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Research Article

Evaluating Exploitation of White Crappie and Black Crappie in Three Southeast Kansas Reservoirs

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White Crappie (*Pomoxis annularis*) and Black Crappie (*P. nigromaculatus*) were studied in three southeast Kansas reservoirs to assess exploitation and determine if current regulations were conducive for sustainable populations. Trap nets were used to sample crappie in Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake. Crappie measuring 210 mm and greater received Floy FD-94 tags that served as entries for rewards to encourage tag reporting. Harvest and angler demographic information were collected when tags were reported. Postcard surveys and motion-sensed cameras were used in conjunction to estimate angler effort and reporting rate on Parsons City Lake. Annual exploitation rates (i.e., percent of fish harvested) determined by tag returns and corrected for nonreporting and tag loss were 28.3%, 21.8%, and 3.9% on Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively. Overfishing was not occurring, so current statewide regulations were likely appropriate, and no changes may be necessary.

1. Introduction

Recreational fishing is very popular in the United States [1]. During 2016, 35.8 million U.S. residents engaged in some form of fishing and spent US$46.1 billion connected to this activity. Thirty million of those residents were freshwater anglers, spending US$29.9 billion [1]. Nationally, crappie (i.e., White Crappie *Pomoxis annularis* and Black Crappie *P. nigromaculatus*) are among the five most harvested freshwater fish, with 7.8 million anglers targeting crappie annually [1, 2]. In Kansas, White Crappie and Black Crappie are, collectively, the second most preferred and fished taxon [3]. Kansas license-holding recreational anglers have public access to 26 federal reservoirs, 40 state fishing lakes, and 200 community-owned lakes [4]. Given the numerous waterbodies and popularity of crappie fisheries, management through harvest regulations is necessary.

Currently, fishery managers are using harvest regulations (e.g., minimum length limits [MLL] and creel limits) to manage crappie populations [5, 6]. Traditionally, satisfactorily growing populations are managed with MLL, while irregular growth is best managed with daily creel limits (e.g., 50 crappie per day in Kansas; [6, 7]). Today, MLL of 203 mm (8 in), 229 mm (9 in), and 254 mm (10 in) are commonly utilized in crappie management [6, 8]. However, natural mortality rates influence harvest regulation effectiveness [6, 7, 9]. Generally, harvest restrictions (e.g., MLL or creel limits) are less effective when natural mortality is high [10, 11]. Exploitation (i.e., percent of fish harvested) is often compensatory rather than additive under high natural mortality rates (i.e., angler impact is minimal; [10]). However, determining whether harvest rates are additive or compensatory requires quantifying or estimating exploitation rates. Ultimately, managing crappie populations under any harvest scenario (e.g., implementing MLL or creel limits) requires understanding natural mortality rates and exploitation rates.

Reward tag studies are often used to assess exploitation rates. If investment is possible, these studies can quantify and estimate angler catch and harvest rates (i.e., total number of fish caught versus harvested; [5]). Additionally, population dynamics (i.e., recruitment, growth, and mortality) can be used to construct harvest models and evaluate population level responses to various harvest scenarios [11]. Age-based approaches are commonly utilized [11]. Specifically, Yield Per Recruit (YPR) models incorporate population dynamics, natural mortality estimates, and exploitation to evaluate various MML [8, 12].

In general, current Kansas statewide crappie regulations are comprised of no MLL and a creel limit of 50 crappie per day Table 1 [15]. However, anglers desire a creel limit of 20 crappie per day, with or without a 254 mm (i.e., 10 in) MLL [3]. Given the high popularity of crappie fishing (e.g., second most preferred fish in Kansas), liberal regulations (e.g., higher than surrounding states (Table 1)), and advancing technology (e.g., live imaging sonar), harvest rates and their influence on crappie populations should be investigated. The Kansas Department of Wildlife and Parks (KDWP) regularly conducts standardized trap-net (i.e., modified fyke net) sampling to monitor size structure and relative abundances over time but has not yet evaluated exploitation. As such, the objective of this study was to determine exploitation rates and evaluate current regulations for crappie in Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake.

2. Study Reservoirs

Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake are in southeastern Kansas (Figure 1). The first two are flood control reservoirs operated by the U.S. Army Corps of Engineers (USACE), whereas Parsons City Lake is a city water supply controlled by the City of Parsons.

Yearly standardized sampling is conducted on Elk City Reservoir and Big Hill Reservoir, while Parsons City Lake is on a triennial schedule. Elk City Reservoir and Parsons City Lake both have one main boat ramp, while Big Hill Reservoir has multiple boat access points. Study reservoirs range from 397 to 1,797 hectares (980 to 4,440 acres; Table 2). Land use percentages vary greatly between the three watersheds resulting in systems with different water quality, water level fluctuation, and species composition (Table 3).

Population dynamics (e.g., age and growth, mortality, and recruitment) for the study reservoirs were provided by Miazga [23]; Table 4. Age and growth parameters include length infinity (367.54, 319.8, and 375.57), Brody Growth Coefficient (0.63, 0.56, and 0.372), and t_0 (−0.41, −0.63, and −0.938) for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively. Length infinity is the theoretical length a fish could reach if it grew indefinitely, also known as the asymptotic length. The Brody Growth Coefficient expresses the rate at which the asymptotic length, or length infinity, is reached. T_0 is the hypothetical age a fish would be when at length zero. These are negative because fish are larger than 0 mm when emerging from the egg. Total annual mortality was 0.907, 0.76, and 0.637 for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively. The recruitment coefficient of determination for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake was 0.3361, 0.81, and 0.8209, respectively.

Table 1: Statewide crappie creel limit and minimum length limits (MLL) of Kansas and the surrounding states.

State	Creel limit	MLL
Kansas	50	None
Oklahoma	37	None
Missouri	30	None
Arkansas	30	None
Colorado	20	None
Nebraska	15	None

Special regulations for specific water bodies are not mentioned in this table [13–18].

All three reservoirs have established predatory fish populations. Elk City Reservoir was stocked with Blue Catfish *Ictalurus furcatus* from 2014 to 2016 [24]. Walleye *Sander vitreus* were stocked in Big Hill Reservoir in 2019 [22]. Parsons received Saugeye *S. vitreus x S. canadense* stockings in 2014 and from 2016 to 2018 [21].

3. Methods

3.1. Standard Collection and Reward Tag Study. We conducted a crappie reward tag study on Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake lasting 20 months (i.e., October 2020-May 2021). All tagged crappie were collected through Kansas Department of Wildlife and Parks (KDWP) standard fall trap-net sampling efforts, with short-duration gill nets, hoop nets, and electrofishing supplemented when trap nets were ineffective (i.e., when crappie moved deeper than trap nets can sample). Total tagging efforts included 250 trap net-nights, 6 short-duration (4 hours) gill nets, 4 hoop nets (1 net-night), and 630 seconds of electrofishing. Trap nets consisted of a 15–30 m (i.e., 50–100 ft) lead attached to two 1.2 × 1.5 m (4 × 5 ft) rectangular frames followed by four 76 cm (2.5 ft) diameter hoops, all 61 cm (2 ft) apart with 1.3 cm (0.5 in) mesh. Nets were set perpendicular to the shore with the frame sitting in 1–4.5 m (3–15 ft) of water, avoiding anoxic hypolimnetic water [25].

One thousand crappie per reservoir, three thousand total, were measured to total length (mm), weighed (g), and tagged with color-coded, unique Floy FD-94 T-bar anchor tags. Tags were implanted into the musculature under the spinous dorsal fin, locking into the pterygiophores [26]. Once placed, the T-bar anchor tags were tugged on to ensure the "*T*" had properly locked into the pterygiophores. To prevent tagging mortality, crappie that appeared stressed or swimming near the surface of the holding tank were not tagged but released immediately. All captured crappie greater than 210 mm were tagged [2, 9, 27, 28]. Tags were inscribed with a reward notice and telephone number to report the tagged fish. Anglers were asked to provide the tag identification number, date of catch, location (i.e., up the river, in the lake, or below the dam), fate (released or harvested), and demographic information (zip code) to collect the reward.

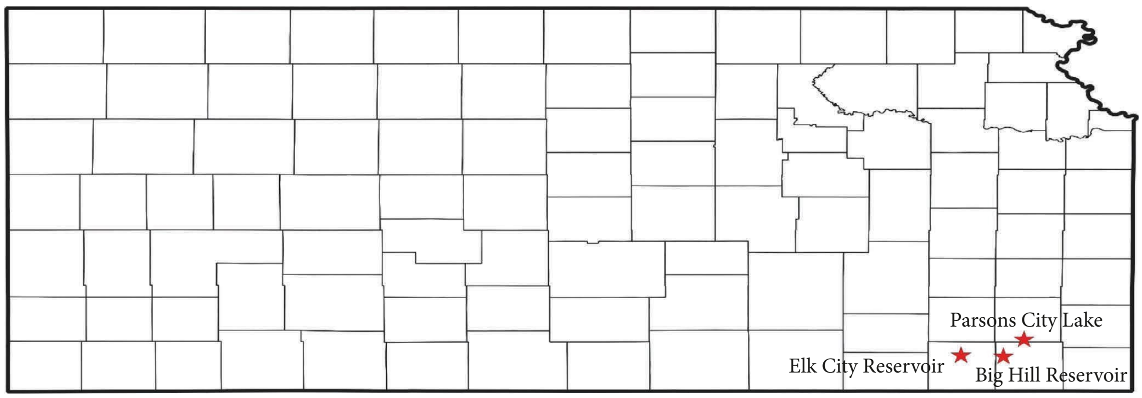

Figure 1: Location of the three study reservoirs in Southeast Kansas.

Table 2: Comparison of reservoir characteristics [19–22].

	Elk city reservoir	Big hill reservoir	Parsons city lake
Year constructed	1966	1981	
Surface area (ha)	1,797	502	397
Max depth (m)	11	13	5.5
Drainage area (km^2)	1650.6	95.3	97.1
Water retention time (d)	370	721	183
Population density (people/sq. km)	2.5	6.7	5.2
Impairments	Eutrophication and siltation	Eutrophication and phosphorus limited	Eutrophication

Table 3: Land use percentages for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake (Verdigris Basin Total Maximum Daily Load: Elk City Lake; Verdigris Basin Total Maximum Daily Load: Big Hill Lake; Neosho River Basin Total Maximum Daily Load: Parsons Lake).

Land use (%)	Elk city reservoir	Big hill reservoir	Parsons city lake
Grassland/Pasture	75	55	49
Cropland	9	22	42.3
Forest	10	11	—
Woody wetland	—	1	4
Developed open space	—	4	—
Developed high-low intensity	—	1	—
Open water	—	5	—
Wetlands	6	—	—
Urban development	—	—	<1

Table 4: Parameters for yield per recruit (YPR) model and population assessment [23].

	Elk city reservoir	Big hill reservoir	Parsons city lake
Length infinity (L_∞)	367.54	319.8	375.57
Brody growth coefficient (K)	0.63	0.56	0.37
Time of length 0 mm (t_0)	−0.41	−0.63	−0.94
Annual mortality rate	0.91	0.76	0.64
Recruitment coefficient of determination	0.34	0.81	0.82

Tag returns included in the analyses were from those captured within 365 days of the 1,000th tag being placed in each reservoir. Anglers were informed of the reward tag study through flyers and KDWP personnel. Flyers were posted at the boat ramps of each water body and state park/lake offices [2]. A small prize was provided to the angler for their first reported tag, valued US$5–10 [29]. Additional tag returns were entries into a drawing for a US$300-valued large hard-sided cooler at each reservoir.

The length and weight data from tagged crappie were used to generate length frequency histograms, calculate proportional size distributions (PSD), and develop length-weight regressions (W_r). PSD were calculated according to Slipke and Maceina [12]. Length categories for White Crappie and Black Crappie include minimum stock (S) length of 13 cm, minimum quality (Q) length of 20 cm, minimum preferred (P) length of 25 cm, minimum memorable (M) length of 30 cm, and minimum trophy (T)

length of 38 cm [30]. White Crappie parameters (e.g., a and b) were used for length-weight regressions e.g., W_r; [12, 30].

3.2. Tag Retention and Mortality. We applied rotenone through the ice to a 0.3-hectare (0.75 acre) pond, clearing it before conducting a tag retention and mortality study [31]. Once the ice melted, 60 fish were captured and transported to the pond. Thirty fish were fin-clipped and the other 30 were tagged [32]. Tagging mortality was estimated as the proportion of dead tagged fish divided by the total number of tagged fish. After one year, fish were collected to assess tag retention. Tag retention was estimated as the proportion of recaptured tagged fish divided by the total number of fish recaptured.

3.3. Surveys and Cameras. We used KDWP standard creel surveys on Elk City Reservoir (2012–2014) and Big Hill Reservoir (2008, 2010-2011, and 2018-2019) to compare angler usage and harvest across all three reservoirs Table 5; [22, 33]. Due to COVID-19 restrictions, a standard roving creel survey on Parsons City Lake for 2021-2022 was not possible. A combination of postcard surveys and motion-sensed cameras were substituted [34, 35]. We placed post-cards on angler windshields and posted a mailbox with a sign at the boat ramp on Parsons City Lake to collect completed surveys. To encourage participation, postcard surveys were entries into the drawing for a cooler, just like crappie reward tags. The reporting rate for the exploitation estimate was determined by Parsons City Lake postcard surveys because it is representative of southeast Kansas fisheries and anglers [32]. The reporting rate was estimated as the number of surveys returned divided by the number of surveys dispersed, then multiplied by 100.

Postcards asked anglers for contact information, zip code, party size, time spent fishing, number and species of fish caught, number and species of fish kept, and if a tagged crappie was caught [36]. The zip code recorded during angler tag reports allowed us to analyze what proportion of anglers were locals (i.e., resided within 30 miles of the reservoir), non-local residents (i.e., Kansas residents who resided more than 30 miles from the reservoir), and non-Kansas-residents. Angler effort per hectare (2.5 acres) and per person was estimated from the postcard surveys. Surveyed angler's daily creel was used to create a stringer table to assess what percentage of anglers would be impacted by various creel limit reductions (Table 6). We focused on a reduction from 50 crappies per day to 20 crappies per day because that is the angler desired creel limit [3].

Motion-sensed Moultrie Game Spy cameras were mounted with lock boxes and cables on trees at the main boat ramp and public fishing dock in the campground of Parsons City Lake. Cameras were mounted approximately four meters off the ground to discourage vandalism and theft. The cameras were programmed to capture one image every three seconds when triggered by motion. Images were recorded for 365 days. From these images, we were able to count vessels and anglers and measure trip duration [34]. Vessels were categorized as motorized or nonmotorized (e.g., canoes and kayaks). Fishing boats were designated to be any floating vessel designed specifically for fishing, or obviously containing fishing equipment (e.g., fishing rods, live imaging sonar, trolling motors). Trip duration was determined by recording the time of entry and exit of fishing vessels, with unique identifiers noted to assist in recognition of vessels upon exiting. Only vessels with both entry and exit times were included in the analysis. We analyzed one weekday and one weekend day per week using a random number generator to select dates [35]. We further analyzed angler effort to differentiate between motorized vessels, non-motorized vessels, and shore anglers. Angler effort per hectare (i.e., 2.5 acres) and per person was estimated and compared between the post card surveys and cameras (Table 5).

3.4. Exploitation. We estimated crappie exploitation rates through voluntary angler tag returns while considering reporting rates and tag loss [12, 32]. Reporting rate was estimated through creel surveys, described above. Tag loss was estimated through our tag retention study, also described above. Immigration and emigration were considered minimal for all population parameters addressed in this study. Exploitation is calculated as u [12, 32]:

$$u = \frac{(\text{number of fish harvested/reporting rate})}{(\text{number of tagged fish} * \text{tag retention rate})}. \quad (1)$$

3.5. Yield per Recruit Model. Crappie population information was obtained through a concurrent crappie age and growth study [23]. Growth was modeled by Miazga [23] using a von Bertalanffy equation (37). Conditional natural mortality was estimated using the Hoenig method in fisheries analysis and modeling simulator [12, 38]. The Hoenig estimator utilizes maximum age [23, 38]. All population data were used to develop age-structured Beverton-Holt YPR models in FAMS [12, 39]. Growth (i.e., von Bertalanffy model and weight-length regressions) was used to develop predicted lengths and weights across representative ages classes (i.e., 0 – maximum observed age). All model simulations were based on yield per 1,000 recruits entering the system. We evaluated multiple MLL (i.e., 203 mm, 229 mm, 254 mm, and 279 mm) at various exploitation rates (i.e., 0.05–0.95; [8]). No MLL is currently in place on these reservoirs, but an angler-imposed 254 mm (10 in) minimum is often observed [3]. Not included in the model, but included in the overall analysis, were the parameters total annual mortality rate (A) and recruitment coefficient of determination Table 4; [23].

4. Results

4.1. Standard Collection and Reward Tag Study. Length frequencies of tagged crappie revealed that Elk City Reservoir was bimodal, Big Hill Reservoir was relatively normally distributed, and Parsons City Lake was positively skewed, with a mode of 210 mm (Figure 2). Crappie were

Table 5: Creel survey angler effort and harvest rates for Elk City Reservoir [33], Big Hill Reservoir [22], and Parsons City Lake (postcard survey and values).

	Elk city reservoir	Big hill reservoir	Parsons city lake (survey)	Parsons city lake (camera)
Hours of effort per hectare	—	11.8	4.0	7.7
Hours of effort per angler	—	3.0	4.4	3.1
Crappie harvested per hectare	1.0	22.8	14.9	—

Table 6: Stringer table for Parsons City Lake.

Creel limit	Number filled	Proportion	Cumulative proportion
0	21	18.42	18.42
2	4	3.51	21.93
3	4	3.51	25.44
4	3	2.63	28.07
5	7	6.14	34.21
6	7	6.14	40.35
7	8	7.02	47.37
8	5	4.39	51.75
9	5	4.39	56.14
10	8	7.02	63.16
11	4	3.51	66.67
12	4	3.51	70.18
13	4	3.51	73.68
14	2	1.75	75.44
15	1	0.88	76.32
16	6	5.26	81.58
17	1	0.88	82.46
18	2	1.75	65.79
19	3	2.63	86.84
20	3	2.63	89.47
21	1	0.88	90.35
23	1	0.88	91.23
25	2	1.75	92.98
28	1	0.88	93.86
30	1	0.88	94.74
31	2	1.75	96.49
33	1	0.88	97.37
37	1	0.88	98.25
40	1	0.88	99.12
49	1	0.88	100.00
50	0	0.00	100.00

tagged from 210 mm to 420 mm, 210 mm to 350 mm, and 210 mm to 360 mm at Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively. Each reservoir varied in PSD (Table 7) and W_r (Figure 3). Elk City Reservoir was the only system with trophy-sized crappie (PSD-T; Table 7). The size classes (i.e., 10 mm length classes) harvested the most at Elk City Reservoir were 330–339.9 and 340–349.9 mm (Figure 2). Big Hill Reservoir and Parsons City Lake harvested 250–259.9 and 220–229.9 mm the most, respectively (Figure 2). Spring (March to May) angling effort comprised 34–57% of tags reported (Figure 4).

Collectively, 251 individual anglers, ranging in age from 10 to 87, reported tags. The maximum number of tags reported by a single angler was 33, with 71.2% of anglers reporting only one tag. Local anglers (i.e., residing within 30 miles of the reservoir) comprised 61.2, 34.9, and 54.5% of all anglers for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively (Figure 5). Non-local Kansas residents (i.e., residing more than 30 miles from the reservoirs but within the state of Kansas) comprised 18.6, 37.3, and 39.4% of anglers for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively. Nonresident anglers on Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake reported 20.2, 27.7 and 6.1% of reward tags, respectively.

4.2. Tag Retention and Mortality. Fourteen fish were retrieved from the pond in April 2022 using rod and reel and gill nets. Previously, floy-tagged fish represented eight individuals, and the control group (fin-clipped crappie) comprised six (i.e., $n = 14$). We observed 100% tag retention and no tagging mortality. While recapture rates were low, we have confidence in our estimates due to high retention and survival rates.

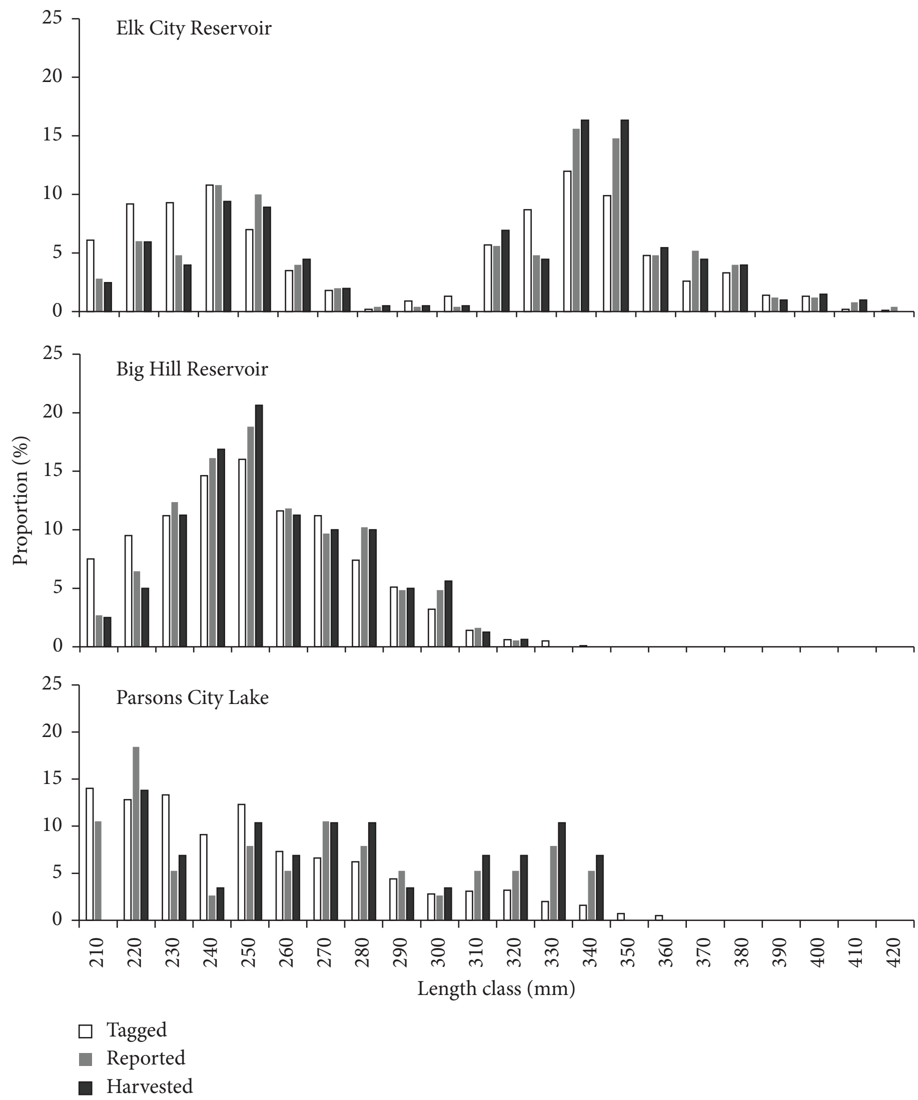

Figure 2: Proportional length frequencies (10 mm length classes) of tagged, reported, and harvested crappie for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake.

Table 7: Calculated proportional size distribution (PSD) of Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake.

PSD	Elk city reservoir	Big hill reservoir	Parsons city lake
Quality	100	100	100
Preferred	64.7	57.1	50.7
Memorable	51.3	5.8	13.9
Trophy	3	0	0

4.3. Surveys and Cameras. On Parsons City Lake, postcard surveys estimated 4.0 ± 0.19SE angler hours per hectare (1.6 ± 0.08SE angler hours per acre) and 4.4 ± 0.15SE hours of effort per person. Individual anglers averaged 4.3 ± 0.18SE hours during weekdays and 4.6 ± 0.25SE hours during weekend days. Parties ranged from 1 to 6 people with an average of 1.9 ± 0.09SE anglers per party. Sixty-three percent of anglers captured 10 fish or less, 76% captured 15 fish or less, and 89.5% of anglers captured 20 fish or less (Table 6). No angler surveyed on Parsons City Lake harvested the legal creel limit of 50 crappie per day. With a creel limit reduction to 20 crappie per day, approximately 10.5% of anglers on Parsons City Lake would be impacted (Table 6). An average of 10.1 ± 0.89SE crappies per person were harvested. There were 14.9 ± 1.49SE crappies harvested per hectare (6.0 ± 0.60SE crappie harvested per acre) on Parsons City Lake.

Motion-sensed cameras estimated 7.7 ± 0.68SE angler hours per hectare (3.1 ± 0.28SE angler hours per acre), and 3.1 ± 0.09SE hours of effort per person on Parsons City Lake. During weekdays, individuals captured at the boat ramp averaged 3.8 ± 0.18SE hours of effort for motorized boats, 5.6 ± 0.35SE hours for nonmotorized vessels, and 0.54 ± 0.14SE hours for shore anglers. Weekend days averaged 4.0 ± 0.12SE hours of effort for motorized boats, 2.1 ± 0.03SE hours for nonmotorized boats, and 1.4 ± 0.24SE hours for shore anglers. Overall average effort captured at the boat ramp for all fishing methods was 3.8 ± 0.10SE hours

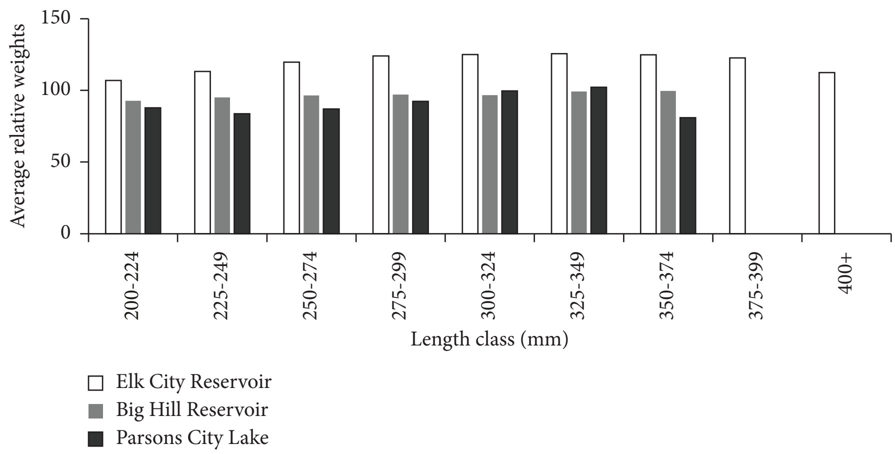

Figure 3: Average relative weights of tagged crappie by length classes of 25 mm, approximately 1 in, for Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake.

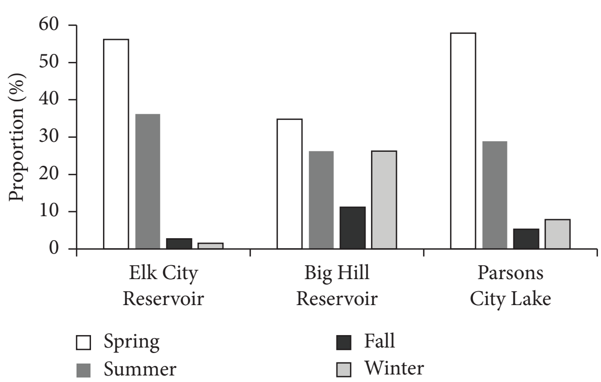

Figure 4: Crappie tags reported by season: Spring (March-May), Summer (June-August), Fall (September-November), and Winter (December-February).

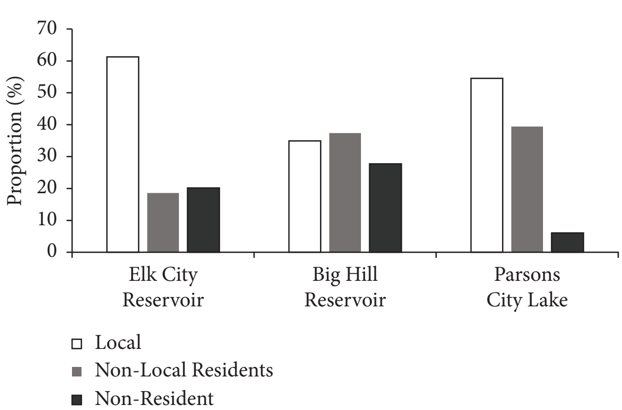

Figure 5: Proportion of local (residing within 30 miles of reservoir), non-local resident (Kansas resident residing more than 30 miles from reservoir), and non-resident anglers who reported tags.

of effort per angler. The camera at the public fishing dock in the campground only captured shore anglers. Weekdays averaged 1.2 ± 0.16SE hours of effort and weekends averaged 1.4 ± 0.13SE hours. Overall average effort for shore angling at the public campground was 1.3 ± 0.10SE hours per angler. Due to some fishing vessels only having an entry or exit captured, camera-based angler effort estimates are likely conservative.

4.4. Exploitation. Exploitation estimates incorporated a 73.5% reporting rate and 100% tag retention. One thousand crappies were tagged per reservoir and 260, 187, and 38 fish were harvested on Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake, respectively. Using these values, exploitation was estimated to be 28.3% on Elk City Reservoir, 21.8% on Big Hill Reservoir, and 3.9% on Parsons City Lake.

4.5. Yield per Recruit Model. Conditional natural mortality was estimated to be 51% for Elk City reservoir, 49% for Big Hill reservoir, and 42% for Parsons City Lake. Crappie populations simulated under a 203, 229, 254, or 279 mm MLL in the YPR model displayed no signs of growth overfishing on Elk City Reservoir, Big Hill Reservoir, or Parsons City Lake under current exploitation rates (Figures 6–8).

5. Discussion

As our data show, crappie population parameters and exploitation rates can vary drastically between systems, even within relatively small geographical areas. The YPR model indicates an exploitation rate of ~75% to begin seeing effects of growth overfishing. However, we found no indication of the occurrence of growth overfishing (e.g., exploitation rates were only 3.9–28.3%), even during a time of increased license sales and angler effort as a result of COVID-19 (D. Breth, Kansas Department of Wildlife and Parks, personal communication). This suggests from a biological perspective that despite the popularity of crappie angling, the current statewide regulations (e.g., 50 crappie per day with no MLL) are likely appropriate, and no changes are necessary.

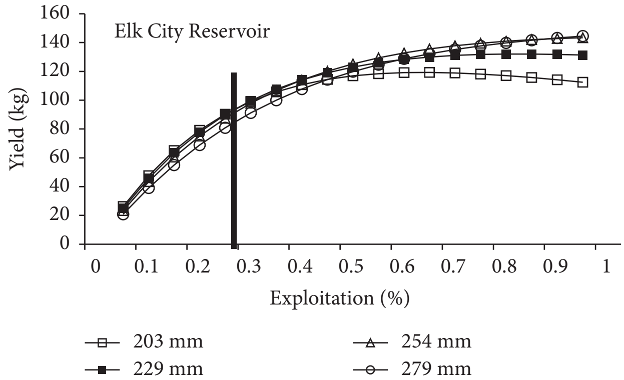

Figure 6: Yield per recruit model for Elk City Reservoir crappie population with various minimum length limits. The vertical line represents the estimated exploitation rate.

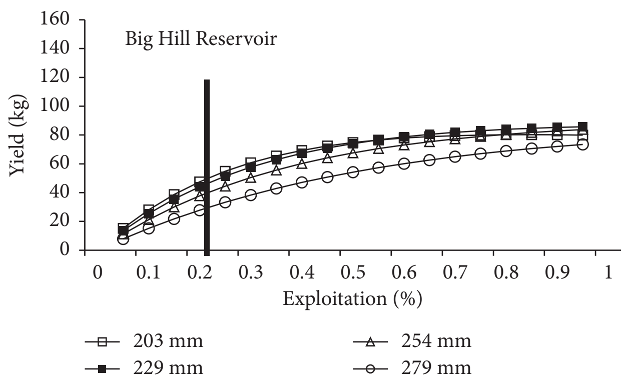

Figure 7: Yield per recruit model for Big Hill Reservoir crappie population with various minimum length limits. The vertical line represents the estimated exploitation rate.

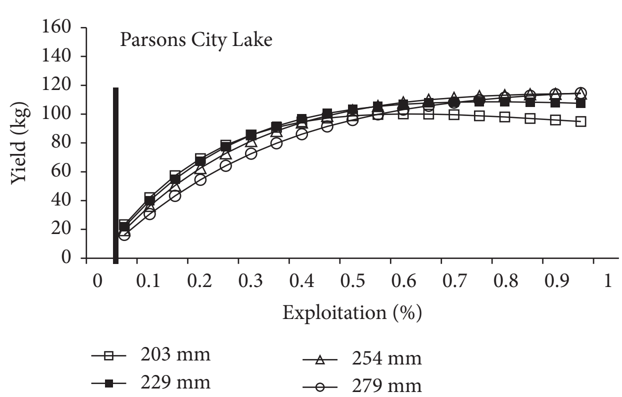

Figure 8: Yield per recruit model for Parsons City Lake crappie population with various minimum length limits. The vertical line represents the estimated exploitation rate.

Elk City Reservoir is a fast-growing crappie fishery and currently the only reservoir with the potential to be overfished. Although, this is improbable because that would require a MLL of 203 mm (8 in; i.e., harvest begins at 203 mm) with a 75% exploitation rate. Elk City Reservoir anglers are unlikely to keep 203 mm (8 in) crappie when the system regularly produces 355–406 mm (14–16 in) fish. According to Neely [33]; 96% of anglers were Kansas residents, and 89% of these were locals. An average of 0.97 crappies per hectare (2.4 crappie per acre) were harvested. The average crappie harvested was 327.7 mm (12.9 in), with a range of 254-355.6 mm (10–14 in; [33]). From 2012 to 2014, no crappie under 250 mm (10 in) were kept [33]. During the reward tag study, only 21.8% of harvested crappie were under 250 mm (10 in) from Elk City Reservoir. Even at twice the estimated exploitation rate, no matter the MLL, overfishing should not be a concern according to the YPR model. As seen in Figure 2, the 2018 year-class was nearly nonexistent (i.e., bimodal histogram), but the following cohort showed strong recruitment, likely a result of sustained high-water levels during the spring of 2019 [22]. If a regulation change was to be made on one of the study reservoirs, we would recommend Elk City Reservoir because its low RCD (33.6) and high A (0.91) suggests it is the least stable of all three populations [23]. More than one year of consistent poor recruitment has the potential to decrease the quality of fishing.

In flood control reservoirs, like Elk City Reservoir, the extended releases and water level fluctuations have a significant impact on crappie year class strength. There is a negative correlation between number of flood release days and relative year class strength [40]. The timing of the high-water levels seems to be a key factor for improving recruitment. Boxrucker and Irwin [5] found that sustained high water levels during prespawn coincides with strong year classes. Maintaining water levels to optimize crappie recruitment can be a difficult task when dealing with flood control reservoirs, so it would be beneficial for managers to form working relationships with the agencies that control water levels to maintain flood control [5]. The 2018 missing year class of Elk City Reservoir was likely not due to water level fluctuation because there were no flood events, but rather inconsistent temperature and weather patterns [24]. This cyclic nature can make crappie management challenging.

Big Hill Reservoir is an average crappie fishery with satisfactory relative weights across all size classes. On Big Hill Reservoir crappie have remained the most preferred species since at least 2008, accounting for 91.9% of harvest in 2018 and 88.4% of harvest in 2019 [22]. The total number of anglers and total hours spent fishing has been steadily declining from 20.19 to 11.84 angler hours per hectare (49.9 to 29.3 angler hours per acre). Conversely, hours of fishing effort per angler have been increasing from 2.04 to 3.0 hours of fishing per angler (Table 5). During 2018-2019, 40% of angling effort was targeting crappie, and 22.8 crappie per hectare (56.3 crappie per acre) were harvested [22]. In Big Hill reservoir, overharvest is not a concern. Angling pressure is consistent throughout the year (i.e., only 36% of angling pressure occurs during spawn), while the RCD (0.82) and A (0.76) fall between Elk City Reservoir and Parsons City Lake [23]. The YPR model suggests growth overfishing is not possible, based on current population parameters. Anglers did not express concern for overharvest during interactions from the reward tag study, but rather excitement for seeing bigger crappie (i.e., greater than 304.8 mm (12 in)) again.

Parsons City Lake is an over-populated stunted fishery, with the highest RCD (0.82) and lowest A (0.64) [23] and exploitation (3.9%) of all three study reservoirs. Nearly 30% of crappie reported were less than 230 mm (9 inches). Reducing the creel limit or implementing a MLL would likely amplify the over-production currently occurring. A common misconception among anglers is that no longer catching multiple crappie over 355.6 mm (14 in), but many smaller crappie (i.e., less than 254 mm (10 in)) instead, is due to growth overfishing. As a result of this, anglers are less likely to keep the fish that the system would benefit from being harvested. Because mechanical or chemical removal is only short-term and not favored by the public, we recommend the biologist implement a top-down trophic approach. Saugeye have been stocked since 2014, so increasing the stocking rate to increase predator presence will likely thin out the smaller crappie and improve growth rates with time. In conclusion, all three crappie populations have different size structures and exploitation rates but remain sustainable under current regulations.

In regard to regulations, the biological aspects of fisheries science are important, but ultimately sport fish biologists serve the public and local constituents. Fishing regulations (e.g., creel limits and MLL) are based on biological (e.g., exploitation, growth, recruitment, and mortality), as well as sociological factors (e.g., angler desires; [41]). Kansas anglers want the statewide regulation (e.g., 50 crappie per day with no MLL) to be reduced to a creel limit of 20 crappie per day, with or without a 254 mm MLL (10 in; [3]), because the high creel limit leads to public perception of overharvest. Generally, crappie populations with irregular growth are best managed with daily creel limits, while satisfactorily growing populations can be managed with MLL [7]. In our data, 90.35% of anglers harvested 20 crappies or less. Our research shows a regulation change is not necessary because crappie populations are not at risk of growth overfishing under current conditions. According to Colvin [7]; for a MLL to be recommended, a population's growth is considered satisfactory when crappie reach 228.6 mm (9 in) by age three. Allen and Miranda [42] found if conditional natural mortality exceeds 30%, regardless of growth, a reduction in exploitation does not significantly impact yield. All three study systems have crappie reaching 228.6 mm by age two [23], but a MLL is not recommended because their high conditional natural mortality rates (i.e., 51, 49, and 42%, respectively) make angler impact minimal [43, 44].

Miranda and Dorr [2] found that crappie ranging from 260 to 320 mm may be prone to size-selective exploitation due to being more vulnerable to fishing bait, but our findings did not support this. The modes for catch and harvest fell just outside of their range. Reward tags were reported on crappie from 210 to 420 mm, with reported and harvested modes of 330 and 340 mm on Elk City Reservoir, 250 mm on Big Hill Reservoir, and 220 mm on Parsons City Lake, respectively. According to Steffen et al. [3]; Kansas anglers are self-imposing a 254 mm (10 in) MLL, which means the majority of crappie harvested are greater than 254 mm (10 in). This holds true for Elk City Reservoir and Big Hill Reservoir, but not for Parsons City Lake. This is likely due to the stunted size structure found at Parsons City Lake. Therefore, the introduction of a 254 mm (10 in) MLL would have minimal impact on harvest because it is essentially already in place where it could be utilized. Sportfish biologists must take an adaptive approach to set and assess regulations, while considering the potential impact of new practices and technologies on their fish populations.

Guided fishing is becoming more popular and is not currently regulated by KDWP. Future research should investigate if fish guiding is or has the potential to substantially increase harvest and negatively impact crappie and other sportfish populations. In addition, it is understood that most fishing guides are utilizing live imaging sonar technology to streamline fishing trips and increase customer satisfaction. Further, live imaging sonar has the perception of increasing the amount and size of fish harvested. There is some evidence live imaging sonar can impact angler catch in certain conditions but does not appear to initiate overexploitation in all crappie populations [45]. With this technology becoming more affordable over time, the number of anglers utilizing it will likely increase. Conversely, a single angler who reported 18% of tags on Big Hill Reservoir consistently caught and harvested crappie without the aid of technology. This success suggests that live imaging sonar is not a necessary tool to be a successful angler. Use of live imaging sonar should be included in future creel surveys or tagging studies to better understand what proportion of anglers are utilizing the technology. Further research is needed to assess the potential impacts live imaging sonar can have on crappie populations, as well as other sportfish species. Kansas reservoirs are generally productive systems [19, 20] and support short-lived and fast-growing crappie populations. Our results suggest tracking size structure and catch rates for relatively short-lived, fast-growing fishes can provide insights into population dynamics. Size structures of study reservoirs reflect recruitment and mortality parameters provided by Miazga [23]. We conclude that an umbrella regulation is not the most effective way to manage crappie populations but is often the only feasible option [43]. There is no biological basis (e.g., growth overfishing) to alter the current Kansas regulations (e.g., a creel limit of 50 crappie per day with no MLL). Implementing a statewide MLL is not recommended. With anglers desiring more restrictions [3], a regulation change would have more of a social, rather than biological basis and influence.

6. Conclusion

Crappie management is complex with no obvious method that works for all systems. Managers must take an adaptive approach to set and assess regulations. Although all three crappie populations of Elk City Reservoir, Big Hill Reservoir, and Parsons City Lake are very different, none are currently at risk of growth overfishing. If a regulation change was made to 20 fish per day, the basis would be social, rather than biological, to appease the anglers. It does not appear that this regulation change would negatively impact Elk City Reservoir or Big Hill Reservoir. With Parsons City Lake having a stunted population, harvest is encouraged so reducing the creel limit could potentially restrict the effectiveness of harvest as a management tool. The current regulations (e.g., 50 fish per day with no MLL) are sufficient to sustain quality crappie fishing in Southeast Kansas.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

Missouri State University Institutional Animal Care and Use Committee approved protocol #2020-15 for 09/11/2020-09/10/2023. Missouri State University Institutional Review Board granted an exemption on 05/20/2021 (see copy of emails below).

Disclosure

A thesis has previously been published [46].

Conflicts of Interest

There authors declare that there are no conflicts of interest.

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