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[Article]

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

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*Abstract*.—Populations of flathead catfish *Pylodictis olivaris* in four reaches of the Kansas River, Kansas, were examined to evaluate the effects of three minimum length limits (305 [the minimum size that anglers are willing to harvest], 610, and 762 mm total length [TL]) on population size structure and number harvested over a 30-year simulation. We used electrofishing and hoopnetting to capture and tag flathead catfish throughout the Kansas River from 2005–2006. Current exploitation (*u*) based on tag returns was probably less than 10%, and total annual mortality *A* ranged from 14% to 28% across all reaches. Increased river access and promotion of this fishery may increase *u* in the future, so model simulations were conducted with conditional natural mortality (*cm*) and *u* ranging from 10% to 40%. Proportional stock density (PSD) and the relative stock density of preferred-length fish (RSD-P) substantially declined (by >25% and >15%, respectively) as *u* increased with the 305-mm TL limit over the 30-year simulation. The PSD showed similar trends across all reaches, indicating that use of different regulations among reaches was not necessary and that differences in growth among reaches were less influential than *u* and *cm*. No substantial differences were observed in size structure under the 610- and 762-mm TL limits among reaches, but under a 762-mm TL limit anglers would have to sacrifice about 42% of the number harvested under the current *cm* level. Mortality caps revealed that each reach could sustain an *A* of about 60% and 55% to maintain current PSD and RSD-P levels, respectively; this result suggests that quality flathead catfish size structure can be preserved. Our results show that the effects (or lack thereof) on flathead catfish and other sport fishes should be evaluated before harvest restrictions are implemented.

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), anglers of flathead catfish *Pylodictis olivaris* 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 that 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 of the species' 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 (1) growth is fast, (2) recruitment is low, or (3) both conditions are present (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

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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 sport fish and serve as guides to measure the influence of management actions (i.e., harvest regulations; Quist et al. 2004). Miranda (2002) suggested that 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. Management regulations can then be used to reduce mortality when it exceeds the mortality cap.

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, Kansas, Makinster (2006) determined that flathead catfish population dynamics differed among four river reaches, which indicated 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. 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 $u$ using Beverton–Holt equilibrium yield models. Mortality caps were also calculated to assess the maximum mortality that 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 to the confluence with the Missouri River in Kansas City. The river has a braided channel with a mean water depth of less than 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., the Republican, Big Blue, and Delaware rivers) regulate discharge. However, only one low-head dam exists on the main-stem Kansas River at river kilometer (rkm) 83 near Lawrence (Sanders et al. 1993). Public access to the river was historically limited, but efforts are underway to increase accessibility with more boat ramps (1 ramp/16 km; D. Nygren, Kansas Department of Wildlife and Parks [KDWP], personal communication). Thus, potential impacts of future increased angler $u$ are needed. Although limited public access probably minimizes hook-and-line exploitation, privately owned bank-lines are probably responsible for much of the current $u$ (A.S.M., personal observation).

*Reach classification*.—Recent studies have shown minimal movement of flathead catfish (Jackson and Jackson 1999; Travnichek 2004). In the Kansas River, mean distance moved by tagged flathead catfish was less than 1 km (Makinster 2006), suggesting that localized reaches may be developed to properly manage this species. Makinster (2006) identified four reaches in the Kansas River that differed in flathead catfish population characteristics (e.g., relative abundance and growth): (1) rkm 0–26, downstream of Johnson County Weir in Kansas City; (2) rkm 27–84, Johnson County Weir to downstream of Bowersock Dam in Lawrence; (3) rkm 85–193, upstream of Bowersock Dam to Maple Hill Bridge near Maple Hill; and (4) rkm 194–274, Maple Hill Bridge to the junction of the Smoky Hill and Republican rivers in Junction City (Figure 1).

*Data collection and fish handling*.—Within each reach of the Kansas River, between eleven and thirty-six 1.6-km sections were randomly selected (depending on reach length), and a minimum of three 300-s stations were completed within each section during May–August of 2005 and 2006. Low-pulse DC electrofishing (1–6 A, 180–250 V, 15–20 pulses/s) was conducted during the day in a downstream direction from a 4.5-m aluminum boat equipped with a Coffelt Model VVP 15 electrofisher powered by a 5,000-W generator. Supplemental sampling using overnight sets of unbaited hoop nets (7 rings, 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 to provide larger sample sizes for age and growth estimates.

All captured fish were measured (total length [TL], nearest mm) and weighed (nearest g). Those greater than 305 mm TL were tagged with an individually numbered t-bar anchor tag (Floy Tag, Inc., Seattle, Washington; Model FD-94) through the dorsal pterygiophores near the dorsal fin insertion, and an adipose

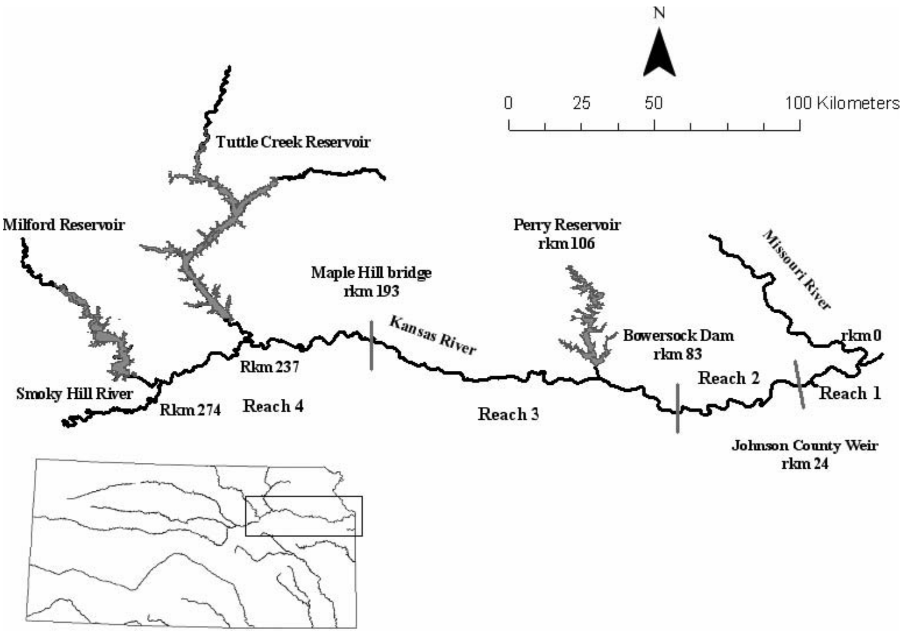


FIGURE 1.—Map of the 274-km Kansas River from its origin (Junction City) to its confluence with the Missouri River (Kansas City). Lines intersecting the river delineate four reaches with differing flathead catfish population dynamics as determined by Makinster (2006).

fin clip was also applied to estimate tag loss. Our recapture rate of tagged fish was about 1% (Makinster 2006), and no recaptured fish was missing its tag. The tagged size was selected based on information from creel surveys in the Missouri River showing that the minimum size of harvested flathead catfish is 305 mm (Travnichek 2004). To encourage tag return by anglers, each tag was labeled with a 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 KDWP web page. Pectoral spines were removed at random from 571 fish (58% of total captures) for age determination; all other fish were assigned ages based on an age–length key (DeVries and Frie 1996). Where abundances allowed, we attempted to obtain equal numbers of spines among reaches. The use of sectioned pectoral spines is relatively common in the literature (Turner 1982; Crumpton et al. 1987; Munger et al. 1994) and may be appropriate in most instances (Kwak et al. 2006) but could lead to age underestimation due to erosion of the central lumen in fish greater than age 5 (Nash and Irwin 1999). However, concern over sacrificing fish prohibited the use of otoliths; thus, we may have underestimated ages of older fish. Growth was determined using pectoral spines that were sectioned with a low-speed Isomet saw (Makinster 2006). Size structure was determined using proportional stock density (PSD; {number of quality-length fish [510 mm TL]/number of 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 of stock-length fish} × 100; Anderson and Neumann 1996). Flathead catfish were released near their original site of capture.

*Length limit simulations*.—Fishery Analysis and Simulation Tools software (Slipke and Maceina 2000) was used to simulate the effects of the three minimum length limits (305, 610, and 762 mm) on flathead catfish size structure and number harvested in four river reaches. A fixed level of recruitment was used (1,000 recruits) to standardize model scenarios, as catch curves suggested relatively consistent recruitment among years (Makinster 2006). We assumed that 305 mm TL was the minimum size of harvested fish (Travnichek 2004); therefore, this simulation approximated a scenario of no length limit.

Mortality estimates were calculated for each reach using fish captured during low-pulse, random electrofishing in summer. 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 hoopnetting and electrofishing. A von Bertalanffy growth function was used to estimate the theoretical maximum length ($L_\infty$), Brody

TABLE 1.—Estimates of slope ($a$) and intercept ($b$) of the length–weight regression, theoretical maximum TL ($L_\infty$), growth coefficient ($K$), age at which TL is 0 ($t_0$), theoretical maximum weight ($W_\infty$), maximum total age (max age), mean relative abundance (CPUE; catch/h), mean proportional stock density (PSD; defined in text), mean relative stock density of preferred-length fish (RSD-P; defined in text), percent total annual mortality ($A$), and time (years) to reach preferred length ($t_p$; 710 mm), quality length ($t_q$; 510 mm), and stock length ($t_s$; 350 mm) for flathead catfish from the Kansas River, Kansas, 2005–2006. Reaches (Figure 1) were delineated by Makinster (2006). Asterisks indicate when model assumptions were violated, and TL of the largest fish in a given reach was used to calculate $L_\infty$, $K$, $t_0$, and $W_\infty$. Numbers in parentheses represent SEs (for CPUE) and 95% confidence intervals (for PSD and RSD-P).

| | River reach | | | |
|---|---|---|---|---|
| Model parameter | 1 | 2 | 3 | 4 |
| Population model | | | | |
| $b$ | 3.07 | 3.07 | 3.03 | 3.06 |
| $a$ | −5.19 | −5.16 | −5.08 | −5.15 |
| $L_\infty$ (mm) | 1095* | 1121 | 1170* | 1131 |
| $K$ | 0.136 | 0.159 | 0.136 | 0.12 |
| $t_0$ (years) | 0.49 | 0.32 | 0.02 | −0.49 |
| $W_\infty$ (g) | 13,643 | 15,574 | 16,939 | 15,921 |
| Max age (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) |
| $A$ (%) | 28 | 17 | 20 | 14 |
| Growth | | | | |
| $t_p$ | 7.7 | 7.1 | 6.9 | 7.6 |
| $t_q$ | 5.2 | 3.9 | 4.1 | 4.7 |
| $t_s$ | 3.6 | 2.4 | 2.7 | 2.6 |

growth coefficient ($K$), and age at which TL is zero ($t_0$; Ricker 1975) for fish in each reach (Makinster 2006). Linear regression was used to estimate length–weight parameters (slope and $y$-intercept from a regression of $\log_{10}$TL and $\log_{10}$[weight]).

We attempted to determine $u$ through angler tag returns. However, we only received 2 of 572 angler tag returns (<1%) throughout the study period. We tagged only five flathead catfish that were already hooked on bank lines to determine angler nonreporting of fish that were known to be captured. Only one angler reported capturing one of these tagged fish (i.e., report rate = 20%). In addition, the seven fish recaptured from our sampling had no tag loss. Therefore, $u$ corrected for nonreporting and tag loss was 1.7%. However, we assumed $u$ was higher (10%) due to presumed nonreporting from illegal bank lines and possible increased future $u$. Conditional natural mortality ($cm$) was estimated from $A$ estimates. Because accessibility to the river was expected to increase with the addition of new boat ramps, we conducted model simulations of $u$ 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 $A$ 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 number harvested (per 1,000 recruits) were calculated for years that were beyond the maximum age in the population.

We used stepwise multiple regression to determine whether a change in PSD, RSD-P, and number of fish harvested (e.g., [PSD for the 610-mm length limit] − [PSD at the 305-mm limit]) was influenced by $u$, $cm$, $K$, and time to reach stock length ($t_s$). Regression models were conducted for all $u$ (four), $cm$ (four), and river reaches (four), so a maximum of 64 observations was used in each model. In these models, the stepwise procedure only retained variables that were significant at the 0.05 level.

*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:

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

where $Z$ is total instantaneous mortality, PSD and RSD-P represent ranges of possible fishery objectives for size structure, $t_q$ is the time (years) for a fish to reach quality length, and $t_p$ is the time to reach preferred length. Estimated values of $Z$ were transformed into $A$ using the equation found in Ricker (1975):

$$A = 1 - e^{-Z},$$

where $e$ is the base of natural logarithms. Currently, no PSD or RSD-P management objectives are established for flathead catfish in the Kansas River; therefore, 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*

We captured 977 flathead catfish during all sampling events in 2005–2006. We collected 397 fish from 462 stations at which random low-pulse electrofishing was conducted; we subsequently used these in the estimates of $A$ and size structure. We captured 412 fish during supplemental electrofishing and 168 fish during overnight hoop-net sets. The PSD among river reaches varied from 0% to 52%, while the RSD-P varied from 0% to 13% (Table 1). Growth varied among all reaches

TABLE 2.—Flathead catfish age range (years) and total length range (mm) by river reach (Figure 1) in the Kansas River, Kansas, 2005–2006.

| Description | River reach 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Age range (years) | 1–13 | 1–21 | 1–13 | 1–19 |
| Total length range (mm) | 135–1,095 | 129–1,130 | 123–1,170 | 118–1,070 |

of the Kansas River. The $t_q$ varied from 3.9 to 5.2 years, $t_p$ ranged from 6.9 to 7.7 years, and $t_s$ varied from 2.4 to 3.6 years (Table 1). Age and TL of flathead catfish varied among all reaches (Table 2). Total annual mortality also varied among river reaches and ranged from 14% to 28%.

### *Size Structure and Number Harvested*

At presumed current levels of *cm* (20%) and *u* (10%), flathead catfish PSD varied from about 42% to 50% under the 305-mm limit scenario (i.e., no length limit) over the 30-year simulation. At all levels of *cm*, PSD under the 305-mm limit declined precipitously from a range of about 25–65% to a range of 5–30% (a size structure dominated by small fish) as *u* increased from 10% to 40% (Figure 2). This trend was observed in all reaches of the river, and a maximum PSD difference of 7% was observed among reaches (as *u* increased, PSD declined from 59% to 34% in reach 2 and from 57% to 25% units in reach 3). Under the 610-mm length limit, PSD declined gradually in each reach and remained above 20% as *u* increased (Figure 2). At a *cm* of 10%, the PSD under the 762-mm length limit was above 55% in each reach as *u* increased. Regardless of CM, river reaches showed similar trends across all levels of *u* (Figure 2).

Over the 30-year simulation of the 305-mm limit scenario, the RSD-P varied from about 13% to 18% under presumed current levels of *cm* (20%) and *u* (10%). Model simulations showed substantial differences in RSD-P under the 610- and 762-mm length limits, particularly when *cm* was less than 30% (Figure 3). For example, with a *cm* of 20% and a *u* of 30% in reach 4, the RSD-P under the 610-mm length limit was about half of that observed under the 762-mm limit. Further, with a *cm* of 10% and a *u* of 30% in reach 3, the RSD-P under the 762-mm limit was above 30%, while that under the 610-mm limit was about 20%.

Over the simulated period, the number of flathead catfish harvested was at least 15% higher under the 305-mm length limit than under the higher length limits across all reaches and levels of *u* (Figure 4). Differences in the number harvested under the various length limits were similar across all reaches. For example, at a *cm* of 10%, about 66% more flathead catfish in reach 1 would be harvested under the 610-mm limit than under the 762-mm limit. Similarly, 68% more flathead catfish would be harvested in reach 3. At a *cm* of 30%, 27% more flathead catfish in reach 2 would be harvested under the 305-mm limit than under the 610-mm limit. Comparatively, 22% more fish would be harvested in reach 4. At a *cm* equal to 40%, about 29% more fish in reach 2 would be harvested under the 610-mm limit than under the 762-mm limit, whereas in reach 3 about 27% more fish would be harvested (Figure 4).

Multiple regression analysis revealed that changes in size structure (PSD, RSD-P) and number of fish harvested were more influenced by *u* and *cm* than by growth (Table 3). For both minimum length limits, *u* explained 90–95% of the variation in the change in PSD, whereas *cm* explained the most variation (32–49%) in the change in RSD-P (Table 3). The change in number harvested was most influenced by *u* (for the 610-mm length limit) or *cm* (for the 762-mm limit). The metrics of growth (*K* and $t_s$) never explained more than 2.6% of the variation in the change in size structure or number harvested (Table 3).

### *Mortality Caps*

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

## Discussion

Population dynamics of flathead catfish vary spatially within a river (Makinster 2006), suggesting that independent localized management actions may be useful (Travnichek 2004). Our modeling simulations, however, suggest that the management of different reaches of the Kansas River independently is not currently needed to sustain quality flathead catfish populations. Implementation of different high mini-

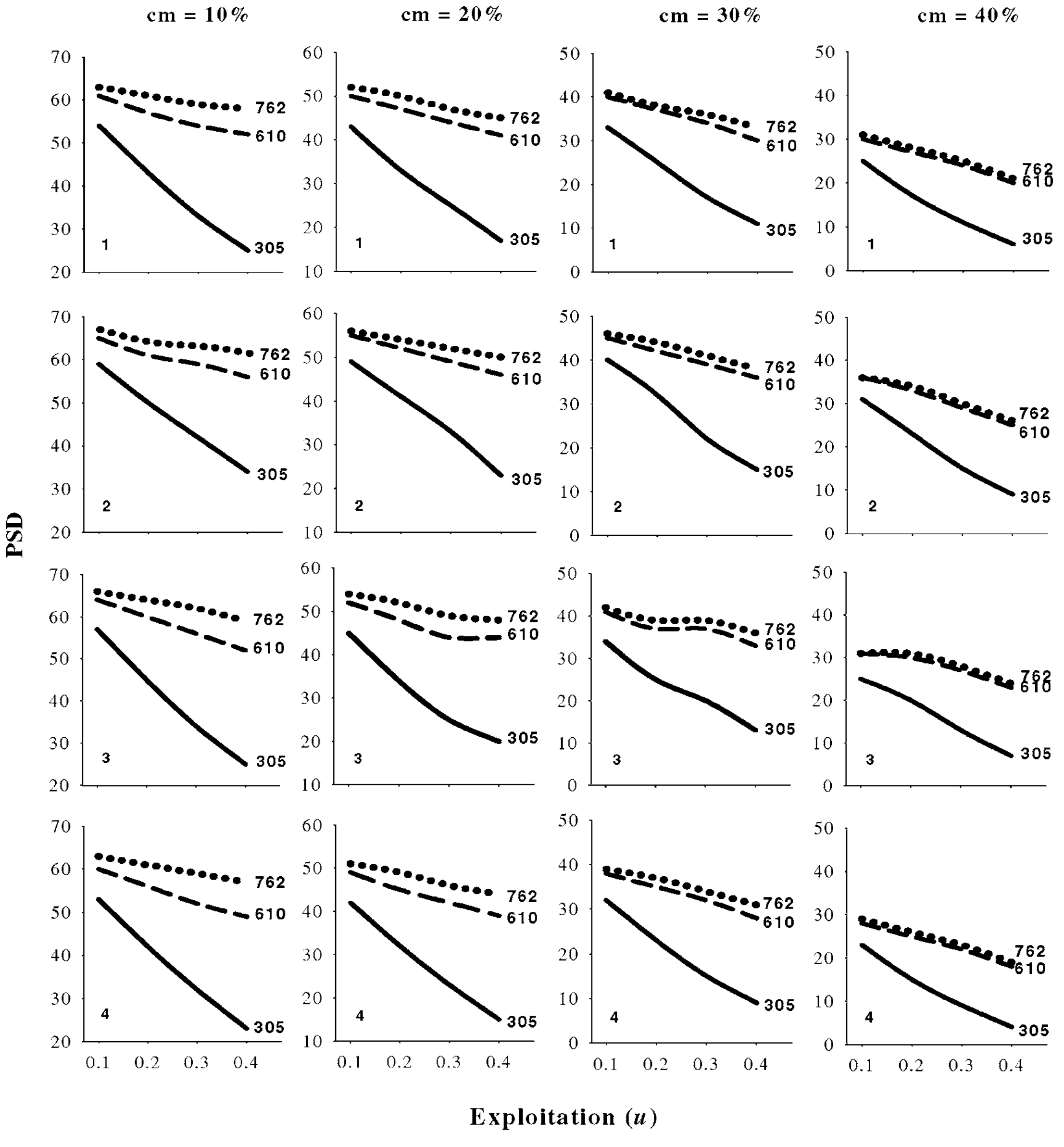


FIGURE 2.—Predicted mean proportional stock density (PSD; %) of flathead catfish during a simulated 30-year implementation of three minimum length limits (305, 610, and 762 mm TL) relative to various ranges of exploitation ($u$) and four levels of conditional natural mortality ($cm$) in four reaches of the Kansas River, Kansas: 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).

mum length limits did not appear to produce substantial differences in flathead catfish size structure among reaches of the Kansas River even though $t_q$ varied by 1.3 years and $t_p$ varied by 0.8 years. Although growth varied among reaches, mortality was more important than growth to improve size structure with minimum length limits, which also has occurred with other sport fish populations (Paukert et al. 2002). Limited access to the Kansas River has probably protected the flathead catfish population from excessive harvest and inherently led to the observed low levels of mortality. However, because angler access to the river is expected to increase with the addition of more boat ramps and efforts by the State of Kansas to promote use of the

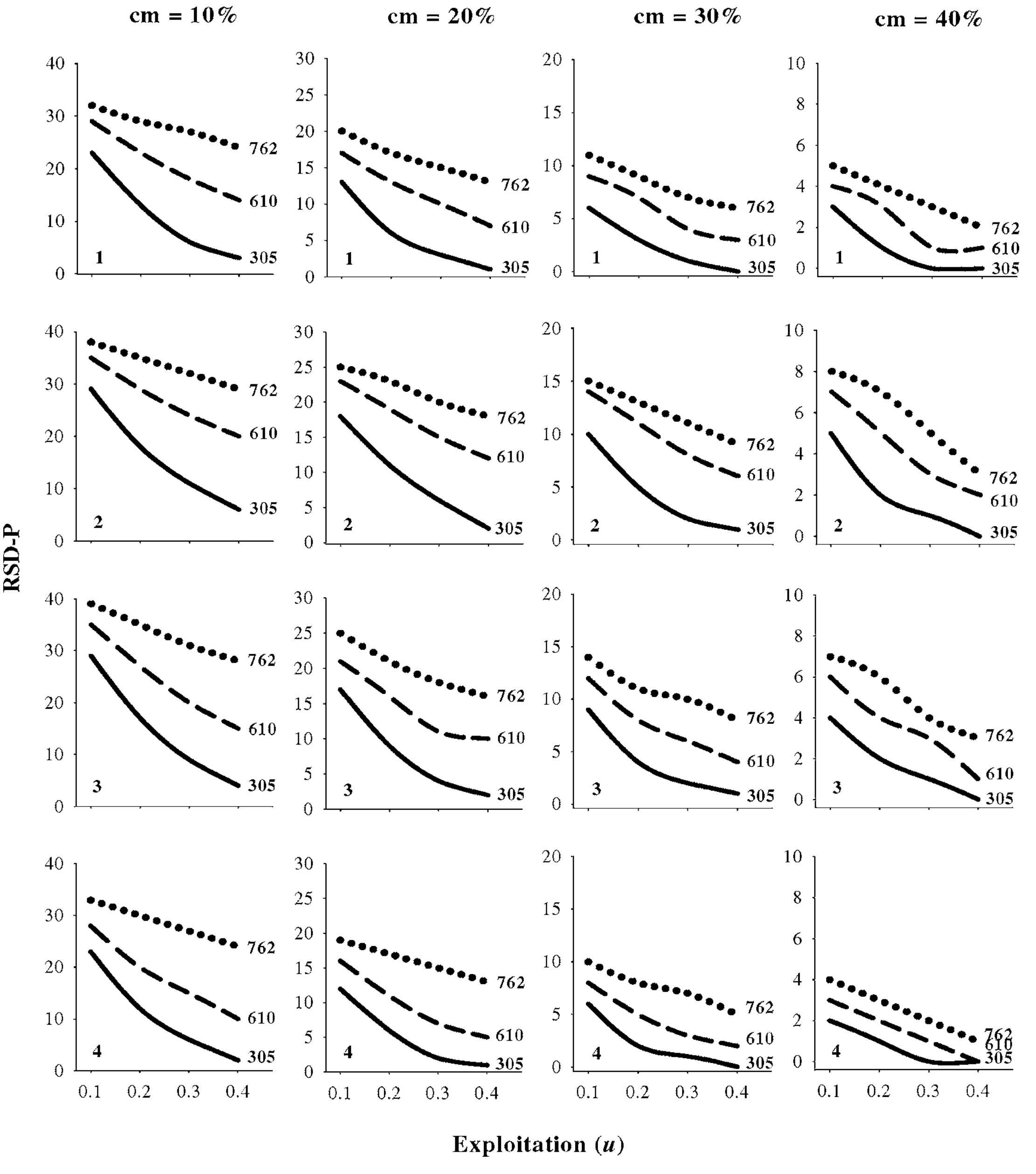


FIGURE 3.—Predicted mean relative stock density of preferred-length flathead catfish (RSD-P; %) during a simulated 30-year implementation of three minimum length limits (305, 610, and 762 mm TL) relative to various ranges of exploitation (*u*) and four levels of conditional natural mortality (*cm*) in four reaches (defined in Figure 2) of the Kansas River, Kansas.

river, increased *u* is likely, particularly in the middle to lower river reaches near major metropolitan areas (i.e., Kansas City and Topeka; Sanders et al. 1993).

Total annual mortality of flathead catfish across all reaches was typically low and was comparable to that of other flathead catfish populations (Daugherty and Sutton 2005; Kwak et al. 2006). We assumed low *u* (about 10%) given the limited access to the river and our limited angler tag returns. However, tag loss would probably have led to underestimates of *u*. Although we did not directly examine tag loss during this study, previous literature suggests high tag retention with similar tags among catfish species (Pellett et al. 1998; Travnichek 2004). Thus, model simulations were

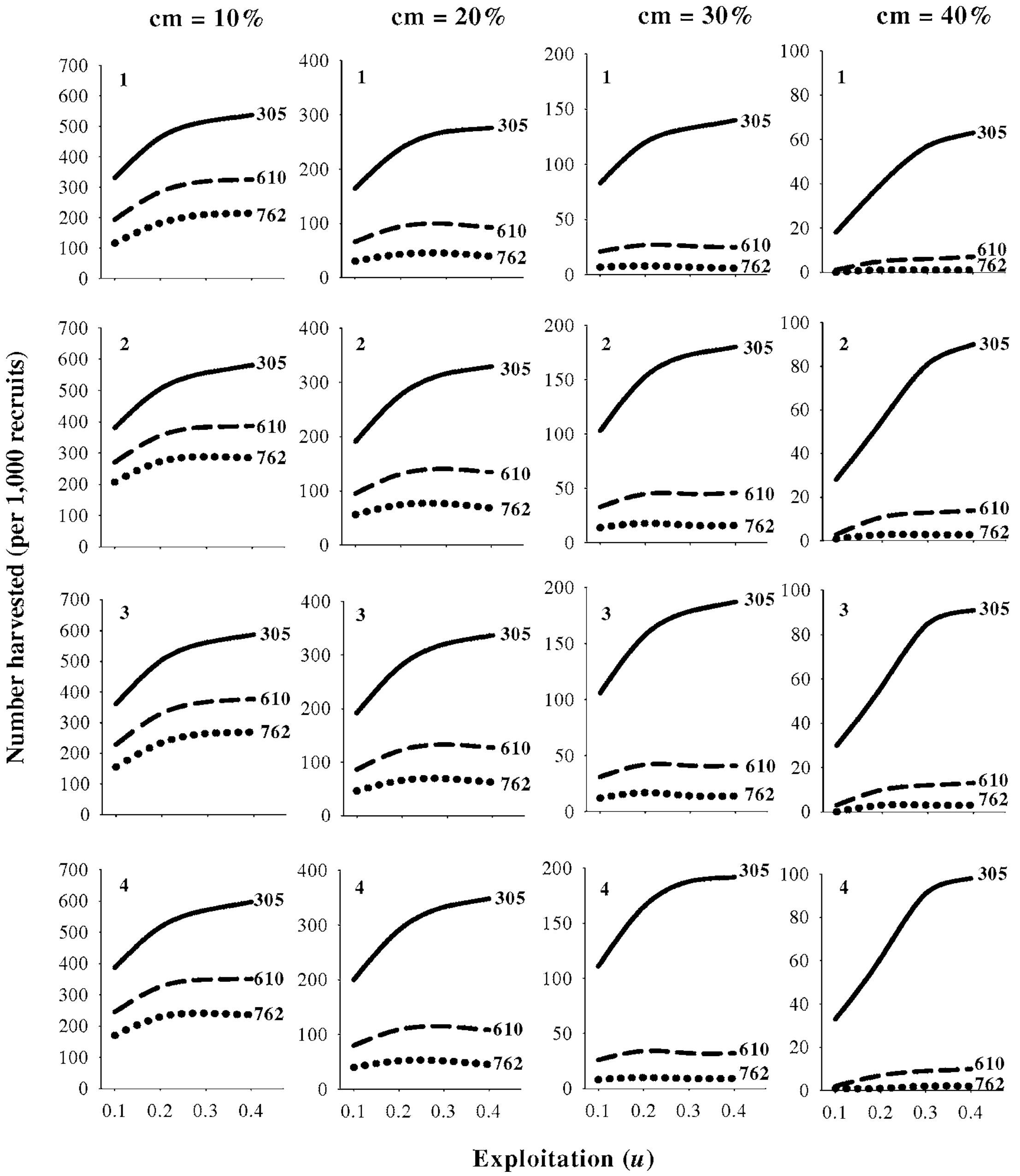


FIGURE 4.—Predicted number of flathead catfish harvested (per 1,000 recruits) during a simulated 30-year implementation of three minimum length limits (305, 610, and 762 mm TL) relative to various ranges of exploitation (*u*) and four levels of conditional natural mortality (*cm*) in four reaches (defined in Figure 2) of the Kansas River, Kansas.

conducted such that *u* occurred at higher than normal levels (14–25%; Quinn 1993) and served as an upper limit for expected *u* 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-length 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 size structure in each reach without a minimum length limit as *u* increased by even 10%. This pattern was evident across all ranges of

TABLE 3.—Results of multiple regression models used to determine whether change in flathead catfish PSD, RSD-P, and number harvested under a 610- or 762-mm minimum length limit (relative to a 305-mm limit) were influenced by exploitation ($u$), conditional natural mortality (cm), Brody growth coefficient ($K$), or time to reach stock length ($t_s$) in the Kansas River, Kansas.

| Dependent variable | Independent variable | Coefficient | Partial $R^2$ | $F$ | $P$ |
|---|---|---|---|---|---|
| | **610-mm Length limit** | | | | |
| Change in PSD | $u$ | 59.02 | 0.950 | 1030.35 | <0.001 |
| | $cm$ | −7.79 | 0.021 | 38.46 | <0.001 |
| | $K$ | −37.71 | 0.008 | 19.39 | <0.001 |
| | $t_s$ | 0.66 | 0.002 | 5.16 | 0.027 |
| Change in RSD-P | $cm$ | −23.09 | 0.317 | 25.02 | <0.001 |
| Change in number harvested | $u$ | −353.80 | 0.629 | 91.45 | <0.001 |
| | $cm$ | 263.89 | 0.290 | 190.13 | <0.001 |
| | $K$ | 832.21 | 0.026 | 24.07 | <0.001 |
| | $t_s$ | 15.59 | 0.013 | 15.43 | <0.001 |
| | **762-mm length limit** | | | | |
| Change in PSD | $u$ | 69.57 | 0.904 | 505.34 | <0.001 |
| | $cm$ | −15.74 | 0.055 | 68.68 | <0.001 |
| | $K$ | −68.10 | 0.013 | 22.03 | <0.001 |
| Change in RSD-P | $cm$ | −32.82 | 0.486 | 50.99 | <0.001 |
| | $u$ | 34.29 | 0.189 | 30.71 | <0.001 |
| Change in number harvested | $cm$ | 483.13 | 0.713 | 134.16 | <0.001 |
| | $u$ | −454.36 | 0.234 | 235.62 | <0.001 |
| | $K$ | 906.17 | 0.013 | 16.62 | <0.001 |
| | $t_s$ | 17.61 | 0.007 | 10.80 | 0.002 |

*cm* and $u$. Recent surveys have indicated that flathead catfish anglers are more inclined to support harvest regulations to protect the "trophy" potential of flathead catfish (Quinn 1993; Arterburn et al. 2002). While we have shown that a minimum length limit would preserve the future quality conditions in each reach with increased $u$, any further size structure increases would necessitate a reduction in the number of fish harvested by anglers. Other studies have suggested similar harvest reductions to increase size structure in populations characterized by fast growth and low natural mortality (Maceina et al. 1998; Slipke et al. 1998; Cornelius and Margenau 1999; Paukert et al. 2002). In our study, the observed *cm* of flathead catfish was low (<20%, assuming $u = 10\%$) 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 that growth is sufficient for the production of quality-size fish. Although growth is sufficient to maintain a quality fishery at low $u$, higher $u$ would negate these effects and result in lower-quality populations unless fish are protected by a minimum length limit.

We observed differences among reaches with model simulations using preferred-length fish. With the current level of $A$ (about 30%), reaches 1 and 4 typically showed lower flathead catfish size structure than 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 suggest that anglers will experience minimal reductions (about 20% under current $A$) in the number of harvested fish under a 762-mm minimum length limit compared with a 610-mm limit. The reach that is best suited for such designation is reach 3 (upstream of Bowersock Dam), since no fish consumption advisories exist in this reach (T. Mosher, KDWP, personal communication). In addition, this reach has a high relative abundance of flathead catfish (about triple that found in reaches 1 and 4; Makinster 2006) and may produce better angler catch rates than other reaches having lower abundance. Designation of management zones exists for other species, particularly salmonids (Anderson and Nehring 1984) and smallmouth bass *Micropterus dolomieu* (Slipke et al. 1998); therefore, similar management actions may be suitable for flathead catfish.

Analysis of mortality caps indicated that flathead catfish $A$ did not exceed the thresholds needed to maintain quality fisheries in the four reaches of the Kansas River. However, we did not capture fish larger than 510 mm in the lowermost reach during summer random electrofishing, probably because of the inefficiency of electrofishing in deepwater habitats (Cunningham 1995). Although no size structure objectives exist for flathead catfish in the Kansas River, the mortality cap estimates indicate that all reaches could sustain a minimum $A$ of 60% to maintain the current size structure at around 50 units under current growth conditions. If managers desire a size structure of 70 units, the minimum $A$ must not exceed about 35% under current growth conditions. However, mortality would have to be reduced (e.g., by harvest regulations), particularly in reaches 2 and 3, to achieve RSD-P objectives of 20% or higher. Mortality caps have similarly been used in studies of PSD objectives in reservoir populations of walleyes *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.

A creel survey at major access points throughout the river and the use of otoliths for aging would have benefited our estimates of mortality and $u$. However, we demonstrated that there were minimal regulation effects when $u$ was 10%. If we had modeled lower estimates of $u$, our results would probably have indicated even less of an effect of harvest regulations. Further, the use of otoliths might have provided stronger age estimates for the older fish (age > 5) captured during our study, as these ages may have been underestimated by use of pectoral spines (Nash and Irwin 1999). If this is the case, then a greater number of older fish is present in the population than that we reported and estimated mortality would be lower, resulting in an even weaker effect of harvest regulations. Future research of lotic sport fish should incorporate these ideas to properly manage these species in other systems.

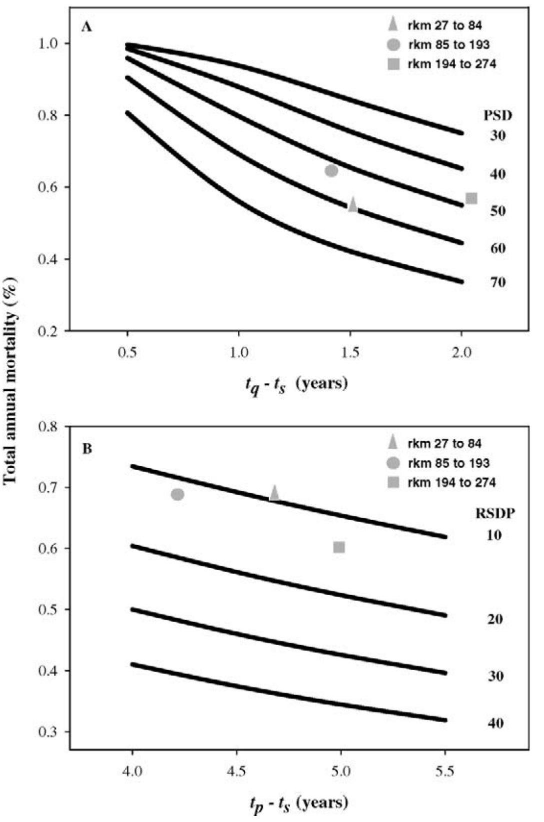


FIGURE 5.—Estimated flathead catfish mortality caps (solid lines) in three reaches of the Kansas River, Kansas (see Figure 1; triangles = reach 2; circles = reach 3; squares = reach 4) based on growth rates within each reach: **(A)** five proportional stock density (PSD; 30–70%) objectives (based on time [years] to reach quality length [$t_q$; 510 mm TL] – time to reach stock length [$t_s$; 350 mm TL]) and **(B)** four objectives (10–40%) for relative stock density of preferred-length fish (RSD-P; based on time to reach preferred length [$t_p$; 710 mm TL] – $t_s$). Reach 1 is omitted because no fish larger than 510 mm TL was captured during electrofishing in 2005–2006.

*Management Implications*

Although use of differing minimum length limits for flathead catfish among Kansas River reaches was not needed, a length limit will be needed to protect the quality flathead catfish fishery throughout the river if $u$ increases. Imposing a minimum length limit suggests a higher proportion of large flathead catfish that could be harvested, but anglers must accept reductions in the number of harvested fish, which is common in most harvest regulation scenarios (e.g., Maceina et al. 1998; Paukert et al. 2002). Therefore, reaches with higher relative abundance may be best suited for a trophy regulation. The current levels of $u$ and mortality do not appear to inhibit the high growth potential of flathead catfish; thus, it is possible to maintain a quality size structure even with the designation of a trophy reach. However, as accessibility to the river increases with more boat ramps and as $A$ approaches the estimated threshold, length limits might be needed 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 when management action is needed (Miranda 2002; Quist et al. 2004). Our study illustrates how population modeling, with the incorporation of human impacts on fisheries, can benefit the management of lotic species. Moreover, this study and others (Anderson and Nehring 1984; Travnichek 2004; Makinster 2006) suggest the need for researchers to examine whether a more localized management approach (river specific versus region specific) is appropriate for popular sport fish species. 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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