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Analyses of the Sauger Fishery with Simulated Effects of a Minimum Size Limit in the Tennessee River of Alabama

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Abstract.—Saugers *Stizostedion canadense* were collected in winter and early spring of 1993–1994 and 1994–1995 to describe population characteristics and exploitation rates in the tailraces of Guntersville, Wheeler, and Wilson dams along the Tennessee River in Alabama. Population modeling simulated the response of the fishery to the effectiveness of a newly imposed 356-mm (total length, TL) minimum size limit. The sauger populations in these three tailraces consisted primarily of fish age 2 and younger that were less than 400 mm long. Total annual mortality between age-1 and age-2 fish was high, based on catch rates of specific year-classes, and ranged from 64% to 83%. Age-1 and age-2 saugers averaged about 270 and 350 mm total length (TL) respectively, and from our observations, sauger anglers routinely harvested fish at age 1. Unadjusted (not corrected for tag nonreporting) exploitation rates over the 2-year period ranged from 16% to 30% at the three tailraces and averaged 24%. However, the two methods used for calculating adjusted exploitation provided nonreporting rates of 15% and 73% for reward tags. Thus, the average adjusted exploitation rate ranged from 28% to 89%. From both age and size-structure data and total and fishing mortality data, sauger exploitation was high. Population modeling indicated that a 356-mm minimum size limit with natural annual mortality rates of 25% and 40% increased yield at exploitation rates ranging from 30% to 80% when compared with no size limit. The magnitude of differences in yields increased at progressively higher levels of exploitation with a size limit. However, we predicted total numerical catch of fish would decrease with the minimum size limit. These analyses indicated that "growth over fishing" had occurred; saugers were harvested at too high a rate before reaching their full growth potential. The new size limit combined with a reduced creel limit from 15 to 10 fish/d for each angler will allow more saugers to realize their full growth potential. Finally, we found that saugers mature at about 300 mm TL, and the size limit protects these fish from harvest.

Populations of sauger *Stizostedion canadense* in the Tennessee River have long been regarded as an important component of the sport fishery in the region. Because of the impoundment of the Tennessee River, saugers migrate to the riverine habitat of dam tailwaters to spawn, where they have traditionally provided an excellent sport fishery in the winter and early spring (Hackney and Holbrook 1978). Although sauger was thought to be a lightly exploited species (≤10% annual rate) in many parts of their range, including the Tennessee River (Carlander 1950; Cobb 1960; Hickman et al. 1990), recent studies have revealed annual exploitation rates of about 50% in the lower Tennessee River (Pegg et al. 1996) which is downstream of where this river flows through Alabama.

Previous investigations revealed that there has been an overall decline in sauger populations in the Tennessee River since the mid-1980s (Scott 1984; Buchanan 1990; Ruane et al. 1990; Yeager and Shiao 1992). Saugers declined to low levels in several main-stem reservoirs of the upper Tennessee River in Tennessee, which prompted the Tennessee Wildlife Resources Agency to initiate a stocking program in 1990. In addition, this agency imposed a minimum length limit of 356 and 381 mm total length (TL) in 1992 in their downstream and upstream jurisdictional portions, respectively (see Figure 1), of the Tennessee River to curtail overexploitation. The Tennessee Valley Authority

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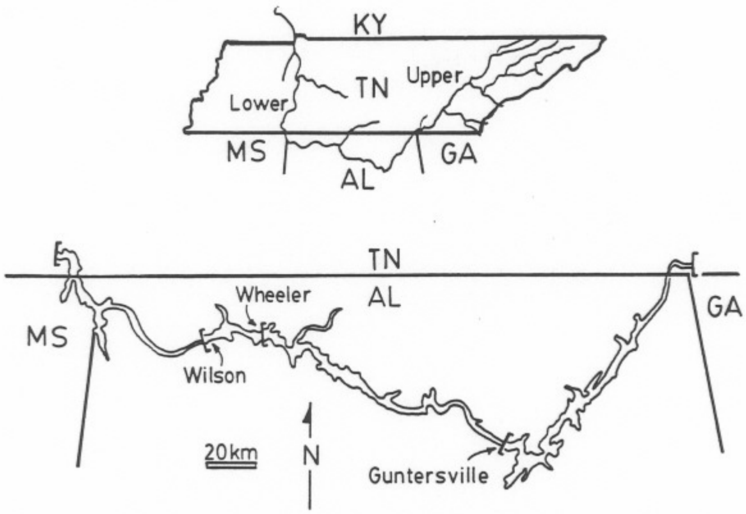

FIGURE 1.—Map of the tailrace sites that were sampled for saugers on the Tennessee River in Alabama.

also initiated special operations at Watts Bar Dam in Tennessee (upstream from Alabama) to provide flow conditions more conducive to sauger reproduction. In the lower Tennessee, sauger stocks have persisted, albeit at historically low abundances, and were dominated by fish age 2 and younger (Buckmeier 1995).

In some reaches of the Tennessee River, saugers migrate through navigation locks (Cobb 1960; Ridley 1980; Hevel 1988; Pegg et al. 1996); thus, the sauger fishery is interstate and a need may exist for common regulations between Tennessee and Alabama. We observed that many small saugers were caught by anglers in Alabama which suggested that exploitation was high or growth rates were low, and these factors prompted the initiation of the project reported in this paper. We describe the status of the sauger population and estimate exploitation at the three tailraces of the Tennessee River in Alabama. We also assess the potential of protecting mature fish from overharvesting by examining length-dependent reproductive condition of fish. Based on this work, on 1 October 1995, the Alabama Department of Conservation and Natural Resources imposed a 356-mm TL size limit and reduced the daily bag from 15 to 10 fish per day. We subsequently conducted population simulations to predict the influence of this minimum size limit on the sport fishing yield and catch.

Methods

Population characteristics.—This project was conducted in the tailraces of Wilson, Wheeler, and Guntersville reservoirs on the Tennessee River in northern Alabama (Figure 1). Saugers were collected in each tailwater two to four times from January to March in 1994 and 1995 with horizontal (1.8 × 45.5-m) experimental monofilament gill nets with five 9.1-m panels of 19, 25, 38, 51, and 64-mm-bar-measure meshes. Two to four nets were fished after sunset for 15 min to 1 h in an attempt to capture approximately 25 to 50 saugers at each tailwater per sample trip.

Total length (mm), weight (g), and sex were recorded for each sauger. Sagittal otoliths were removed and read independently twice in whole-view with a dissecting microscope and reflected light. When disagreements between the two whole-view readings occurred, the otolith was cracked, polished, and viewed with a fiber optic filament to discern annuli (Heidinger and Clodfelter 1987).

Gonads were excised and weighed (g), and a gonad weight of zero was assigned to immature fish. The gonadosomatic index (GSI) was computed as gonad weight/(body weight − gonad weight). Gonads of male fish collected in 1995 were not processed.

Exploitation.—Saugers were captured in December and January 1993–1994 and 1994–1995 with horizontal (1.8 × 36.5-m) experimental monofilament gill nets. Each net consisted of three 12-m panels of 25, 38, and 51-mm-bar-measure meshes. Nets were fished for 15 to 45 min after sunset, which coincided with low angling pressure and highest sauger activity (Cobb 1960). After capture, saugers were placed in a holding tank con-

TABLE 1.—The population dynamic parameters and variables used to simulate sauger populations from the Alabama portion of the Tennessee River.

Variable or parameter	Definition
Recruitment	Long-term average of 100 age-1 fish recruited to the fishery each year
Growth	Coefficients for the von Bertalanffy equation:
	L_{inf} = 550 mm TL, K = −0.401, and t_0 = −0.582;
	Regression equation of weight (WT, g) to total length (TL, mm):
	$WT = 0.00000143TL^{3.316}$
Maximum age	10 years
Natural mortality	Conditional natural mortality rates of 25% and 40% per year after age 1
Exploitation	20–80% per year at 10% intervals
Size structure	Minimum relative stock density (MIN-RSD) based on 356 mm TL minimum size limit:
	MIN-RSD = $N \geq$ 356 mm TL/$N \geq$ 203 mm TL

taining a commercial formulation of quinaldine, salt, and chelating agents. Lengths were recorded and anchor tags (Floy FD68B) were attached to each fish with a Floy Mark II tag gun; fish were released immediately after tagging. To examine bias in the exploitation estimates due to tag loss, 12% of all saugers were double tagged and released each year. An identification number, the word "reward" and an address for anglers to return the tag for their reward was printed on each tag. Data forms and information posters were distributed at local tackle shops and stores to promote tag returns. Anglers who caught tagged saugers were asked on the forms to provide information if the fish was kept or released, but this information was not always provided. Anglers sending in tags received a randomly determined cash reward of US$5–50.

Exploitation rates during both sample years were adjusted by the angler nonreporting rate in order to better estimate fishing mortality. Nonreporting rates were determined by a concurrent creel survey (Maceina et al. 1996) in the Guntersville and Wilson tailwaters and by distributing questionnaires to anglers. Anglers were asked by the creel clerk during the interview if they had caught a tagged sauger. If anglers responded "yes," they were then asked if they had returned the tag to claim their reward. The number of anglers who reported they had caught a tagged sauger but did not return the tag was divided by the number of anglers who reported catching tagged saugers to estimate the nonreporting rate. Data from the creel survey were pooled in 1993–1994 and 1994–1995 to estimate nonreporting rates.

We also estimated nonreporting rates by distributing questionnaires to the first 100 sauger anglers interviewed in March 1995. The questionnaire placed on a card asked anglers if they knew of the tagging program and how they learned of it. The questionnaire stated that the angler would receive a US$5–50 reward for returning the card. To obtain the reward, the questionnaire had to be placed in an envelope, stamped, and mailed to Tennessee Tech University. Thus, the process of an angler sending in the questionnaire was structured to resemble that of the angler sending in a reward tag. The number of questionnaires returned by anglers was subtracted from 100 (the total number distributed) and that number represented a nonreporting rate.

Population modeling simulations.—The software program MOCPOP (version 2.1) developed by Beamesderfer (1991), which follows the computations of the generalized inland fishery simulator (Taylor 1981), was used to model the response of the Tennessee River sauger population in Alabama to the initiation of a 356-mm size limit compared with no size limit. Modeling was conducted for exploitation rates that encompassed the potential range based on our exploitation data at two different natural mortality rates, and results were compared between simulations with and without the size limit (Table 1). We did not attempt to address the decline in the daily creel from 15 to 10 because the effects were uncertain, but exploitation would probably be reduced. To simulate the population, recruitment to age 1 was arbitrarily set at a constant 100 fish/year. We believed that the conditional natural mortality rate for saugers age 1 and older was about 25% because saugers up to 10 years old have been collected (Brown 1990; Churchill 1992). However, minimum size limits can reduce yield if natural mortality is high. Thus, we also conducted simulations assuming conditional natural mortality was 40% per year. In this study, we did not collect any saugers older than age 4, and growth data for older fish were augmented by information collected by Churchill (1992) and Buckmeier (1995) on sauger populations in the Tennessee portion of the Tennessee River. Additional life history information is presented in Table 1. A minimum relative stock density (MIN-RSD) size-structure index was computed as number of fish 356 mm TL or larger divided by the total number of fish, and was derived for each modeling scenario. Based on our personal experience of catching and tagging saugers, we assumed angling mortality of released saugers was nil. Finally, sauger emigration and immigration from specific tailwaters has occurred (Pegg et al. 1996; our unpublished observations), but the impact was considered negligible in this analysis.

Data analysis.—The relative abundance of saugers at each tailwater was described by calculating mean catch per effort (CPE; N/h) for fish collected with gill nets. Temporal differences in CPE for each age-class at each tailwater were tested with a t-test. Overall annual survival was estimated by the percent decline in CPE between ages 1 and 2 and ages 2 and 3. Differences in mean length at age among sites and between sexes were tested with t-tests or analysis of variance with Tukey's multiple-range test to separate mean values. Length-frequency and year-class-frequency histograms were constructed to examine the size and age structure of the sauger populations in each tailwater.

The rate at which saugers were caught by anglers each year was calculated by dividing the number of tags returned by anglers by the total number of saugers tagged. When anglers did not report keeping or releasing a sauger, their returns were proportionally divided into kept or released categories based on the returns that did provide that information (Pegg et al. 1996). Exploitation (harvest) rate was calculated for each tailwater by dividing the number of tagged saugers kept by the total number of saugers tagged at each tailwater. Exploitation rates were also adjusted for nonreporting by our two different methods. A Kolmogorov–Smirnov test was performed to detect differences in length-frequency distributions between tagged saugers and saugers caught by anglers.

Results

Population Characteristics

Of the 367 saugers that were collected from 1 December 1993 through 31 March 1994 (i.e., 1994) in the Guntersville, Wheeler, and Wilson dam tailwaters, only the 1990–1993 year-classes were observed (Figure 2). The 1993 and 1992 year-classes represented 57% and 37%, respectively, of the total sample. From 1 December 1994 through 31 March 1995 (i.e., 1995), 233 saugers were collected in the same three tailwaters, and only fish from the 1991–1994 year-classes were represented (Figure 2). For both years combined, age-1 and age-2 fish made up 95% of all saugers collected. Strength of the 1994 year-class was poor and represented only 27% of all fish collected in 1995 year, whereas, the 1993 year-class was most common (69%). Length-frequency distributions pooled for both years among the three tailraces showed that most saugers caught in gill nets were skewed towards smaller fish (<400 mm TL), which were primarily age-1 and age-2 fish (Figure 3).

Based on age-specific catch rates with gill nets, annual survival rates of saugers between ages 1 and 2 were low: 17%, 27%, and 36% at the Wilson, Wheeler, and Guntersville tailraces, respectively (data from Table 2). Survival between ages 2 and 3 was less than 4% at all three tailraces. These estimates assumed that the effects of immigration and emigration were nil.

Length at age 1 for saugers collected from the Guntersville tailrace was significantly lower ($P <$ 0.05) than that observed at the Wheeler and Wilson tailraces (Table 3). However, by age 2 and age 3, no detectable differences in length were apparent. Although the 1993 sauger year-class was more abundant than the 1994 year-class, the 1993 fish were larger at age 1 in both the Guntersville and Wheeler tailraces. However, by age 2, the abundant 1993 year-class was shorter in length than age-2 fish from the 1992 year-class at all three tailraces. Length at age 3 was generally not much longer than at age 2 among study locations. This may have been due to low sample size or high exploitation rates of larger saugers, which would select for faster-growing fish.

Among all three tailraces, the average total lengths for age-1 males (269 mm) and females (268 mm) were similar. However, female fish at age 2 averaged 363 mm, which was larger ($P <$ 0.05) than an average of 345 mm observed for males. The same trends were evident for age-3 saugers, as females and males averaged 392 and 378 mm, respectively, but low sample size (N = 29) and high variance hindered the detection of statistical differences (P = 0.34).

Peak gonadosomatic index values were positively correlated to length for both male and female fish (r = 0.75–0.77, $P <$ 0.01; Figure 4). Peak GSI values were observed for female fish collected in February and March, while peak male GSIs were

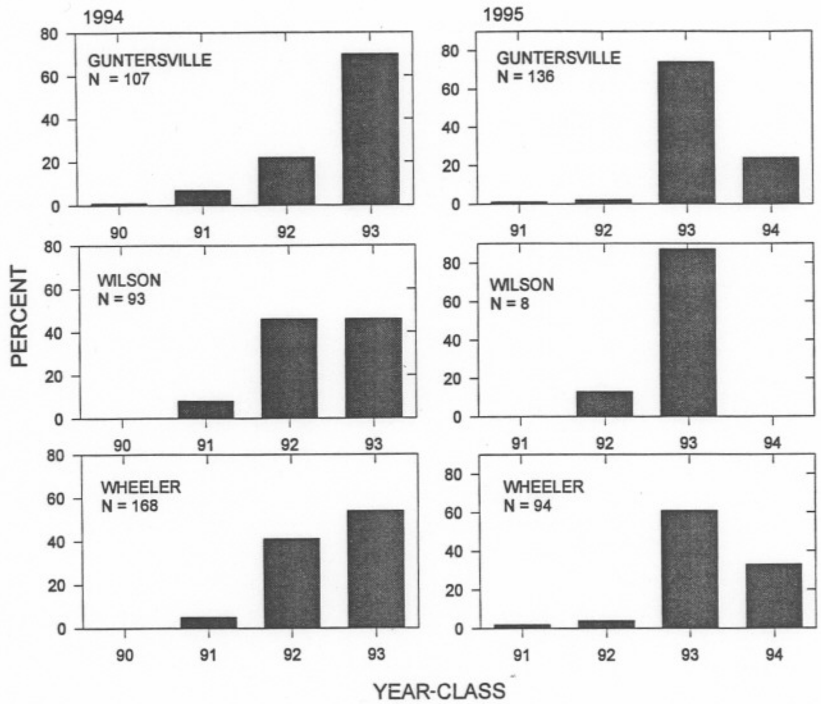

FIGURE 2.—Year-class frequency distributions of saugers sampled below Guntersville, Wilson, and Wheeler dams, 1994 and 1995.

observed from January to March. For female fish, GSIs greater than 0.10 were evident for most fish greater than 300 mm, and we assumed that females with GSIs greater than 0.10 probably would contribute to egg deposition. Male fish appeared sexually mature at a slightly smaller size than females (Figure 4). Higher GSIs were observed for males greater than 356 mm, but many males were mature below this length, as flowing milt was observed during our collections.

Exploitation

Size of saugers caught by anglers was not significantly different ($P > 0.10$) from the sizes of fish that were tagged (Figure 5). No tag loss was reported by 28 anglers that caught fish that were double tagged. Thus, exploitation rates were not adjusted for size-selective angler catch rates or tag loss. Ninety percent of all tag returns occurred by 1 May of each sample year.

For the 2 years, unadjusted exploitation rates ranged from 16% at the Wilson tailrace in 1994 to 30% at the Guntersville tailrace in 1995. Of the 494 saugers tagged at the three tailraces in 1994, 22% of all tags were returned, whereas, anglers returned tags from 27% of the 343 fish that were tagged in 1995. From creel survey interviews, we estimated that 15% of the anglers did not return tags. However, only 27% of the anglers returned the cards from the questionnaire survey for a reward, which conferred a nonreporting rate of 73%. The overall unadjusted exploitation rate was 24% for all data pooled but was adjusted to 28%, assuming a 15% nonreporting rate, and rose to 89% for the 73% nonreporting rate. Based on total mortality rates between age 1 and age 2 that ranged from 64% to 83%, exploitation likely ranged from 40% to 60%.

Population Modeling Simulations

At a natural annual mortality rate of 25%, we predicted yield of saugers would be greater with the 356-mm size limit compared with no size limit over a wide range of exploitation rates (Figure 6). As exploitation increased, the disparity between yields increased with the minimum size limit from 11% at a low range of exploitation to 81% at the highest exploitation rate. Maximum yields were predicted at exploitation rates of 30 and 50%, respectively, for populations without and with the size limit. However, over the range of exploitation, number of saugers caught was about 25–34% low-

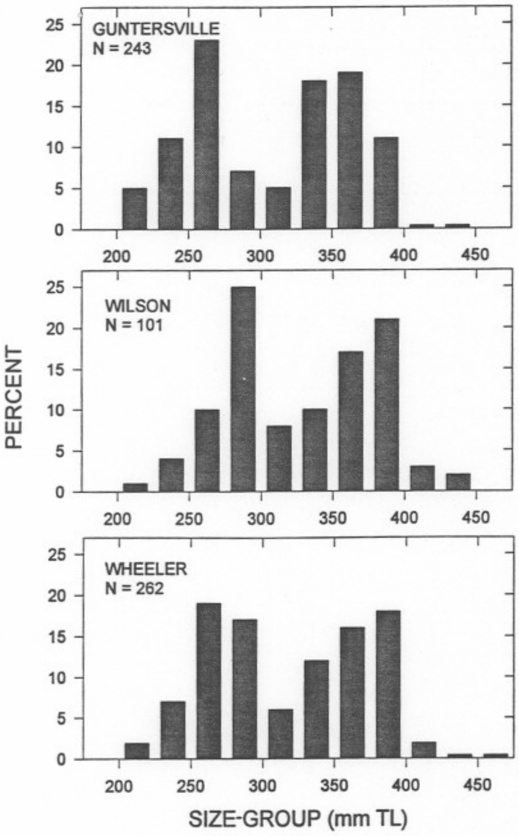

FIGURE 3.—Length-frequency distributions of saugers sampled below Guntersville, Wilson, and Wheeler dams. Data were pooled for 1994 and 1995.

er with the minimum size. The proportion of fish greater than 356 mm (MIN-RSD) declined more sharply with no minimum size as exploitation increased. Also, size limit differences for this index increased at progressively higher levels of harvest.

At a higher natural mortality rate of 40%, predicted yields declined as expected, but at exploitation rates from 30 to 80%, yields were higher in populations modeled with the 356-mm size limit (Figure 6). However, the disparities between yields with and without the minimum size limit were not as great as those computed when natural mortality was 25%. At an exploitation rate of 20%, yield with and without the size limit would be the same, but the difference in yields increased from 7% to 50% as exploitation increased. Maximum yields were predicted at exploitation rates of 40 and 80%, without and with the size limit, respectively. About 40% less sauger would be caught with the size limit if natural mortality was 40% per year. Similar to previous results, the MIN-RSD dropped dramatically with higher exploitation with no minimum size and differences increased with higher harvest.

Discussion

Examination of age and size-structure data and age-specific catch rates indicated that sauger mortality rates were high because of high exploitation. Compared with our work, a similar age-frequency distribution was observed by Churchill (1992) and Buckmeier (1995), who reported that age-1 and age-2 saugers were abundant, while age-3 and older fish were rare in the lower Tennessee River and in the Cumberland River. Populations in the upper Tennessee River consist of larger, older fish (Hickman et al. 1990; Buckmeier 1995) because of low angling pressure and a 381-mm size limit. Although saugers can reach lengths up to 550 mm in the Tennessee River, we sampled few fish greater than 400 mm. In the upper Tennessee River, Churchill (1992) collected a substantial number of saugers greater than 400 mm, while at the three Tennessee River tailraces in Alabama, the percentage of sauger larger than 400 mm never exceeded 5%. The lack of a length limit and a liberal bag limit for sauger in Alabama led to overfishing, which reduced the number of age-classes in the fishery. Although uncertain due to variable nonreporting rates, annual exploitation was probably 40–60%, similar to the 50% rate reported from the lower Tennessee River (Pegg et al. 1996). Growth of saugers to age 2 was similar in the Alabama and Tennessee portions of the Tennessee River (Churchill 1992; Buckmeier 1995) and was not a

TABLE 2.—Mean catch per hour (CPE) of age-1, age-2, age-3, and all saugers from the Guntersville, Wheeler, and Wilson tailraces. Values for 1995 followed by an asterisk are significantly different from 1994 values for that age-class ($P < 0.05$).

	Age 1		Age 2		Age 3		All	
Tailrace	1994	1995	1994	1995	1994	1995	1994	1995
Guntersville	13.94	1.55*	7.42	4.97	2.02	0.12*	23.7	6.7*
Wheeler	13.21	1.95*	6.08	3.55	0.62	0.21	19.1	5.9*
Wilson	3.06	0.00*	3.30	0.53*	0.42	0.05*	6.8	0.6*

TABLE 3.—Means and ranges of total lengths-at-age and sample sizes for age 1–3 saugers collected in 1994 and 1995 from the Guntersville, Wheeler, and Wilson tailraces. Along a row, lengths followed by the same letter are not significantly ($P > 0.05$) different.

	Guntersville		Wheeler		Wilson	
Year and age	N	Mean (range) length, mm	N	Mean (range) length, mm	N	Mean (range) length, mm
1994						
Age 1	75	260 (212–302) y	89	276 (224–361) z	43	280 (220–312) z
Age 2	24	365 (266–397) z	69	370 (306–415) z	43	365 (292–403) z
Age 3	7	375 (338–405) z	8	378 (280–425) z	7	407 (374–445) z
1995						
Age 1	33	239 (205–283) y	31	251 (195–330) z		
Age 2	100	348 (255–399) z	56	346 (278–430) z	7	304 (298–377) z
Age 3	2	420 (397–443) z	4	382 (353–392) z	1	418 z

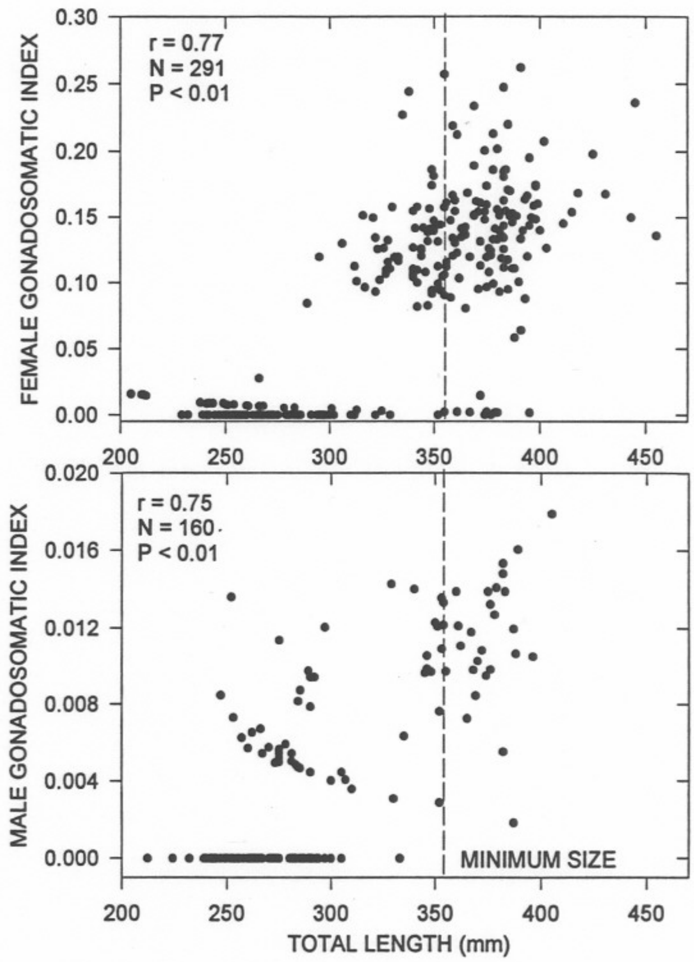

FIGURE 4.—Gonadosomatic index values for female (upper) and male (lower) saugers versus total length for fish collected in February and March 1994 and 1995.

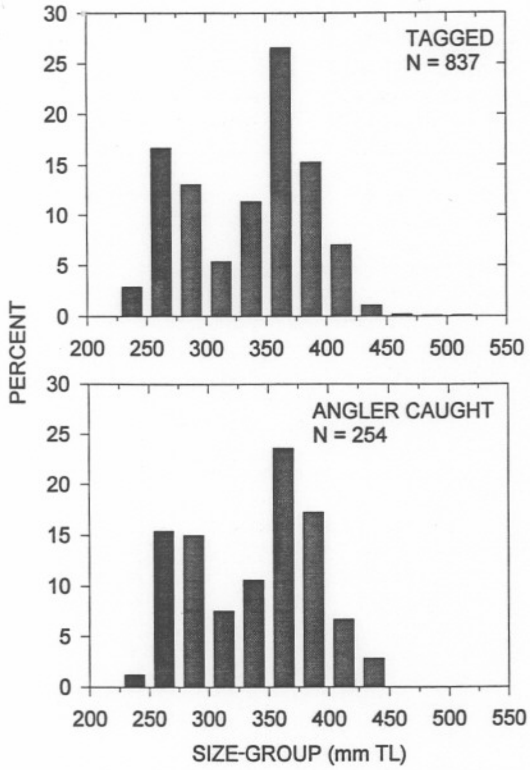

FIGURE 5.—Length-frequency distributions of saugers tagged below Guntersville, Wheeler, and Wilson dams and subsequently caught by anglers. Caught fish included both harvested and released fish.

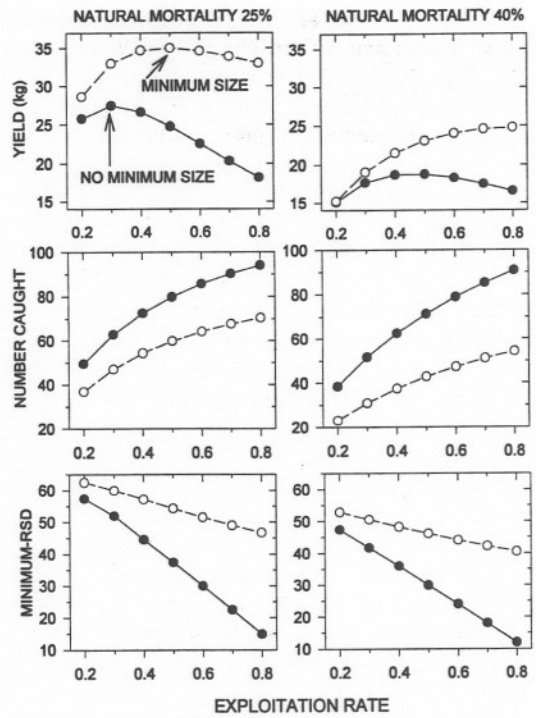

FIGURE 6.—Simulated yield, number caught, and the minimum relative stock density (RSD) for saugers modeled with conditional natural mortality rates of 25% and 40% and either a 356-mm TL minimum size or no minimum size.

factor in assessing and managing this interstate fishery.

Our modeling suggested that the newly imposed 356-mm size limit will result in increased yields at low and high exploitation rates. Before the size limit, model simulations suggested that "growth over fishing" occurred; up to 356 mm, growth exceeded the influence of natural mortality and a large proportion of the population was harvested before the full growth potential of this fishery was realized. Based on our observations of the fishery, sauger anglers catch and harvest saugers because they like to consume this fish. Thus, higher yields in weight should allow for greater potential consumption. However, we did not address the angler attitudes towards the trade-off between catching fewer, but larger, fish with the size limit compared with catching more, but smaller, fish without a size limit. Our modeling indicated that this trade-off occurs with the size limit (see Figure 6). Our concurrent creel survey showed that 81% of all sauger anglers favored a size limit. Finally, most male and female saugers were mature at 300–356 mm, and protection of these fish from harvest increases the probability that these fish will spawn at least once before becoming vulnerable to harvest. Slight differences in sauger growth rates were observed among the three tailraces, but these differences were not great enough to affect the results of a minimum size limit.

The nonreporting rate of tagged fish estimated by two different methods varied greatly (15 and 73%), and this discrepancy is enigmatic. High nonreporting rates for tagged crappie *Pomoxis* spp. when a similar questionnaire was used were observed in Mississippi (L. E. Miranda, Mississippi Cooperative Fish and Wildlife Unit, personal communication). The comparatively low 15% nonreporting rate calculated from creel survey responses could be a low estimate because anglers were interviewed in person by the creel clerk, which could have prompted anglers to falsely report their tag returns to avoid personal embarrassment. Another bias could have been that the tag was never noticed by the angler. The questionnaire survey revealed a nonreporting rate of 73%, which was similar to the 61% nonreporting rate observed by Weaver and England (1986) in a reward study of crappies. They observed no difference in the effect of $5–20 rewards on the number of tags returned and found that some of the tags were being kept as mementos. Sauger exploitation rates in our study would have approached 100% in two of three tailraces if the nonreporting rate was 73%. This, in conjunction with age-structure data reflective of low survival, indicated that nonreporting exceeded the 15% nonreporting rate observed in the creel survey.

We found that saugers were highly exploited in the Tennessee River of northern Alabama. We predict that the 356-mm size limit and the reduction in the bag limit will reduce growth overfishing and will allow higher numbers of saugers to realize greater growth potential. The 356-mm size limit protects age-1 saugers, and most fish now recruit to the fishery at age 2. Continued monitoring of the sauger population and enforcement of new size and creel limits are crucial to maximizing sauger yields in Alabama.

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