings, railroads, etc.) also degrades aquatic habitats and has been linked to reduced biotic integrity and extirpation of some fishes (Allan, 2004). Similar to agriculture, streams in watershed with relatively high (>10%; Allan, 2004) urban or impervious surfaces have lower biotic integrity (Roth *et al*., 1996; Wang *et al*., 2001) or fish density (Stewart *et al*., 2001). Although these studies indicate that fish assemblage structure is altered by land use such as agriculture and urbanization, fewer studies have focused on population-level metrics of individual fish species. However, many countries mandate the

*Correspondence to: Craig P. Paukert, US Geological Survey, Kansas Cooperative Fish and Wildlife Research Unit, Division of Biology, Kansas State University, Manhattan, KS 66506, USA. E-mail: cpaukert@ksu.edu

[†] Present Address: Arizona Game and Fish Department; Research Branch, 5000 West Carefree Highway, Phoenix, AZ 85086-5000, USA.

[‡]This article is a U.S. Government work and is in the public domain in the U.S.A.

evaluation of the water chemistry and biota of rivers (Gergel *et al*., 2002), and therefore there is a need to identify how land use not only affects biotic assemblages, but fish populations dynamics within the assemblages.

Spatial variation of habitat within river systems is highly influenced by physical gradients (i.e. land use, flow regime, depth; Vannote *et al*., 1980; Sanders *et al*., 1993; Allan, 2004), and fish populations may be strongly influenced by these density-independent processes (Gido *et al*., 1997; Wildhaber *et al*., 2003; Smith and Kraft, 2005). Growth and abundance of large river species can vary throughout a river system (e.g. Quist and Guy, 1998, 1999; Eitzmann *et al*., 2007; Makinster and Paukert, in press) suggesting the need for spatial evaluation of population characteristics. Although studies have suggested longitudinal patterns in fish assemblages (e.g. Tramer and Rogers, 1973; Hughes and Gammon, 1987; Gido *et al*., 1997; Chick *et al*., 2006; Lasne *et al*., 2007), fewer studies have examined longitudinal patterns in population dynamics of a species within a river.

Flathead catfish are a native, large river fish in the Great Plains, USA that occurs in may low-gradient large rivers and reservoirs in the Great Plains. Previous investigations of flathead catfish population indices (e.g. relative abundance and growth) have focused on how river systems differ throughout the species' range (Minckley and Deacon, 1959; Turner and Summerfelt, 1971; Munger *et al*., 1994; Kwak *et al*., 2006). Flathead catfish habitat use studies indicate that these fish prefer large woody debris (Minckley and Deacon, 1959; Weller and Winter, 2001; Daugherty and Sutton, 2005b). Although flathead catfish occur in modified river systems and may be fluvial generalists, these fish were more abundant along natural river banks compared to revetted bank in the Mississippi River (Pennington *et al*., 1983). Growth of flathead catfish is related to the environment (river or reservoir) or if the population is native or introduced (Kwak *et al*., 2006; Sakaris *et al*., 2006). However, little information exists on the variability in growth among reaches or habitats within a river. The high variability in abundance and growth among populations (e.g. Kwak *et al*., 2006), which infers system specificity (Daugherty and Sutton, 2005a) and suggests degrees of density-dependent or -independent mechanisms may vary spatially to influence flathead catfish populations within a river.

The objective of this study is to identify if longitudinal patterns in flathead catfish population dynamics exist in the Kansas River. Specifically, we wanted to (1) determine if flathead catfish population relative abundance and growth differ longitudinally, and (2) evaluate how these differences relate to riparian land use and instream habitat modifications or density-dependent processes. We hypothesized that flathead catfish abundance and growth would be higher in reaches with increased woody debris, braided channels and less urban development as flathead catfish have been associated with cover (Minckley and Deacon, 1959; Weller and Winter, 2001; Daugherty and Sutton, 2005b) and these areas represent least disturbed conditions of the Kansas River.

METHODS

Study area

The Kansas River is formed by the junction of the Smoky Hill River and the Republican River near Junction City, Kansas and flows 274 km to the confluence of the Missouri River in Kansas City, Kansas. The entire drainage area covers nearly 160 000 km^2 and drains about 12% of the Missouri River watershed (Galat *et al*., 2005). Reservoirs exist on most major tributaries to the Kansas River controlling approximately 80% of the river drainage (Sanders *et al*., 1993), but only one low-head dam exists on the mainstem Kansas River, located at rkm 83 near Lawrence, Kansas (Figure 1). Exposure of the historically braided channel to reduced flow has lead to the accumulation of fine-grained particles and thus, a reduction of backwater habitat (Quist *et al*., 1999). Mean water depth is typically <1.5 m (Makinster and Paukert, in press). Placement of large rock (riprap) along the river shoreline is a common practice to prevent bank erosion, and 16% of the river has bank stabilization structures (Sanders *et al*., 1993). The highly urbanized portions of the river near Kansas City and Topeka, Kansas contain concrete along the riverbanks for further stabilization. Two major cities are adjacent to the Kansas River: Kansas City has a population of 147 700 (based on 2003 census) and is about the lower 16 km of the Kansas River; Topeka is located between rkm 130 and 145 has a population of 122 000 (Figure 1). Other cities near the Kansas River (but have a smaller urban footprint adjacent to the Kansas River) include Lawrence (rkm 82–85), which has 82 000 residents; Manhattan (rkm 237–241) which has a population of 44 700 residents; Junction City (rkm 272–274) which has 18 000 residents. In

DOI: 10.1002/rra

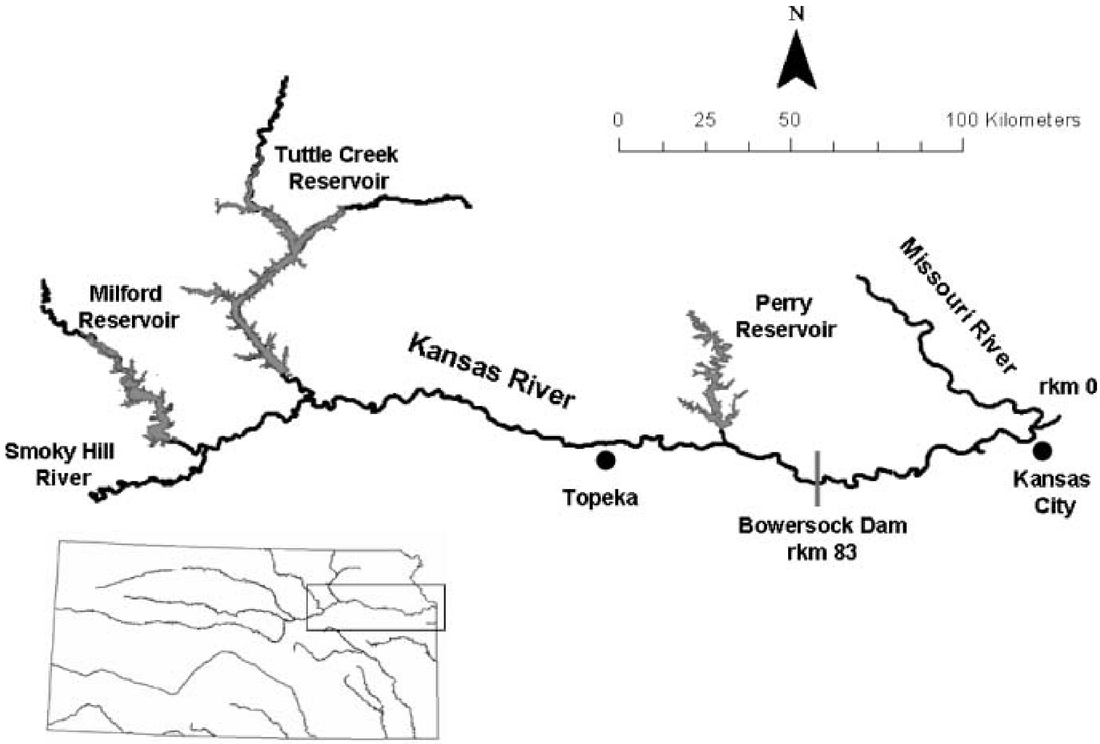

Figure 1. Map of the 274 km long Kansas River from its formation below Milford Reservoir at the junction of the Smokey Hill River to its confluence with the Missouri River (Kansas City). The two largest cities adjacent to the Kansas River (Topeka and Kansas City, Kansas) are also noted

addition, Fort Riley, a military base of 28 000 military and family members, is adjacent to the Kansas River from about rkm 262 to 274.

Fish sampling. The Kansas River was divided into 16 river reaches with the goal of 16 km reaches, but actual lengths ranged from 10 to 26 rkm (mean = 16.1 km), based on barriers and logistics (each segment could be sampled in 1 day). For example reaches were modified in length to adjust for Bowersock Dam, located at rkm 83 (Eitzmann *et al*., 2007) and a water intake weir at Kansas City (rkm 26) and Topeka, Kansas (rkm 140; Makinster, 2006). Within each reach, a minimum of three, 1.6 km sections were randomly selected to collect fish, and within each section, a minimum of three, 300 s electrofishing stations were sampled (see Eitzmann *et al*., 2007 for details).

Daytime electrofishing was completed during May–August in 2005 and 2006, using low frequency pulsed DC current (1–6 A; 180–250 V; 15–20 pulses s^{-1}) from a 4.5 m aluminium boat with a Coffelt Model VVP 15 electrofisher powered by a 5000-W, single phase, 240-V AC generator. Additionally, supplemental sampling using overnight sets of unbaited hoop nets (7-ring, 1-m diameter, 5.1-cm mesh, 3.6-m long) and high frequency pulsed DC electrofishing (8–15 A; 300–500 V; 40–60 pulses s^{-1}) was conducted to increase the number of tagged flathead catfish at large as well as provide increased sample sizes for ageing analysis. However, only random electrofishing sampling was used to assess relative abundance of flathead catfish.

All flathead catfish were measured (total length [TL], nearest mm), weighed (nearest g), and fish >305 mm TL (minimum size harvested by anglers; Travnichek, 2004) received an individually numbered *t*-bar anchor tag (Makinster and Paukert, in press). Pectoral spines were removed from a subsample of flathead catfish for later age determination. All unaged fish were assigned ages based on an age-length key (DeVries and Frie, 1996). Flathead catfish were released near their original site of capture. Minimum movement of recaptured flathead catfish was estimated as the distance from the original tagging location to the recapture.

Habitat classification. We used 1-m resolution satellite imagery from 3 August 2005 and 24 September 2006 to determine the riparian and instream habitat characteristics throughout the Kansas River. Both images were collected at similar flows (57 and 68 $m^3 s^{-1}$) and heights (1.36 and 1.42 m) at a gage station at rkm 206 so comparisons between years were consistent. We created in geographic information systems software a transect perpendicular to the river channel at 1.6 km intervals throughout the river and measured the distance of riparian area (200 m on each side of the bankfull height) that was urban (obvious roads, parking lots, sand pits and other man-made disturbances), agriculture (row crops and grasslands) and forested land (larger trees and vegetation). In addition, bankfull width, which was defined as the width of the river between the most pronounced banks (Armantrout, 1998) (m) was measured at each transect. Within the bankfull width, the number of channels (areas of flowing water) and islands (number of sand bars or areas of terrestrial vegetation) that intersected the transect was quantified at each transect. For example, if the transect crossed flowing water, then a sand bar, and then flowing water, the number of channels would be two and the number of islands would be one. All analyses were conducted in ArcGIS version 9.2.

Prior to sampling an electrofishing station, shoreline habitat of that station was classified as riprap (consistent length of man-made shoreline with rocks or concrete rubble of various sizes) or log jam (stockpile of woody debris partially inundated extending from the shoreline into the water where main beam was >4.5 m long; Eitzmann *et al*., 2007). Previous studies have indicated these habitats are preferred by flathead catfish (Minckley and Deacon, 1959; Daugherty and Sutton, 2005b) and other large river fishes (Eitzmann *et al*., 2007) and therefore were selected for analysis for this study. Within each 1.6 km section, both log jams and riprap were sampled when available, and only one shoreline habitat was sampled per electrofishing station (Eitzmann *et al*., 2007). Because these habitats were only sampled when available, the proportion of 1.6 sections that had at least one of the habitats sampled could be used as an index of the presence of that habitat type in a particular reach.

Pectoral spine processing for growth analysis. Growth was estimated using pectoral spines that were sectioned using a low-speed Isomet saw. A minimum of three cross sections were cut between the distal end of the basal process and the proximal end of the spine furrow to minimize age underestimation due to the erosion of the central lumen (Nash and Irwin, 1999). Spine sections were then mounted on slides and the number of visible annuli, the distance (mm) from the focus to each annuli, and the radial distance (mm) from the focus to the outer edge of the spine was used to back-calculate mean length at age. Two independent readers examined each spine and discrepancies between readers were solved with a concert read. Because spines can underestimate ages of older fish (Nash and Irwin, 1999), only mean length at ages 1 and 3 were used in the analysis.

Data analysis. All population parameters (i.e. relative abundance and growth) were determined for each of the 16 reaches to identify longitudinal patterns throughout the Kansas River. Flathead catfish relative abundance within each river reach was evaluated using catch per hour of electrofishing (CPUE) for three sizes of fish: $\leq$200 mm TL (age 1), 201–400 mm TL (subadults; age 2–3) and >400 mm TL (adult; age $\geq$4). Our data indicated all age 1 fish were <200 mm TL (mean TL = 165 mm). Designation of subadult and adult fish was determined from Munger *et al*., (1994), where >50% of flathead catfish were sexually mature at 400 mm TL.

Habitat variables based on the satellite imagery (proportion of riparian zone in urban, agriculture and forested land use, the number of islands and channels and bankfull width) were summarized by each river reach so these indices could be related to flathead catfish abundance and growth. In addition, the relative presence of riprap and log jams during electrofishing was examined for each river reach. Availability of log jam and riprap shoreline habitat was determined by the proportion of 1.6 river sections that had at least one sample of that habitat divided by the total number of 1.6 segments sampled in that reach. For example if 10–1.6 rkm sections were sampled in a reach and three of those sections has riprap, the proportion of riprap in that reach was 0.30.

Principal components analysis (PCA) was conducted to reduce the dimensionality of the flathead catfish population and riparian and instream habitat indices (Johnson, 1998). For all 16 segments, two PCAs were conducted, one for flathead catfish population variables and one for riparian and habitat variables. The fish PCA included mean CPUE of age 1, subadult and adult flathead catfish (3 indices), and mean length at ages 1 and 3 (2 indices). A habitat PCA included the proportion of 1.6 km sections that contained riprap and log jams, proportion of riparian area that was urban, agriculture and forested, the mean number of channels and islands, and the mean total bankfull width. Each PCA axis was interpreted and spearman correlations were used to relate the fish principal component scores (PCs) to the habitat PCs. PCs were also plotted by river reach to visualize flathead catfish population characteristics and habitat characteristics throughout the Kansas River. Spearman correlation analysis was used to evaluate if growth (mean TL at ages 1 and 3), was associated with catch rates of flathead catfish,

DOI: 10.1002/rra

suggesting density dependence. For this analysis, CPUE of all sizes of flathead catfish was correlated with mean TL at ages 1 and 3, of all three sizes of flathead catfish.

RESULTS

A total of 397 flathead catfish were collected from 462 random electrofishing stations and used in the spatial analysis of population indices of the 16 river reaches. A total of 572 flathead catfish were tagged (which included fish collected with supplemental sampling; Makinster, 2006) with only 15 fish recaptured (5 angler returns and 10 recaptures during electrofishing sampling). All recaptured fish were found <6 km from their original tagging location (mean = 0.5 km) and were at large 29–430 days. Flathead catfish collected during summer random electrofishing ranged from 63 to 915 mm TL and was dominated by fish from 100 to 500 mm TL (88%). Fish between 500 and 700 mm TL and >700 mm TL comprised 10 and 2% of the catch, respectively.

Relative abundance of age 1 flathead catfish was highly variable among river segments (mean = 4.7; range: 0.4–14.7 fish h^{-1}; Table I). Mean CPUE of subadult fish was 3.7 fish h^{-1} (range: 0.7–8.9 fish h^{-1}), and mean CPUE of adult fish was 2.2 fish h^{-1} (range: 0.3–4.8 fish h^{-1}). Back-calculated mean length at age indicated that flathead catfish attained 128–195 mm TL by age 1, and 293 to 418 mm by age 3, depending on river segment (Table I). There appeared to be no flathead catfish density-dependent associations within river segments. High CPUE of all sizes of flathead catfish was not associated with mean length at age 1 ($r = -0.12$, $p = 0.65$) or age 3 ($r = 0.13$; $p = 0.64$). In addition, CPUE of age 1, subadult or adult flathead catfish was not related to mean length at age 1 (ps > 0.50) or age 3 (ps > 0.41). Increased CPUE of flathead catfish was not related to decreased growth.

Flathead catfish CPUE of all sizes classes were consistently high in the middle segments of the Kansas River. Flathead catfish CPUE was always in the top 25% of all reaches in the rural areas between rkm 85 and 129 (Figure 2). The lowest CPUE for each size (<1 fish h^{-1}) was at rkm 0–26 (Kansas City), and 194–257 (age 1), rkm 178–193, 210–241 (subadult), and rkm 0–26, 49–64, 178–208 and 242–257 (adults). Relative abundance of flathead catfish was highest in the middle river reaches, but lowest near Kansas City and upper river reaches. Mean length at age 1 was highest (>180 mm TL) in the generally rural areas between rkm 178 and 241 (Figure 2), and mean length at age 3 was highest at rkm 85–96, 113–129 and 194–225. The slowest growth occurred at rkm 0–26 (Kansas City), 49–64, 130–177 (Topeka and nearby upstream reaches) and 242–257 (reaching <150 mm at age 1), and at rkm 0–26 and 130–161 (reaching <360 mm at age 3). The slowest growth to age 1 (and second slowest to age 3) occurred at rkm 141–161.

The flathead catfish PCA revealed that PC1 was primarily an index of flathead catfish abundance of all sizes, and accounted for 51% of the variation (Table I). Component loadings were >0.50 for each size class of flathead catfish abundance. High PC2 loadings were associated with increased mean lengths at ages 1 and 3 and explained 36% of the variation. River segments that scored high on PC1 axis one had high relative abundance, whereas river segments that scored high on PC2 had fast flathead catfish growth.

The proportion of the watershed that was urban ranged from 0 to 0.54, with only the reaches in Topeka (rkm 130–140) and Kansas City (rkm 0–26) had >0.50 of their riparian area as urban (Figure 3). The remaining reaches

Table I. Component loadings and population parameters from a principal components analysis using five indices of flathead catfish abundance and growth from the Kansas River, Kansas, USA

	Component loading		Population parameters	
	PC1	PC2	Mean	Range
CPUE age 1 (no h^{-1})	0.59	−0.10	4.7	0.4–14.7
CPUE subadult (no h^{-1})	0.58	−0.11	3.7	0.7–8.9
CPUE adult (no h^{-1})	0.54	0.06	2.2	0.3–4.8
Mean length at age 1 (mm)	−0.02	0.71	165	128–195
Mean length at age 3 (mm)	0.15	0.69	376	293–419
Eigenvalue	2.53	1.81		
Variance explained (%)	51	36		

DOI: 10.1002/rra

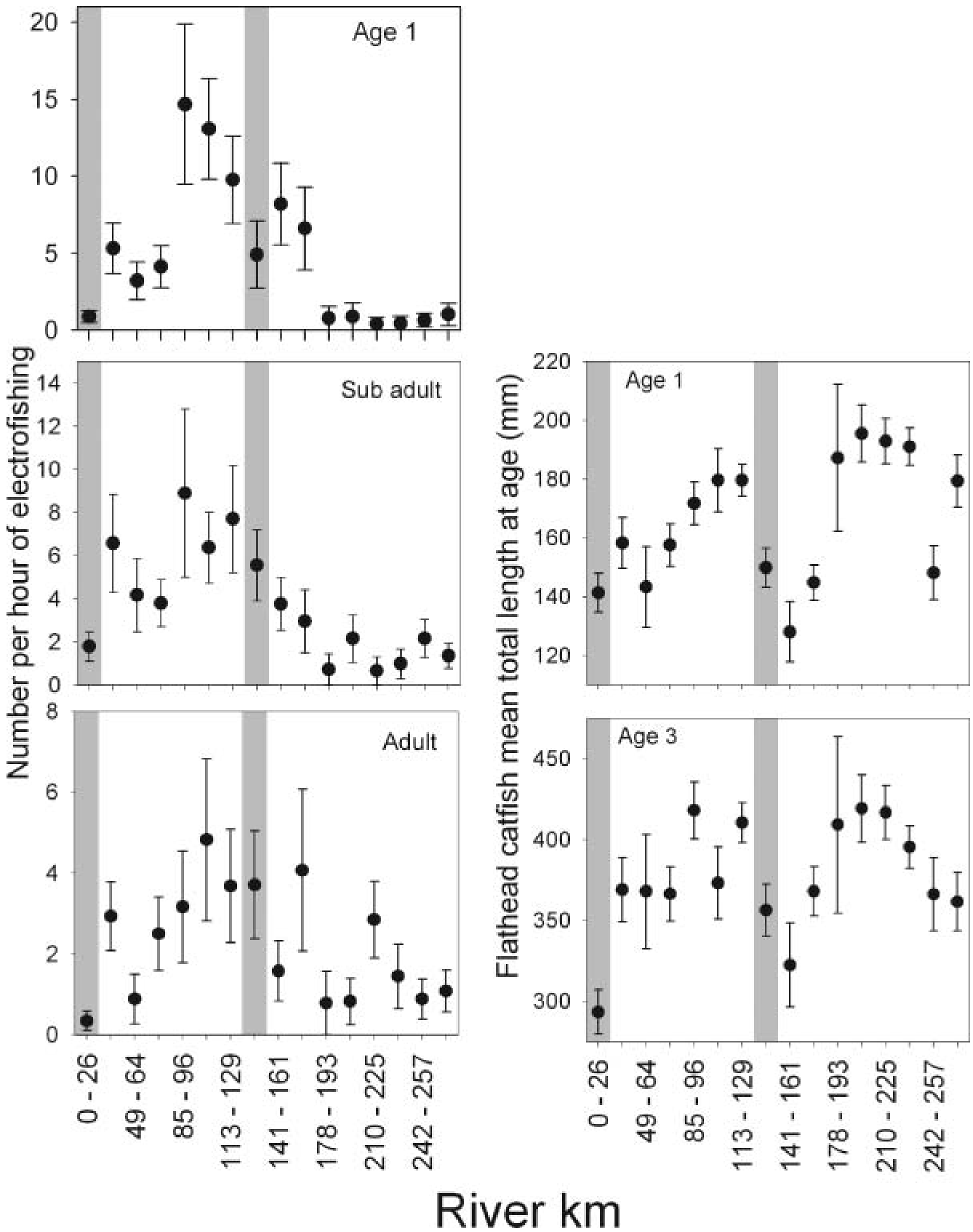

Figure 2. Longitudinal patterns in the mean flathead catfish catch per hour of electrofishing for age 1, subadult and adult flathead catfish and mean flathead catfish length at ages 1 and 3. Error bars represent one standard error. Shaded areas represent river reaches with high urban influence

were always on average <0.20 urban. Although the reach between rkm 141 and 161 had on average low proportion of urban area (and slow flathead catfish growth; Figure 2) the lower section of this reach (rkm 141–145) had up to 0.33 as urban whereas the remaining sections of this reach had no urban in the riparian area. The reaches with high urban influence also had the lowest proportion in agriculture (<0.10), and the highest proportion of the instream habitat as riprap (>0.80 of the rkm had riprap). In contrast, river reaches in more rural areas (rkm 178–193 and rkm 210–225) had few rkm with riprap (<0.25). In general, the number of islands and channels increased in upriver reaches (but the number of islands was still low at rkm 130–140 near Topeka; Figure 3). Mean bankfull width also varied with apparent urban influence. The narrowest bankfull widths occurred at rkm 258–274 (Junction City and

DOI: 10.1002/rra

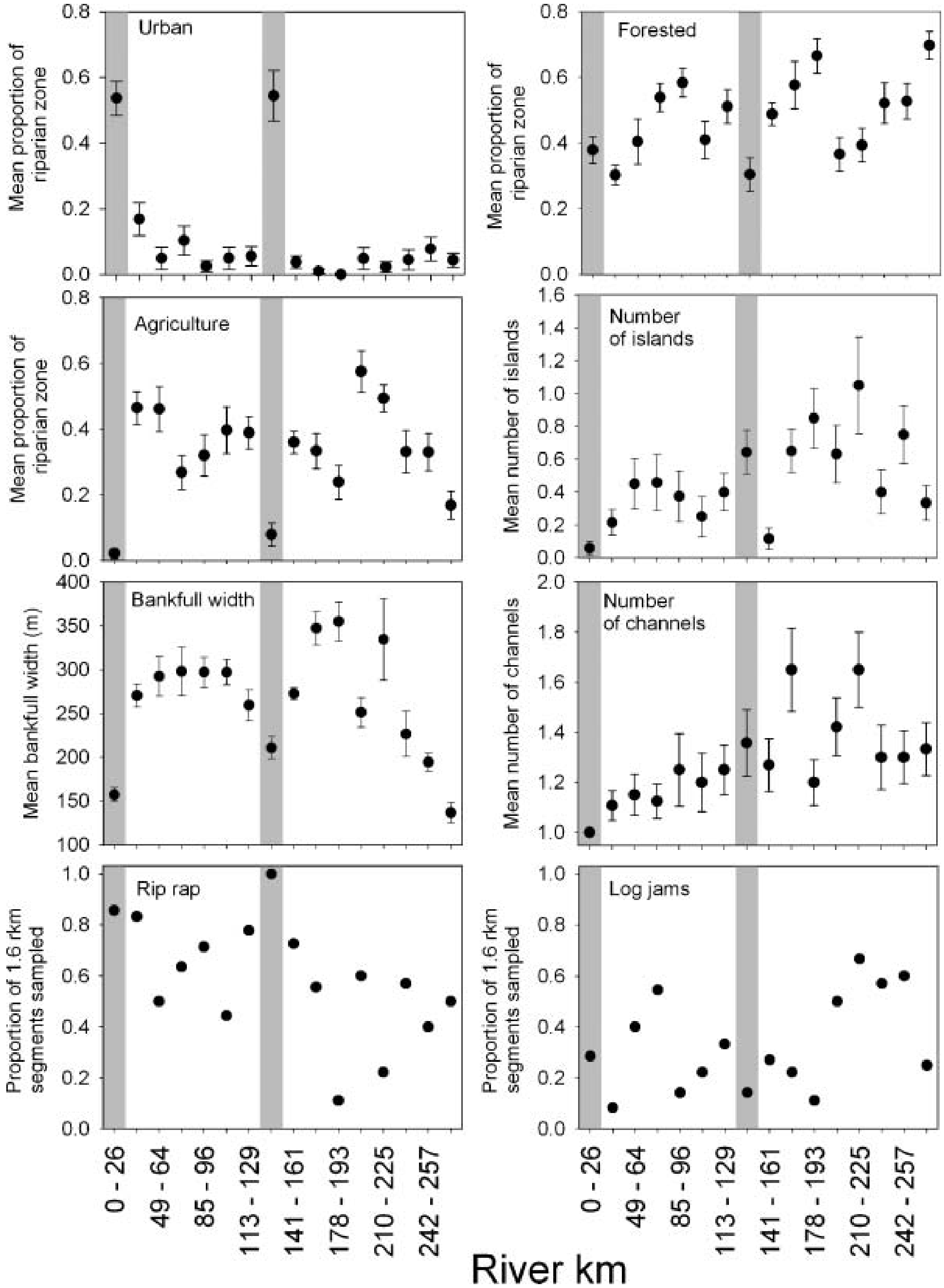

Figure 3. Longitudinal patterns in the mean proportion of the riparian zone (200 m on each side of river) that is urban, forested and agriculture, mean number of instream islands, channels and mean bankfull width based on cross section of satellite imagery of the Kansas River, fall, 2005–2006. Error bars represent one standard error. The mean number of 1.6 km segments that contained riprap and log jams is also shown, and is based on fish sampling at those sites and not satellite imagery. Shaded areas represent river reaches with high urban influence

Fort Riley), but was similar to rkm 0–26 (Kansas City) and rkm 130–140 (Topeka) (Figure 3). In general, Kansas City and Topeka, the two largest cities by population, had a low proportion of agriculture and forest in the watershed and narrowest bankfull widths, fewest islands, but the highest proportion of riparian area in riprap and urban development (Figure 3).

Table II. Component loadings and parameters from a principal components analysis using eight instream and riparian metrics from the Kansas River, Kansas, USA

	Component loading			Population parameters	
	PC1	PC2	PC3	Mean	Range
Riparian					
Urban	−0.44	0.25	0.31	0.11	0.0–0.54
Agriculture	0.35	0.37	−0.48	0.33	0.02–0.58
Forested	0.19	−0.74	0.18	0.48	0.30–0.70
Instream					
Number channels	0.35	0.21	0.32	1.29	1.0–1.65
Number of islands	0.39	0.16	0.42	0.48	0.06–1.05
Bankfull width (m)	0.35	0.01	−0.44	263	137–355
Riprap	−0.44	0.24	−0.13	0.59	0.11–1.00
Log jams	0.24	0.35	0.39	0.33	0.08–0.67
Eigenvalue	3.5	1.4	1.2		
Variance explained (%)	43	18	15		

Riparian values are mean proportion of 200 m transects on each side of the river at 1.6 river km intervals. Number of channels, islands and bankfull width were calculated from the same transects. Riprap and log jams are the proportion of electrofishing samples in each of those habitats.

PC1 of the habitat PCA explained 43% of the variation in the environmental data and was primarily an index of urbanization (Table II). River reaches that scored high on PC1 has a low proportion of urban area in the watershed and fewer sites with riprap. Habitat PC2 explained 18% of the variation and was primarily a gradient of riparian forested areas (Table II), whereas PC3 explained 15% of the variation and river reaches with narrower bankfull widths and less agriculture in the riparian zone, and more log jams and islands scoring high on PC3 (Table II).

The lowest habitat PC1 values were located between rkm 0 and 26 (Kansas City) and 130–140 (Topeka) with the highest values between rkm 162 and 257 (Figure 4). Habitat PC2 was highly variable with reaches from rkm 178 to 274 having the highest and lowest values. Habitat PC3 was generally highest in the upper river reaches (similar to plots of the number of channels and islands; Figure 3), but was also high at rkm 0–26 (Kansas City) and 130–140 (Topeka). Flathead catfish PC1, an index of catfish abundance, was highest near reaches (rkm 85–129) and lowest in the upper reaches (rkm 178–274) and near Kansas City (rkm 0–26). However, flathead catfish PC2, and index of growth, was lowest near the urban areas of Kansas City (rkm 0–26) and midriver reaches (rkm 130–177), and highest in the rural areas between rkm 178 and 241 (Figure 4).

Flathead catfish PC1 decreased with habitat PC3, which tended to be a gradient of riparian agriculture, stream width and number of islands and log jams ($r = -0.57$, $p = 0.02$). Wide, agricultural river reaches with fewer islands and jog jams tended to have higher abundance of flathead catfish (Figure 5). However, flathead catfish PC1 was not related to habitat PC1, an index of urban instream and riparian land use ($r = -0.08$, $p = 0.78$), or habitat PC2 ($r = 0.03$, $p = 0.92$). Flathead catfish PC2, an index of growth, increased with habitat PC1, an index of urban land use ($r = 0.67$, $p = 0.005$; Figure 5). River reaches with increased urbanization had slower growth than areas with less urbanization. Flathead catfish PC2 was not related to habitat PC2 ($r = 0.04$, $p = 0.89$) or PC3 ($r = 0.06$, $p = 0.82$).

DISCUSSION

Spatial variability among habitats within lotic systems has direct management and conservation implications for fish communities. Anthropogenic structures serve as potential sources of fish community fragmentation initiating possible localized responses in fish species' population dynamics (Chick *et al.*, 2006). The results of this study suggest population dynamics of flathead catfish vary longitudinally throughout the Kansas River, and are related to instream and riparian habitats linked to urbanization. In the Kansas River, other large river native fishes (shovelnose

DOI: 10.1002/rra

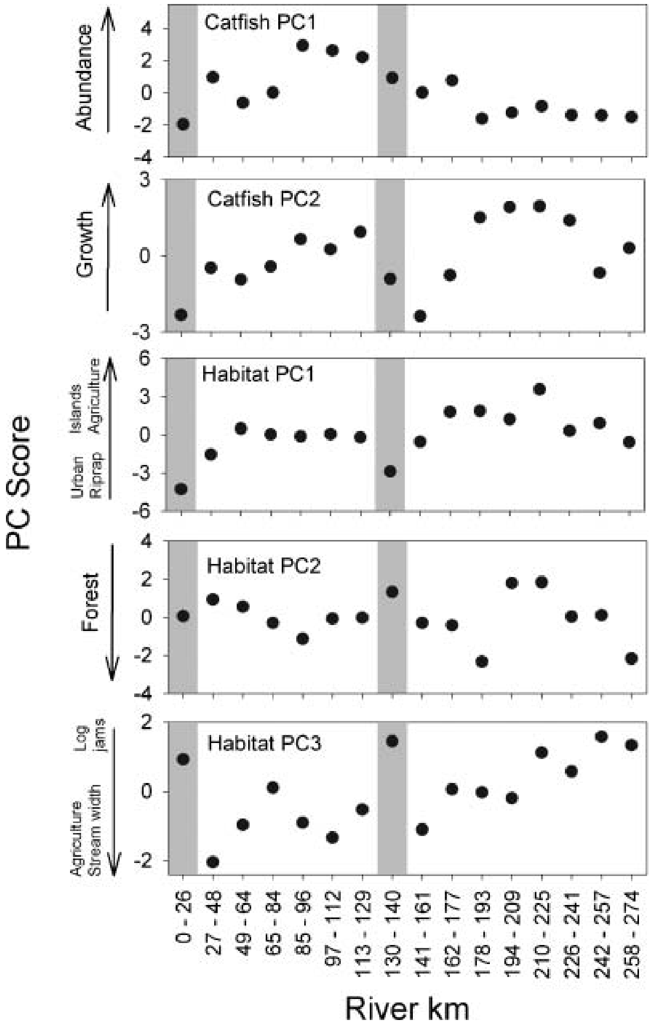

Figure 4. Longitudinal patterns of principal component scores for riparian and instream habitat, and flathead catfish growth and abundance in the Kansas River, 2005–2006. Shaded areas represent river reaches with high urban influence

sturgeon *Scaphirhynchus platorynchus* and channel catfish *Ictaluris punctatus*) had higher abundance in near rkm 85–96 and lower near 258–274 (Quist and Guy, 1998, 1999), which follows the same pattern as our study. However, the studies by Quist and Guy (1998, 1999) were limited to only two river reaches. Our study suggests that these patterns are evident at a larger spatial scale and may be related to urbanization and river modifications.

Flathead catfish in the Kansas River may follow similar trends observed by Daugherty and Sutton (2005a) in terms of high relative abundance and low exploitation, particularly in middle reaches of the river. However, we did not detect density-dependent trends in flathead catfish growth, indicating abiotic factors (anthropogenic sources) may influence the population characteristics of flathead catfish. Increased urbanization in the watershed has been linked to reduced fish diversity, richness and biotic integrity (Roth *et al*., 1996; Wang *et al*., 2001), and our study suggests that it may be linked to fish growth as well. Our low abundance estimates in some urbanized river reaches (i.e. Kansas City) may suggest that increased exploitation from increased human population may reduce abundance. However, exploitation throughout the Kansas River is <10% and total annual mortality is also low (14–28%; Makinster and Paukert, in press), which is characteristic of lightly exploited fish populations (Daugherty and Sutton, 2005a). These results, coupled with the limited movement among reaches, which is consistent with other native flathead catfish populations (Skains and Jackson, 1995; Dobbins *et al*., 1999; Travnichek, 2004;

DOI: 10.1002/rra

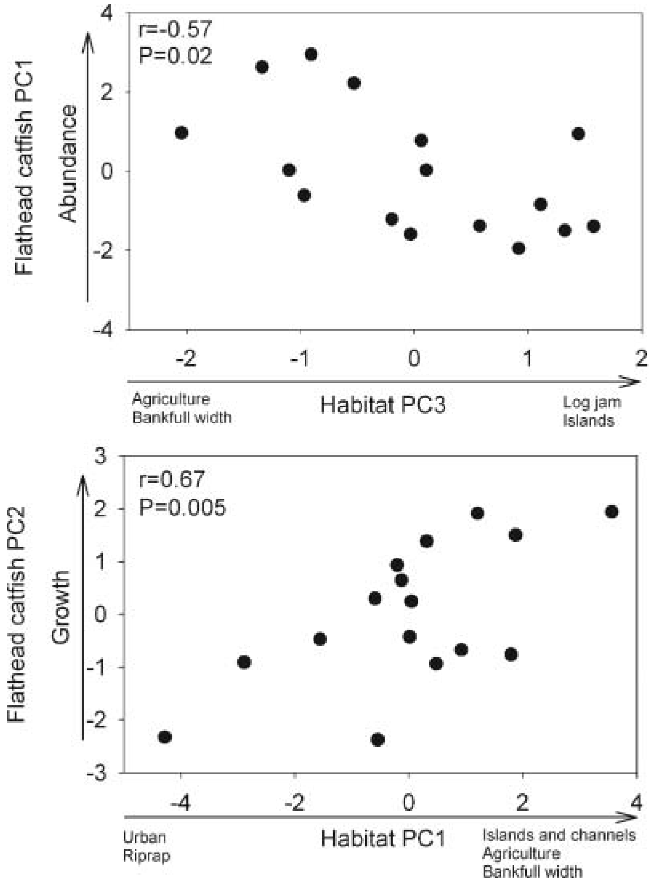

Figure 5. Relationship between flathead catfish principal component (PC) 1 (abundance) and PC2 (growth) with habitat PC1 (urbanization) and PC3 (agriculture and bankfull width)

Daugherty and Sutton, 2005b), suggest that, in the Kansas River, the flathead catfish population has minimal exploitation and movement, and that other factors are affecting abundance and growth.

Flathead catfish abundance tended to be lower in areas with islands, log jams and reduced agriculture, which was surprising. These conditions are more similar to natural Great Plains Rivers and therefore it was expected that flathead catfish abundance would be higher in these areas. Flathead catfish commonly use log jams for cover, foraging and spawning (Insaurralde, 1992; Daugherty and Sutton, 2005b) and we expected higher abundances in reaches with more log jams. However, all river reaches still contained log jams and therefore may have provided suitable habitat for flathead catfish. Catchability of flathead catfish was assumed to be similar among all habitats and river reaches. However, we cannot rule out that differential catchability in different habitats may have affected our abundance estimates. Agricultural land use, which is likely related to increased nutrients (Allan, 2004), may increase productivity which may increase prey fishes for flathead catfish (which were not sampled for this study). Other studies have indicated that higher fish densities were in areas of higher agricultural and lower urban land use (Stewart *et al*., 2001; Wang *et al*., 2001), which is similar to our study. Although biotic diversity may be reduced with increased agriculture (Roth *et al*., 1996; Wang *et al*., 1997, 2001), these land-use practices may provide population-level benefits within a species by increasing productivity that may increase fish abundance.

Flathead catfish growth was slowest in the urbanized reaches near major metropolitan areas on Kansas City and Topeka, Kansas, but still was relatively fast compared to other native riverine populations. Kwak *et al*. (2006) compiled growth from 19 native riverine flathead catfish populations, and the Kansas River population in this study was above average for mean length at ages 1 and 3. Even the slowest growing flathead catfish in the study reaches of

DOI: 10.1002/rra

the Kansas River were in the upper 50% of all native riverine populations. Quist and Guy (1998) attributed faster channel catfish growth in the Kansas River to greater prey availability in silt and detrital substrates (urbanized areas) compared to sand-dominated areas. In our study, flathead catfish growth was fastest in less urban areas, suggesting urban areas do not provide more suitable resources for fast growth. Although the percentage of urban land in a watershed is typically <10% (Benke and Cushing, 2005), the impacts even at these low levels can be substantial (Wang *et al*., 2001). The reach that had the some of the slowest growth (Kansas City) was the most modified reach of the Kansas River with instream sand dredging, urban riparian areas and engineered (riprap) banks (Sanders *et al*., 1993) and suggest urbanization may negatively impact flathead catfish. Most studies evaluating the effects of land use on fishes use community-based multimetric indices and indicate that increased urban or agriculture land is linked to decreased biotic integrity (Allan, 2004), but few studies have linked individual fish growth to urbanization. However, Bartl and Keckeis (2004) determined that larval fish growth was lower in modified river reaches compared to urban modified reaches. Urbanization of rivers may lead to increased runoff into river, increased pollutants, reduced instream habitats and increased channelization (Allan, 2004) and has been linked to reduced fish density (Wang *et al*., 2001). Diet analysis was not examined in this study, but given that flathead catfish are piscivorous (Minckley and Deacon, 1959; Pine *et al*., 2005), perhaps differences in prey-fish densities or assemblages allow for this differential growth.

Recognizing the spatial variability in population dynamics of riverine fishes is important to determine factors that influence fish populations. Although several studies recognize spatial variation in fish communities (Gido *et al*., 1997; Chick *et al*., 2006; Lasne *et al*., 2007), relatively few studies investigate spatial variation of population dynamics within a species. The effect of land use and river modification on fish and macroinvertebrates has been linked at the community scale through biotic integrity metrics (e.g. Karr, 1981; Wang *et al*., 2001). Our study suggests that land use may also influence growth and possibly abundance of an individual species. However, anthropogenic effects are not mutually exclusive and other factors (e.g. prey availability, substrate, water quality) also influence abundance and growth of fishes. Although correlative relationships were evident between flathead catfish growth and urbanization, one of the reaches with the slowest growth was only partially in an urban area and therefore other factors may affect growth of flathead catfish in the Kansas River. Nonetheless, our study suggests that conservation and management of riverine fishes may need to consider the spatial effects and discrete population characteristics within a river. Flathead catfish in the Kansas River are sedentary (Makinster, 2006) and therefore differences in reach-level population characteristics indicate management at the reach scale may be feasible.

ACKNOWLEDGEMENTS

We thank J. Eitzmann and M. Thompson for their extensive help with field and laboratory data collection. Also, D. Nygren and T. Mosher with the Kansas Department of Wildlife and Parks for assistance with project development and comments, and K. Gido, W. Dodds and two anonymous reviewers with comments on early drafts of this manuscript. Funding for this project was provided by the Kansas Department of Wildlife and Parks through Federal Aid in Sportfish Restoration F50R. The Kansas Cooperative Fish and Wildlife Research Unit is jointly sponsored by the Kansas Department of Wildlife and Parks, Kansas State University, the US Geological Survey and the Wildlife Management Institute.

REFERENCES

Allan JD. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systemmatics* **35**: 357–384.

Armantrout NB. 1998. *Glossary of Aquatic Habitat Inventory Terminology*. American Fisheries Society: Bethesda, Maryland.

Bartl E, Keckeis H. 2004. Growth and mortality of introduced fish larvae in a newly restored urban river. *Journal of Fish Biology* **64**: 1577–1592.

Benke AC, Cushing CE. 2005. *Rivers of North America*. Elsevier Academic Press: San Diego, California; 1144.

Chick JH, Pegg MA, Koel TM. 2006. Spatial patterns of fish communities in the Mississippi River System: assessing fragmentation by low-head dams. *River Research and Applications* **22**: 413–4427.

Daugherty DJ, Sutton TM. 2005a. Population abundance and stock characteristics of flathead catfish in the lower St. Joseph River, Michigan. *North American Journal of Fisheries Management* **25**: 1191–1201.

DOI: 10.1002/rra

Daugherty DJ, Sutton TM. 2005b. Seasonal movement patterns, habitat use, and home range of flathead catfish in the Lower St. Joseph River, Michigan. *North American Journal of Fisheries Management* **25**: 256–269.

DeVries DR, Frie RV. 1996. Determination of age and growth. In *Fisheries Techniques*, 2nd edn, Murphy BR, Willis DW (eds). American Fisheries Society: Bethesda, Maryland; 483–512.

Dobbins DA, Cailteux RL, Nordhaus JJ. 1999. Flathead catfish abundance and movement in the Apalachicola River, Florida. In *Catfish 2000: Proceedings of the international Ictalurid Symposium*, Irwin ER, Hubert WA, Rabeni CF, Shramm HL Jr, Coon T (eds). American Fisheries Society Symposium 24: Bethesda, Maryland; 199–201.

Eitzmann JL, Makinster AS, Paukert CP. 2007. Distribution and growth of blue sucker in a Great Plains USA river. *Fisheries Management and Ecology* **14**: 255–262.

Galat DL, Berry CR Jr, Peters EJ, White RG. 2005. The Missouri River basin. In *Rivers of North America*, Benke AE, Cushing CE (eds). Elsevier Academic Press: San Diego, California; 427–480.

Gergel SE, Turner MG, Miller JR, Melack JM, Stanley EH. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic Sciences* **64**: 118–128.

Gido KB, Propst DL, Molles MC Jr. 1997. Spatial and temporal variation of fish communities in secondary channels of the San Juan River, New Mexico and Utah. *Environmental Biology of Fishes* **49**: 417–434.

Hughes RM, Gammon JR. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. *Transactions of the American Fisheries Society* **116**: 196–209.

Insaurralde MS. 1992. Environmental characteristics associated with flathead catfish in four streams. Ph.D. Dissertation, Mississippi State University, Mississippi State, Mississippi, USA.

Johnson D. 1998. *Applied Multivariate Methods for Data Analysis*. Duxbury Press: Pacific Grove, California.

Karr JR. 1981. Assessment of biotic integrity using fish communities. *Fisheries* **6**: 21–26.

Kwak TJ, Pine WE III, Waters DS. 2006. Age, growth, and mortality of introduced flathead catfish in Atlantic rivers and a review of other populations. *North American Journal of Fisheries Management* **26**: 73–87.

Lammert M, Allan JD. 1999. Assessing biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates. *Environmental Management* **23**: 257–270.

Lasne E, Bergerot B, Lek S, Laffaille P. 2007. Fish zonation and indicator species for the evaluation of the ecological status of rivers: example of the Loire basin (France). *River Research and Applications* **23**: 877–890.

Makinster AS. 2006. Population dynamics of flathead catfish in the Kansas River. MS Thesis, Kansas State University, Manhattan, Kansas, USA.

Makinster AS, Paukert CP. in press. Effect and utility of minimum length limits and mortality caps for flathead catfish in discrete river reaches of a large prairie river. *North American Journal of Fisheries Management.*

Minckley WL, Deacon JE. 1959. Biology of flathead catfish in Kansas. *Transactions of the American Fisheries Society* **88**: 344–355.

Munger CR, Wilde GR, Follis BJ. 1994. Flathead catfish age and size at maturation in Texas. *North American Journal of Fisheries Management* **14**: 403–408.

Nash MK, Irwin ER. 1999. Use of otoliths versus pectoral spines for aging adult flathead catfish. In *Catfish 2000: Proceedings of the International Ictalurid Symposium*, Irwin ER, Hubert WA, Rabeni CF, Shramm HL Jr, Coon T (eds). American Fisheries Society Symposium 24: Bethesda, Maryland; 309–316.

Pennington CH, Baker JA, Potter ME. 1983. Fish populations along natural and revetted banks on the lower Mississippi River. *North American Journal of Fisheries Management* **3**: 204–211.

Pine WE III, Kwak TJ, Waters DS, Rice JA. 2005. Diet selectivity of introduced flathead catfish in coastal rivers. *Transactions of the American Fisheries Society* **134**: 901–909.

Quist MC, Guy CS. 1998. Population characteristics of channel catfish from the Kansas River, Kansas. *Journal of Freshwater Ecology* **13**: 351–359.

Quist MC, Guy CS. 1999. Spatial variation in population dynamics of shovelnose sturgeon in the Kansas River. *Prairie Naturalist* **31**: 65–74.

Quist MC, Tillma JS, Burlingame MN, Guy CS. 1999. Overwinter habitat use of shovelnose sturgeon in the Kansas River. *Transactions of the American Fisheries Society* **128**: 522–527.

Roth NE, Allan JD, Erickson DL. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* **11**: 141–156.

Sakaris PC, Irwin ER, Jolley JC, Harrison D. 2006. Comparison of native and introduced flathead catfish populations in Alabama and Georgia: growth, mortality, and management. *North American Journal of Fisheries Management* **26**: 867–874.

Sanders R, Huggins MDG, Cross FB. 1993. The Kansas River system and its biota. In *Proceedings of the Symposium on Restoration Planning for the Rivers of the Mississippi and Missouri River Ecosystem*, Hesse LW, Stalnaker CB, Benson NG, Zuboy JR (eds). Report Number 19; U.S. National Biological Survey: Washington, DC; 295–326.

Skains JA, Jackson DC. 1995. Linear ranges of large flathead catfish in two Mississippi streams. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* **47**: 1993. 539–546.

Smith TA, Kraft CE. 2005. Stream fish assemblages in relation to landscape position and local habitat variables. *Transactions of the American Fisheries Society* **134**: 430–440.

Stewart JS, Wang L, Lyons J, Horwatich JA, Bannerman R. 2001. Influences of watershed, riparian-corridor, and reach-scale characteristics on aquatic biota in agricultural watersheds. *Journal of the American Water Resources Association* **37**: 1475–1487.

Tramer EJ, Rogers PM. 1973. Diversity and longitudinal zonation in fish populations of two streams entering a metropolitan area. *American Midland Naturalist* **90**: 366–374.

Travnichek VH. 2004. Movement of flathead catfish in the Missouri River: examining opportunities for managing river segments for different fishery goals. *Fisheries Management and Ecology* **11**: 89–96.

Turner PR, Summerfelt RC. 1971. Food habits of adult flathead catfish, *Pylodictis olivaris* (Rafinesque), in Oklahoma reservoirs. *Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners* **24**(1970): 387–401.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* **37**: 130–137.

Wang L, Lyons J, Kanehl P. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management* **28**: 255–266.

Wang L, Lyons J, Kanehl P, Gatti R. 1997. Influence of watershed land use on habitat quality and biotic integrity in Wisconsin streams. *Fisheries* **22**(6): 6–12.

Wang L, Lyons J, Rasmussen P, Seelbach P, Simon T, Wiley M, Kanehl P, Baker E, Niemela S, Stewart PM. 2003. Watershed, reach, and riparian influences on stream fish assemblages in the northern lakes and forest ecoregion, USA. *Canadian Journal of Fisheries and Aquatic Sciences* **60**: 491–505.

Weller RR, Winter LD. 2001. Seasonal variation in home range size and habitat use of flathead catfish in Buffalo Springs Lake, Texas. *North American Journal of Fisheries Management* **21**: 792–800.

Wildhaber ML, Lamberson PJ, Galat DL. 2003. A comparison of measures of riverbed form for evaluating distributions of benthic fishes. *North American Journal of Fisheries Management* **23**: 543–557.

DOI: 10.1002/rra