*North American Journal of Fisheries Management* 29:1183–1194, 2009
© Copyright by the American Fisheries Society 2009
DOI: 10.1577/M08-165.1

[Article]

# Fishery and Population Characteristics of Blue Catfish and Channel Catfish and Potential Impacts of Minimum Length Limits on the Fishery in Lake Wilson, Alabama

MICHAEL P. HOLLEY,[1] MATTHEW D. MARSHALL, AND MICHAEL J. MACEINA*

*Department of Fisheries, Auburn University, Alabama 36849, USA*

*Abstract*.—A popular recreational and commercial fishery for blue catfish *Ictalurus furcatus* and channel catfish *I. punctatus* exists at Lake Wilson, Alabama (Tennessee River). We examined the fishery, exploitation, angler size selectivity, and population demographics of these two species at Lake Wilson. In addition, we explored management strategies to enhance the fishery of trophy blue catfish. Currently, Alabama has no bag or minimum-length-limit regulations for catfish, except for the harvest of fish over 864 mm total length (TL). From April to October 2006, catfish harvest was high (8 kg/ha), and angler catch and harvest rates averaged 1.5 and 1.2 fish/h, respectively. The majority of fish harvested were between 300 and 600 mm TL, and anglers harvested larger fish in proportion to the sample population. Catfish were collected by low-frequency (15-MHz) DC electrofishing; they were aged with otoliths from 180 and 122 blue catfish and channel catfish, respectively, subsamples of 2,905 blue catfish and 699 channel catfish. Fish over 300 mm TL were tagged with Carlin dangler tags to estimate exploitation. Accounting for tag loss and variations in angler nonreporting rates (20–70%), we estimated that annual exploitation ranged from 8% to 22% for blue catfish and from 4% to 11% for channel catfish. Of the tagged fish harvested, 33% came from seven commercial fishers. Blue catfish and channel catfish displayed different life histories, which pointed to contrasting management strategies for increasing yield. Blue catfish were longer-lived (maximum age = 25 years), expressed slower growth (von Bertalanffy $K = 0.081$), and had lower natural mortality ($M = 0.16$) than channel catfish (maximum age = 12 years; von Bertalanffy $K = 0.148$; $M = 0.29$). Increasing minimum length limits from 300 to 660 mm for blue catfish would increase yield up to 50%, prevent growth overfishing, and increase the abundance of memorable-length (890-mm) blue catfish over our range of estimated exploitation. However, for channel catfish, minimum length limits greater than 300 mm would result in a lower yield. High length limits could drastically reduce the angler harvest of catfish but increase the abundance of memorable-length and larger blue catfish. Even so, the anglers surveyed preferred to harvest smaller fish. Fishing mortality was probably equal to natural mortality for blue catfish, but for channel catfish fishing mortality was less than natural mortality. On the basis of these observations, angler catches, the lack of angler species recognition, and the abundance of small catfish, we currently do not recommend bag or minimum length limits for this fishery.

Recently, interest in population assessment and management of catfish (Ictaluridae) fisheries in North America has been increasing (Arterburn et al. 2002). However, comprehensive synthesis of data that include estimates of growth, exploitation, natural mortality, angler harvest and size preferences, and bag and length limit evaluations is lacking. Lake Wilson, an impoundment of the Tennessee River in northern Alabama, has historically supported a popular commercial and recreational catfish fishery. In 1990, 43% of all fishing effort was directed at catfish, and nearly 100,000 kg of catfish was harvested (16 kg/ha) in Lake Wilson (Janssen and Bain 1996). Given that the average catfish harvest from U.S. reservoirs as reported by Miranda (1999) was 2.8 kg/ha, with a maximum harvest of 30 kg/ha, catfish harvest from Lake Wilson is high. In this reservoir, blue catfish *Ictalurus furcatus* and channel catfish *I. punctatus*, represent 63% and 34% of the total catfish harvest, respectively, the harvest of flathead catfish *Pylodictis olivaris* being negligible (Janssen and Bain 1996). In Alabama, about 34% of anglers fish for catfishes; in the USA overall (not including the Great Lakes), 28% of the total freshwater angling effort is directed towards these fish (USFWS 2007).

Typically, blue catfish and channel catfish are harvested by both recreational and commercial fishers for consumptive purposes (see papers in Irwin et al. 1999). Exploitation rates of these fish are highly variable throughout U.S. water bodies (see Irwin et al. 1999). In the upper Mississippi River, exploitation rates, primarily from commercial fishing, probably exceeds 50% for channel catfish and has been

* Corresponding author: maceimj@auburn.edu
[1] Present address: Alabama Division of Wildlife and Freshwater Fisheries, Post Office Box 158, Estaboga, Alabama 36260, USA.

Received July 16, 2008; accepted January 21, 2009
Published online July 30, 2009

associated with declines in yield and recruitment (Slipke et al. 2002).

In Alabama, exploitation rates have not been estimated for catfish; based on observations from Lake Wilson, recreational harvest and possibly commercial harvest of catfish remain high, accounting for interest in the status and sustainability of this catfish fishery. In addition, catfish tournaments, where large, "trophy"-sized catfish are sought, are now prevalent along the Alabama section of the Tennessee River (a former world record 50.3-kg blue catfish was caught in Lake Wheeler in 1996 just upstream from Lake Wilson). The increase in trophy catfish angling and tournament activity has raised concern for maintaining quality catfish fisheries (Irwin et al. 1999; Arterburn et al. 2002). Alabama does not regulate recreational or commercial fishing for any catfish species, and no gear restrictions, creel limits, or length limits have been imposed. The only exception is that only one catfish (any species) over 864 mm total length (TL) can be harvested per day.

The goals of this project were to assess both the commercial and recreational fishery for blue catfish and channel catfish, describe population characteristics, and evaluate length limits for blue catfish and channel catfish. Recent advancements in aging techniques for catfishes based on use of otoliths (Nash and Irwin 1999; Buckmeier et al. 2002; Maceina and Sammons 2006) indicate that catfishes live longer, grow more slowly, and probably have lower natural mortality rates than reported previously, when ages were estimated from pectoral spines. Thus, these fish may be more vulnerable to overfishing than previously thought, which based on data collected by Janssen and Bain (1996) was possible in Lake Wilson. In this paper, we provide the results of a creel survey that examined the catfish fishery on Lake Wilson. We estimated exploitation rates and angler size selectivity for blue catfish and channel catfish and also described longevity, growth, and natural mortality. Finally, we conducted simulation modeling to assess and evaluate potential length limits for both catfish species and to predict the impact of these length limits on abundance of memorable-length (890 mm) blue catfish.

## Methods

*Creel survey.*—This study was conducted on Lake Wilson, a 24-km-long, 6,275-ha main-stem impoundment on the Tennessee River in Alabama (Figure 1). A roving creel survey was conducted from 15 April to 31 October 2006 to collect angler data on effort, catch, and harvest, as well as opinions related to potential regulations related to the catfish fishery. Catfish were harvested mainly from May through September in this reservoir (Janssen and Bain 1996). Nonuniform probabilities ($P$) were assigned to count and survey anglers from three reservoir sections traversing about 8 km each. Higher sampling effort ($P = 0.50$) was directed in the upstream section of the reservoir near the Wheeler Dam tailrace because Janssen and Bain (1996) observed a high proportion of fishing effort was directed at catfish in this section of Lake Wilson. The lower two sections were assigned $P$-values of 0.25. After data were tabulated, section probabilities to compute angler effort were adjusted to reflect variable angler effort among the three reservoir sections. The fishing season was divided into three time blocks: (1) 15 April to 31 May, (2) 15 June to 31 July, and (3) 15 September to 31 October; within each block, 8 weekdays and 8 weekend days were surveyed, for a total of 48 d. Sampling units within each day were four randomly chosen 5-h periods (0800–1300, 1000–1500, 1300–1800, or 1400–1900 hours).

Anglers were interviewed on the water and asked questions concerning catch, time, species sought, and the location of the angler's residence. Anglers from the three counties adjacent to the study area (Colbert, Lauderdale, and Lawrence) were considered "local." If anglers were targeting catfish, they were asked if they were aware of the exploitation study on catfish and if they would be willing to return a tag from a catfish for a small reward. We measured (TL; mm) a sample of fish ($N = 162$) harvested by anglers. Individual weights of these fish were predicted from $\log_{10}$(weight) $\log_{10}$(length) regression equations from fish obtained from our electrofishing samples.

Catfish anglers were also asked for their opinion of a regulation that would be beneficial toward maintaining or enhancing trophy-size blue catfish in the population. Finally, catfish anglers were asked if they had answered the above questions in a previous interview; if so, we did not include these data in the analysis to avoid duplicate responses.

Estimates of fishing effort, catch, and harvest, and associated 95% confidence intervals were calculated using equations (1)–(11) in Malvestuto et al. (1978). Total weight harvested was computed by multiplying the average predicted weight of catfish harvest times the number harvested. Data related to anglers' awareness of whether a tagging program was in place, their willingness to return a tag from a fish, and their opinions on regulations were calculated by percent of responses. To test differences in responses to a regulation for homogeneity between Alabama residents and nonresidents, we used chi-square analysis.

*Catfish collection and processing.*—Blue catfish and channel catfish were collected by using a Smith-Root

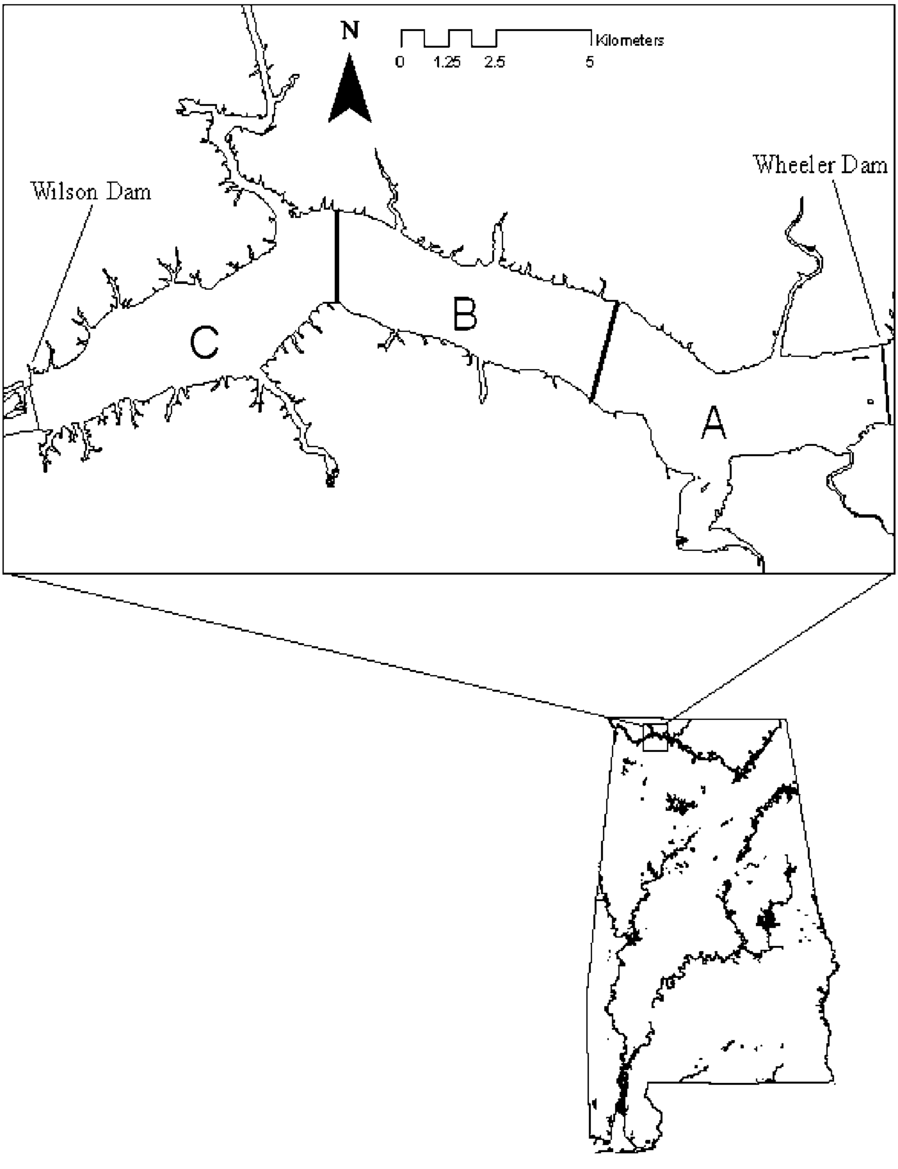


FIGURE 1.—Location of Lake Wilson and the three creel survey sections (A–C).

(7.5 GPP) boat electrofisher with low-frequency pulsed (15 pulses/s) DC; most of the sampling effort was directed to the upper 8 km of the reservoir near the Wheeler Dam tailrace. We disproportionally sampled this region because this was the region fished by the majority of catfish anglers (see Results). In addition, we initially observed that our electrofishing catch rates were about 10 times greater in the vicinity of the tailrace than in other regions of the reservoir and we wanted to tag as many fish as possible. A chase boat was used to assist in netting surfacing fish. Electrofishing was conducted in October 2004 and 2005; May–June 2005, 2006, and 2007; July 2007; and August 2005 and 2007.

All catfish were placed into a 400-L live well for processing. Total length was measured to the nearest millimeter. Fish weighing less than 5.0 kg were weighed to the nearest 1 g; catfish larger than 5.0 kg were weighed to the nearest 10 g. For catfish greater than 300 mm TL, Carlin dangler tags were attached with stainless steel wire posterior to the first dorsal spine and between the pterygiophores. Each tag had an individual number and indicated the name, address, and phone number of the Fisheries Department at Auburn University.

A subsample of the catfish collected were retained for otolith extraction and aging. Ages were estimated from 180 blue catfish (size range 195–1,291 mm) and 122 channel catfish (range 199–646 mm), according to the methods of Buckmeier et al. (2002). Ages were estimated by two independent readers and when a discrepancy in age assignment occurred, a concert read was made and an age was assigned. We fit von Bertalanffy (Ricker 1975) equations to mean lengths-at-age data to describe growth. Male blue catfish and channel catfish grew faster than females (Holley 2006). Growth data were pooled to include both sexes for each species, because we wanted to model the overall population response for each species. For both species, length-at-age data were highly variable. For blue catfish, the standard deviation associated with the mean for 50-length-groups increased significantly ($r = 0.86$; $P < 0.01$); for channel catfish, this measure was not statistically important ($r = 0.54$; $P = 0.13$). Accordingly, 29% of the blue catfish over 650 mm were aged even though these fish made up only 5% of the electrofishing sample. Similarly, for channel catfish, 17% of the fish over 500 mm were aged when, in fact, these fish accounted for only 6% of the sample. Thus, we were able to ameliorate some of the potential bias of assigning ages to unaged fish by using a length–age key (Bettoli and Miranda 2001). These data were used to estimate total annual mortality from catch-curves (Ricker 1975; Maceina 2007). Inspection of residuals computed from a linear catch-curve regression for blue catfish showed that a nonlinear piecewise regression (Maceina 2007) was more appropriate, and we used this technique to estimate differential length or age mortality for these fish. Criteria listed by Brenden and Bence (2008) and Maceina and Hunter (2008) were used to select an optimal final model to describe this relation. To estimate total mortality of channel catfish, we used linear catch-curve regression (Ricker 1975).

*Exploitation and angler size selectivity.*—Monthly exploitation ($\mu$) of tagged catfish was calculated from the equation

$$\mu = \frac{(N_h)}{(N_t)\cdot(1 - P_{\text{nr}})(1 - P_t)},$$

where $N_h$ is the number of tagged fish reported as harvested, $N_t$ is the number of tagged fish at large, $P_{\text{nr}}$ is the angler nonreporting rate, and $P_t$ is the tag loss rate. Although we did not estimate angler nonreporting, we computed a range of nonreporting rates between 20% and 70%, based on previous studies (Zale and Bain 1994; Maceina et al. 1998; Miranda et al. 2002). Loss of Carlin dangler tags was 15.7% over a 6-month period for blue catfish (Kevin Sullivan; Missouri Department of Conservation, personal communication), so we used this rate (2.617%/month) of tag loss to adjust exploitation estimates. Monthly exploitation rates from September 2005 to August 2008 ($N = 36$ months) were averaged and multiplied by 12 to estimate average annual exploitation.

To facilitate angler tag returns, we offered rewards with randomly assigned values of US$5–50. Postage-paid envelopes were available at local businesses, which included a survey card for anglers to complete with such information as their name, address, date and location the fish was caught, gear used, angler type (commercial or recreational), and disposition of the fish caught (harvested or released). Each month, the number of fish at large was computed by removing the number harvested and the number of tags lost from the total number tagged (fish were being tagged throughout the study). The length-frequency distributions of harvested and tagged fish were compared with Kolmogorov–Smirnov (KS) two-sample tests to determine whether fish were harvested in proportion to the tagged population.

The effect of fish length on the probability of angler harvest of blue catfish was analyzed by logistic regression (Miranda and Dorr 2000). All tags returned by anglers when the fish was harvested (October 2004 to August 2008) were used to determine angler size selectivity. Because blue catfish grow slowly in Lake Wilson (this paper), length was not corrected for the time between angler capture and tagging.

*Simulation modeling.*—The effects of three potential length limits (304, 356, and 406 mm) on the yield and harvest of blue catfish and channel catfish fishery were explored using the Fishery Analysis and Simulation Tools (FAST version 3.0) software program (Slipke and Maceina 2006). All fishery and population variables computed from the FAST software were derived from the Jones modification of the Beverton–Holt equilibrium yield equation (Quinn and Deriso 1999). In addition, we predicted the impact of a high (660 mm) minimum length on yield, harvest, and abundance of memorable-length (890 mm) blue catfish. We modeled the response of memorable-length blue catfish instead of trophy-length (1,140 mm). In the model, the predicted time to reach trophy length approach maximum age, and only a very small fraction of these fish would remain in the simulated population regardless of rates of exploitation or a range of minimum length limits. For each species, the weight–length relationship was derived from catfish sampled; other model input parameters included fishing mortal-

TABLE 1.—Life history parameters used to model the blue catfish and channel catfish fisheries in Lake Wilson.

| Parameter | Blue catfish | Channel catfish |
|---|---|---|
| von Bertalanffy growth coefficients[a] | | |
| $L_\infty$ (mm) | 1,303.3 | 646.0 |
| $K$ | 0.081 | 0.148 |
| $t_0$ (years) | −0.243 | −2.002 |
| Maximum age (years) | 25 | 12 |
| Exploitation | 0.04–0.20 | 0.04–0.20 |
| Instantaneous natural mortality | 0.122–0.184 | 0.222–0.384 |
| Average conditional natural mortality | 0.146 | 0.249 |
| $\log_{10}$(weight) : $\log_{10}$(length) coefficients | | |
| Intercept | −6.250 | −5.778 |
| Slope | 3.452 | 3.276 |
| Length limits (mm TL) | 304, 356, 406, 660 (and variable) | 304, 356, 406 (and variable) |
| Initial number of recruits | 100 | 100 |

[a] $L_\infty$ = the maximum (asymptotic) length, $K$ = the growth coefficient, and $t_0$ = the time at which length is theoretically zero.

ity, natural mortality, and growth (Table 1). Instantaneous natural mortality rates ($M$) for each species were estimated from the five equations (Hoenig 1983; Peterson and Wroblewski 1984; Chen and Watanabe 1989; Jensen 1996; Quinn and Deriso 1999) presented in FAST (Slipke and Maceina 2006) and then averaged. Conditional natural mortality (CM) was computed from average $M$ as $\text{CM} = 1 - e^{-M}$. In the model, fishing mortality encompassed the range of estimated exploitation rates. Maximum potential yield and harvest were examined by using surface response isopleths to plot the response of yield and harvest to variable minimum lengths and exploitation rates.

TABLE 2.—Ninety-five percent confidence intervals around the means for various fishery statistics for anglers targeting catfish in the Wheeler Dam tailrace. The estimates are for 1 April to 31 October 2006. Anglers from Colbert, Lawrence, and Lauderdale counties in Alabama were considered local anglers. For fishery statistics 1–10, the confidence intervals were computed from the equations provided by Malvestuto et al. (1978). For fishery statistics 11 and 12, the confidence intervals were computed by multiplying the standard error by the $t$-value (1.96). For fishery statistics 13 and 14, the confidence intervals are from a binomial distribution (McClave and Dietrich 1988).

| Fishery statistic | Estimate |
|---|---|
| 1. Fishing effort (h) | 72,900 ± 28,230 |
| 2. Fishing effort (h/ha) | 11.62 ± 4.50 |
| 3. Catfish catch ($N$) | 109,500 ± 43,990 |
| 4. Catch per area ($N$/ha) | 17.45 ± 7.01 |
| 5. Catch rate ($N$/h) | 1.50 ± 0.60 |
| 6. Total catfish harvest ($N$) | 87,100 ± 37,140 |
| 7. Weight of catfish harvest (kg) | 49,200 ± 20,980 |
| 8. Harvest per area ($N$/ha) | 13.88 ± 5.92 |
| 9. Weight of catfish harvest per area (kg/ha) | 7.84 ± 3.34 |
| 10. Harvest rate ($N$/h) | 1.19 ± 0.50 |
| 11. Mean total length of catfish harvested (mm) | 381 ± 13 |
| 12. Mean weight of catfish harvested (g) | 565 ± 83 |
| 13. Local anglers (%) | 22 ± 3 |
| 14. Alabama anglers (%) | 51 ± 4 |

## Results

### *Creel Survey*

Information was obtained from 1,102 anglers, of which 50% were targeting catfish; similarly, about 50% of the total fishing effort on Lake Wilson (144,700 h) was directed toward catfish (Table 2). Of the 551 catfish anglers interviewed, only one was a commercial fisher. Thus, our creel survey represented the recreational fishery. Between 1 April and 31 October 2006, catfish anglers caught a total of 109,500 catfish (average 1.50 fish/h) and harvested about 80% of these fish (Table 2). Total harvest was 49,200 kg (7.84 kg/ha; average weight harvested = 0.57 kg), blue catfish and channel catfish representing 63% and 37%, respectively, of the total catfish harvest during the creel survey. We observed no harvest of flathead catfish during the creel survey. For anglers seeking catfish, 79, 8, and 13% fished in sections A, B, and C of Lake Wilson, respectively.

Local residents from three counties surrounding Lake Wilson were 22% of the catfish anglers, whereas 49% of the catfish anglers were from out-of-state (primarily Tennessee; Table 2). Among catfish anglers, 53% were aware of the tagging study that was being conducted, and all anglers responded that they would return a tag for a reward. Most catfish anglers (71%, total surveyed = 473) would support management decisions to increase abundance of trophy-sized blue catfish; however, some anglers stated they release large blue catfish and raised concerns about imposing bag and length limits on smaller catfish. The support of a regulation(s) to increase abundance of trophy-sized blue catfish was similar between residents and nonresidents of Alabama ($\chi^2 = 1.35$; $P = 0.71$).

### *Angler Exploitation and Size Selection*

A total of 2,905 blue catfish (TL range = 122–1,291 mm) and 699 channel catfish (TL range = 65–646 mm)

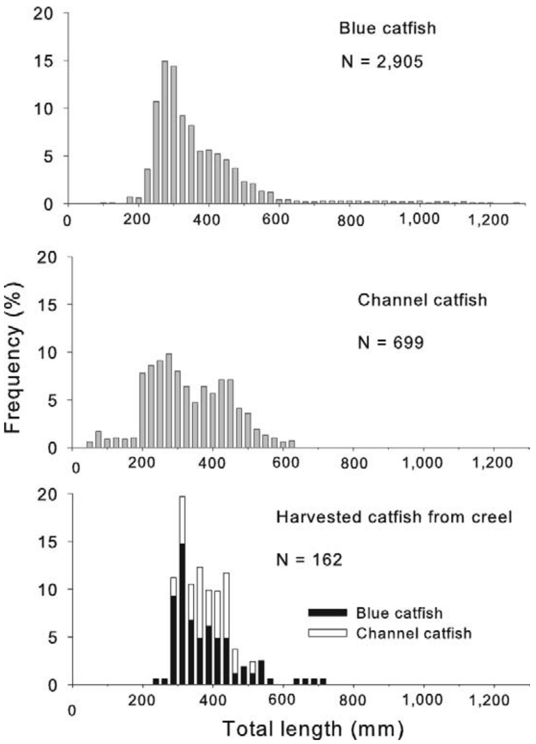


FIGURE 2.—Length-frequency distributions of blue catfish, channel catfish sampled by electrofishing, and blue and channel catfish harvested by recreational anglers and measured during the creel survey at Lake Wilson, 2006.

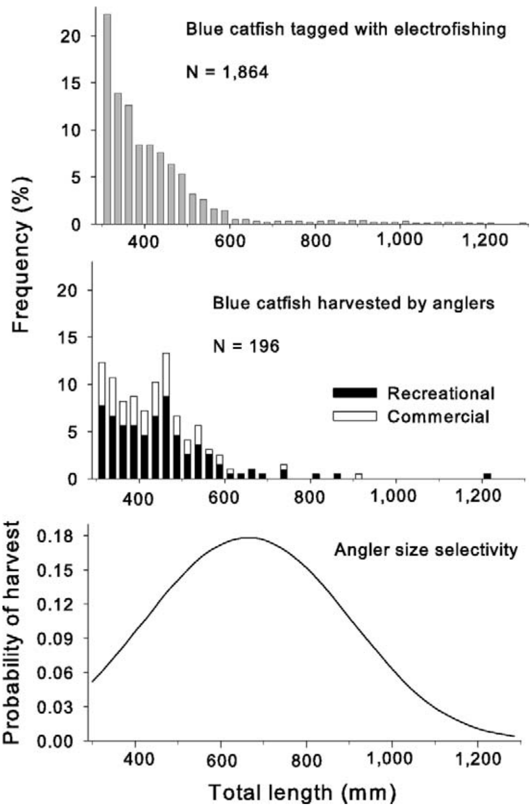


FIGURE 3.—Length-frequency distributions of blue catfish (>300 mm TL) tagged by electrofishing (top panel) and fish harvested by recreational and commercial fishers (middle panel), along with the predicted probability of harvest by length based on the logistic regression $p = 1 - e^{0.0138(TL)-0.00001(TL**2)-6.0969}$, where $p$ is angler length preference (bottom panel).

were collected from October 2004 to August 2007 with electrofishing (Figure 2). Of the blue catfish and channel catfish collected, 1,854 and 321, respectively, were tagged and released.

Lengths of catfish harvested by anglers that we measured during the creel survey ranged from 242 to 711 mm (mean 381 mm); 88% of fish harvested were greater than 300 mm (Figure 2). Thus, we considered 300 mm as the size of catfish that would be retained by most anglers. Eighty-five percent of the fish retained by anglers were between 300 and 600 mm TL; few fish greater than this length were harvested.

Most tagged catfish were caught by anglers between April and October, 82% and 67% of the tagged blue catfish and channel catfish, respectively, being were returned by anglers during these months. Recreational anglers ($N = 115$) returned 67% of the tags and seven commercial anglers returned 33% of the tags. Of the 68 catfish harvested by commercial fishers, 96, 3, and 1% were captured with trotlines, hook-and-line, and gill nets, respectively. The mean time between tagging and tag return by anglers was 368 d (SD = 320 d) and ranged from 3 to 1,237 d.

For blue catfish, anglers returned 209 tags and 94% of these fish were harvested. Lengths of harvested blue catfish ranged from 301 to 1,215 mm (Figure 3). Estimates of the average annual exploitation, which ranged from 8.2% to 22.1%, included tag loss and three rates (20–70%) of angler nonreporting. Recreational and commercial fishers harvested similar (KS = 0.53; $P = 0.9$) lengths of blue catfish which averaged 448 mm.

Anglers harvested longer blue catfish in proportion to fish that were tagged (KS = 2.63; $P < 0.0001$; Figure 3). In addition, logistic regression predicted peak harvest selectivity (0.18) at about 660 mm, and the relationship between probability of harvest and length was parabolic (Wald $\chi^2 = 28.3$; $P < 0.0001$; concordance = 0.62; Figure 3). Probability of harvest decreased from about 0.10 (about 400 mm) to 0.05 (about 300 mm), given the high relative abundance of these smaller blue catfish, which were all tagged, as

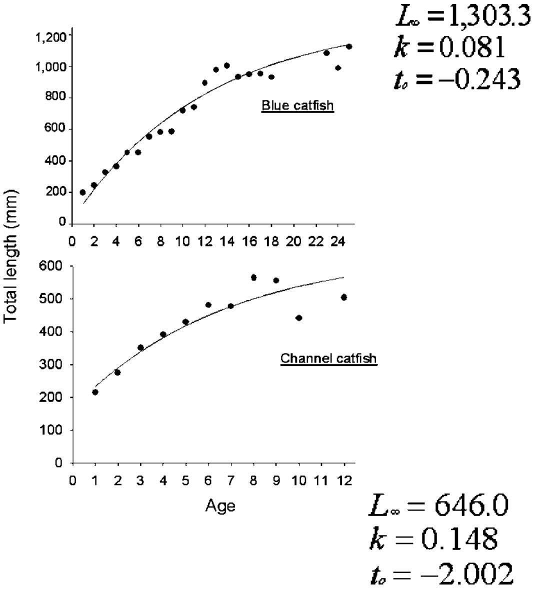


FIGURE 4.—Von Bertalanffy growth equations (lines) and observed mean total lengths at age (circles) for blue and channel catfish. Parameters are defined as follows: $L_\infty$ = the theoretical maximum length, $k$ = the growth coefficient, and $t_0$ = the time at which length is theoretically zero.

indicated by electrofishing. Angler selectivity declined for fish larger than 660 mm (Figure 3).

A total of 11 and 2 tagged channel catfish were harvested by recreational and commercial fishers, respectively (TL range = 350–627 mm). Average annual exploitation ranged from 4.0% to 10.8% after accounting for tag loss and considering three non-reporting rates. The lengths of harvested channel catfish appeared to be larger than the lengths of the tagged fish. However, because of the low numbers of channel catfish harvested, we did not attempt to use logistic regression to predict angler size selectivity; moreover, no difference in lengths of angler-harvested and electrofished tagged fish was detected (KS = 1.18; $P = 0.12$).

### *Longevity, Survival, and Growth*

Maximum ages observed for channel catfish and blue catfish were 12 and 25 years, respectively. Based on the von Bertalanffy growth coefficient ($K$) and associated confidence intervals, channel catfish growth was faster ($K = 0.148$; 95% confidence interval 0.095–0.202) than for blue catfish ($K = 0.081$; 95% confidence interval 0.043–0.119). A higher maximum age and theoretical length infinity for blue catfish was related to greater sizes of blue catfish (Figure 4). Predicted times for blue catfish to obtain 304, 356, and 406 mm was 3.0, 3.7, and 4.4 years, respectively, compared with 2.3, 3.4, and 4.7 years for channel catfish. The times for blue catfish to reach preferred (760 mm), memorable (890 mm), and trophy (1,140 mm) lengths were 11, 14, and 25 years, respectively.

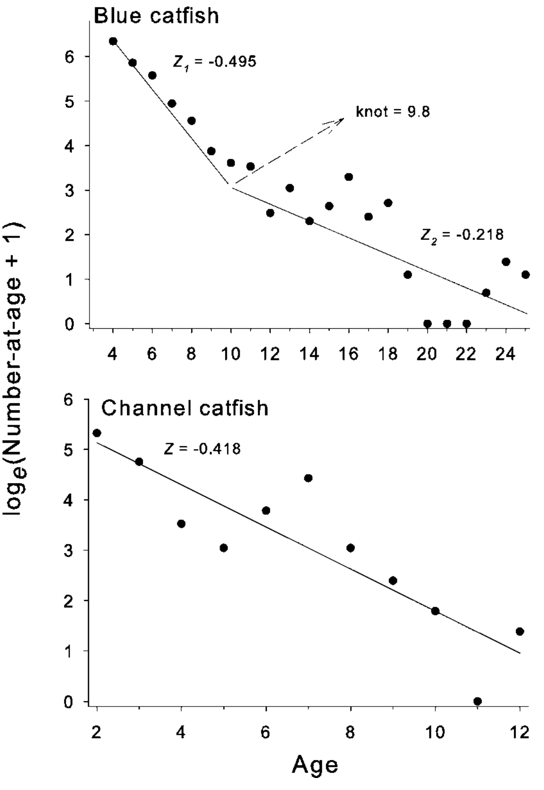


FIGURE 5.—Catch-curve regressions for blue and channel catfish, where $Z_i$ is the total instantaneous annual mortality rate for the species and age bracket in question. The equation for blue catfish is piecewise linear; the "knot" occurs at 9.8 years.

From growth data and lengths of catfish harvested by anglers, we assumed channel catfish and blue catfish recruited into the fishery at ages 2 and 3 years, respectively. Linear catch-curve regression for 2–12-year-old channel catfish indicated their average annual survival was 66% ($Z = -0.420$; Figure 5). For 3–25-year-old blue catfish, linear catch-curve analysis estimated that average annual survival was 75% ($Z = -0.284$), but inspection of the data and additional analysis suggested age (size)-dependent differences in survival in this population. The piecewise nonlinear catch-curve regression estimated that average annual survival was 61% ($Z = -0.495$) for 3–10-year-old blue catfish but was 80% ($Z = -0.218$) for 10–25–year-old fish (Figure 5). The estimated knot in the piecewise nonlinear catch-curve regression was 9.8 years, which

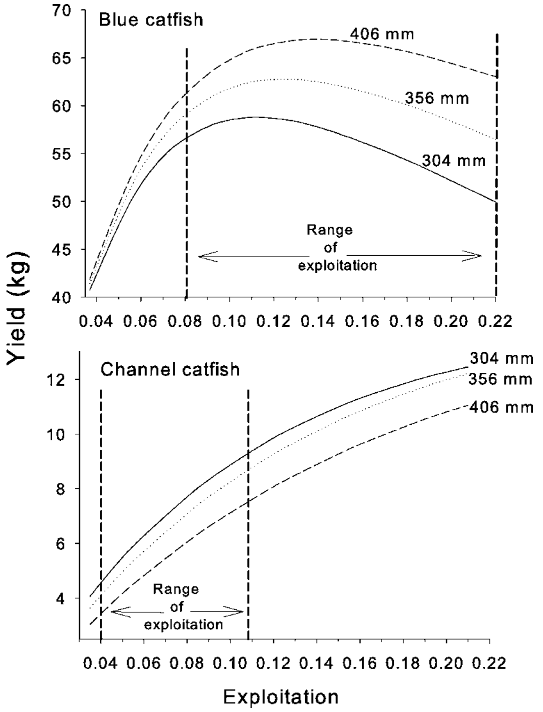


FIGURE 6.—The effect of three different minimum length limits (304, 356, and 406 mm) on the yield of blue and channel catfish over a range of exploitation rates. The exploitation rates reflect a 2.617%/month tag loss rate and angler nonreporting rates varying from 20% to 70%.

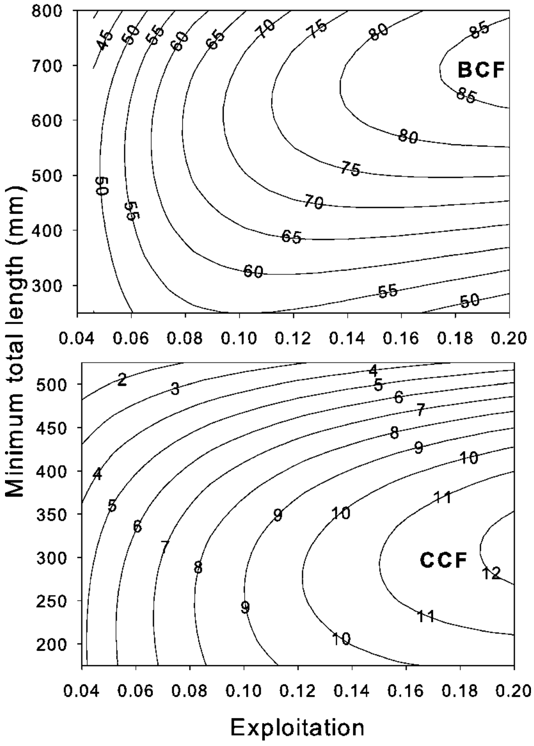


FIGURE 7.—Isopleths showing the predicted responses of yield (kg/100 recruits) to variable minimum length limits and exploitation rates for blue catfish (BCF) and channel catfish (CCF).

from the von Bertalanffy equation conferred a length of 725 mm. Thus, based on lengths of fish recorded during the creel and angler size selectivity estimated from tag returns, differential mortality in this blue catfish population was probably the result of higher harvest rates of smaller fish by anglers. Estimates of *M* for channel catfish ranged from 0.229 to 0.384 and averaged 0.287. For blue catfish, *M* ranged from 0.122 to 0.184 and averaged 0.158 (Table 1).

### *Simulation Modeling to Predict the Effects of Length Limits*

Yields of blue catfish and channel catfish responded differently to minimum length limits (Figure 6). Over the range of exploitation observed, the predicted yield of blue catfish increased as the minimum length limit increased from 304 to 406 mm. The opposite prediction was observed for channel catfish: yields declined at progressively higher minimum lengths. At the 304 mm minimum length limit, growth overfishing occurred when blue catfish exploitation rates exceeded 11%. This level of exploitation was well within our range of potential exploitation rates in this fishery. In addition, at exploitation rates of 14–18%, we predicted that slight growth overfishing would occur for the 356- and 406-mm minimum lengths for blue catfish. At the high end of our exploitation rate (22%), the predicted yield of blue catfish was 26% higher with the 406-mm minimum length limit than with the 304-mm limit. For the range of our estimates of exploitation for channel catfish, growth overfishing was not evident.

Isopleths of yield as a function of exploitation and minimum length showed that to maximize blue catfish yield in this fishery, a minimum length limit of about 660 mm would be necessary at an exploitation rate of 17% or higher (Figure 7). Even at lower levels of exploitation (i.e., 10%), predicted yield would increase if progressively higher minimum lengths were instituted for this fishery. Conversely, at our high estimate of exploitation (11%) for channel catfish, maximum yields would be obtained at a minimum length limit of about 300 mm (Figure 7).

If a minimum length limit of 660 mm was enforced for this blue catfish fishery, not only would total yield increase (Figure 7), but also the abundance of memorable-length (890 mm TL) blue catfish in the

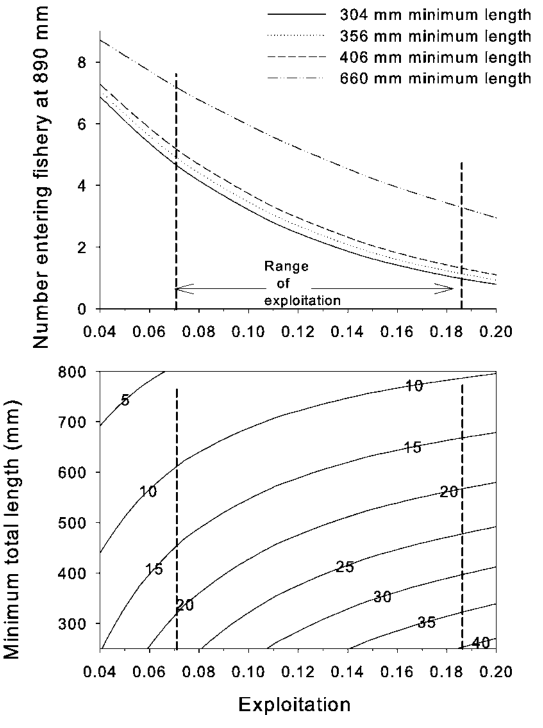


FIGURE 8.—The top panel shows the predicted number of memorable-length blue catfish (890 mm TL) at various exploitation rates and four different minimum lengths limits. The bottom panel shows the total number of blue catfish that could be harvested (per 100 recruits) at various exploitation rates and the same minimum length limits. The exploitation rates reflect a 2.617%/month tag loss rate and angler nonreporting rates varying from 20% to 70%.

fishery would increase about 50% to 350% (8–22% exploitation rate; Figure 8), and this difference would increase as exploitation rose. Abundance of memorable-length blue catfish would vary little among minimum length limits of 304, 356, and 406 mm unless actual exploitation over these minimum length limits was very low. Although yield and abundance of memorable-length blue catfish would increase with a 660-mm minimum length limit, blue catfish harvest by anglers would decline about 50% compared with, for example, a 300-mm minimum length limit over the range of exploitation rates (Figure 8).

## Discussion

Fishing effort for catfish on Lake Wilson was 50% of the total fishing effort. Similarly, Janssen and Bain (1996) found catfish were the primary fish sought by anglers in the Wheeler Dam tailrace. In the Truman Dam tailrace, Missouri, Graham and Deisanti (1999) reported 47% of all anglers targeted catfish. Total harvest of catfish was higher (7.8 kg/ha) in Lake Wilson than in other U.S. reservoirs (mean $\pm$ SD = 2.8 $\pm$ 3.9 kg/ha; Miranda 1999). Despite high fishing pressure (11.6 h/ha) and catfish harvest, harvest rates (1.19 fish/h) remained high and were greater than those observed in the Truman Dam tailrace (0.14 and 0.29 fish/h, respectively; Graham and Deisanti 1999) and the Missouri River after a commercial fishing ban ($\leq$0.23 fish/h; Stanovick 1999).

Catfish harvest (1 April–31 October) was 72% higher in 1990 than in 2006 (84,706 and 49,200 kg, respectively; Janssen and Bain 1996). The decrease in catfish harvest was attributed to two factors: a decrease in commercial fishers and differences in creel survey types. Freshwater commercial fishers accounted for 33% of all catfish tag returns during our study, but these fishers were rarely encountered ($N$ = 2) in the creel survey. From 2000 to 2006, the number of freshwater commercial fishing licenses purchased in Alabama and the three counties (Colbert, Lauderdale, and Lawrence) surrounding Lake Wilson decreased by about 30% and 50%, respectively (Alabama Department of Wildlife and Freshwater Fisheries, unpublished data). The average number of commercial licenses sold in these counties from 2000 to 2006 (mean = 15) also drastically declined from the numbers sold from 1976 to 1982 (mean = 290). This decline in commercial fishers in the region was probably associated with a decline in catfish harvest on Lake Wilson.

Roving creel surveys obtain harvest information from incomplete fishing trips and instantaneous counts of angler effort, whereas creel surveys at access points compute harvest information from completed fishing trips and the amount of effort is derived from the number of boats at the access point. Roving creel surveys rely on anglers reporting fish harvested; for fish species with higher bag limits, harvest tends to be underestimated (Mallison and Cichra 2004). Thus, the access point creel survey conducted by Janssen and Bain (1996) probably provided higher catch and effort estimates than did the roving creel survey that we conducted. We found that catfish anglers comprised 79% of all anglers in the tailrace section of Lake Wilson, whereas Janssen and Bain (1996) surveyed two nearby access points that probably provided higher effort and catch estimates. Nevertheless, our recent creel survey indicated that Lake Wilson still has a high catch and harvest catfish fishery.

A disproportionally high number of tags (33%) were returned by just seven commercial fishers, whereas 115 recreational anglers on Lake Wilson harvested a total of only 141 tagged blue catfish and channel catfish. A survey of the Missouri River found commercial fishers accounted for 38% of catfish harvest, but were only 11% of anglers (Stanovick 1999). Timmons (1999) reported over 65% of blue catfish and channel catfish tag returns were by commercial fishers in Kentucky Lake, Kentucky. In the upper Mississippi River, commercial fishers caused a decline in channel catfish yield through growth and recruitment overfishing (Pitlo 1997; Slipke et al. 2002) and resulted in a minimum size increase. Commercial fishing can impact catfish fisheries (Pitlo 1997), but commercial fishing for catfish appears to be declining in Alabama.

Our range of estimated exploitation rates (8–22%) for blue catfish was similar to estimates reported in Lake Kentucky (17%; Timmons 1999) and in the Truman Dam tailrace, Missouri (8–15%; Graham and Deisanti 1999). Exploitation of channel catfish in Lake Wilson ranged from 4% to 11%, also similar to rates reported from the Truman Dam tailrace in Missouri (6–15%; Graham and Deisanti 1999) and Lake Kentucky (11%; Timmons 1999). Hubert (1999) reviewed previous studies and found channel catfish exploitation ranged from 1% to 30%. Shrader et al.(2003) estimated channel catfish exploitation in Brownlee Reservoir and the Snake River in Oregon varied between water bodies from 2% to 31%.

If tagging mortality was high for the catfish we tagged, then our exploitation estimates would have been underestimated. However, if tag loss was less than the liberal rate we used (31%/year loss), then our estimates of exploitation would be inflated. The high percentage of Carlin dangler tags returned more than 6 months after tagging (60%) and the tags ($N$ = 15) returned after 30 months possibly indicated high tag retention by catfish. Tag loss rates of 0% for catfish have been reported (Graham and Deisanti 1999; Travnichek 2004), but Shrader et al. (2003) reported a 23% annual tag loss rate for Carlin dangler tags for channel catfish. If we assumed no tag loss, then our estimates of exploitation would decrease by about 20%. Angler nonreporting ranging from 20% to 70% probably accurately encompassed the range of non-reporting. About 50% of catfish anglers were unaware of the catfish tagging program in the creel survey and tag returns from these uninformed anglers were unlikely. A nonreporting rate of 50% was within estimates reported in previous studies (Zale and Bain 1994; Maceina et al. 1998). Despite some uncertainty in our estimates of exploitation, our ranges probably encompassed an accurate rate of exploitation.

From the creel survey and angler tag returns, most anglers harvested catfish between 300 and 600 mm TL. Catfish anglers harvested proportionally larger blue catfish than were harvested by electrofishing, but the selection of fish larger than 660 mm declined with length. Piecewise catch-curve regression also showed higher mortality of smaller blue catfish, probably caused by size-selective angler harvest. The length-frequency distribution of sampled and angler-harvested catfish supported observations of higher mortality of smaller catfish; these distributions were highly truncated from 300 to 600 mm, then were relatively flat for fish larger than this (see Figure 2).

Estimates of longevity, growth, and natural mortality of blue catfish and channel catfish varied between species, resulting in completely different predictions with respect to the utility of minimum lengths limits to manage this fishery. Because blue catfish lived longer, grew more slowly, and probably exhibited lower natural mortality rates, this catfish species was sensitive to exploitation and would be likely to respond favorably to minimum length limits, whereas channel catfish would not. Progressively higher minimum length limits from 300 to 660 mm for blue catfish would increase yield (kg), prevent growth overfishing, and increase the abundance of memorable-length blue catfish. With no minimum length limits and exploitation probably greater than 11%, slight growth overfishing for blue catfish has probably already occurred in this fishery. However, for channel catfish, growth overfishing was not observed, minimum length limits provided no yield benefits for channel catfish, and in fact, minimum length limits greater than 304 mm would probably reduce yield.

Although fishing mortality for small blue catfish was probably higher than natural mortality and growth overfishing has probably occurred, we do not recommend high minimum length limits for blue catfish. The number of blue catfish harvested would decrease up to twofold with a minimum length limit as high as 660 mm, which is unlikely to be acceptable to catfish anglers fishing on Lake Wilson. The majority of harvested catfish ranged in length from 300 to 600 mm, but anglers did show some harvest selectivity for fish up to 660 mm. Although growth overfishing for blue catfish might have occurred if exploitation was greater than 11% with an angler minimum length limit of 304 mm, only a 16% reduction in yield would be realized if exploitation approached our high exploitation estimate (22%) compared with yield at an exploitation rate of 11%. Finally, we suspect catfish anglers may not be able to differentiate between blue catfish and channel catfish on Lake Wilson, which also would negate the utility of species-specific length limits.

Many of our results assumed electrofishing collected an unbiased sample of catfish from Lake Wilson. Information pertaining to sampling bias of catfish associated with electrofishing compared with that of other gears is sparse (Santucci et al. 1999). In rivers and streams, Vokoun and Rabeni (1999) recommended low-pulsed DC electrofishing gear to collect blue catfish for age, growth, and size-structure data; however, these authors recommended baited hoop nets be used to collect channel catfish. In 2004–2005, we attempted to collect primarily channel catfish by using bait hoop nets as described by Sullivan and Gale (1999). After extensive efforts we terminated this sampling, having caught only five channel catfish with this gear.

Anglers are becoming more interested in catching, releasing, and protecting larger trophy-size catfish (Arterburn et al. 2002), although 68% of catfish anglers in their survey did not consider themselves trophy anglers. Several catfish tournaments where anglers target larger catfish are held annually on Lake Wilson and other reservoirs on the Tennessee River. The majority of catfish anglers (71%) on Lake Wilson supported a regulation that could enhance a fishery of trophy-size blue catfish; however, they did not consider large blue catfish (≥9 kg) of harvest value because of poor taste and quality of flesh. To protect and enhance the abundance of large blue catfish in Lake Wilson, the Alabama Division of Wildlife and Freshwater Fisheries recently (October 2008) imposed a regulation to permit the harvest of only one large blue catfish (864 mm) per day. This regulation did not compromise the current catfish fishery on Lake Wilson, because anglers did not select or prefer these larger fish for consumption.

Both recreational and commercial fishers on Lake Wilson were more concerned about catching fish for consumption and thus targeted and retained smaller catfish. In Texas, obtaining catfish for consumption was also an important motive for catfish anglers and catching a trophy catfish was of low importance; nonetheless, catching a trophy catfish was more important for anglers targeting blue catfish and flathead catfish than for those targeting channel catfish (Wilde and Ditton 1999).

Only a dramatic increase in the minimum length or imposition of a reduced bag (or both) would appreciably increase the abundance of memorable-length blue catfish in the population. Such actions would probably be unacceptable to anglers and have little effect on the characteristics of the fishery (i.e., high harvest of small fish). For blue catfish to reach memorable or trophy lengths takes 14 and 25 years, respectively, which further compounds the imposition of restrictive bag or length limits. Because our electrofishing sampling indicated high abundance of small catfish (200–300 mm) and recruitment appeared high, the fishery seems to be sustainable at the current levels of exploitation. Creel results indicated catch and harvest rates remain high. Although slight growth overfishing may be occurring for blue catfish, this was not evident for channel catfish. Fishing mortality rates are likely to be similar to natural mortality rates for blue catfish but less than natural mortality rates for channel catfish. On the basis of these findings, we do not recommend additional length and bag limits at this time.

## Acknowledgments

The funding for this research was provided by the Alabama Division of Wildlife and Freshwater Fisheries through Federal Aid in Sport Fish Restoration Project F-40. R. Hunter, B. Ricks, S. Sammons, and D. Stormer assisted with field work. D. DeVries and R. Wright provided valuable comments to improve this paper.

## References

Arterburn, J. E., D. J. Kirby, and C. R. Berry. 2002. A survey of angler attitudes and biologist opinions regarding trophy catfish and their management. Fisheries 27(5):10–21.

Bettoli, P. W., and L. E. Miranda. 2001. Cautionary note about estimating mean length at age with subsample data. North American Journal of Fisheries Management 21:425–428.

Brenden, T. O., and J. R. Bence. 2008. Comment: use of piecewise regression models to estimate changing relationships in fisheries. North American Journal of Fisheries Management 28:844–846.

Buckmeier, D. L., E. R. Irwin, R. K. Betsill, and J. A. Prentice. 2002. Validity of otoliths and pectoral spines for estimating ages of channel catfish. North American Journal of Fisheries Management 22:934–942.

Chen, S., and S. Watanabe. 1989. Age dependence and natural mortality coefficient in fish population dynamics. Bulletin of the Japanese Society of Scientific Fisheries 55:205–208.

Graham, K. A., and K. Deisanti. 1999. The population and fishery of blue catfish and channel catfish in the Harry S. Truman Dam tailwater, Missouri. Pages 361–376 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Holley, M. P. 2006. An evaluation of the recreational catfish fishery in Wilson Reservoir, Alabama. Master's thesis. Auburn University, Auburn, Alabama.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. U.S. National Marine Fisheries Service Fishery Bulletin 82:898–903.

Hubert, W. A. 1999. Biology and management of channel catfish. Pages 3–22 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Irwin, E. R., W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. 1999. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Janssen, F. W., and M. B. Bain. 1996. A quantitative comparison of two quality Tennessee River tailrace fisheries. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 48(1994):482–492.

Jensen, A. L. 1996. Beverton and Holt life history invariants result in optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53:820–822.

Maceina, M. J. 2007. Use of piecewise nonlinear models to estimate variable size related mortality rates. North American Journal of Fisheries Management 27:971–977.

Maceina, M. J., P. W. Bettoli, S. D. Finely, and V. J. Dicenzo. 1998. Analyses of the sauger fishery with simulated effects of a minimum size limit in the Tennessee River of Alabama. North American Journal of Fisheries Management 18:66–75.

Maceina, M. J., and R. W. Hunter. 2008. Use of piecewise regression models to estimate changing relationships in fisheries. Response to comment. North American Journal of Fisheries Management 28:847–848.

Maceina, M. J., and S. M. Sammons. 2006. An evaluation of different aging structures to age freshwater fish from a northeastern U.S. river. Fisheries Management and Ecology 13:237–242.

Mallison, C. T., and C. E. Cichra. 2004. Accuracy of angler-reported harvest in roving creel surveys. North American Journal of Fisheries Management 24:880–889.

Malvestuto, S. P., W. D. Davies, and W. L. Shelton. 1978. An evaluation of the roving creel survey with nonuniform probability sampling. Transactions of the American Fisheries Society 107:255–262.

McClave, J. T., and F. H. Dietrich, Jr. 1988. Statistics. Dellen Publishing Company, San Francisco.

Miranda, L. E. 1999. Recreational catfish harvest in reservoirs in the USA. Fisheries Management and Ecology 6:499–513.

Miranda, L. E., R. E. Brock, and B. S. Dorr. 2002. Uncertainty of exploitation estimates made from tag returns. North American Journal of Fisheries Management 22:1358–1363.

Miranda, L. E., and B. S. Dorr. 2000. Size selectivity of crappie angling. North American Journal of Fisheries Management 20:706–710.

Nash, M. K., and E. R. Irwin. 1999. Use of otoliths versus pectoral spines for aging adult flathead catfish. Pages 309–316 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Peterson, I., and J. S. Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 41:1117–1120.

Pitlo, J., Jr. 1997. Response of upper Mississippi River channel catfish populations to changes in commercial harvest regulations. North American Journal of Fisheries Management 17:848–859.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Santucci, V. J., Jr., D. H. Wahl, and D. F. Clapp. 1999. Efficiency and selectivity of sampling methods used to collect channel catfish in impoundments. Pages 317–328 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Shrader, T. M., B. Moody, and M. Buckman. 2003. Population dynamics of channel catfish in Brownlee Reservoir and the Snake River, Oregon. North American Journal of Fisheries Management 23:822–834.

Slipke, J. W., A. D. Martin, J. P. Pitlo, Jr., and M. J. Maceina. 2002. Use of the spawning potential ratio for the upper Mississippi River channel catfish fishery. North American Journal of Fisheries Management 22:1295–1300.

Slipke, J. W., and M. J. Maceina. 2006. Fisheries analysis and simulation tools, version 3.0. Auburn University, Auburn, Alabama.

Stanovick, J. S. 1999. Recreational harvest rates, release rates, and average length of catfish on the Missouri River, Missouri, before and after the commercial fishing ban. Pages 443–446 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Sullivan, K. P., and C. M. Gale. 1999. A comparison of channel catfish catch rates, size distributions, and mortalities using three different gears in a Missouri impoundment. Pages 293–300 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Timmons, T. J. 1999. Movement and exploitation of blue and channel catfish in Kentucky Lake. Pages 187–192 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Travnichek, V. H. 2004. Movement of flathead catfish in the Missouri River: examining opportunities for managing river segments for different fishery goals. Fisheries Management and Ecology 11:89–96.

USFWS (U.S. Fish and Wildlife Service). 2007. 2006 national survey of fishing, hunting, and wildlife-associated recreation. USFWS and Bureau of the Census, Washington, D.C.

Vokoun, J. C., and C. F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. Pages 271–286 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Wilde, G. R., and R. B. Ditton. 1999. Differences in attitudes and fishing motives among Texas catfish anglers. Pages 395–406 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Zale, A. V., and M. B. Bain. 1994. Estimating tag reporting rates with postcards as tag surrogates. North American Journal of Fisheries Management 14:208–211.

All in-text references underlined in blue are linked to publications on ResearchGate, letting you access and read them immedia