FLATHEAD CATFISH POPULATION DYNAMICS IN THE KANSAS RIVER

by

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ABSTRACT

We investigated the spatial variation of flathead catfish *Pylodictis olivaris* relative abundance, condition, size structure, growth, and total annual mortality in the 274-km Kansas River. A randomized, electrofishing regime was used to collect fish throughout the river between May-August, 2005-2006. Relative abundance of age 1 fish (≤ 200 mm), subadult (> 200-400 mm), and adult fish (> 400 mm) ranged from 0.34 to 14.67 fish per hour, with lowest abundance of all sizes of fish occurring in the lowermost river segment. Increased abundance of age 1 flathead catfish appeared to be related to availability of riprap habitats, but no relation was found among larger fish. Body condition (relative weight) decreased with increased fish size and was consistent across river segments. Proportional stock density (PSD) remained consistent across all river segments ranging from 21 to 75. Mean length at age 3 ranged from 293 to 419 mm total length among river segments with the slowest growth occurring in the lowermost segment and fastest growth in upper segments of the river. Total annual mortality estimated from catch curves followed a similar trend and varied from 11-28% throughout the river with exploitation likely < 10% based on tag returns. Discriminant function analysis suggested flathead catfish abundance and growth differed among four reaches of the Kansas River. Simulation modeling of 305 mm, 610 mm, and 762 mm minimum length limits revealed PSD and relative stock density of preferred-sized fish (RSD-P) declined substantially (> 25 PSD units and > 15 RSD-P units) as exploitation increased regardless of river reach, suggesting different regulations among reaches was not needed. No substantial differences were observed in flathead catfish size structure with the 610 and 762 mm length limits among reaches; however, anglers would have to sacrifice about 50% of the number flathead catfish harvested under current mortality conditions with a 610 mm length limit. Estimated mortality caps revealed that each reach could sustain about 60% and 55% total annual mortality to maintain current PSD and RSD-P levels, respectively. Spatial differences in population dynamics need to be considered when evaluating riverine fish populations. Maintaining a quality fishery for flathead catfish in the Kansas River may require more restrictive harvest regulations if exploitation increases.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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PREFACE

This thesis was my own personal work; however, it is written in the third person because it is formatted for submission into *Transactions of the American Fisheries Society* (chapter 1) and *North American Journal of Fisheries Management* (chapter 2).

Chapter 1

Longitudinal patterns in flathead catfish population dynamics within a large prairie river

ABSTRACT

We investigated the spatial variation of flathead catfish *Pylodictis olivaris* relative abundance, condition, size structure, growth, and total annual mortality in the 274-km Kansas River. A randomized, electrofishing regime was used to collect fish throughout the river between May-August, 2005-2006. Relative abundance of age 1 fish (≤ 200 mm), subadult (> 200-400 mm), and adult fish (> 400 mm) ranged from 0.34 to 14.67 fish per hour, with lowest abundance of all sizes of fish occurring in the lowermost river segment. Abundance of age 1 flathead catfish appeared to be related to availability of riprap habitats, but no relation was found among larger fish. Condition decreased with increased fish size and was consistent across river segments. Proportional stock density remained consistent across all river segments ranging from 21 to 75. Mean length at age 3 ranged from 293 to 419 mm total length among river segments with the slowest growth occurring in the lowermost segment and fastest growth in upper segments of the river. Total annual mortality estimated from catch curves followed a similar trend and varied from 11 to 28% throughout the river. Discriminant function analysis suggested flathead catfish population dynamics differed throughout the Kansas River. Spatial differences in population dynamics need to be considered when evaluating riverine fish populations.

INTRODUCTION

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).

Fish populations may be strongly influenced by these density-independent control patterns (Buynak et al. 1989; Gido et al. 1997; Wildhaber et al. 2003; Smith and Kraft 2005), but also may develop more localized, longitudinal zones where density-dependent processes dominate. Kirby (2001) found channel catfish (*Ictalurus punctatus*) population characteristics (i.e. growth, abundance) differed within segments of the Big Sioux River, South Dakota, suggesting the need for spatial evaluation of population characteristics. Changes in natural hydrographs and in-stream habitat have proved detrimental to several native species (Quist et al. 1999; Gido et al. 2002), while perhaps improving conditions of others. For example, Quist and Guy (1998) suggested faster channel catfish growth (*Ictalurus punctatus*) in silt substrate, urbanized areas of the Kansas River compared to sand-dominated areas lower in invertebrate productivity. Further, Scott et al. (1986) found faster cutthroat trout (*Oncorhynchus clarki*) growth in a warm, urbanized creek versus an unmodified creek. Therefore, longitudinal differences and degree of river modifications may be associated with varying population dynamics of fishes.

Midwestern U.S. rivers have been altered by various anthropogenic activities. Commercial sand dredging operations increase bank erosion and channel widening (Sanders et al. 1993). The inflow of pollutants from both agricultural and industrial sources has been implicated in decreases of species diversity (Tramer and Rogers 1973). In addition, dams restrict fish migrations and restrict the longitudinal zonation of fish communities typical of naturally-flowing systems (Chick 2006). In the Kansas River, Kansas, placement of large rock (riprap) along the river shoreline is a common practice to prevent bank erosion. Lower portions of the river (i.e. highly urbanized; near Kansas City, Kansas) contain concrete along the riverbanks for further stabilization. Subsequent scour of underlying sediment bed creates deepwater pools suitable for benthic fishes in this shallow river, including flathead catfish (*Pylodictis olivaris*; Minckley and Deacon 1959; Jackson 1999).

Several 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). However, fewer studies have examined longitudinal patterns in population dynamics of a species within a river. Previous investigations of flathead catfish population indices (e.g. relative abundance, 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). These studies infer system specificity (Daugherty and Sutton 2005), and suggest degrees of density dependent or independent mechanisms may vary spatially to influence flathead catfish populations within a river.

The objectives of this study focus on identifying longitudinal patterns in flathead catfish population dynamics in the Kansas River. Specifically, our goals were to (1) determine if flathead catfish population dynamics (i.e. growth, relative abundance, size structure, mortality) differ longitudinally, and (2) evaluate how these differences relate to habitat modifications or density-dependent processes.

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 (Metcalf 1966; 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). Discharge is influenced by Milford Dam impounding the Republican River near Kansas River kilometer (rkm) 274, Tuttle Creek Dam impounding the Big Blue River at rkm 237, and Perry Dam impounding the Delaware River at rkm 106. Exposure of the historically braided channel to reduced flow has lead to accumulation of fine-grained particles and thus, a reduction of backwater habitat (Quist et al. 1999). Mean water depth is typically < 1.5 m (current study), and mean annual discharge is approximately 214 m^3/s (Galat et al. 2005). Only one low-head dam exists on the mainstem Kansas River, located at rkm 83 near Lawrence, Kansas (Figure 1.1). Two weirs located on the mainstem river at rkm 24 and rkm 140 serve as sites of water intake for the cities of Kansas City and Topeka, respectively. Presence of bank stabilization structures has been estimated at 16% of the mainstem Kansas River (see Sanders et al. 1993 for detailed description).

Fish sampling

The Kansas River was divided into 16 approximately 16-km river segments based on logistical access and possible barriers (e.g. weirs and low-head dams) that may influence fish populations. Our goal was to sample one 16-km segment per day. Within each river segment, a minimum of three 1.6-km sections were randomly selected to collect fish, and within each section, a minimum of three 300-sec. electrofishing stations were sampled in suitable areas (i.e. sufficient depth to float our boat).

Daytime electrofishing was completed during May-August in 2005 and 2006, using low pulse, DC current (1-6 A; 180-250 V; 15-20 pulses/s) from a 4.5-m aluminum boat equipped with a 15-hp outboard motor and mounted with a Coffelt Model VVP 15 electrofisher powered by a 5,000-watt, single phase, 240-volt 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 electrofishing (8-15 A; 300-500 V; 40-60 pulses/s) was conducted to increase the number of tagged flathead catfish at large as well as provide increased sample sizes for aging purposes.

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 (model FD-94; Floy Tag Inc., Seattle, Washington) inserted through the dorsal pterygiophores near the dorsal fin insertion, and an adipose fin clip to estimate tag loss. To encourage tag returns by anglers, each tag was labeled with a phone number, email address, and ‘K-State’. Pectoral spines were removed from 571 flathead catfish (58% of total captured) 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. Movement of recaptured flathead catfish was estimated as the distance from the original tagging location to the recapture while acknowledging greater distances were possible than those calculated.

Habitat classification

Shoreline habitat of each electrofishing station within each 1.6-km section was classified into one of three categories: mud-bank (MU), rip-rap (RR; consistent length of rocky shoreline with rocks of various sizes), and log jam (LJ; stockpile of woody debris partially inundated extending from the shoreline into the water where main beam was > 4.5 m long). Only one shoreline habitat was sampled per electrofishing station. Where available, at least one of each habitat type was sampled in each 1.6-km section. Water depth was measured during 2005 from transects at the top, middle, and bottom of each electrofishing station using an electronic depthfinder along transects perpendicular from the shoreline towards the river channel to a distance of approximately 30-m. This distance was believed to be the maximum extent of the electrofishing field.

Because water levels fluctuated up to 5-m during our sampling, water depth measurements needed to be standardized across time. Seven United States Geological Survey gauging stations on the mainstem Kansas River provided gauge height data over the last decade to standardize our measured electrofishing depths. Calculated mean water depths were corrected to 10-year mean gauge heights based on data from the upstream gauging station nearest each electrofishing station. We then calculated the weekly mean gauge height when our depth measurements were taken during electrofishing sampling. The weekly mean gauge height was then subtracted from the 10-year mean gauge height giving a standardized number for each gauging station range. This standardized value was then subtracted from the mean depths at each electrofishing station allowing comparison of mean water depth across the entire Kansas River throughout the summer.

Population indices

All population parameters (i.e. relative abundance, size structure, condition, growth, mortality) were determined for each 16-km segment to identify longitudinal patterns throughout the Kansas River. Flathead catfish relative abundance within each river segment was evaluated using catch per hour of electrofishing (CPUE) for three sizes of fish: ≤ 200 mm TL (age 1), 201 – 400 mm TL (subadults; age 2-3), and > 400 mm TL (adult; age ≥ 4). Our data indicated all age 1 fish were < 200 mm TL (mean TL = 165 mm). CPUE of age 1 fish was assumed to be an index of flathead catfish recruitment in the Kansas River. 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. Size structure was determined from length frequency histograms and proportional stock density (PSD; number of quality fish / number stock fish *100; Anderson and Neumann 1996). Condition of flathead catfish was examined using relative weight (W_r), with fish < 130 mm TL excluded from this analysis (Bister et al. 2000). Mean relative weight was calculated for each river segment and size class (i.e. age 1, subadult, and adult) to minimize length-related bias.

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 images of each spine section were captured and analyzed using ImagePro image analysis software. 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.

Back-calculation of length at age of all captured flathead catfish was examined using the Fraser-Lee method and incorporated into a von-Bertalanffy growth model using FAST software (Fishery Analysis and Simulation Tools; Slipke and Maceina 2000). Brody growth coefficient (K), the theoretical time where total length equals 0 (t_0), and the theoretical maximum length (L_∞) were estimated based upon back calculations of age. For river segments and reaches not fitting model assumptions or had unrealistic L_∞ calculations (> 1,600 mm), L_∞ was held constant at the largest fish collected in that reach. Total annual mortality (A) and survival (S) of each river segment and reach were estimated from the descending limb of catch curves using weighted regression (Ricker 1975).

Data analyses

To assess longitudinal patterns in flathead catifish population dynamics, we plotted population attributes (mean CPUE and W_r of each size class, PSD, K, total annual mortality, and mean lengths at age 3), by 16-km river segments and visually assessed if longitudinal patterns were evident. These 16 river segments provided sufficient resolution to determine longitudinal trends and also provided sufficient numbers of flathead catfish (> 10 fish/segment in all segments but two) to calculate these population indices. Pearson correlation analysis was used to evaluate if growth (K and mean TL at age 3), condition (W_r), or size structure (PSD) was associated with catch rates of flathead catfish, suggesting density dependence. For this analysis, CPUE of all sizes of flathead catfish was correlated with K, mean TL at age 3, mean W_r of all three sizes of flathead catfish, and PSD. Only samples from random electrofishing sites were used in the analysis of CPUE, W_r, total annual mortality, and survival.

The relative availability of shoreline habitat was examined for each 16-km river segment. Availability of mud bank, log jam, and riprap shoreline habitat was determined from the proportion of each habitat sampled to all that were sampled in each river segment. Instances where a habitat was not sampled indicated none was available for particular 1.6-km sections.

We hypothesized *a priori* that habitat modifications in the river may affect flathead catfish population characteristics. Therefore, we divided the Kansas River into four reaches based on possible fish barriers and large habitat alterations: rkm 0-24 (below Johnson County Weir in Kansas City, Kansas), rkm 25-82 (below Bowersock Dam in Lawrence, Kansas), rkm 83-138 (below the Topeka water intake weir in Topeka, Kansas), and rkm 138-274 (above the Topeka weir to the junction of the Smoky Hill and Republican rivers in Junction City, Kansas).

A stepwise discriminant function analysis (DFA) was used to examine if differences in flathead catfish population indices (i.e. CPUE of each size class, PSD, W_r, Brody growth coefficient K, and mean TL at age 3) were evident and to test our *a priori* classification (Johnson 1998; Paukert and Wittig 2002). Results were cross-validated using a jackknife correction procedure. Proportional stock density was not calculated for 3 out of 16 segments due insufficient sample size (< 18 fish). Also, W_r was not calculated for age 1 fish in 4 out 16 segments, subadult fish in 3 of 16 segments, and adult fish in 1 of 16 segments due to low sample sizes (< 5 fish of each size class). Therefore, only CPUE of each size class, PSD, K, and mean TL at age 3 were included in our DFA. All variables not meeting the assumption of normality were transformed (log or arc-sine square root) to better meet this assumption. Analysis of covariance (ANCOVA) was used to determine if relative abundance of the three flathead catfish size classes differed among shoreline habitats. River kilometer was used as a covariate as flathead catfish abundance may also differ longitudinally throughout the Kansas River.

ANCOVA was also used to determine if mean adjusted water depth differed among shoreline habitats where river kilometer was again used as a covariate. Analysis of variance (ANOVA) was used to test CPUE among years to examine any differences possibly influencing estimates of abundance (i.e. differences in flow, water temperature). All statistical analyses were considered significant at α level 0.10.

RESULTS

A total of 977 flathead catfish were captured during all sampling in 2005-2006. Three hundred ninety-seven flathead catfish were collected from 462 low pulse, random electrofishing stations and subsequently used in the spatial analysis of population indices of the 16 river segments. Four hundred twelve flathead catfish were captured during supplemental electrofishing, and overnight sets of hoop nets collected 168 flathead catfish. A total of 572 flathead catfish were tagged with only seven fish recaptured (1% recapture rate; two angler returns and five recaptures during electrofishing sampling). All recaptured fish were found < 1 km from their original tagging location and were at large 90 to 268 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%; Figure 1.2). Fish between 500 and 700 mm TL and > 700 mm TL comprised 10% and 2% of the summer random catch, respectively. Length distribution of flathead catfish captured from all sampling ranged from 63 to 1191 mm TL (Figure 1.2).

Pectoral spines were examined from 571 flathead catfish and ages of all flathead catfish collected ranged from 1 to 21 years (Figure 1.3). Age 1 flathead catfish comprised 25% of the catch, age 2 fish comprised 22%, age 3 fish comprised 16%, and age 4 fish comprised 13%. Collection of flathead catfish older than age 9 comprised only 3% of the catch (Figure 1.3).

Change in mean CPUE among all size classes between years sampled was not significant (ANOVA; *P*'s > 0.35), thus data were pooled for further analysis. Relative abundance (CPUE) of age 1 flathead catfish was highly variable among river segments (mean = 3.97; range: 0.45 – 14.67 fish/hour). Mean CPUE of subadult fish was 3.46 fish/hour (range: 0.65 – 8.89 fish/hour), where mean CPUE of adult fish was 1.99 fish/hour (range: 0.78 – 4.06 fish/hour). Flathead catfish CPUE of all sizes classes were consistently high in the middle segments of the Kansas River near Lawrence, Kansas, with lower CPUE in the lower and upper river segments (Figure 1.4).

Mean W_r of age 1 fish were consistently higher than subadult and adult fish throughout all river segments (mean = 109; range 101 – 120). Subadult fish mean W_r was 94 (range = 90 – 99), while adult fish mean W_r was 87 (range = 84 – 94). Condition of all size classes of flathead catfish was relatively stable among all river segments (Figure 1.4).

Back-calculated mean length at age indicated that flathead catfish attained 382 mm TL by age 3 for all segments combined. Mean TL at age 3 showed variation among river segments (range: 293 – 419 mm TL), with the lowest growth in the lowermost segment of the river and peaks in growth between river segments 50 to 70 and 110 to 130. The Brody growth coefficient *K* also varied substantially with the lowest values in middle segments (Figure 1.4).

Proportional stock density (PSD) was typically high but varied among river segments (mean = 54; range: 21-100; Figure 1.5), and did not follow any consistent patterns. However, 54% of river segments had PSD between 30 and 50. Total annual mortality also varied substantially (mean = 0.21; range: 0.11 – 0.33), and was typically lowest in the lower and upper river segments. Middle river segments typically showed similar estimates of mortality (Figure 1.5).

There appeared to be no flathead catfish density-dependent associations within river segments. High CPUE of flathead catfish was not associated with W_r of age 1 (r = 0.02, N = 11, $P = 0.958$) subadult (r = -0.23, N = 13, P = 0.459), and adult fish (r = 0.28, N = 12, $P = 0.379$), PSD (r = -0.03, N = 12, $P = 0.939$), mortality (r = 0.19; N = 12, $P = 0.557$), Brody growth coefficient K (r = 0.07; N = 13, $P = 0.831$), or mean length at age 3 (r = 0.17; N = 16, $P = 0.520$). Increased CPUE of flathead catfish was not related to decreased condition, size structure, mortality, or growth.

The proportion of shoreline habitats sampled in this study varied spatially (Figure 1.6), with fewer river kilometers containing riprap in the upper segments of the river. The proportion of 1.6-km sites sampled containing riprap was typically > 30% downstream of river segment 90. In contrast, proportion of sites sampled containing mud banks was typically > 50% upstream of river segment 100 (Figure 1.6). Mean adjusted water depth in 2005 was highly variable among river segments (Table 1.1). Mean depth was > 1.0 m in all but one segment downstream of river segment 80, whereas mean depth was < 0.25 m in uppermost river segments. No relationship was detected among shoreline habitat type and mean adjusted depth across all river segments (ANCOVA; F = 1.92, d.f. = 2, 242, $P = 0.148$). Flathead catfish relative abundance was influenced by shoreline habitat sampled. Mean CPUE of age 1 flathead catfish was highest in riprap (P

= 0.003; Table 1.2). Relative abundance of subadult and adult flathead catfish was typically higher in riprap habitat, but the relationship was not significant (Table 1.2).

The stepwise discriminant function analysis using relative abundance of all flathead catfish size classes, PSD, *K*, and mean TL at age 3 suggested river reaches (based on physical barriers) had different population characteristics (Wilk's lambda = 0.014, d.f. = 18, 12, P = 0.074) explaining approximately 75% of the variation along the first canonical axis. Based on individual ANOVA F-tests, the four most important variables contributing to the discriminant analysis were CPUE of age 1 fish (F = 6.86, d.f. = 3, 9, *P* = 0.01), subadult fish (F = 11.31, d.f. = 3, 9, *P* = 0.002), adult fish (F = 5.62, d.f. = 3, 9, *P* = 0.02), and mean length at age 3 (F = 6.22, d.f. = 3, 9, *P* = 0.01). Results of the cross-validation procedure showed 9 of the 16 segments (56%) were misclassified in our *a priori* groups. Therefore, abundance and growth appeared to discriminate among river reaches, but this relationship had low predictive power.

After further inspection of Figures 1.4 and 1.5, however, we conducted another DFA using the variables mentioned previously to test for the presence of reaches based on subjective inspection of the data rather than potential barriers. The following reaches were defined: rkm 0 – 26, reach 1; rkm 27 – 84, reach 2; rkm 85 – 193, reach 3; and rkm 194 – 274, reach 4. These variables explained 94% of the variation along the first canonical axis (Wilks' lambda = 0.003, d.f. = 18, 12, *P* = 0.007). Relative abundance of all flathead catfish size classes were the most influential variables along the first canonical axis (F's: 10.1 – 36.7, d.f. = 3, 9, *P*'s < 0.004), along with mean length at age 3 (F = 5.98, d.f. = 3, 9, *P* = 0.02). Results of the cross-validation procedure showed 4 of the 16 segments (25%) were misclassified in our groups. Therefore, flathead catfish population characteristics (primarily abundance and growth) did appear to differentiate different river reaches based on subjective inspection of the data (Table 1.3).

DISCUSSION

Spatial variability among habitat 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 consistent with studies of other species and/or rivers. For example, Paukert and Rogers (2004) attributed higher condition of flannelmouth sucker (*Catostomus latipinnis*) to the increased number of tributaries in intermediate reaches of the 363-km Colorado River below Glen Canyon Dam, Arizona. In the Kansas River, Quist and Guy (1999) observed higher abundance, condition, and growth of shovelnose sturgeon (*Scaphirhynchus platorynchus*) in urban segments (river segments 50 to 60 of present study) compared to undeveloped segments (river segments 150 to 160 of present study). Finally, Wildhaber et al. (2003) found a direct relationship between shallow, smooth bed-form sites and shovelnose sturgeon relative abundance in the Missouri River between Montana and Missouri. Similar studies regarding flathead catfish, however, are limited.

Relative abundance of all sizes of flathead catfish was variable throughout the Kansas River. The lowermost and uppermost reaches of the river contained the lowest relative abundances observed and corroborated with similar estimates of 0.32 to 9.46 fish/hour found in the Lumber River, North Carolina (Kwak et al. 2004), and 0.48 to 14.28 fish/hour in the lower Mississippi River, Kentucky – Mississippi (Driscoll et al.

1999). Middle reaches, however, showed higher relative abundances, particularly among age 1 fish, and were comparable to estimates of 8.77 to 16.62 fish/hour in Contentnea Creek, North Carolina (Kwak et al. 2004). Age 1 flathead catfish abundance was higher in riprap habitat but larger fish abundance was variable among habitats. These man-made habitats (riprap) were more common in lower reaches of the river and flathead catfish appeared to utilize these habitats when available, which is similar to other studies (Minckley and Deacon 1959; Jackson 1999). However, we were only able to infer a preference for riprap habitat with age 1 fish, suggesting rocky shorelines may serve as refugia for young flathead catfish (Minckley and Deacon 1959).

Condition of all flathead catfish was consistent across all reaches of the Kansas River. However, we observed an inverse relationship between condition and fish size across all reaches contrasting with results found by Guier et al (1984) and similar to the findings of Daugherty and Sutton (2005). Guier et al. (1984) found increased condition as total length increased, but these authors studied an introduced flathead catfish population where growth has been shown to exceed that in native systems (Young and Marsh 1990; Kwak et al. 2004). Daugherty and Sutton (2005) suggested the inverse trend of native flathead catfish condition may be related to insufficient quantities of sufficiently sized prey, which may have occurred in our study.

Flathead catfish in the Kansas River may follow similar trends observed by Daugherty and Sutton (2005) 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 condition, growth, and size structure (in contrast to Daugherty and Sutton [2005]), indicating abiotic factors (anthropogenic sources) may influence flathead catfish population characteristics. Kirby (2001) found similar inverse trends in length and condition of channel catfish in the Big Sioux River, South Dakota, and suggested seasonal differences in condition likely caused the observed trend. Additional study of flathead catfish condition across seasons may help in the assessment of this trend.

Flathead catfish growth was slowest in the lowermost reach and comparable to other Midwestern rivers (Barnickol and Starrett 1951; Minckley and Deacon 1959; Daugherty and Sutton 2005). The fastest growth was observed in the uppermost reaches and was similar to introduced populations (Pisano et al. 1983; Young and Marsh 1990; Kwak et al. 2006). These results contrast with Quist and Guy (1998) who 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 sand-dominated, upper reaches of the river. 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 assemblages allow for this differential growth. Future investigation of flathead catfish diet and prey assemblage in the Kansas River may elucidate this hypothesis.

Size structure of flathead catfish differed in the lowermost reach of the Kansas River with the majority of fish below quality length (510 mm TL; Bister et al. 2000). This reach (which also had the slowest growth) represents the most physically modified reach of the Kansas River with sand dredging the predominant factor causing change (Sanders et al. 1993), and suggests urbanization may negatively impact flathead catfish. Size structure of all other reaches appeared similar and were comparable to unexploited populations in the Flint River, Georgia (PSD = 58; Quinn 1989), and the St. Joseph River, Michigan (PSD = 49; Daugherty and Sutton 2005).

Total annual mortality of flathead catfish in the Kansas River remained consistently lower than other populations (Quinn 1993; Summerfelt et al. 1972). Lowest mortality was observed in the upper reaches and was most similar to unexploited populations of flathead catfish in North Carolina rivers (Kwak et al. 2006). The lowermost reach had the highest observed mortality and was similar to the St. Joseph River, Michigan (Daugherty and Sutton 2005). The high mortality observed in the lower reach may be related to human-induced habitat changes (i.e. dredging, shoreline stabilization), or may be related to higher exploitation as this reach was adjacent to the large metropolitan area of Kansas City, Kansas.

Our limited data suggests minimal movement of flathead catfish in the Kansas River. The distance between capture and recapture events was always less than 1 km, even for fish at large 268 days. Other studies of flathead catfish are mixed. Pugh and Schramm (1999) found 93% of tagged flathead catfish > 40 cm moved less than 1 km from their original tagging location. However, Kwak et al. (2004) used radio telemetry to investigate the migratory patterns of introduced populations of flathead catfish and was the first to document the large home ranges of flathead catfish (20.0-45.0 km). Additional research of flathead catfish movement in the Kansas River is needed, but our data concurs with several studies (Skains and Jackson 1995; Dobbins et al. 1999; Travnichek 2004), suggesting flathead catfish movement in native riverine systems may be limited.

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; Kwak et al. 2004; Chick 2006), relatively few studies investigate spatial variation of population dynamics within a species. Our study, coupled with other, more limited studies (Quist and Guy 1998, 1999) indicate that summarizing population characteristics throughout a river may mask differences within a river. Further studies on spatial variation within a river and the mechanisms for the variation (e.g. urbanization, habitat modification, angler harvest) are needed.

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Table 1.1. Description of Kansas River segments and associated mean adjusted water depths (m), river kilometer (rkm) range, USGS gauging station code, and the nearest city of each river segment. Depth measurements were collected from 246 random electrofishing stations and were corrected to the 10-year mean gauge height during May – August, 2005. The USGS gauging station code corresponds to rkm groups used during the standardization of electrofishing station depth measurements. Standard error (SE) are given in parentheses. n/a indicates segments that were not sampled in 2005.

River segment	**Mean adjusted depth (m)**	**River kilometer (rkm) range**	**USGS station code**	**Nearest Kansas city**
0	2.94 (0.2)	0 - 26	06892950	Kansas City
20	0.70 (0.2)	27 - 48	06892350	Edwardsville
30	1.48 (0.1)	49 - 64	06892350	Bonner Springs
40	1.62 (0.1)	65 - 84	06892350	Lawrence
50	1.94 (0.1)	85 – 96	06891000	Lawrence
60	1.91 (0.1)	97 – 112	06891000	Lecompton
70	2.14 (0.2)	113 – 129	06889000	Topeka
80	2.02 (0.1)	130 – 140	06889000	Topeka
90	n/a	141 – 161	06889000	Maple Hill
100	0.75 (0.1)	162 – 177	06888350	Maple Hill
110	0.82 (0.1)	178 – 193	06888350	Belvue
120	0.78 (0.1)	194 - 209	06887500	Wamego
130	0.82 (0.2)	210 - 225	06887500	St. George
140	0.96 (0.1)	226 - 241	06887500	Manhattan
150	0.22 (0.1)	242 - 257	06879100	Ogden
160	0.20 (0.1)	258 – 274	06879100	Fort Riley

Table 1.2. Results of analysis of covariance on relative abundance (catch per hour) of age 1 (≤ 200 mm total length, [TL]), subadult (> 200 – 400 mm TL), and adult (> 400 mm TL) flathead catfish among riprap, log jam, and mub bank shoreline habitat types in the Kansas River, Kansas, 2005-2006. Standard error (SE) are given in parenthesis.

	Mean CPUE (SE) habitat					
Size class	**Rip rap**	**Log jam**	**Mud bank**	**F**	**DF**	**P**
Age 1	7.13 (1.06)	2.53 (0.97)	2.04 (0.37)	6.344	2, 91	0.003
Subadult	6.27 (0.82)	1.46 (0.51)	1.95 (0.37)	2.106	2, 95	0.127
Adult	2.80 (0.44)	1.42 (0.50)	1.55 (0.31)	0.110	2, 69	0.896

Table 1.3. Flathead catfish estimates of abundance (catch per hour electrofishing; [CPUE]), and condition (relative weight; [W_r]), of age 1 (≤ 200 mm total length, [TL]), subadult (> 200 – 400 mm TL), and adult fish (> 400 mm TL), growth (Brody growth coefficient; [K]), theoretical maximum length (L-∞), mean total length (TL) at age 3, size structure (proportional stock density; [PSD]), and total annual mortality (A), of flathead catfish from the Kansas River, Kansas, May – August, 2005-2006. Standard errors (SE) are given in parentheses. Reaches were based on a discriminant function analysis grouping reaches by visual inspection of Figures 1.4 and 1.5.

	River reach (rkm range)			
Parameter	**1 (0-26)**	**2 (27-84)**	**3 (85-193)**	**4 (194-274)**
Abundance				
CPUE age 1	0.88 (0.4)	4.32 (0.9)	9.19 (1.3)	0.72 (0.3)
CPUE subadult	1.78 (0.7)	4.89 (1.02)	5.79 (0.9)	1.43 (0.3)
CPUE adult	0.34 (0.2)	2.23 (0.5)	3.44 (0.6)	1.31 (0.3)
Condition				
Age 1 W_r	101.4 (3.8)	108.8 (2.9)	109.9 (1.6)	107.1 (3.9)
Subadult W_r	89.7 (2.3)	94.6 (1.6)	93.5 (1.1)	97.0 (1.3)
Adult W_r	87.2 (2.9)	88.4 (1.3)	88.1 (1.1)	85.3 (1.5)
Growth				
K	0.136 (0.01)	0.159 (0.01)	0.136 (0.01)	0.120 (0.01)
L-∞	1095	1121 (17.7)	1170	1131 (22.8)
Mean TL age 3	293 (13.7)	367 (12.0)	392 (7.4)	398 (9.3)
Size structure				
PSD	0	52 (11)	44 (7)	48 (11)
Mortality				
A	0.28	0.17	0.20	0.14

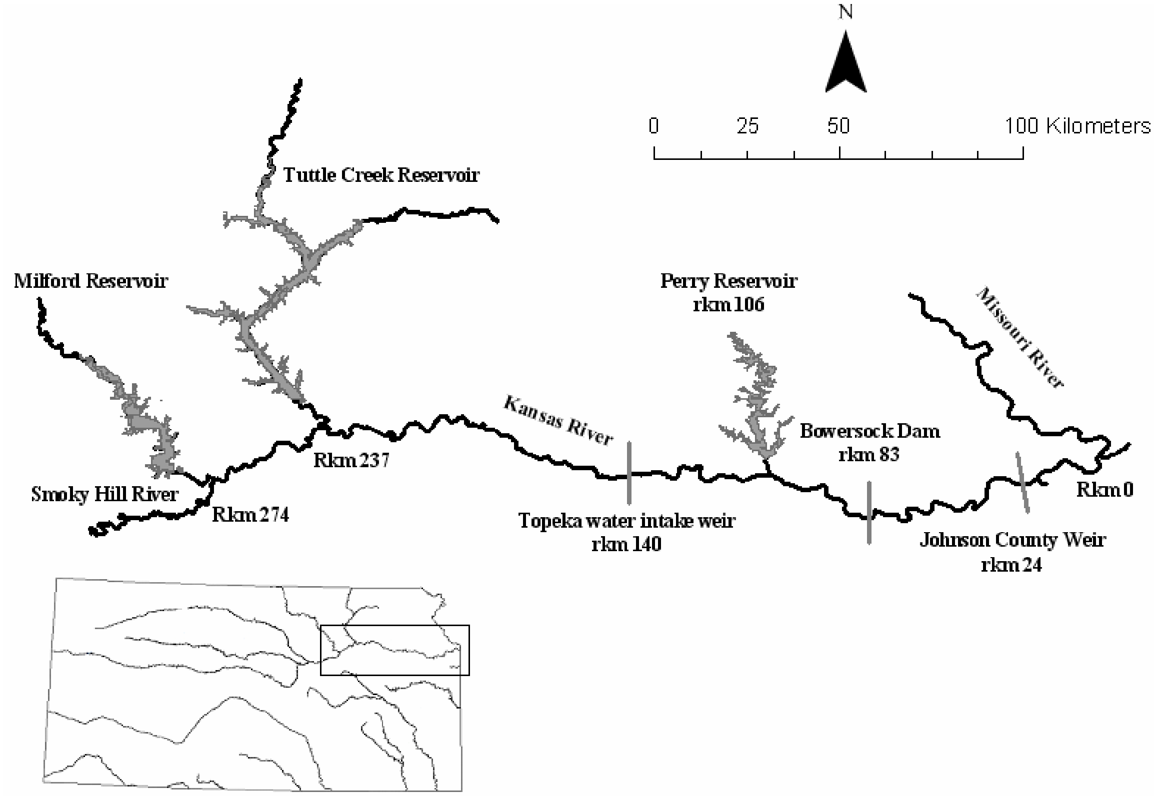

Figure 1.1. Map of the 274-km Kansas River from its formation (Junction City) to its confluence with the Missouri River (Kansas City). Lines intersecting the river indicate upper and lower bounds of reaches determined from the discriminant function analysis (DFA).

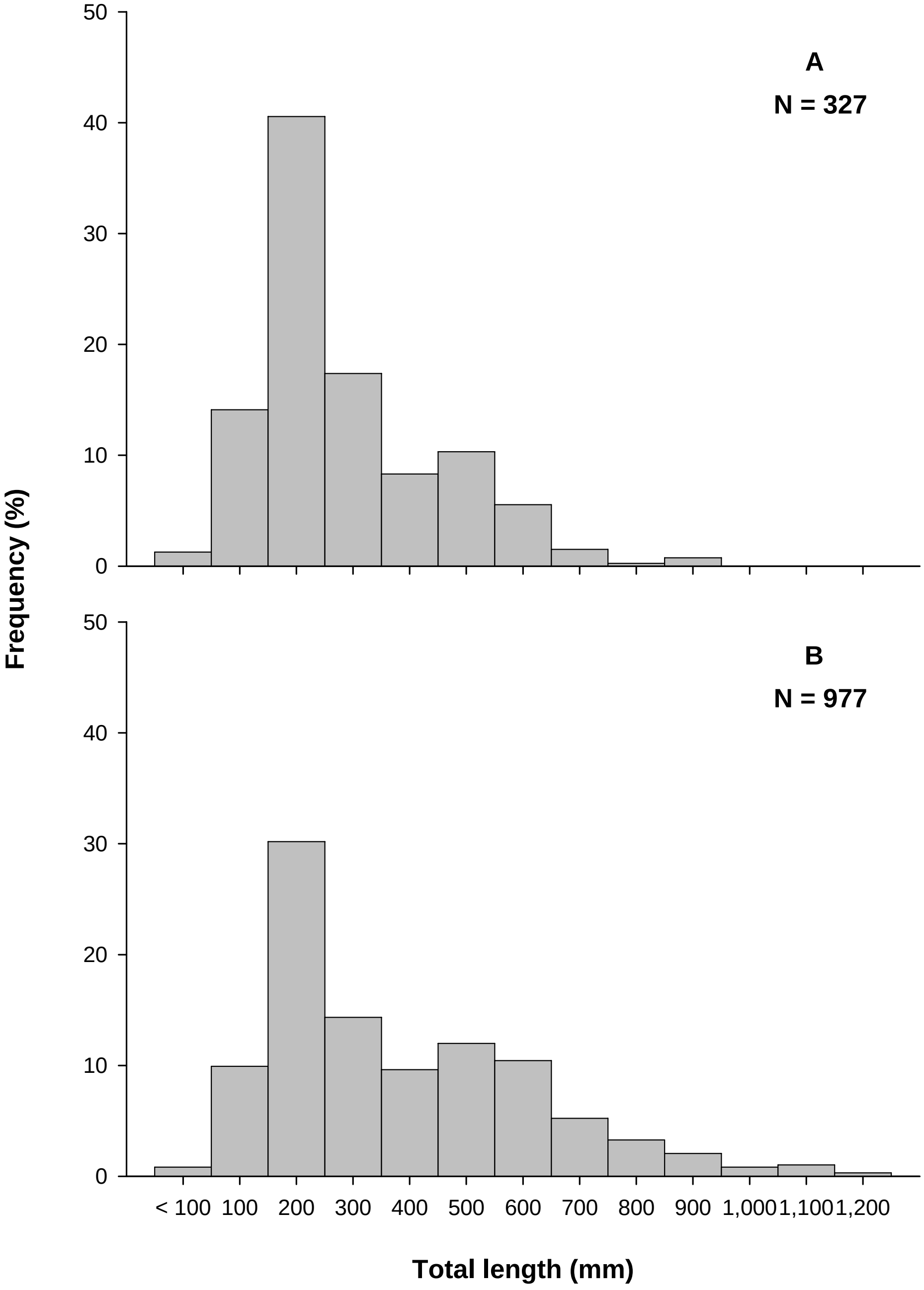

Figure 1.2. Length frequency of flathead catfish captured during summer random electrofishing (A), and all combined sampling (B) from the Kansas River, Kansas, during May-August, 2005-2006.

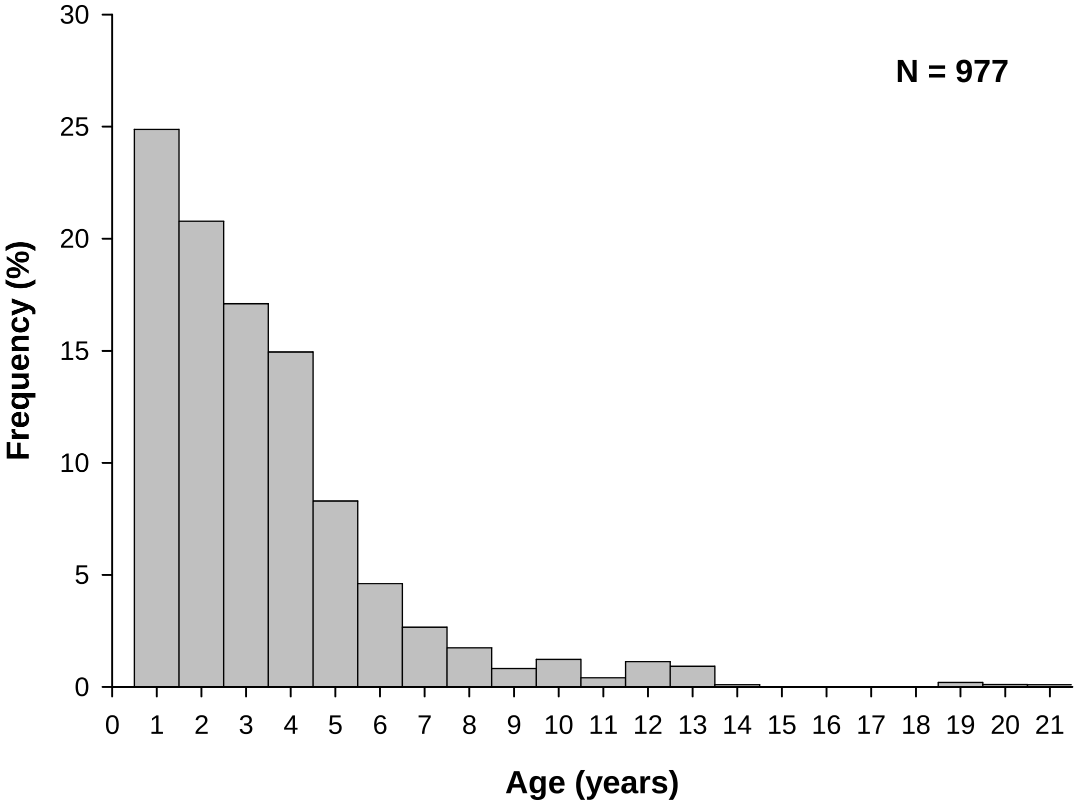

Figure 1.3. Age-frequency distribution of flathead catfish captured from all combined sampling in the Kansas River, Kansas, 2005-2006.

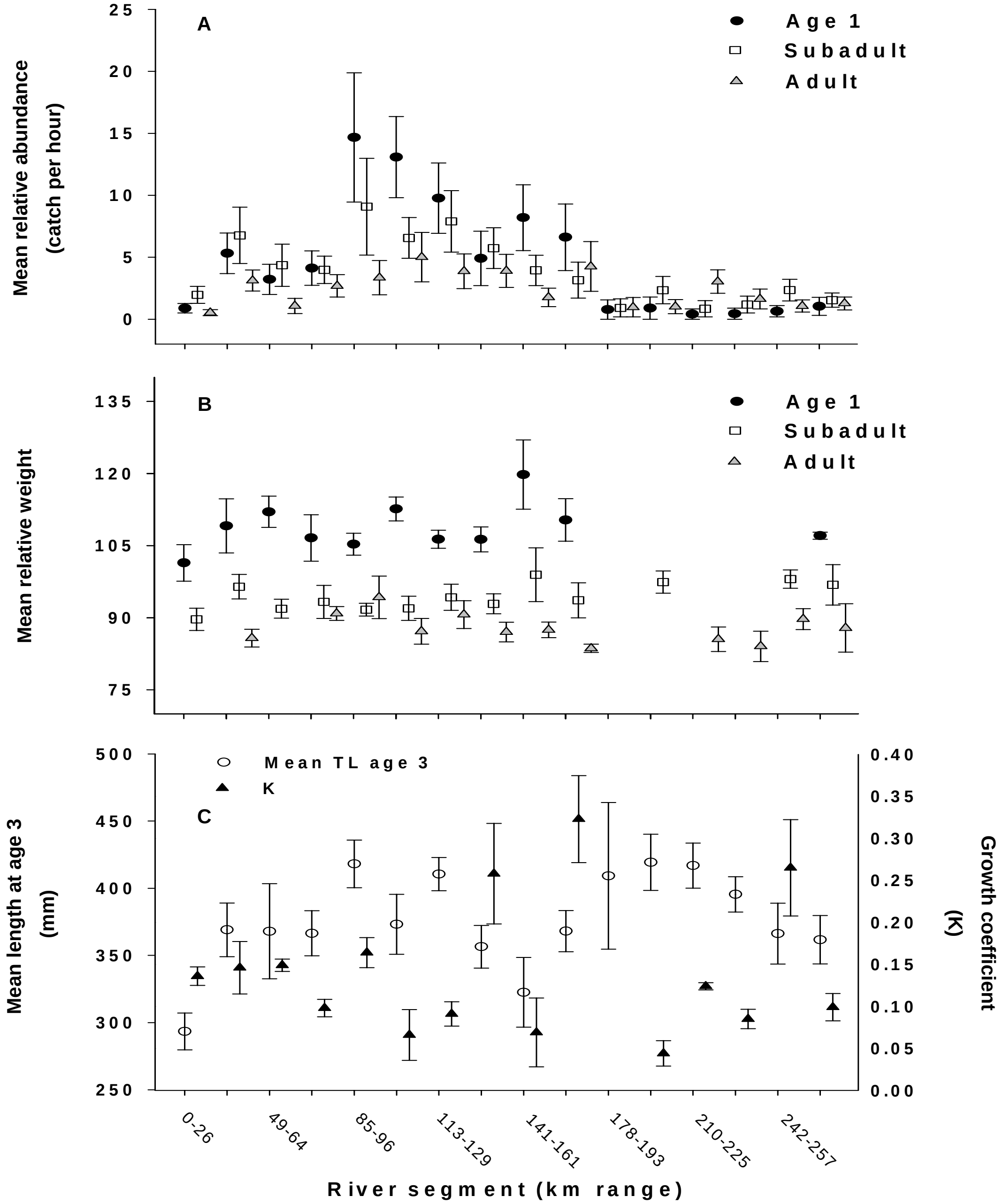

Figure 1.4. Flathead catfish mean relative abundance (A) and mean relative weight (B) of age 1 (≤ 200 mm total length, [TL]), subadult (> 200 – 400 mm TL), and adult (> 400 mm TL) size classes, and mean length at age 3 and Brody growth coefficient K (C) by river segment, Kansas River, Kansas, 2005-2006. Values are offset slightly on x-axis for clarity. Error bars represent ± 1 standard error.

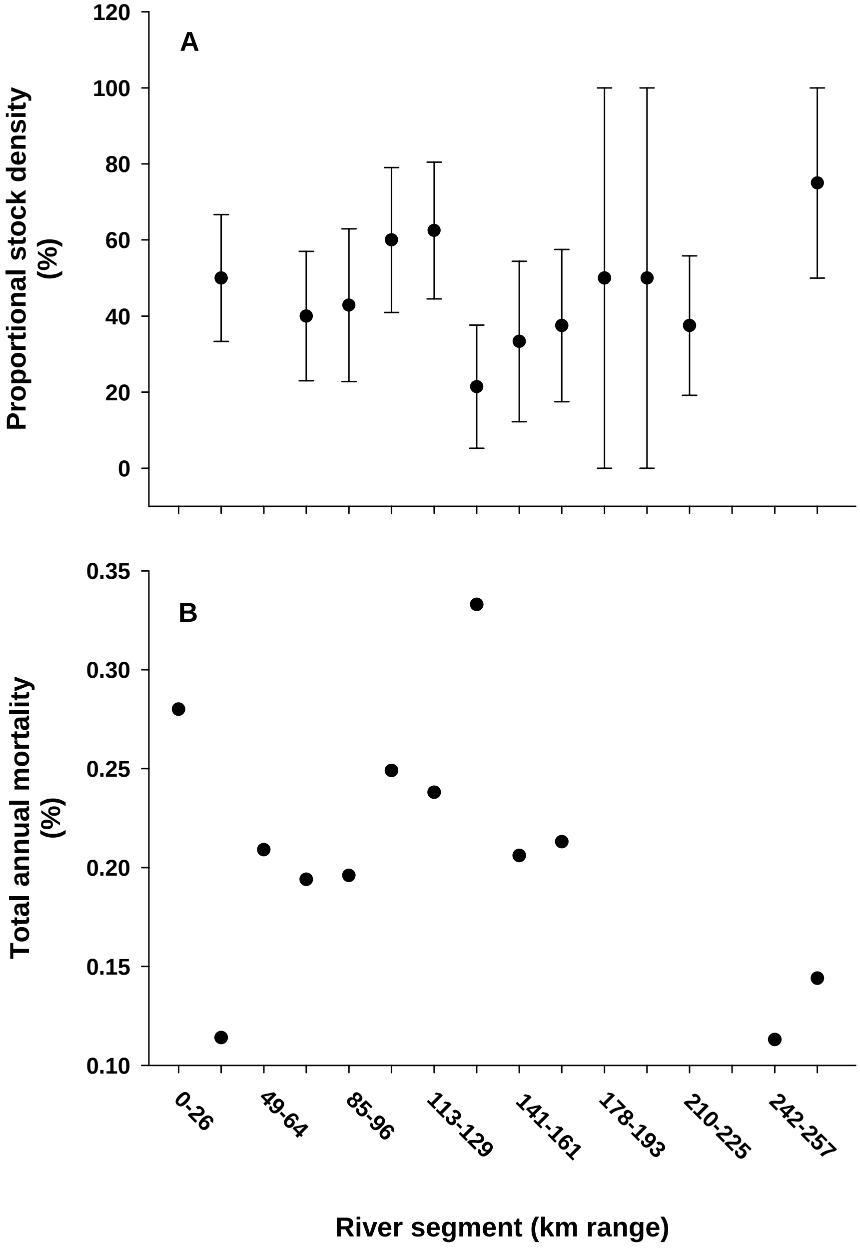

Figure 1.5. Flathead catfish proportional stock density (PSD; number of quality sized fish [510 mm TL] / number of stock sized fish [350 mm TL]; A), and total annual mortality (B) by river segment from 462 random electrofishing stations in the Kansas River, Kansas, May to August 2005-2006. Missing values represent segments with low sample size (< 5 fish). Error bars represent ± 1 standard error.

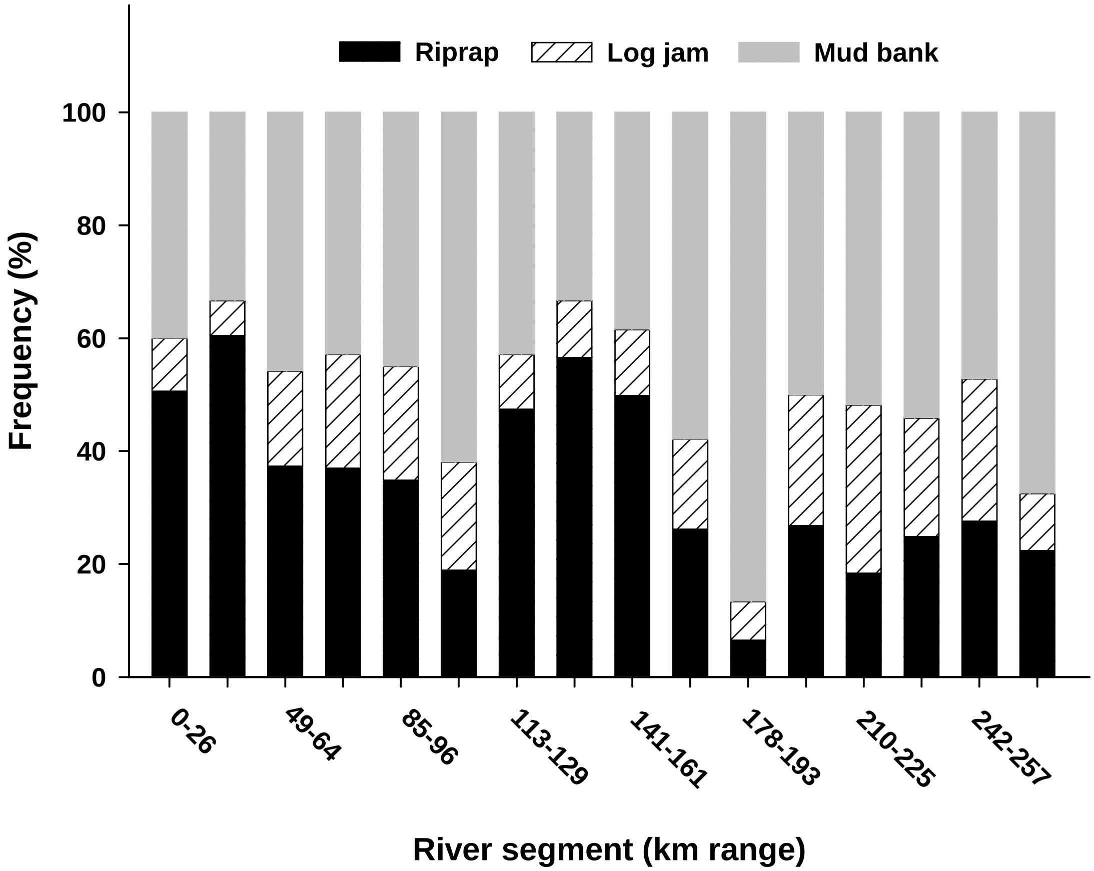

Figure 1.6. Proportion of shoreline habitat (riprap, log jam, mud bank) sampled during 462 random electrofishing stations in the Kansas River, Kansas, during May-August 2005-2006. River segments represent groups of 16 river kilometers (rkm).

Chapter 2

Effects and Utility of Minimum Length Limits and Mortality Caps for Flathead Catfish in Reaches of a Large Prairie River

ABSTRACT

Flathead catfish *Pylodictis olivaris* populations in four reaches of the Kansas River were examined to evaluate the effects of a 305-mm (minimum size anglers are willing to harvest), 610-mm, and a 762-mm minimum length limit on population size structure over a 30-year simulation. We used electrofishing and hoop nets to capture and tag flathead catfish throughout the Kansas River from 2005-2006. Current exploitation, based on tag returns, was likely < 10% and total annual mortality ranged from 14 to 28% across all reaches. Increased river access and the promotion of the flathead catfish fishery may increase exploitation in the future so model simulations were conducted with conditional natural mortality (*cm*) and conditional fishing mortality (*cf*) ranging from 10 to 40%. Proportional stock density (PSD) of flathead catfish and relative stock density of preferred-length fish (RSD-P) showed substantial declines (> 25 PSD units and > 15 RSD-P units) as exploitation increased with the 305-mm length limit over the 30-year simulation. Proportional stock density showed similar trends across all reaches suggesting different regulations among reaches was not necessary. No substantial differences were observed in flathead catfish size structure with the 610 and 762 mm length limits among reaches, but anglers would have to sacrifice about 42% of the number fish harvested under current mortality conditions with a 762-mm length limit. Mortality caps revealed that each reach could sustain about 60% and 55% total annual

mortality to maintain current PSD and RSD-P levels, respectively, suggesting quality flathead catfish size structure could be preserved.

INTRODUCTION

The popularity of catfish (Ictaluridae) angling has recently increased in the United States. Currently, resource agencies in at least 34 states have developed programs designed specifically for catfish management (Michaletz and Dillard 1999). Although catfish anglers are typically harvest oriented (Schramm et al. 1999; Wilde and Ditton 1999), flathead catfish *Pylodictis olivaris* anglers are more focused on capturing trophy fish (Quinn 1993; Arterburn et al. 2002). Native to the Mississippi, Mobile, and Rio Grande river drainages (Kwak et al. 2004; Daugherty and Sutton 2005), flathead catfish now are distributed throughout the United States in both lotic and lentic environments. A recent survey has shown focused, intense management of trophy flathead catfish may be necessary to fulfill angler desires (Arterburn et al. 2002).

While information exists regarding lotic populations of flathead catfish (Mayhew 1969; Guier et al.1984; Lee and Terrell 1987; Quinn 1989; Kwak et al. 2004), knowledge regarding flathead catfish management within native Midwestern watersheds is lacking. Flathead catfish are long-lived (i.e. > 20 years; Jackson 1999), typically show low mobility (Funk 1957, Minckley and Deacon 1959; Jackson and Jackson 1999; but see Kwak et al. 2004) and are generally associated with cover (large, woody debris; Insaurralde 1992). The susceptibility of flathead catfish to high localized exploitation has increased agency awareness of the need to evaluate the use of restrictive length limits and mortality thresholds.

Minimum length limits are appropriate when growth is fast and/or recruitment is low (Maceina et al. 1998; Paukert et al. 2002). Also, any harvest regulation is only effective if exploitation is high and natural mortality is relatively low (Slipke et al. 1998; Lovell and Maceina 2002). Movement studies of flathead catfish provide knowledge of habitat use and requirements, and may strongly affect any management strategies designed for a given species. Populations of less mobile fish, for example, may be negatively impacted through localized exploitation, habitat destruction, or reduced food availability (Coon and Dames 1989; Pugh and Schramm 1999). Flathead catfish exhibiting little movement may also benefit from area-specific management goals; i.e. differing angling restrictions among river segments (Travnichek 2004). Although the possibility of confusing anglers may be a concern with different restrictions by river reaches, localized regulations may allow agencies to cater to harvest-oriented anglers while providing trophy opportunities for specialized anglers (Arterburn et al. 2002; Travnichek 2004).

Mortality estimates are essential in the management of sportfish and serve as guides to measure the influence of management actions (i.e. harvest regulations; Quist et al. 2004). Miranda (2002) suggested resource managers develop size-based mortality caps (thresholds) to determine the upper limits of acceptable mortality, above which management objectives become ineffective. Using mortality caps, managers can set size structure goals under various management schemes (i.e. length limits) and levels of exploitation, and can adjust regulations to achieve the management goals. Efforts to adjust for increases in mortality beyond the threshold can be implemented to curtail fishery mortality.

Recent studies have shown limited flathead catfish movement (Travnichek 2004), and spatially-variable population dynamics of riverine species within Midwestern rivers (Quist and Guy 1998, 1999; Makinster 2006). In the Kansas River, Makinster (2006) determined flathead catfish population dynamics differ among four river reaches suggesting that management of the reaches could differ based on various management goals. Localized management within lotic and lentic systems exists for several species (Anderson and Nehring 1984; Molsa et al. 1999); however, no study has evaluated similar management of flathead catfish within a river environment. The objective of this study was to evaluate the simulated response of size structure and number of fish harvested to differing flathead catfish length limits among different reaches of the Kansas River, Kansas. We conducted population response simulations of three minimum length limits (305, 610, and 762 mm), on four reaches within the river under four levels of exploitation using Beverton-Holt equilibrium yield models. Mortality caps were also calculated to assess the maximum sustainable mortality the flathead catfish population could sustain in each reach to maintain current size structure conditions.

METHODS

Study area

The Kansas River flows 274 km in eastern Kansas from near Junction City, Kansas, to the confluence with the Missouri River in Kansas City, Kansas. The river has a braided channel with a mean water depth of < 1.5 m (Makinster 2006), and a mean annual discharge of approximately 214 m^3/s (Galat et al. 2005). Several reservoirs on adjacent tributaries (e.g. Republican River, Smoky Hill River, Big Blue River, Delaware River) regulate discharge. However, only one lowhead dam exists on the mainstem

Kansas River, at rkm 83 near Lawrence, Kansas (Sanders et al. 1993). Public access to the river was historically limited, but efforts are underway to increase accessibility with more boat ramps (one ramp per 16 km; D. Nygren, Kansas Department of Wildlife and Parks, *personal communication*). Thus, potential impacts of future, increased angler exploitation are needed.

Reach classification

Recent studies have shown minimal movement of flathead catfish (Jackson and Jackson 1999; Travnichek 2004). In the Kansas River, mean distance moved of tagged flathead catfish was < 1 km (Makinster 2006), suggesting localized reaches may be developed to properly manage this species. Makinster (2006) identified four reaches in the Kansas River that differed in their population characteristics (e.g. relative abundance and growth) of flathead catfish and were: rkm 0 – 26, downstream of Johnson County Weir in Kansas City, Kansas; rkm 27 – 84, Johnson County Weir to downstream of Bowersock Dam in Lawrence, Kansas; rkm 85 – 193, upstream of Bowersock Dam to Maple Hill bridge near Maple Hill, Kansas; and rkm 194 – 274, Maple Hill bridge to the junction of the Smoky Hill and Republican Rivers in Junction City, Kansas (Figure 2.1).

Data collection and fish handling

Within each reach of the Kansas River, 11 to 36 1.6-km sections were randomly selected (depending on reach length), and a minimum of three, 300-sec. stations were completed within each section during May-August in 2005 and 2006. Daytime, low-pulse DC electrofishing (1-6 A; 180-250 V; 15-20 pulses/s) was conducted in a downstream direction from a 4.5-m aluminum boat equipped with a Coffelt Model VVP 15 electrofisher powered by a 5,000-watt generator. Supplemental sampling using overnight sets of unbaited hoop nets (7-ring, 1-m diameter, 5.1-cm mesh, 3.6-m long) and electrofishing (8-15 A; 300-500 V; 40-60 pulses/s) was conducted throughout the river during summer to increase the number of tagged flathead catfish as well as provide larger sample sizes for age and growth estimates.

All flathead catfish captured were measured (total length [TL], nearest mm) and weighed (nearest g). Flathead catfish greater than 305 mm TL were tagged with an individually numbered t-bar anchor tag (model FD-94; Floy Tag Inc., Seattle, Washington) through the dorsal pterygiophores near the dorsal fin insertion, and an adipose fin clip to estimate tag loss. This size was selected based on information from creel surveys in the Missouri River showing the minimum size of harvested flathead catfish is 305 mm (Travnichek 2004). To encourage tag return by anglers, each tag was labeled with a corresponding phone number, email address (flathead@ksu.edu), and "K-State". The study was publicly promoted with flyers at major access points and a listing on the Kansas Department of Wildlife and Parks' webpage. Pectoral spines were removed from 571 flathead catfish (58% of total captured) for age determination with all unaged fish assigned ages from an age-length key (DeVries and Frie 1996). Growth was determined using pectoral spines that were sectioned using a low-speed Isomet saw (see Makinster 2006 for detailed description). Size structure was determined using proportional stock density (PSD; number of quality-length fish [510 mm TL] / number stock-length fish [350 mm TL]*100), and relative stock density of preferred length fish (RSD-P; number of preferred-length fish [710 mm TL] / number stock-length fish *100; Anderson and Neumann 1996). Flathead catfish were released near their original site of capture.

Length limit simulations

The Fishery Analysis and Simulation Tools (FAST; Slipke and Maceina 2000) software was used to simulate the effects of three minimum length limits, 305 mm, 610 mm, and 762 mm, on flathead catfish size structure and number harvested in four river reaches. The dynamic pool model in FAST was used with a fixed level of recruitment (1000 recruits), as catch curves suggested relatively consistent recruitment among years (Makinster 2006). We assumed 305 mm TL was the minimum size of harvested fish (Travnichek 2004), and therefore used this simulation as a ‘no length limit’ scenario.

Mortality estimates were calculated for each reach using fish captured during low pulse, summer random electrofishing. Total annual mortality (A) and survival (S) were estimated from the descending limb of catch curves using weighted regression (Ricker 1975). Growth parameters were estimated for each reach using fish captured from summer random electrofishing and supplemental hoop nets and electrofishing. A von Bertalanffy growth function was used to estimate the theoretical maximum age (L_∞), Brody growth coefficient (k), and age where total length is zero (t_0; Ricker 1975) for each individual reach (Makinster 2006). Linear regression was used to estimate length-weight parameters (slope and y-intercept from a $\log_{10}$-length and $\log_{10}$-weight regression).

We attempted to determine exploitation rates through angler tag returns. However, we only received two of 572 angler tag returns (< 1%) throughout the study period. We tagged five flathead catfish that were already hooked on bank lines to determine angler non-reporting of fish that were known to be captured. Of the five, only one angler reported capturing a tagged fish (20% report rate). Therefore, exploitation corrected for non-reporting was still likely < 10%. Conditional natural mortality (cm)

was estimated from total annual mortality estimates. Because accessibility to the river was expected to increase with the addition of new boat ramps, we conducted model simulations of conditional fishing mortality (*cf*) and *cm* from 10 to 40% at 10% intervals for each potential length limit. The upper limit of 40% was determined from estimates of flathead catfish total annual mortality reported in the literature (Summerfelt et al. 1972; Kwak et al. 2006). Model simulations were conducted for 30 years and estimates of flathead catfish size structure (PSD and RSD-P) and the number harvested (per 1,000 recruits) were calculated for years greater than the maximum age in the population.

Mortality caps

Mortality caps for flathead catfish populations in each reach of the Kansas River were calculated based on models described in Miranda (2002). We chose to use model 2 where mortality caps were calculated based on PSD and RSD-P using the formulas below:

$$Z = -(\log_e \text{PSD} \times (t_q - t_s)^{-1}),$$

$$Z = -(\log_e \text{RSD-P} \times (t_p - t_s)^{-1}),$$

where Z is the total instantaneous mortality, PSD and RSD-P represent a range of possible fishery objectives for size structure, t_q is the time (years) to reach quality length, t_p is the time (years) to reach preferred length, and t_s is the time (years) to reach stock length. Estimated values of Z were transformed into A using the equation $A = 1 - e^{-z}$ (Ricker 1975). Currently, no PSD or RSD-P management objectives are established for flathead catfish in the Kansas River; therefore, so mortality caps were conducted for PSD objectives of 30, 40, 50, 60, and 70 in each reach, and RSD-P objectives of 10, 20, 30, and 40 in each reach.

RESULTS

Model parameters

A total of 977 flathead catfish were captured during all sampling in 2005-2006. Three hundred ninety-seven flathead catfish were collected from 462 low pulse, random electrofishing stations and subsequently used in the estimates of total annual mortality and size structure. Four hundred twelve flathead catfish were captured during supplemental electrofishing, and overnight sets of hoop nets collected 168 flathead catfish. Flathead catfish PSD among river reaches varied from 0 to 52, while flathead catfish RSD-P varied from 0 to 13 (Table 2.1). Growth varied among all reaches of the Kansas River. Age and total length of flathead catfish varied from 1 to 13 years and 135 to 1,095 mm TL in reach 1, 1 to 21 years and 129 to 1,130 mm TL in reach 2, 1 to 13 years and 123 to 1,170 mm TL in reach 3, and 1 to 19 years and 118 to 1,070 mm TL in reach 4. The time to reach quality and preferred length varied from 3.9 to 5.2 and 6.9 to 7.7 years, respectively, while the time to reach stock length varied from 2.4 to 3.6 years (Table 2.1). Total annual mortality also varied among river reaches from 14 to 28% in reaches 4 and 1, respectively (Makinster 2006).

Size structure and number harvested

At presumed current levels of conditional natural mortality and exploitation (*cm* = 20% and *cf* = 10%), flathead catfish PSD varied from about 42 to 50 under the no length limit scenario over the 30-year simulation. At all levels of *cm*, flathead catfish PSD with the 305-mm length limit (i.e. no length limit) declined precipitously from about 50 to a size structure dominated by small fish (< 10) as *cf* increased from 10 to 40% (Figure 2.2). This trend was observed in all reaches of the river with a maximum difference of 7 PSD units observed among reaches (PSD reduction from 59 to 34 units in reach 2 and 57 to 25 units in reach 3 as exploitation increased). With the 610-mm length limit, PSD appeared to decline gradually in each reach and remained above 20 as *cf* increased (Figure 2.2). At *cm* = 10%, flathead catfish PSD for the 762-mm length limit was above 55 in each river reach as *cf* increased. Regardless of *cm*, river reaches showed similar trends across all levels of *cf* (Figure 2.2).

Flathead catfish RSD-P varied from about 13 to 18 with presumed current conditions of mortality and exploitation (*cm* = 20%, *cf* = 10%) under the no length limit scenario over the 30-year simulation. Model simulations showed substantial differences in RSD-P under the 610- and 762-mm length limits, particularly when *cm* was < 30% (Figure 2.3). For example, with *cm* = 20% and *cf* = 30% in reach 4, RSD-P with the 610-mm length limit was about half of that observed with the 762-mm length limit. Further, with *cm* = 10% and *cf* = 30% in reach 3, RSD-P with the 762-mm length limit was above 30 while the values with the 610-mm length limit was about 20.

The number of flathead catfish harvested was at least 15% higher with the 305-mm length limit than the higher length limits across all reaches and levels of exploitation over the 30-year simulation (Figure 2.4). Differences in the number of fish harvested under the various length limits were similar across all reaches of the river. For example, at *cm* = 10%, about 66% more flathead catfish in reach 1 would be harvested with the 610-mm length limit than the 762-mm length limit. Similarly, 68% more flathead catfish would be harvested in reach 3. At *cm* = 30%, 27% more flathead catfish in reach 2 would be harvested with the 305-mm length limit than the 610-mm length limit. Comparatively, 22% more fish would be harvested in reach 4. At *cm* = 40%, about 29% more fish in reach 2 would be harvested with the 610-mm length limit than with the 762-mm length limit, whereas in reach 3, about 27% more fish would be harvested (Figure 2.4).

Mortality caps

The difference in time to reach quality-length (t_q) and stock-length (t_s) for reaches 1 to 4 varied from 1.4 to 2.1 years. The difference in time to reach preferred size (t_p) and t_s varied from 4.1 to 5.0 years, depending on reach. Reach 1 was excluded from the extrapolation of mortality caps due to no flathead catfish above 510-mm TL collected during summer random electrofishing. The observed total annual mortality for each river reach was less than the estimated mortality caps to maintain a PSD objective of 70 (Figure 2.5) implying this objective could be met in all reaches of the river under current conditions. To maintain the observed flathead catfish PSD in each reach (44-52; Table 2.1), reach 2 could support about 60% total annual mortality, reach 3 about 70%, and reach 4 about 63%. To maintain current RSD-P levels (5-13; Table 2.1), reaches 2 and 3 could sustain about 70% total annual mortality, and reach 4 about 63% (Figure 2.5). Therefore, high flathead catfish size structure could be maintained at relatively high levels of total annual mortality under current conditions.

DISCUSSION

Population dynamics of flathead catfish to vary spatially within a river (Makinster 2006), suggesting independent, localized management actions may be useful (Travnichek 2004). Our modeling simulations, however, suggest managing different reaches of the Kansas River independently is not currently needed to sustain quality flathead catfish populations. Implementation of different, high minimum length limits did not appear to produce substantial differences in flathead catfish size structure among reaches of the

Kansas River even though growth varied by 1.3 and 0.8 years to reach quality and preferred length, respectively. Limited access to the Kansas River has likely protected the flathead catfish population from excessive harvest and inherently led to our observed low levels of mortality. However, with angler access to the river expected to increase with the addition of more boat ramps and efforts by the state of Kansas to promote use of the river, increased exploitation is likely, particularly in the middle to lower river reaches near major metropolitan areas (i.e., Kansas City and Topeka, Kansas; Sanders et al. 1993).

Total annual mortality of flathead catfish across all reaches was typically low and was comparable to other flathead catfish populations (Daugherty and Sutton 2005; Kwak et al. 2006). We assumed low exploitation (about 10%) given the limited access of the river and our limited angler tag returns. Model simulations were conducted to exceed flathead catfish populations experiencing relatively high levels of exploitation (14 – 25%; Quinn 1993) and served as an upper limit for expected exploitation in the Kansas River.

While establishing different length limits among the four reaches of the Kansas River produced similar estimates of size structure (stock and quality sized fish only) and number harvested, a minimum length limit may be necessary to sustain future quality flathead catfish in each reach. Model simulations indicated substantial declines in flathead catfish size structure in each reach without a minimum length limit as exploitation increased by even 10%. This pattern was evident across all ranges of conditional natural mortality and exploitation. Recent surveys indicated flathead catfish anglers may be more inclined to support harvest regulations to protect the "trophy" potential of flathead catfish (Quinn 1993; Arterburn et al. 2002). While we showed that a minimum length limit would preserve the future quality conditions in each reach with increased exploitation, anglers would have to sacrifice the number of harvested flathead catfish for increases in size structure. Other studies suggested similar reductions in the number of fish harvested to increase size structure where growth was fast and natural mortality is low (Maceina et al. 1998; Slipke et al. 1998; Cornelius and Margenau 1999; Paukert et al. 2002). The observed natural mortality of flathead catfish was low (< 20%, assuming 10% exploitation) in all reaches of the river and growth was among the highest reported in the literature for native populations (Kwak et al. 2006; Makinster 2006), suggesting sufficient growth to quality size exists. Although growth is sufficient to maintain a quality fishery at low exploitation, higher exploitation would negate these effects and result in lower quality populations without protecting fish with a minimum length limit.

We observed differences among reaches with model simulations using preferred-length fish. With current total annual mortality (about 30%), reaches 1 and 4 typically showed lower size structure of flathead catfish compared to reaches 2 and 3 (Makinster 2006). An alternative approach to cater to “trophy” flathead catfish anglers (Arterburn et al. 2002), would be to designate one reach within the Kansas River as ‘trophy potential’ by imposing a high minimum length limit. Our model simulations suggested anglers would experience minimal reductions (about 20% under current total annual mortality) in the number of harvested fish with a 762-mm minimum length limit compared to a 610-mm minimum length limit. The reach best suited for such designation is reach 3 (upstream of Bowersock Dam, Lawrence, Kansas) since no consumption advisories exist in this location (T. Mosher *personal communication*). In addition, this reach has a high relative abundance of flathead catfish (about triple the relative abundance found in reaches 1 and 4; Makinster 2006), suggesting increased angler catch rates compared to other reaches with lower flathead catfish abundance. Designation of management zones exist for other species, particularly salmonids (Anderson and Nehring 1984) and smallmouth bass (*Micropterus dolomieu*; Slipke et al. 1998), suggesting that similar management actions may be suitable for flathead catfish.

Analysis of mortality caps indicated flathead catfish total annual mortality did not exceed the thresholds needed to maintain quality fisheries in the four reaches of the Kansas River. However, we did not capture flathead catfish above 510 mm in the lowermost reach of the river during our summer random electrofishing likely due to the inefficiency of electrofishing in deep-water habitats (Cunningham 1995). Although no size structure objectives exist for flathead catfish in the Kansas River, the mortality cap estimates suggested all reaches could sustain a minimum of 60% total annual mortality to maintain the current size structure around 50 under current growth conditions for quality-sized fish. If managers desire an objective of 70, the minimum total annual mortality must not exceed about 35% under current growth conditions. For preferred-length fish, all reaches could sustain a minimum of 55% total annual mortality to maintain current conditions indicating an RSD-P objective of 20 is reasonable if mangers were so inclined. However, mortality would have to be reduced (e.g. harvest regulations), particularly in reaches 2 and 3 to achieve this regulation. Mortality caps have similarly been used in studies regarding PSD objectives in reservoir populations of walleye (*Sander vitreus*; Quist et al. 2004) and increases in harvest size of paddlefish (*Polyodon spathula*;

Scholten and Bettoli 2005), and can serve as a guide for future management of flathead catfish.

MANAGEMENT IMPLICATIONS

Although differing minimum length limits for flathead catfish among Kansas River reaches was not needed, a length limit is needed to protect the quality flathead catfish fishery throughout the river if exploitation increases. Imposing a minimum length limit suggests a higher proportion of large flathead catfish could be harvested, but anglers must accept reductions in the number of harvested fish. Therefore, reaches with higher relative abundance may be best suited for a trophy regulation. The current levels of exploitation and mortality do not appear to inhibit the high growth potential of flathead catfish, suggesting a quality size structure can be maintained, even with the designation of a trophy reach. However, as accessibility to the river increases with more boat ramps and total annual mortality approaches the estimated threshold, length limits may need to be considered to protect against overharvest. Flathead catfish populations in each reach should also be monitored to elucidate the possible effects of the length limit on growth. The implementation of PSD objectives for each reach and subsequent use of mortality caps can serve as warnings to managers when mortalities approach the maximum threshold and management action is needed (Miranda 2002; Quist et al. 2004). Mortality caps represent an additional tool for managers to use while establishing fishery goals and their simple application warrants their use in other systems and species.

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Table 2.1. Estimates of flathead catfish slope (*a*) and intercept (*b*) of length:weight regression, theoretical maximum length (L_∞), growth coefficient (*K*), age when total length is 0 (t_o), theoretical maximum weight (W_∞), maximum total age (maxage), mean relative abundance (CPUE; catch per hour), mean proportional stock density (PSD; number of quality-length fish [510 mm TL] / number of stock-length fish [350 mm TL] *100), mean relative stock density of preferred-length fish (RSD-P; number of preferred-length fish [710 mm TL] / number of stock-length fish * 100), percent total annual mortality (*A*), the age to reach preferred-length (t_p, 710 mm; years), the age to reach quality-length (t_q, 510 mm; years), and the age to reach stock-length (t_s, 350 mm; years) from the Kansas River, Kansas, 2005-2006. Reaches were based on Makinster (2006). Asterisks indicate when model assumptions were violated and total length of the largest fish in the given reach was used to calculate L_∞, *K*, t_o, and W_∞.

	River reach (rkm range)			
Model parameter	**1 (0–26)**	**2 (27–84)**	**3 (85–193)**	**4 (194-274)**
Population model				
b	3.07	3.07	3.03	3.06
a	-5.19	-5.16	-5.08	-5.15
L_∞ (mm)	1095*	1121	1170*	1131
K	0.136	0.159	0.136	0.12
t_o (mm)	0.49	0.32	0.02	-0.49
W_∞ (g)	13,643	15,574	16,939	15,921
maxage (years)	13	21	13	19
Population indices				
CPUE	3.0 (0.9)	11.4 (1.7)	18.4 (2.0)	3.5 (0.5)
PSD	0	52 (11)	44 (7)	48 (11)
RSD-P	0	5 (5)	5 (4)	13 (7)
A (%)	0.28	0.17	0.20	0.14
Growth				
t_p (years)	7.7	7.1	6.9	7.6
t_q (years)	5.2	3.9	4.1	4.7
t_s (years)	3.6	2.4	2.7	2.6

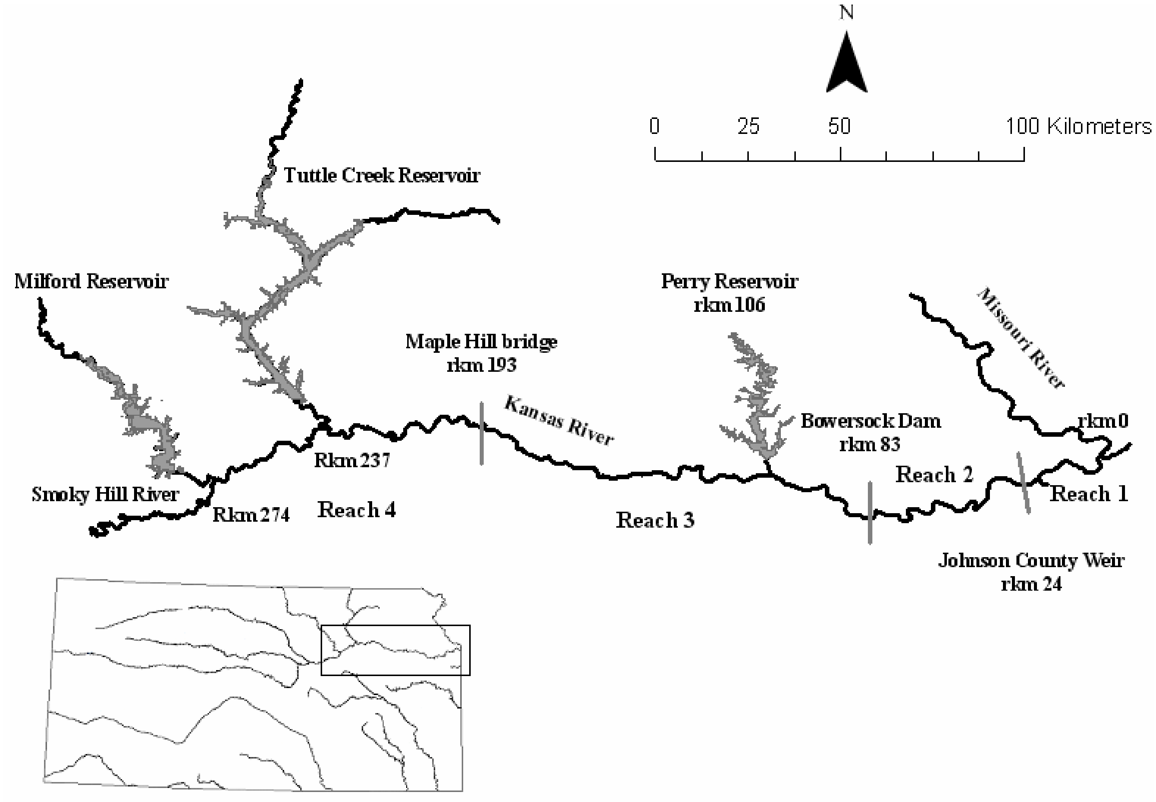

Figure 2.1. Map of the 274-km Kansas River from its formation (Junction City) to its confluence with the Missouri River (Kansas City). Lines intersecting the river indicated upper and lower bounds of reaches determined by Makinster (2006).

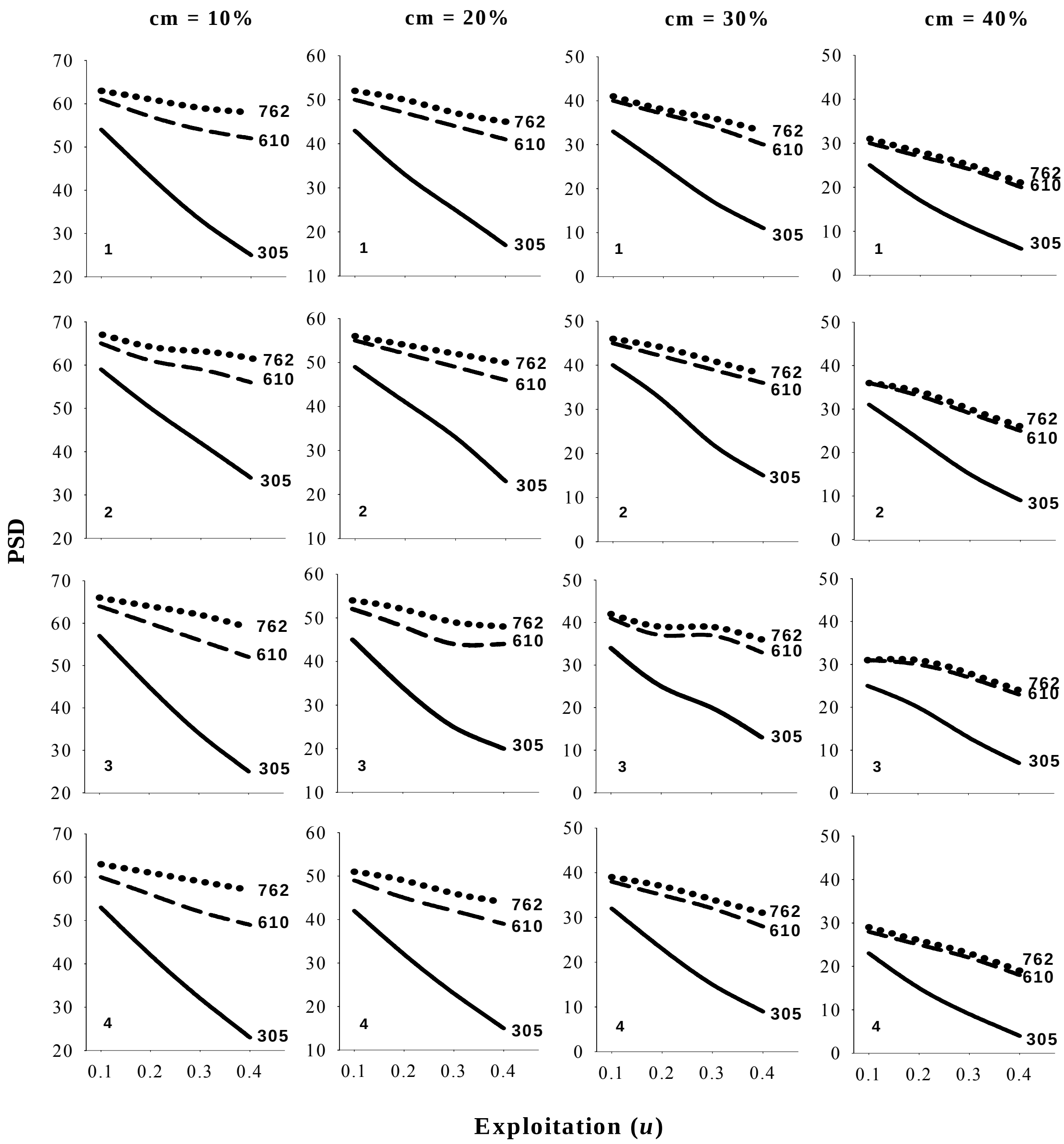

Figure 2.2. Predicted mean proportional stock density of flathead catfish captured during summer random electrofishing against various ranges of exploitation (*u*) for four levels of conditional natural mortality (*cm*) in the Kansas City reach (row 1), the Lawrence reach downstream of Bowersock Dam (row 2), the Lawrence reach upstream of Bowersock Dam (row 3), and the Maple Hill reach (row 4) of the Kansas River, Kansas, May-August 2005-2006.

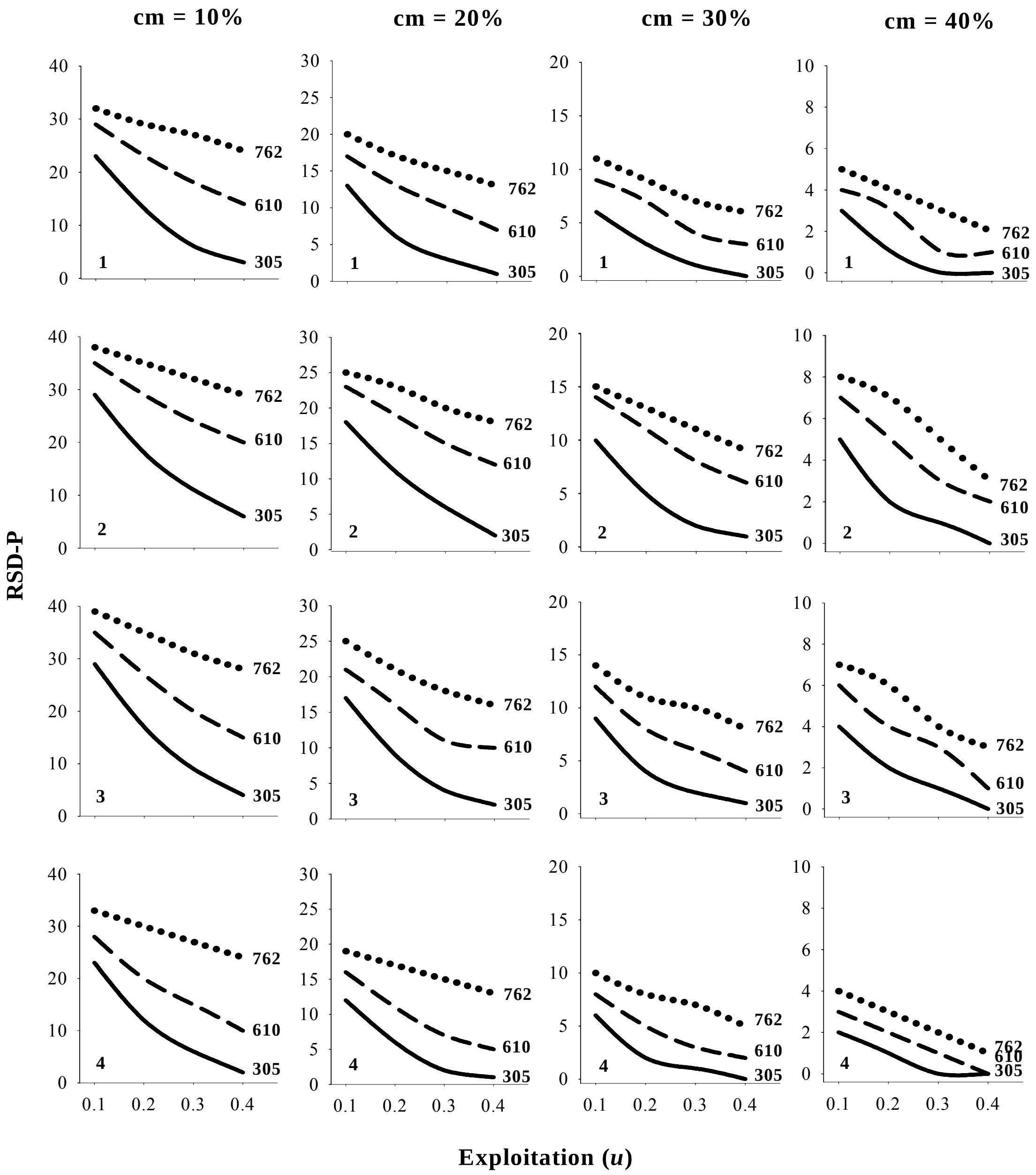

Figure 2.3. Predicted mean relative stock density of preferred length (RSD-P) flathead catfish captured during summer random electrofishing against various ranges of exploitation (*u*) for four levels of conditional natural mortality (*cm*) in the Kansas City reach (row 1), the Lawrence reach downstream of Bowersock Dam (row 2), the Lawrence reach upstream of Bowersock Dam (row 3), and the Maple Hill reach (row 4) of the Kansas River, Kansas, May-August 2005-2006.

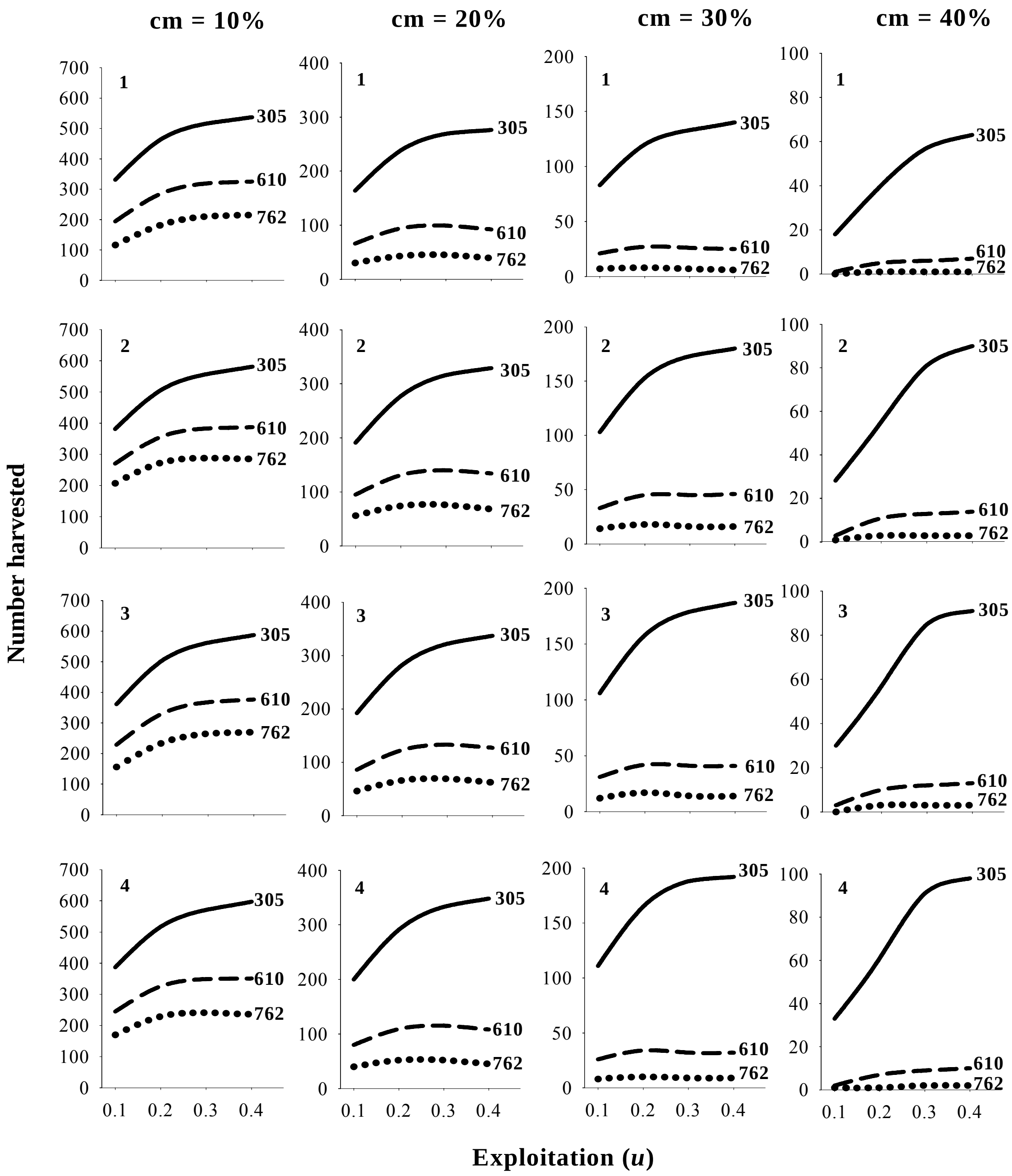

Figure 2.4. Predicted number of flathead catfish harvested (per 1000 recruits) against various ranges of exploitation (*u*) for four levels of conditional natural mortality (*cm*) in the Kansas City reach (row 1), the Lawrence reach downstream of Bowersock Dam (row 2), the Lawrence reach upstream of Bowersock Dam (row 3), and the Maple Hill reach (row 4) of the Kansas River, Kansas, May-August 2005-2006.

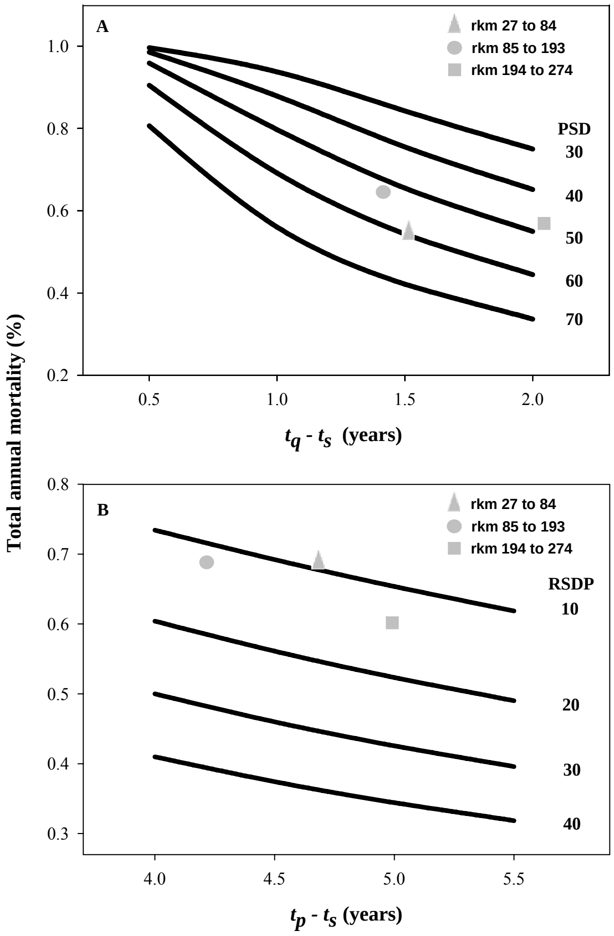

Figure 2.5. Estimated mortality caps for five PSD objectives (A; top panel) and four RSD-P objectives (B; bottom panel) in three reaches of the Kansas River (below Bowersock Dam to Johnson County Weir, reach 2 [triangle]; above Bowersock Dam to Maple Hill Bridge, reach 3 [circle]; and above Maple Hill bridge to the confluence of the Smoky Hill and Republican Rivers, reach 4 [square]) based on growth rates found within each reach (the number of years to reach quality-length [t_q; 510-mm TL] minus the number of years to reach stock-length [t_s; 350-mm TL], top panel; the number of years to reach preferred-length [t_p; 710-mm TL] minus the number of years to reach stock-length, bottom panel). Reach 1 (below Johnson County Weir) was omitted from analysis due to no capture of flathead catfish > 510-mm TL during summer random electrofishing.