Potential for a Minimum-length Limit Regulation to Improve Floodplain Lake Crappie Fisheries in Arkansas

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Abstract: Compared to reservoirs and small impoundments, sport fisheries management infrequently has been attempted in large-river systems. In river systems of the southeastern United States, black crappie (*Pomoxis nigromaculatus*) and white crappie (*P. annularis*) represent popular sport fisheries in floodplain lakes and other off-channel habitats. Using floodplain lakes in the lower White River, Arkansas as a study area, crappie population data from 16 representative lakes were used to define basic stock structure statistics and evaluate whether minimum-length limits could potentially improve crappie fisheries in this system. Modeling indicated that implementation of a 254-mm minimum-length limit for crappies would reduce the number of fish harvested by half and minimally increase yield when exploitation was high. Modeling also suggested the length limit would increase mean size (length and weight) harvested, with more substantial increases observed when recruitment was held constant. In the presence of high recruitment variability (incoming number of recruits CV >75%), length-limit implementation exhibited similar trends with yield and harvest as with low recruitment variability (incoming number of recruits CV <50%), and produced minimal improvement in population size structure. However, within this modeling scenario, greater variability was observed in all predicted population statistics over long-term time scales, which suggested that years of high-quality crappie fisheries would be balanced with as many poor years. Modeling suggested that minimum-length limits provided minimal benefits for crappie fisheries in lower White River floodplain lakes. These findings were generally similar to previous studies on these species done in reservoirs and small impoundments.

Key words: crappies, large rivers, floodplain lakes, length limits, population modeling

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Large-river systems, which herein includes their floodplains and other off-channel habitats, are among the most productive and dynamic ecosystems on earth (Bayley 1995). However, development of appropriate fisheries management in these systems has generally lagged behind that in natural lakes and man-made impoundments for various reasons. First, large-river systems in temperate regions are frequently the target of non-fisheries uses designed to promote commerce, economic development, and greater standards of living (e.g., navigation, hydroelectric power production, irrigation, and flood control) (Sheehan and Rasmussen 1999). Second, the diversity of habitats in large-river systems and the temporal variability within these habitats impedes the collection of representative, or at times, even comparable samples. For example, habitats exhibit vast seasonality in terms of flows, depths, and use by fishes (Sparks 1995), which necessitates that multiple-gear approaches be used to obtain representative samples (Gutreuter et al. 1995, Schramm 2004). This approach runs counter to traditional fisheries stock assessment tools developed for marine fisheries, which emphasize single-gear catch-effort models to support management (Coates et al. 2004). Third, there is a general perception by some that large-river fisheries may be "unmanageable" because of their complex and poorly understood dynamics and tendency to fall under multiple regulatory jurisdictions. As a result, many agencies are reluctant to develop large-river management programs they believe impractical.

Despite the rarity of fisheries management in large-river systems, significant sport fisheries exist in these systems throughout North America. In the Mississippi River Valley, white crappie (*Pomoxis annularis*) and black crappie (*P. nigromaculatus*) are popular recreational fisheries in floodplain lakes of many large-river systems (Miranda 2005). In Arkansas, crappies are the second most sought-after sport fish (Duda et al. 2000), with anglers spending almost US$100 million annually on crappie fishing (Arkansas Game and Fish Commission [AGFC] 2002). Like other states, Arkansas has developed a comprehensive management plan for crappies (AGFC 2002), but nearly all of the supporting research has been conducted in reservoirs. In fact, little research has been done nationally regarding crappie biology or management in large-river systems. The objectives of this study were to 1) define basic population statistics for a large-river crappie population, and 2) assess whether minimum-length limits, a common management strategy for crappies in reservoirs, could potentially improve large-river crappie fisheries. Results will be useful for fisheries managers that are increasingly dealing with fisheries issues in large-river systems.

Methods

Study Area

The White River is the largest river basin in Arkansas, having an area of 44,400 km^2 and draining 34% of the state (Robison and Buchanan 1988). The river rises in northwestern Arkansas, flows northward into Missouri, and then southward back into Arkansas before flowing into the lower Mississippi River at river kilometer (RKm) 964. The upper White River is influenced by coldwater hypolimnetic discharges below Norfork and Bull Shoals reservoirs in northern Arkansas. In this reach of the river, water temperatures rarely exceed 24 C (Robison and Buchanan 1988). However, the 476 kilometers of the river downstream of Batesville, Arkansas, is characteristic of a lowland warmwater river because of the thermally-moderating influences of several large warmwater tributaries, namely the Buffalo, Black, and Cache rivers (Ken Shirley, AGFC, unpublished data and report). This reach of the river has an active floodplain and undergoes seasonal flood pulses (Lubinski 2004). The 65,000-ha White River National Wildlife Refuge (WRNWR) is located in this reach of the river between RKm 16 and RKm 161 at Clarendon, Arkansas. Seasonal flooding in the refuge is affected both by the White River and backflow from the Mississippi River. Personal communications with WRNWR biologists indicate that floodplain lakes within the refuge contain the most significant crappie fisheries in the White River basin. Traditionally, the lower White River crappie fishery has been managed only with a daily creel limit of 30 fish per day, which is the same regulation in effect for all southeastern Arkansas waters.

Fish Collections

Crappies in the lower White River system mostly inhabit the hundreds of floodplain lakes and associated sloughs, bayous, and ditches adjacent to the main river channel. The WRNWR contains approximately 350 floodplain lakes of widely varying sizes, morphologies, connectivity, and accessibility (Lubinski 2004). Sixteen of the approximately 50 refuge lakes with road and boat access were randomly selected for population assessments as described by Lubinski et al. (2008). Selected lakes were 3 to 48 ha in surface area and 0.6–4.7 m in average depth. Although accessibility to anglers may have resulted in biased estimates of some population statistics, angling also was observed on nearby lakes without road or boat access.

Crappie populations were assessed using nighttime boat-mounted electrofishing during October and November 2002. Electrofishing was done using a Smith-Root 7.5 GPP electrofishing unit that provided a pulsed-DC output; settings were standardized for water temperature and conductivity to achieve a standard power output of approximately 3,000 W during sampling (Burkhardt and Gutreuter 1995). Six, 10-min samples (three samples at 1000V-15 Hz and three samples at 500V-60 Hz) (Schramm and Pugh 2000) were collected from each lake. Collected crappies were placed in coolers on ice and returned to the laboratory for analysis. Because white and black crappies are frequently managed concurrently with the same regulations, they were pooled as "crappies" in all analyses as done in previous studies (e.g., Allen 1997, Maceina et al. 1998, and Isermann et al. 2002).

Population Statistics

All crappies collected were measured to nearest mm and weighed to the nearest g in the laboratory. The weight-length equation for crappies was generated using ordinary least-squares regression procedures on $\log_{10}$-transformed individual weights and lengths for all lakes combined. Catch rates (as catch$\cdot$ h^{-1}) were calculated separately for each lake.

Crappies were aged by inspection of sagittal otoliths. Whole otoliths immersed in glycerin were double-blind read under a dissecting microscope, with annular measurements determined using digital imaging software. Two independent readers viewed all otoliths for age confirmation, with age discrepancies resolved by concert read or excluded from further analysis if no agreement was reached. A von Bertalanffy growth model (Slipke and Maceina 2004) was fitted for crappies using mean length at age from all lakes pooled. Non-linear modeling techniques were used to estimate the parameters L_∞ (theoretical maximum length for the population), t_0 (time in years when length would theoretically equal zero), and K (growth coefficient). All of these parameters were needed for subsequent modeling.

Instantaneous total mortality (Z) and annual mortality (A) of crappies were estimated from standard catch-curve analysis (Ricker 1975). Because insufficient numbers of crappies were collected from some lakes that precluded reliable estimates of Z and A, individuals from all lakes were pooled to develop a cumulative catch curve for the entire system. This was additionally justified because lake-specific management of crappie fisheries is impractical in large-river systems that contain many small backwater lakes and interconnected sloughs and bayous in their floodplains. Examples of catch curves pooled in this manner can be found in Allen (1997) and Miranda and Bettoli (2007). Size structure was assessed using standard relative size structure indices (PSS_Q, PSS_P, and PSS_M) (Guy et al. 2006).

Effects of Minimum-Length Limits

Using the age, growth, and mortality data generated as described above, we simulated implementation of a 254-mm minimum-length limit using the FAST model (Slipke and Maceina 2004). The length limit chosen represented a common minimum-length limit for crappie populations in the United States (Allen and Miranda 1995, Hale et al. 1999). Mortality statistics estimated above contained a degree of uncertainty. To account for this likelihood, length-limit modeling was conducted at different levels of conditional natural mortality (n). At values of n ranging from 20%–60% (stepped by 10%), the yield-per-recruit (YPR) model was implemented to examine the effects of a 254-mm minimum-length limit on fish yield (kg), number of fish harvested, and mean weight of fish harvested (g) at variable levels of fish exploitation (µ). During YPR modeling, conditional fishing mortality (m) was similarly varied from 0.1 to 0.7 (stepped by 0.05); von Bertalanffy growth parameters and weight-length equations generated from this study were used in modeling. Modeling assumed steady-state equilibrium conditions where recruitment was held constant. Alternatively, we used a 200-mm length limit to simulate a no-length limit scenario as previously done by Hale et al. (1999) and Allen and Pine (2000).

To simulate the effects of variable recruitment on the crappie fishery, the dynamic pool (DP) model in FAST (Slipke and Maceina 2004) was used. Effects of recruitment variability were modeled using a 50-year simulation with an initial population size of 1,000 and coefficients of variation on population size of 10%, 25%, 50%, 75%, 100%, and 125%. The effects of variable recruitment were assessed in relation to fish yield (kg), number of incoming recruits and biomass (kg), number of fish harvested, and population size structure (PSS_Q, PSS_P, and PSS_M). Estimates of m and n generated from previous modeling were used to depict crappie mortality rates from ages 1 through 6. For mortality from age 0 through 1, n was assumed to be 0.90 and m was assumed to be zero as recommended by Slipke and Maceina (2004).

Results

A total of 410 crappies (336 white crappie; 74 black crappie) were collected from lower White River floodplain lakes. Mean catch rate was 26 fish/h (range 6 – 43 across lakes). PSS_Q was 43 (± SE of 3), PSS_P was 22 (±2), and PSS_M was 9 (±2). Crappie populations contained up to seven year classes; 79% of the population was age 1 and 2, with ages >2 comprising only 8% of the population. Age-0 fish were 13% of the sample, though boat-mounted electrofishing was believed to have underrepresented this group. Non-linear modeling produced von Bertalanffy growth parameters of 384 mm for L_∞ (95% CI, 205 – 563), –0.64 for t_0 (–2.21 – 0.94), and 0.27 for K (–0.08 – 0.61). Catch-curve analysis with catches combined across the 16 lakes produced an instantaneous total annual mortality rate (Z) of 0.810 (95% CI, 0.38 – 1.23), which translated to an interval total annual mortality (A) of 56% (95% CI, 32 – 71%).

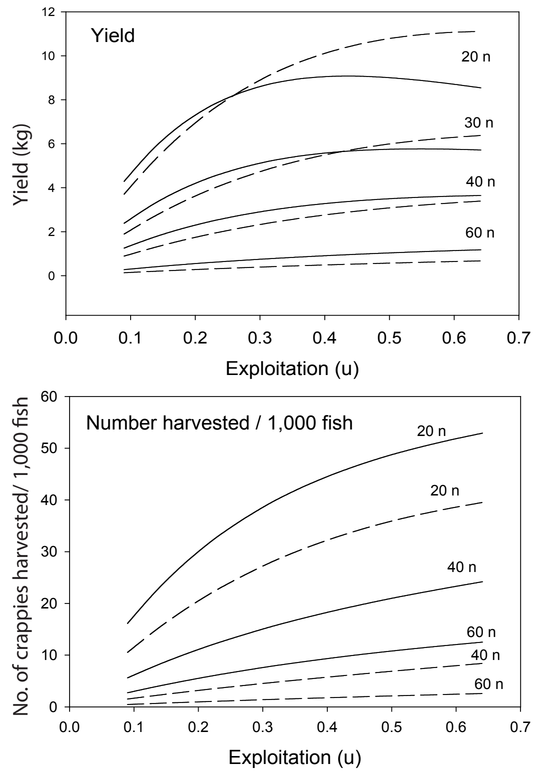

Figure 1. Results from yield-per-recruit modeling that incorporated variable conditional natural mortality (n) into predictions of crappie population yield and harvest rate with and without a 254-mm minimum-length limit. Solid lines = 200-mm minimum-length limit, which represented no length limit; dashed lines = 254-mm minimum-length limit. Predictions for 50 n were excluded to avoid cluttering in the graph.

Yield-per-recruit (YPR) modeling assessing the effectiveness of a 254-mm length limit incorporated different levels of conditional natural mortality. Using the six empirical models contained in FAST (Slipke and Maceina 2004), instantaneous natural mortality (M) estimates ranged 0.316 – 0.768 and averaged 0.494. Calculating conditional natural mortality (n) for each value of M as $1 – e^{–M}$ (Miranda and Bettoli 2007), resulted in estimates of n ranging from 27–54% (mean 38%). Thus, the 254-mm length limit was modeled at five different values of n (20%, 30%, 40%, 50%, and 60%), which encompassed the entire range of n estimates generated from the different natural mortality models. This accounted for probable er-

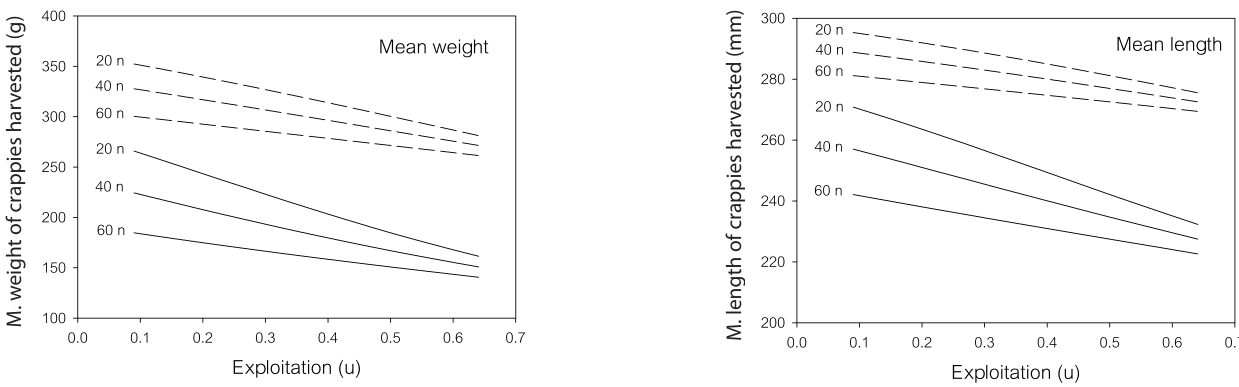

Figure 2. Results from yield-per-recruit modeling that incorporated variable conditional natural mortality (*n*) into predictions of crappie population mean weight and length with and without a 254-mm minimum length limit. Solid lines = 200-mm minimum-length limit, which represented no length limit; dashed lines = 254-mm minimum-length limit. Predictions for 50 *n* and 30 *n* were excluded to avoid cluttering in the graph.

Table 1. Results from dynamic pool modeling that incorporated recruitment variability of crappie populations into predictions of population statistics. Predictions were based on 50-year simulations with mean number of recruits set at 1,000 fish per year. Values in parentheses represent coefficients of variation. Minimum-length limits: 200 = no length limit; 254 = 254-mm length limit.

Variability (as CV of incoming no. of recruits)	Minimum-length limit (mm)	Yield (kg)	Population size	Population biomass (kg)	Number harvested	PSS_Q (%)	PSS_P (%)	PSS_M (%)
10	200	4.65 (5)	216 (5)	20.9 (4)	23.0 (6)	41.7 (7)	13.6 (8)	2.7 (17)
	254	3.64 (5)	234 (5)	25.6 (5)	11.7 (6)	45.3 (5)	18.7 (7)	3.8 (13)
25	200	4.74 (11)	221 (13)	21.1 (10)	23.4 (14)	42.0 (18)	13.7 (21)	2.8 (34)
	254	3.64 (14)	235 (12)	25.6 (11)	11.6 (14)	45.6 (12)	18.8 (19)	3.9 (24)
50	200	4.89 (22)	229 (25)	21.8 (19)	24.1 (27)	43.7 (34)	14.4 (46)	2.9 (71)
	254	4.00 (22)	254 (23)	27.9 (17)	12.8 (24)	47.0 (36)	20.0 (41)	4.2 (56)
75	200	5.07 (30)	238 (34)	22.6 (26)	25.1 (37)	46.8 (49)	16.6 (100)	3.7 (129)
	254	3.67 (37)	239 (34)	25.9 (31)	11.7 (38)	49.6 (38)	21.2 (71)	4.4 (83)
100	200	5.20 (34)	245 (39)	23.2 (30)	25.7 (42)	50.2 (56)	17.6 (108)	4.2 (146)
	254	3.65 (43)	239 (40)	25.9 (36)	11.7 (45)	52.2 (47)	22.6 (87)	5.3 (124)
125	200	5.30 (37)	249 (42)	23.6 (32)	26.2 (45)	50.9 (59)	19.1 (119)	5.0 (183)
	254	4.16 (39)	272 (39)	29.4 (32)	13.3 (42)	53.5 (54)	23.5 (97)	6.2 (160)

ror in *n* estimation and was consistent with the approach used by Maceina et al. (1998) to address a similar dilemma.

Length-limit implementation resulted in reduced crappie yield at *n* of 40%–60% compared with no length limit regardless of exploitation level (Figure 1). At 30% *n*, the minimum-length limit enhanced crappie yield, but only when exploitation rates exceeded 40%. At 20% *n*, crappie yield was enhanced when exploitation rates exceeded 25%, and significantly enhanced yield at exploitation rates greater than 40%. When exploitation was less than 25%, the minimum-length limit produced small decreases in crappie yield regardless of level of *n* (Figure 1). Length-limit implementation reduced number of crappies harvested per 1,000 fish relative to no length limit by 20%–60%, with the percent decrease being greatest at greater levels of *n* (Figure 1). Mean size (as length and weight) of crappies harvested under the 254-mm length limit was always greater compared to no length limit regardless of exploitation level or *n* rate (Figure 2). However, mean size also decreased linearly as exploitation rates increased regardless of the *n* rate (Figure 2).

Dynamic pool modeling that incorporated the effects of variable recruitment indicated that a 254-mm length limit could be marginally effective in enhancing the size structure of crappies over long-term time scales (Table 1). PSS_Q, PSS_P, PSS_M, crappie population size, and total crappie population biomass were predicted to increase after implementation of a 254-mm length limit over a 50-year time period. However, number harvested and yields were predicted to decline (Table 1). Evident from modeling was that as recruitment variability increased from 10% to 125%, mean levels of all population measures and their variability also increased over long-term time scales.

Discussion

Modeling results suggested that a 254-mm minimum-length limit provided minimal benefits to lower White River floodplain lake crappie fisheries. The length limit resulted in greater yields, but only when conditional natural mortality rates were low (<30%) and exploitation rates were high (>40%). This conclusion is consistent with Allen and Miranda (1995), who suggested from reservoir studies that only under conditions of high (hence, above-average) growth and low natural mortality (less than 30%–40%) would minimum-length limits be effective at improving yields in crappie populations. Thus, they recommended minimum-length limits would be effective for crappies in a limited number of scenarios. Preliminary modeling results generated from this study suggest these recommendations are applicable to the lower White River. Findings also may be applicable for floodplain lake crappie fisheries in other large-river systems with similar dynamics.

Despite the paucity of historical fisheries data for the lower White River, it is unclear how realistic a high growth–low natural mortality scenario might be for floodplain lakes in this river system. Using the von Bertalanffy growth equation derived from this study, crappies were estimated to be 3.4 years old at a total length of 254 mm in lower White River floodplain lakes. This suggested much slower growth than that reported by Maceina et al. (1998) for crappies in Weiss Lake, Alabama, where crappie reached 254 mm by age 2.4, a full year sooner. Growth at ages 1 and 2 for crappies in Weiss Lake also was much greater than growth at ages 1 (130 mm) and 2 (233 mm) for White River crappies, though fish were of similar length by age 5. From 22 separate studies, Allen and Miranda (1995) reported that average-growing white crappie reached 254-mm total length at about 2.7 years age in central and southern U.S. reservoirs. Crappies from their slow-growth and fast-growth modeling scenarios reached 254 mm at ages 3.2 and 1.9 years, respectively. These data suggest that White River crappie populations exhibited below-average growth in terms of estimated age at length when compared to reservoir crappie populations in the central and southern United States.

Conditional natural mortality rates approximating 20%–30% that may enhance yield at observed growth rates (refer back to Figure 1) were at the lower end of conditional natural mortality values generated from models, which ranged from 27%–54% and averaged 38%. Previous estimates of angling-related mortality (as μ or F) have been derived from reservoirs and small impoundments with high angling pressure. Allen et al. (1998) reported estimates of crappie exploitation and total mortality from 30 different systems in the southern and central United States. From these studies, crappie exploitation ranged from 0%–84% overall, but averaged 46%. On average, these studies suggested that exploitation of crappies accounted for 62% of the total mortality of crappies. In this study, using estimates of 0.494 for M, 56% for A, and 0.810 for Z, interval natural mortality (as $v = MA/Z$ for a Type 2 fishery) (Miranda and Bettoli 2007) and interval angling mortality (as $\mu = A - v$) (Miranda and Bettoli 2007) were estimated to be 34% and 22%, respectively. Given these estimations, fishing mortality comprised approximately 39% of the total mortality of crappies in these floodplain lakes. Thus, the estimated exploitation of 22% for lower White River floodplain lakes also was at the lower end of the range of reported values for crappies. An age-frequency distribution of the lakes provided some evidence that suggested either exploitation or natural mortality were greater than estimated from modeling, as only 8% of the crappies collected from sampling ($n = 410$) were age 3 or older. Undoubtedly, a tag-rewards study would provide more definitive estimates of exploitation and would increase confidence in model predictions. Nevertheless, crappie fisheries in lower White River floodplain lakes may be marginal in the sense that growth, exploitation, or both may not be great enough or natural mortality low enough for crappies to consistently benefit from implementation of minimum-length limits as a management strategy. This scenario is similar to previous evaluations done for reservoir crappie fisheries. Although research done exclusively in large-river floodplain lakes is lacking, Carlson et al. (2004) drew similar conclusions for the crappie fishery in Lake Chicot, Arkansas, which is a large oxbow lake now isolated from the lower Mississippi River by levees.

The suggestion offered above also assumes constant annual recruitment by crappies, which we believe is an unlikely scenario in a large-river system anywhere. Reservoir studies have indicated that crappie recruitment can be strongly related to system hydrology (e.g., Sammons et al. 2002, Maceina 2003), a characteristic that can vary by orders of magnitude in most large-river systems on a seasonal or annual basis. Under scenarios of variable recruitment (incoming number of recruits CV 10%–125%) in the lower White River, modeling suggested that a 254-mm length limit produced only small increases in population size and biomass and did not enhance crappie yield. Predictably, mean size of crappies harvested also would be increased. Size structure was marginally increased (6%–10%) at all levels of recruitment variability, which was consistent with modeling done by Allen and Pine (2000). Larger size structures (e.g., PSS_Q 50 or greater) consistently resulted when recruitment variability was greatest (population size CV 100% or greater). However, the variability of those predicted estimates also was greater (<10% at 10% CV compared to 50% at 125%). Thus, minimum-length limits may have the potential to enhance crappie size structures in the lower White River, but inherent recruitment variability may inevitably lead to as many good years as poor years with respect to crappie size structures over long-term time scales. Additionally, in the presence of high recruitment variability, detectable changes in crappie population abundance or size structure may be difficult to discern even when long evaluation periods are used (Carlson et al. 2004).

On the other hand, in the absence of any other information, a conservative management approach would be that any length limit would protect adult crappies and ensure that the adequate spawning stock is available. In a system with high exploitation and no length limit, failed year classes could produce rapid declines in crappie numbers. In these situations, it has been speculated that length limits might moderate recruitment variability (e.g., Miller et al. 1990, Colvin 1991, Webb and Ott 1991, Maceina and Stimpert 1998), though these suggestions have not been validated in the field. Miranda and Allen (2000) suggested that minimum-length limits might be more effective in reducing recruitment variability in more stable environments where variability is not excessive. Although these recommendations are speculative, it is probably unlikely that length limits would moderate recruitment variability in large-river systems given the complex nature of processes regulating fish population dynamics in these systems.

In summary, minimum-length limits would likely be marginal at enhancing crappie fisheries in lower White River floodplain lakes. This finding would likely be applicable to many floodplain lake crappie fisheries given that aspects of the lower White River (e.g., variable annual flood pulses) and its crappie population (e.g., variable recruitment, average mortality and growth, unknown exploitation) are probably commonplace in other large-river systems in North America. However, this conclusion cannot be made with total certainty. Future studies that more thoroughly quantify population statistics, especially exploitation, are needed from this and other systems to validate this conclusion and further evaluate potential management schemes for this and other large-river systems.

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