Weight-length Relationships and Growth Data for Blue Catfish from Four Tennessee Waterbodies

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Abstract: The blue catfish (*Ictalurus furcatus*) is an important sport and commercial species in Tennessee for which state-specific biological data are lacking. We report weight-length relationships and age and growth data for blue catfish ($n = 773$) collected from three exploited and one unexploited Tennessee waterbodies: Lake Barkley, Kentucky Lake, and the Mississippi River, and Fort Loudoun Reservoir. There were significant differences between blue catfish weight-length relationships between waterbodies. Catfish age ranged from age 0 to 34 and length at age estimates were significantly different among some, but not all studied waterbodies. Recommendations are provided regarding research necessary to fill blue catfish data gaps that hinder management of this widespread and economically important species.

Key words: blue catfish, *Ictalurus furcatus*, weight-length relationships, length at age, growth, otoliths, Tennessee

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Throughout much of the southeastern and midwestern United States, the blue catfish (*Ictalurus furcatus*) is an important sport and commercial species (Graham 1999, USFWS and USCB 2006). Blue catfish comprises the heaviest annual commercial catch of any catfish in Tennessee (unpublished data, Tennessee Wildlife Resources Agency, TWRA), with its white flesh being preferred by consumers relative to that of other catfishes (D. Shelton, Cool Cats Fish Market, personal communication). Based in part on sport angler feedback, the TWRA modified commercial and sport-fishing regulations in 2003, making Tennessee the first state to impose a maximum size limit on catfish of any species (Tennessee Wildlife Resources Commission Proclamation 03–02). Given the recreational and commercial importance of catfish in Tennessee, it is notable that basic, state-specific biological information is generally lacking for catfishes. This report presents blue catfish weight-length relationships and age and growth data for fish representing three exploited and one unexploited Tennessee waterbodies.

Methods

Study Area

Lake Barkley, Kentucky Lake, and the Mississippi River were selected for study as exploited waterbodies based on high levels of catfish harvest there from 1988 through 2006 (unpublished data, TWRA). Fort Loudoun Reservoir was added to the study to represent an unexploited reservoir, as recreational harvest has been discouraged and commercial harvest prohibited there since 1979 due to PCB (polychlorinated biphenyls) contamination (B. Wilson, TWRA, personal communication).

Sample Collection

Catfish samples from Lake Barkley and Kentucky Lake were collected from commercial fish wholesalers (Hart's Fish Market, Paris, Tennessee; B&F Fish Market, Perryville, Tennessee; Quillen's Fish Market, Paris, Tennessee; Cool Cats Fish Market, McKinnon, Tennessee) during May–October 2007 and 2008. Fish were unselectively gathered from wholesaler swim tanks or from live wells of commercial fishing boats as catches were being offloaded. Commercial fishers selling to wholesalers fished mainly with gill nets, but they occasionally used trot-lines to harvest catfish. Processing procedures used by commercial fish wholesalers prevented our efforts to gather fish sex information.

Mississippi River sampling occurred during November 2006 and 2007. Three sampling methods were used at each of three collection locations along the Mississippi River (Caruthersville, Missouri; Ashport, Tennessee; Randolph Point, Tennessee). Boat electrofishing using low-frequency pulsed-DC (15 pulses/sec) was carried out in 10-min passes around wing dikes, rip-rap, and sand bars, with an electrofishing boat accompanied by two chase boats to increase netting efficiency (Travnichek 2004). A 4.88-m knotless shrimp trawl (complete shrimp trawl, model TRL16C, Memphis Net and Twine Co., Inc, Memphis, Tennessee) was towed for 5 min around wing dikes, rip-rap, and sand bars. Two experimental gill nets (46-m net with stretched mesh sizes ranging 2.54–10.16 cm; 55-m net with stretched mesh sizes ranging 6.35–8.89 cm) were fished behind wing dikes for 4–8 h during the day.

Fort Loudoun Reservoir was sampled in January and February 2007 using 38- to 91-m long trot-lines set at various locations. A total of nine lines were set at once (total of 36 sets) and various baits (threadfin shad, *Dorosoma petenense*; common carp, *Cyprinus carpio*; and fathead minnow *Pimephales promelas*) were fished on 2/0 hooks hanging from 61-cm trotters. Trotters were spaced 152 cm apart and lines were fished overnight at depths ranging from about 0.9–15.2 m.

Study Sample

A minimum of ten fish per 25-mm length interval starting at 200 mm total length was sought for each waterbody. All fish were measured (total length (TL), nearest mm) and weighed (nearest g). Sagittal otoliths (otoliths) were removed and placed in individual data envelopes (data recorded: collection location, sample date, fish length, fish weight) in which they were dried for 2 wk before being cleaned of soft tissue and debris using sharp-tipped forceps. Clean otiliths were individually embedded in epoxy (EasyCast Epoxy resin and hardner, Fields Landing, California; maroon 21 flat embedding mold, model 2449M-AB, SPI Supplies, West Chester, Pennsylvania) and allowed to harden for 3 days before being sectioned (LECO VC-50 low-speed isomet saw) just anterior to the anti-rostrum on the rostral side of the otolith and ground with 320-grit sand paper (while still embedded in epoxy) to the central portion of the sulcus toward the post-rostrum side of the otolith. Processed otoliths were examined under a stereo-microscope (50× magnification, side illumination) and assigned ages by a single reader as described by Buckmeier et al. (2002).

Data Analyses

Association between catfish weight and length was determined according to Ricker (1975) using linear weight-length regressions (weight and length data both $\log_{10}$ transformed). Analysis of covariance (ANCOVA) was used to test for significant differences in the weight-length regression slopes between pairs of study lakes (every pair combination tested). In instances when a significant difference between slopes was not found, ANCOVA using an equal slope (dummy variable) for each waterbody was used to test for significant differences in weight-length regression intercepts according to methods fully explained in Pope and Kruse (2007). Catfish growth in each waterbody was expressed as a von Bertalanffy growth model (Ricker 1975) using FAST (Fisheries Analyses and Simulation Tools) (Slipke and Maceina 2003). For said analyses, the model parameter L_∞ was assigned as the length of the largest fish collected in each waterbody. FAST was also used to calculate mean length at age directly from the aged samples. ANCOVA was used to compare slopes of the mean TL at $\log_{10}$(age) regressions for Kentucky Lake, Mississippi River, and Fort Loudoun Reservoir, and a Tukey multiple comparison test was used to identify significant catfish growth differences among these waterbodies. Because the convergence criteria for the Lake Barkley mean TL at $\log_{10}$(age) regression failed using SAS (thus precluding ANCOVA), an unpaired Student's *t*-test was used to evaluate mean total catfish length at age for Lake Barkley versus the remaining three waterbodies. Size of catfish when they entered and exited the fishery, and duration that catfish resided within the fishery were calculated for comparison purposes, including values for Fort Loudoun Reservoir regardless of its unexploited status. Catfish entering the fishery were arbitrarily (Tennessee has no minimum length limit for catfish) defined as being 205 mm TL and those exiting the fishery were defined as being 864 mm TL (Tennessee's maximum length limit for catfish). Unless noted otherwise above, all analyses were conducted using SAS (2008).

Results

Samples Collected

A total of 773 blue catfish were collected as follows: Lake Barkley, 169 fish, length range 275–1115 mm TL; Kentucky Lake, 166 fish, length range 266–1191 mm TL; Mississippi River, 248 fish, length range 70–830 mm TL; Fort Loudoun Reservoir, 190 fish, length range 255–1105 mm TL. Forty-one of the Mississippi River fish were age 0 and were excluded from weight-length and growth analyses.

Weight-length Relationships

Linear regressions of $\log_{10}$ transformed weight-length data resulted in slopes ranging from 2.87 to 3.46 and intercepts ranging from –6.21 to –4.6 for the four waterbodies and a slope of 3.21 and intercept of –5.59 for pooled data (Figure 1). ANCOVA revealed weight-length regressions of the following pairs of waterbodies to be significantly different based on slope comparisons: Lake Barkley versus Kentucky Lake ($P<0.0001$; Kentucky Lake fish adding body weight more rapidly with increasing body length than Lake Barkley fish), Lake Barkley versus Fort Loudoun Reservoir ($P<0.0001$; Fort Loudoun Reservoir fish adding body weight more rapidly with increasing body length than Lake Barkley fish), Kentucky Lake versus Mississippi River ($P<0.0001$; Kentucky Lake fish adding body weight more rapidly with increasing body length than Mississippi River fish), Mississippi River versus Fort Loudoun Reservoir ($P<0.0001$; Fort Loudoun Reservoir fish adding body weight more rapidly with increasing body length than Mississippi River fish). Comparisons between weight-length regression slopes revealed insignificant differences for Lake Barkley versus Mississippi River fish ($P>0.0648$) and Kentucky Lake versus Fort Loudoun Reservoir fish ($P>0.0451$). Subsequent ANCOVA testing for significant differences between weight-length regression intercepts for the last two pairs of waterbodies revealed that the intercepts of

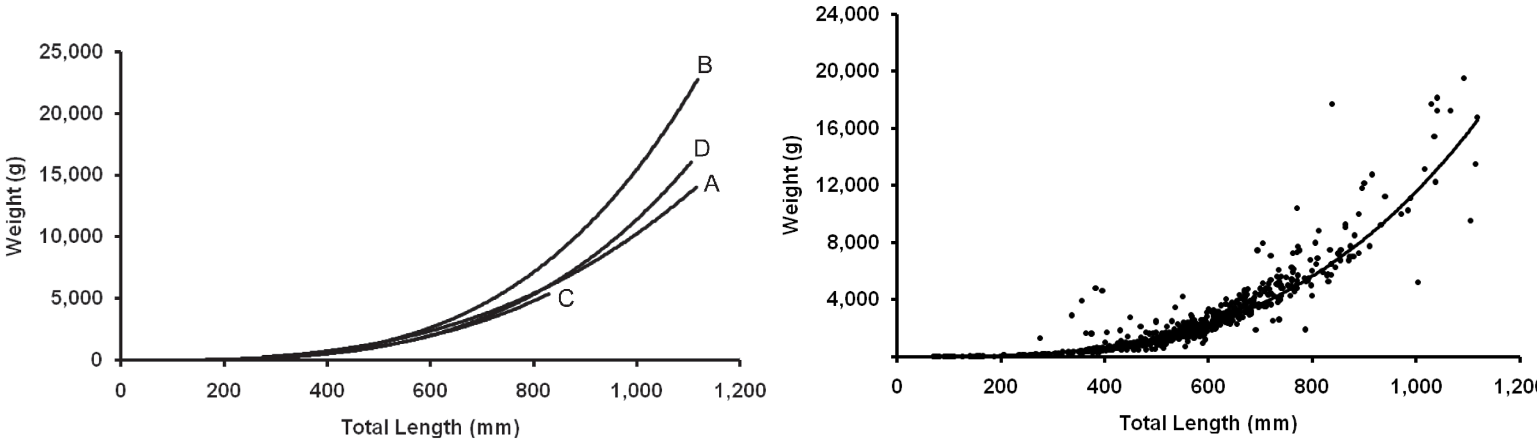

Figure 1. Weight (W)-total length (TL) relationships for blue catfish, *Ictalurus furcatus,* in Tennessee waterbodies (curves depict untransformed relationship; following formulas, r^2 values, and n values represent $\log_{10}$ transformed linear regressions). Top: waterbody–specific relationships; (A) Lake Barkley; $\log_{10}(W) = -4.60 + 2.87 \log_{10}(TL)$ ($r^2 = 0.74$, $n = 168$); (B) Kentucky Lake; $\log_{10}(W) = -6.21 + 3.46 \log_{10}(TL)$ ($r^2 = 0.96$, $n = 166$); (C) Mississippi River; $\log_{10}(W) = -5.33 + 3.10 \log_{10}(TL)$ ($r^2 = 0.97$, $n = 205$); (D) Fort Loudoun Reservoir; $\log_{10}(W) = -6.16 + 3.41 \log_{10}(TL)$ ($r^2 = 0.96$, $n = 190$). Bottom: pooled data relationship for four studied waterbodies; $\log_{10}(W) = -5.59 + 3.21 \log_{10}(TL)$ ($r^2 = 0.95$, $n = 773$).

the Lake Barkley and the Mississippi River relationships were significantly different (dummy slopes = 3.08, $P < 0.0001$; Lake Barkley fish weighing more overall than Mississippi River fish, but adding body weight at a similar rate per increase in body length) as were the intercepts of the Kentucky Lake and Fort Loudoun Reservoir relationships (dummy slopes = 3.43, $P < 0.0001$; Kentucky Lake fish weighing more overall than Fort Loudoun Reservoir fish, but adding body weight at a similar rate per increase in body length). In the latter two cases, the overall weight of blue catfish for Lake Barkley (intercept = –5.187) was larger than that of Mississippi River fish (intercept = –5.279), as was the overall catfish weight of Kentucky Lake (intercept = –6.112) versus that of Fort Loudoun Reservoir (intercept = –6.229).

Age and Growth

Estimated ages of blue catfish ranged from 0–34 yr overall in the four studied waterbodies, with age ranges for each as follows: Lake Barkley, 2–18 yr; Kentucky Lake, 2–14 yr; Mississippi River, 0–21 yr; and Fort Loudoun Reservoir, 5–34 yr (Table 1, Figure 2). The age 34 blue catfish from Fort Loudoun Reservoir (874-mm TL female) represents the oldest estimated age reported for this species that we are aware of (age 25 blue catfish were reported from Wilson Reservoir, Alabama, by Holley [2006] and the Ohio River, Kentucky, by Henley [2007]). Parameters for the von Bertalanffy growth equation were as follows for the four waterbodies: Lake Barkley, $L_\infty = 1115$ mm TL, $k = 0.11$, $t_0 = -0.693$; Kentucky Lake, $L_\infty = 940$ mm TL, $k = -0.126$, $t_0 = -1.217$; Mississippi River, $L_\infty = 830$ mm TL, $k = -0.145$, $t_0 = -1.019$; and Fort Loudoun Reservoir, $L_\infty = 1105$ mm TL, $k = -0.044$, $t_0 = -1.227$.

Table 1. Mean total length at age (mm ± SE) for blue catfish, *Ictalurus furcatus*, in four Tennessee waterbodies.[a]

Age	Lake Barkley[b]	Kentucky Lake[b]	Mississippi River[b]	Fort Loudoun Reservoir[c]
0			108 ± 5	
1			236 ± 18	
2	318 ± 18	271 ± 4	271 ± 9	
3	405 ± 16		376 ± 10	
4	479 ± 22	535 ± 14	428 ± 10	
5	559 ± 20	525 ± 22	471 ± 7	329 ± 25
6	547 ± 17	550 ± 14	522 ± 16	281 ± 15
7	575 ± 12	560 ± 21	558 ± 24	317 ± 19
8	631 ± 23	595 ± 29	602 ± 20	382 ± 27
9	681 ± 19	670 ± 29	664 ± 77	445 ± 38
10	709 ± 49	704 ± 40	679 ± 8	446 ± 16
11	693 ± 87	740*	650 ± 36	441 ± 14
12	787*			472 ± 36
13			688 ± 78	474 ± 12
14	1,092*			508 ± 21
15			812*	527 ± 32
16				579 ± 24
17	1,115*			592 ± 18
18	1,035*			602 ± 24
19				636 ± 26
20				625 ± 20
21			830*	718 ± 50
22				710 ± 63
23				729 ± 73
24				667 ± 44
25				759 ± 49
26				826 ± 28
27				812 ± 73
28				839 ± 40
32				837*
33				900*
34				874*
Number of fish	169	155	248	190

a. Length at age values representing a single fish are each denoted by an asterisk.
b. Exploited waterbody.
c. Unexploited waterbody.

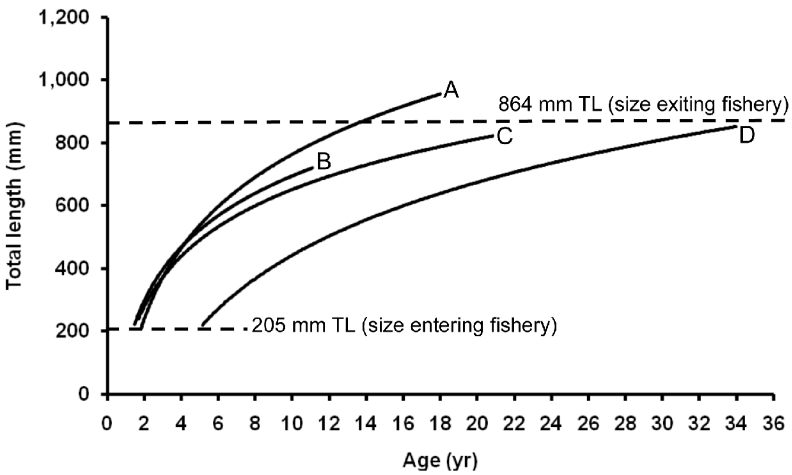

Figure 2. Blue catfish, *Ictalurus furcatus,* von Bertalanffy growth curves for four Tennessee waterbodies: A. Lake Barkley, B. Kentucky Lake, C. Mississippi River, D. Fort Loudoun Reservoir. Length at age (L_t in mm) growth curve formulas, related r^2 values, and n values as follows (t = age in yr): Lake Barkley, $L_t = 1115\ \{1-e^{-0.11(t+0.693)}\}$, $r^2 = 0.83$, $n = 169$; Kentucky Lake, $L_t = 940\ \{1-e^{-0.126(t+1.217)}\}$, $r^2 = 0.92$, $n = 155$; Mississippi River, $L_t = 830\ \{1-e^{-0.45(t+1.019)}\}$, $r^2 = 0.97$, $n = 207$; Fort Loudoun Reservoir, $L_t = 1105\ \{1-e^{-0.044(t+1.227)}\}$, $r^2 = 0.96$, $n = 190$.

The von Bertalanffy equation predicted that blue catfish spend roughly 11 yr in the fishery in Lake Barkley, entering at age 1.5 and reaching the maximum length limit at age 12.5 (Figure 2). Blue catfish in Kentucky Lake recruited into the fishery at about age 1.5 and remained in the fishery until at least age 11 (i.e., the age of the oldest sample used in the analysis) (Figure 2). In the Mississippi River, blue catfish entered the fishery at about age 1.5 and remained in the fishery until they were at least age 21 (i.e., the age of the oldest sample used in the analysis) (Figure 2). Blue catfish in Fort Loudoun Reservoir entered the fishery at age 3.5 and remained in the fishery until age 34 (Figure 2). Estimated ages of blue catfish upon reaching memorable size (891 mm TL; see Anderson and Neumann 1996) were age 15 and 34 in Lake Barkley and Fort Loudoun Reservoir, respectively (Figure 2).

Weight of catfish as they entered the fishery ranged from 58 to 228 g in the four waterbodies, with entry size catfish in Kentucky Lake weighing the most and those in Fort Loudoun Reservoir weighing the least. Due to a lack of data, the weight of blue catfish at the midpoint age within the fishery and weight at the age when leaving the fishery could only be estimated from the populations sampled in Lake Barkley and Fort Loudoun Reservoir. Lake Barkley blue catfish were estimated to have a fishery midpoint weight of 1778 g and a fishery exit weight of 6761 g; whereas Fort Loudoun Reservoir catfish were estimated to have a fishery midpoint weight of 1659 g and a fishery exit weight of 7244 g. However, fishery midpoint blue catfish within Lake Barkley were estimated to be age 6, whereas those in Fort Loudoun Reservoir were estimated to be age 15. Furthermore, blue catfish exiting the fishery at the maximum length limit within Lake Barkley were estimated to be age 13, whereas those in Fort Loudoun Reservoir were estimated to be age 34.

Analysis of covariance revealed a significant difference in the mean TL at $\log_{10}$(age) regressions for blue catfish among Kentucky Lake, Mississippi River, and Fort Loudoun Reservoir ($P<0.0001$). A Tukey multiple comparisons test indicated significant differences in catfish total length at age between Kentucky Lake and Fort Loudoun Reservoir ($P<0.05$; with catfish in Kentucky Lake generally being longer at a given age than those in Fort Loudoun Reservoir) and Mississippi River versus Fort Loudoun Reservoir ($P<0.05$; with catfish in the Mississippi River generally being longer at a given age than those in Fort Loudoun Reservoir). That same test indicated no significant difference in catfish total length at age between Kentucky Lake and the Mississippi River ($P>0.05$). Results of *t*-tests between Lake Barkley and Mississippi River data revealed significant differences for age 2 catfish ($P<0.029$), age 4 catfish ($P<0.020$), and age 5 catfish ($P<0.0001$), with blue catfish in Lake Barkley generally being longer at a given age than those in the Mississippi River. Similar testing of blue catfish age 2–10 between Lake Barkley and Kentucky Lake revealed no significant differences ($P<0.033$), while similar testing between Lake Barkley and Fort Loudoun Reservoir revealed catfish mean total length between ages 5–11 to be significantly different ($P<0.001$ for each of the seven age comparisons), with blue catfish in Lake Barkley being generally longer at a given age than those in Fort Loudoun Reservoir.

Discussion

The $\log_{10}$ transformed weight-length relationships for each of the four waterbodies provided a high level of explanation of catfish weight based on length, with r^2 values for Kentucky Lake, Mississippi River, and Fort Loudoun Reservoir all above 0.95, and Lake Barkley equal to 0.74. Increased sampling within Lake Barkley

($n = 168$) probably would have resulted in a better weight-length fit, as several small fish in that sample displayed high weights. Two types of differences were exhibited through paired comparisons of the weight-length relationships of the four waterbodies: differences between slopes denoting different rates of growth linking changes in catfish weight and length between waterbodies (Lake Barkley versus Kentucky Lake, Lake Barkley versus Fort Loudoun Reservoir, Kentucky Lake versus Mississippi River, Mississippi River versus Fort Loudoun Reservoir) and differences between intercepts denoting overall catfish weight differences between waterbodies (Lake Barkley versus Mississippi River, Kentucky Lake versus Fort Loudoun Reservoir). Possible explanations for the two types of difference are many (e.g., growth associated genetic differences between catfish populations, forage base differences between waterbodies, inorganic nutrient level differences between waterbodies, etc.) and it theoretically seems that both types of difference could result from a similar cause. We consider it interesting that although Lake Barkley and Kentucky Lake are only about 15 km apart and run roughly parallel to one another for 80 km and thus might generally be considered to possess many environmental and biological similarities, blue catfish in Kentucky Lake gained weight at a faster rate than blue catfish in Lake Barkley.

Neither of the two methods used to estimate the age of blue catfish (i.e., the use of fin spines and otoliths as the aging structure) has been validated. Catfish ages estimated by reading otoliths have generally been endorsed as being more accurate than those estimated by reading pectoral fin spines; however, the discrepancy between these methods is typically reduced or absent regarding fish younger than age 3–5 (Nash and Irwin 1999, Buckmeier et al. 2002). Age and growth estimation studies of fishes are ideally conducted with multiple readers to reduce systematic observation bias and facilitate an assessment of aging precision (e.g., Isermann et al. 2003). However, given the exigencies facing fishery management agencies, some aging efforts rely on single readers. While single reader studies add a degree of uncertainty to age and growth results, bias injected into an age and growth analysis by an experienced reader should be consistent such that general comparisons between analyses of a single species conducted by the same reader would be valid.

Age estimates used in this study were based on direct time of capture (DTOC) length at age data. The DTOC method facilitates rapid accumulation of length at age data and requires less expensive aging equipment (such that the method is preferred by some biologists for some studies). However, the DTOC method is associated with two sources of potential bias regarding growth analysis. First, if fishes from different waterbodies are captured during significantly different seasonal growth periods, differences in growth since last annulus formation will increase the variance associated with the length at age model. In the present study, this bias may have been spread evenly among the studied waterbodies, as sample collection from study lakes generally proceeded similarly throughout the overall sampling period. Secondly, each length at age value is specific to a particular year class of fish and each mean length at age value is year-class specific when using the DTOC method. Hence, if significant differences in growth among year classes within a waterbody exist, overall variance associated with a DTOC supported growth model becomes inflated. The ability to determine just how egregious this bias is can only be determined in light of a concurrent assessment of the growth of each year class within the pooled sample. Thus, results stemming from a DTOC growth study do not necessarily correspond to mean length at age data stemming from averaging length at age data over independent year classes and conclusions derived from comparisons of results between studies using these two methods must be considered tentative.

This report is the third providing age and growth information for blue catfish in Tennessee, the first Tennessee study to do so based on reading otoliths, and the first to use the DTOC method to assess growth (see Conder and Hoffarth 1965, Hale and Timmons 1990). Some of the more notable comparisons between our growth results and those of others are as follows. Blue catfish growth reported by this study within the Tennessee portion of Lake Barkley was faster for age 1–5 fish compared to blue catfish growth reported by Freeze (1977) for the Kentucky portion of the lake; blue catfish growth reported by this study for Kentucky Lake was faster than any of the previous five studies of blue catfish growth in said lake in either Tennessee or Kentucky waters (Conder and Hoffarth 1965; Porter 1969; Freeze 1977; Hale and Timmons 1989, 1990); and blue catfish growth reported by this study for the Mississippi River was slower than that reported by Kelley and Carver (1966) in their study of blue catfish in the Mississippi River Delta.

Significant differences in growth between the four studied waterbodies provided evidence regarding the potential importance of gathering waterbody-specific data to support at least some catfish management decisions in Tennessee. The most striking difference in fish growth among the four studied waterbodies was that blue catfish in Fort Loudoun Reservoir (an unexploited waterbody) grew at a considerably slower rate than conspecifics in Lake Barkley, Kentucky Lake, and the Mississippi River (all exploited waterbodies). Those results, as well as the presumed 30-yr minimization of fishing mortality in Fort Loudoun Reservoir and the relatively larger proportion of older blue catfish in the Fort Loudoun Reservoir study sample (Table 1), suggested the influence of density-dependent growth affecting the study populations. It has been proposed, in waters outside Tennessee, that slow blue catfish growth was linked to low levels of exploitation and overpopulation resulting in the stunting of growth (Hale and Timmons 1990, Boxrucker and Kuklinski 2006). This study was not intended to enable definitive conclusions regarding density-dependent growth, and certainly other biotic and abiotic factors as well as differences in capture techniques used among the studied waterbodies could have influenced the aforementioned results. Nevertheless, given the significance of density-dependent growth as it concerns harvest regulations, including management practices aimed at establishing and maintaining trophy fisheries, the implications of our results seem to warrant further study.

Based on our results and the literature, we note the following types of studies to be particularly important regarding the reduction of blue catfish data gaps. Studies aimed at validating blue catfish aging methods as well as those determining the relationship between ages estimated using pectoral spines versus otoliths are needed to establish the scientific validity of data used in management decisions. In addition, given that age estimation using otoliths requires killing fish while that using pectoral spines does not, the relative correspondence between the aforementioned aging methods looms in importance. Studies that facilitate an applied understanding of differences between blue catfish growth study results gathered using DTOC methods versus back-calculation methods would help to improve studies designed for particular management purposes and given various management resource limitations. Studies focusing on blue catfish waterbody-specific growth, year-class growth, population density, and density-dependent growth are needed in Tennessee and elsewhere to provide biological underpinning regarding our understanding of a wide variety of environmental and fishery related phenomena. The foregoing is an expensive "wish-list," and activities aimed at evaluating environmental issues (e.g., biocontamination monitoring, reservoir flow-regime evaluation studies, etc.) might provide opportunity to reduce management study costs through study designs incorporating cooperative sampling.

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