Fisheries Technical Session

Stock Characteristics and Habitat Use of Catfishes in Regulated Sections of 4 Alabama Rivers

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Abstract: We sampled 3 species of catfish (blue catfish *Ictalurus furcatus,* channel catfish *I. punctatus,* and flathead catfish *Pylodictis olivaris*) from 3 different habitat types (tailrace, main channel, tributary) in 4 river systems in Alabama to quantify their relative distribution, age structure, growth, and habitat use. Blue and flathead catfish were more abundant than channel catfish in all systems, and flathead catfish were both most numerous and had the greatest average length in 3 of the 4 systems. Blue and flathead catfish had similar age distributions containing both juveniles and adults, while channel catfish were dominated by young and immature fish. Flathead catfish abundance did not differ across habitat types, although they tended to be found near woody debris and in higher flow. Blue catfish catch rates did not differ among habitats, although their abundance tended to be higher in pebble/cobble substrates. Channel catfish catch rates similarly did not differ across habitat types, but they were significantly more abundant in samples with higher flows and clearer water. Growth rates were highest for flathead catfish in 3 of the 4 systems, followed by blue catfish and channel catfish. When compared to growth rates observed in other states, flathead catfish grew more slowly in Alabama, while channel and blue catfish grew at similar rates as observed elsewhere. Both flow and the presence of woody debris in tailraces appear important to the coexistence of these species in Alabama's waters.

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Catfishes represent a valuable sportfishery throughout many regions of the United States, being highly esteemed by anglers for both their fighting characteristics and flavor (McCoy 1953, Prather 1959, Moss and Tucker 1988). In several states, catfish are considered the most preferred or most highly targeted sportfish (Harrison 1957, Paragamian 1990, Jackson and Dillard 1991, Lemmons and Schnell 1994). In a 1996 survey, catfish ranked third in number of angler fishing days of effort behind black basses and crappie species (U.S. Dep. Int., Fish and Wildl. Serv. and Dep. Comm., Bur. Census 1996). In a 1982 survey, catfish were ranked as the most preferred fish for consumption in Alabama (Moss and Tucker 1988). Surveys on the Coosa River, Alabama, indicated catfish were the most highly sought group of species (Fish. Info. Manage. Systems 1992, 1993, 1994). The commercial fishery is also important, with catfishes historically contributing up to 89% of the full-time commercial angler catch (Spencer et al. 1965).

The 3 most important commercial and sport catfish species in Alabama are blue, channel, and flathead catfish. Because some species of catfish may be as susceptible to overharvest as other sportfish species such as largemouth bass (Quinn 1989), knowledge of the current population status is essential for developing adequate management strategies. Toward this end, 23 states have created statewide bag and/or size limits on catfish in their waters in an effort to manage stocks (Lemmons and Schnell 1994, Quinn 1995).

Growth, age, and relative abundance information clearly are important to the development of any management program. In addition, information on habitat use can be used by managers to enhance habitat suitability and assess the potential for competition among species. For example, channel and flathead catfish are typically associated with woody structure (Minckley and Deacon 1959, Paragamian 1990, Lemmons and Schnell 1994) and channel catfish have been shown to concentrate in the warmest sections of reservoirs, prefer low to moderate turbidity, and in rivers prefer low water velocity (McMahon and Terrell 1982). Deep scour holes near riprap were important components of channel catfish winter habitat in Nebraska waters (Newcomb 1989). Flathead catfish adults typically are most abundant near cover associated with current in streams and reservoirs (Lee and Terrell 1987, Lemmons and Schnell 1994) but are absent in areas of slack water, with few specimens reported in back coves (Lee and Terrell 1987). In streams, juvenile flathead catfish prefer riffle habitats where they can be found under or around stones (Minckley and Deacon 1959); however, in reservoirs where riffle habitat is unavailable, juvenile flathead catfish have been found near woody debris and riprap associated with current (Lemmons and Schnell 1994).

While information is available regarding growth of blue catfish, little work has explored blue catfish habitat use. In 1 study, blue catfish were found to remain near areas of deep water in the Upper Alabama River (Ala. Power Co. 1994). A Missouri study of all 3 species found channel catfish located in slow moving water near mud banks, flathead catfish in fast water near dikes, and blue catfish evenly distributed between these 2 habitats (Robinson 1977). While channel and flathead catfish both have been reported to be associated with cover, different preferences for flow near cover might reduce the potential for direct competition for habitat.

While information regarding habitat use from other regions of the country is available for channel and flathead catfish, there is relatively little information concerning habitat preferences of blue catfish and relative abundances of all 3 species within systems. Further, because age and growth information exists for populations outside of Alabama, data collected in the present study are important for comparative purposes. The specific objectives of this study were to (1) determine relative abundances of blue, channel, and flathead catfish in 4 Alabama river systems (2) determine habitat associations of these species in the 4 systems, and (3) provide information regarding population characteristics (including age and growth) of these 3 species for comparison to populations outside of Alabama.

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Methods

Study Areas

We sampled 4 Alabama waters, each located within separate river systems. Study areas were labeled by the dam below which sampling occurred. The 4 study areas were Wheeler Lock and Dam (hereafter called Wheeler) on the Tennessee River, Armistead I. Seldon Lock and Dam (Seldon) on the Black Warrior River, Mitchell Dam (Mitchell) on the Coosa River, and Millers Ferry Lock and Dam (Millers Ferry) on the Alabama River. The Black Warrior, Coosa and Alabama rivers are portions of the Mobile Delta drainage system, while the Tennessee River is a portion of the Mississippi River drainage system.

Within each study area, fixed stations within each of 3 distinct habitat types were sampled—the immediate tailrace, a tributary, and a downstream main channel site. Tailrace habitats were defined as a region bounded by the dam to a point no more than 1.5 km downstream. Tributary habitat sites were 1–2 km in length, were located 5–16 km downstream of the dam, and fed directly into the river. Main channel habitat sites were 1–2 km in length and were located 10–16 km downstream of the damn.

Fish Collection

During 1995 we sampled once in the winter, summer, and fall, and twice during spring within each system. Samples were collected within each habitat unit during every trip to determine habitat type preference. Sampling including at least 3 gill net-nights per habitat type and variable electrofishing effort dependent upon conditions. Experimental gill nets consisted of 30.5 × 3.1 m monofilament nets with 5 6.1-m panels having 32-mm, 51-mm, 64-mm, 77-mm, and 103-mm bar mesh. Nets were set during late afternoon and recovered the following morning. We used 2 boat-mounted configurations to collect fish with electrofishing. The first was a typical configuration with forward drop probes as anodes and the boat as the cathode. We used pulse frequencies of either 15 pps or 30 pps at 500–1,000 volts to target catfish species (Corcoran 1979, Quinn 1986, Cunningham 1995). In the second method, we used forward drop probes as anodes and insulated aircraft cables lowered to the bottom with chains as cathodes, with the same pulse rate and voltage settings. Gill nets and standard electrofishing were used at all 3 habitat types while cable electrofishing was conducted in the tailrace and main channel habitats.

In the field, we weighed (spring scales [1 kg to nearest 10 g, 5 kg to nearest 500 g, 10 kg to nearest 1 kg, 30 kg to nearest 1 kg]) and measured (nearest mm) each fish and determined sex using morphological characteristics of the genital region. Because catfish are scaleless and their otoliths have been considered difficult to age (Crumpton et al. 1984), pectoral spines provide the best means of obtaining age and growth data (Sneed 1951). Thus, we removed left pectoral spines for all collected fish in a manner based upon the method described by Sneed (1951) which involved grasping the spine and rotating it ventrally until the spine was dislocated and could be pulled free of the fish.

To evaluate habitat use, we collected 8 abiotic variables during each trip. Specific habitat variables were tested using regression analysis comparing the habitat variables to catch per unit effort (CPUE) for each species. Within each of the 3 habitat types we measured flow (at 0.6×depth), mean depth (obtained using 2 methods—mean depth was recorded using a recording depth finder during each electrofishing effort, and a mean depth for the entire habitat unit was obtained by using the charting depth finder on 3 to 5 transects across the river width), water temperature and dissolved oxygen depth profiles (1-m depth intervals), conductivity (1 m below surface), and transparency (Secchi depth). In addition, once at each habitat unit at each site we qualitatively determined substrate type and abundance of woody debris (bottom sample with an Eckman dredge), with substrate classified as follows: 1=silt/clay, 2=sand, 3=pebble, 4=cobble, 5=boulder/bedrock, and woody debris classified with higher numbers representing greater amounts of woody debris (Paragamian 1990).

Spine Preparation

After disarticulation, spines were frozen and stored, and later soaked in soapy water to facilitate removal of remaining tissue. Once tissue was removed, spines were placed in 95% ethyl alcohol to accentuate annular rings (Conder and Hoffarth 1962). We made a single cut in the basal recess portion of the pectoral spine using a Buehler Isomet low speed bone saw equipped with a micrometer (Blouin and Hall 1990, McElroy et al. 1990), mounted the cut spine in black clay, and viewed it with cross-directed fiber optic light under a dissecting microscope to observe annual rings. All spines were aged independently by 2 readers. Differences were resolved by a second set of independent counts, and unresolved spines (blue catfish=1.3%, channel catfish=2.1%, flathead catfish=3.2%) were eliminated from the data set. Examination of eliminated fish showed no systematic size, species, or site bias.

In previous studies, varying methods and sectioning locations have been used in the preparation and reading of pectoral spines for aging catfish species. Historically most studies have found basal recess (BR) sections of the pectoral spines the best location for aging catfish (Sneed 1951, Marzolf 1955). However, due to resorption of annuli by the increasing size of the central lumen in the basal recess sections (Marzolf 1955, Minckley and Deacon 1959), several authors have recently used sections of the articulating process (AP) for aging (Langemeier 1965, Turner 1980, Quinn 1988). Despite this, the morphology of the AP sections dictate BR sections should still be used for backcalculation of length-at-age (Langemeier 1965, Turner 1980). Crumpton et al. (1984) found that BR, mid-spine, and AP spine sections all resulted in identical age assignments for channel catfish, white catfish *Ameiurus catus,* and brown bullhead *A. nebulosus* in Florida. To test whether differences may be present in the current study, a randomly selected subsample (N=110, or 8.5%) of AP sections was compared with corresponding BR sections.

To account for resorption of annuli in larger fish, we developed an objective method for deciding whether annuli had been reabsorbed similar to that proposed by Langemeier (1965). We used an ocular micrometer to measure the distance from (1) the focus of the central lumen to the outside of the central lumen and (2) from the focus to each annulus and calculated the mean annular distances for each age class within each river system. The mean radius obtained for the last annulus in age-1 fish was then used as a threshold value to determine whether reabsorption of the first annulus had occurred in older fish. This same process was used to determine threshold values for fish in all age groups in all systems. Mean values were determined within species in each system to account for variability in growth among species and systems. This method accounted for the resorption of annuli; however, it is based on the assumption that recent growth rates are similar to previous growth rates.

Data Analysis

We compared relative abundances across river systems by combining fish collected with all 3 methods across all time periods in each system. Abundances were then directly compared in terms of total catch and total weight. Mean length was computed for each species and compared using ANOVA (α=0.05).

We determined mortality rates by $\log_e$-transforming the number of individuals of each year class captured with electrofishing and regressing the value against age to create a catch curve for each species in each system. The slope (z) of the descending limb of the catch curve was used to determine mortality rates (Ricker 1975).

Length-at-age values were determined by back-calculating to the last annulus using the direct proportion method. By using only the last annulus, each fish collected represented only 1 data point on length-at-age curves. Growth was compared using the slopes of length-at-age curves with analysis of covariance (ANCOVA).

Habitat type preferences were determined by evaluating electrofishing catch-per-unit-effort (CPUE) differences through time in each habitat type for each system. Electrofishing was selected as the method used for comparison because of the size bias often associated with gill nets. CPUE data from the 2 electrofishing methods were tested for differences and combined when possible. Habitat variables were evaluated by first regressing each variable individually against catch rate to determine whether it could independently predict CPUE for each species. The variables were then entered into stepwise multiple regression analysis to evaluate the relative importance of each to catfish catch rates. Because of non-normal distributions, the effect of temperature on catch rate was tested using a 2 dimensional Kolmorgorov-Smirnov (2DKS) test (Garvey et al. 1998).

Results

Fish Collection

We collected 1,292 catfish across habitats and systems during 18 October 1994 through 1 December 1995, of which 530 were blue catfish, 243 were channel catfish, and 519 were flathead catfish. Both methods of electrofishing appeared generally ineffective at temperatures below about 18 C (Fig. 1). This pattern of catches was significant for all catfishes combined (2DKS, D=0.119, P=0.007) and for flathead catfish alone (2DKS, D=0.100, P=0.04). For blue catfish and channel catfish the pattern of catches with respect to temperature could not be distinguished from random. While catch rates of 0 occurred at all temperatures, the frequency of non-0 catch rates increased greatly above 18 C. Given this, we did not include electrofishing samples obtained when surface water temperature was below 18 C in catch rate data.

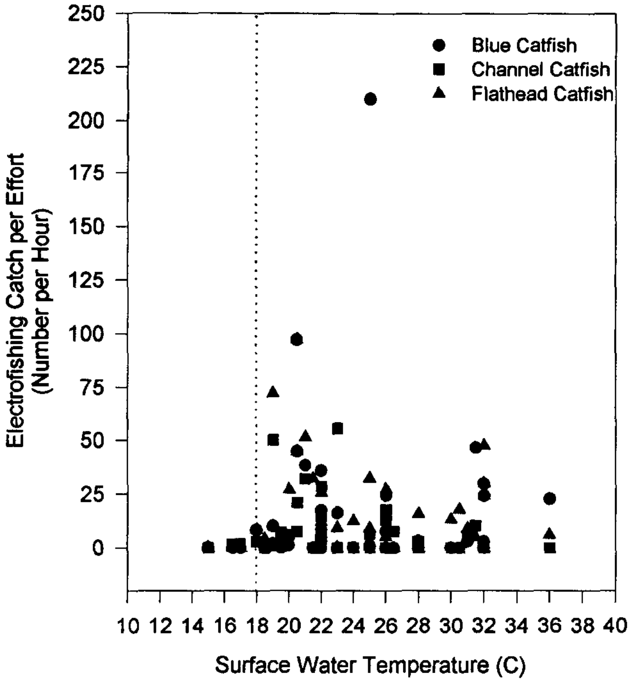

Figure 1. Standard electrofishing catch per effort (N/hour) as a function of surface water temperature (°C). Vertical dotted line represents 18 C below which electrofishing efficiency was greatly reduced.

Channel and blue catfish catch rates did not differ between electrofishing techniques (paired *t*-tests: T=0.10, P=0.93 for blue catfish, T=1.10, P=0.28 for channel catfish); however, catch rates of flathead catfish were higher with standard electrofishing than with the cable method (paired *t*-test: T=2.75, P=0.01). Therefore, catch data from both gears were combined for blue and channel catfish while only standard electrofishing data were used for flathead catch rate comparisons.

Relative Abundance and Size

Relative abundance estimates were calculated separately from catch rate comparisons by combining total catch of all 3 collection methods. Differences in relative abundance were found among species within systems (χ^2 test, df=6, P=0.001), with blue and flathead catfish more abundant than channel catfish across systems. In Wheeler, flathead catfish dominated, followed by blue catfish, and channel catfish.

Flathead and blue catfish were similarly abundant in Seldon, with channel catfish contributing less. In Mitchell, flathead and blue catfish were most abundant and channel catfish least abundant. Millers Ferry blue catfish were most commonly sampled, followed by flathead catfish and channel catfish (Fig. 2, left panels).

Flathead catfish biomass was generally greater than blue and channel catfish biomass. At Seldom, Mitchell, and Millers Ferry, flathead catfish dominated the biomass, followed by blue catfish and channel catfish (Fig. 2, right panels). In contrast, blue catfish in Wheeler contributed most of the catfish biomass, followed by flathead and channel catfish.

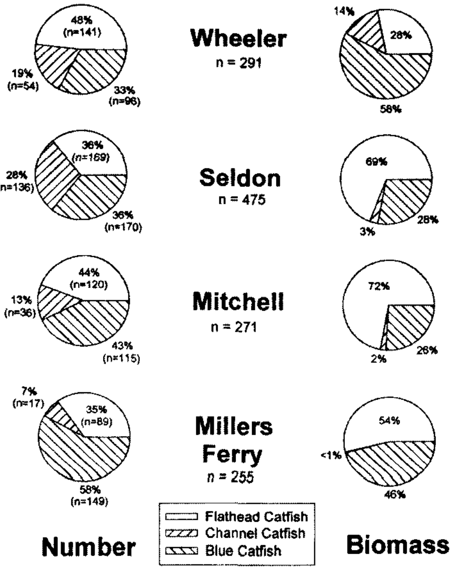

Figure 2. Relative species abundance in terms of total number (left panels) and biomass (right panels) in each system.

Table 1. Mean length (TL in mm ± 1 SE) of blue, channel, and flathead catfish in 4 Alabama systems. Superscript letters that differ within a row indicate significant differences among systems.

	Systems			
	Wheeler	Seldom	Mitchell	Millers Ferry
Blue catfish	498^{a}±15 mm	312^{c}±13 mm	382^{b}±14mm	312^{c}±16 mm
Channel catfish	423^{a}±9 mm	199^{c}±7 mm	260^{b}±18 mm	227^{bc}±15 mm
Flathead catfish				
Tail race	289^{c}±13 mm	513^{a}±27 mm	435^{b}±31 mm	549^{a}±31 mm
Main channel	320^{b}±41 mm	306^{b}±19 mm	512^{a}±32 mm	345^{b}±32 mm
Tributary	406^{a}	407^{a}±109 mm	491^{a}±54 mm	315^{a}±93 mm

In addition to total weight differences, length differences occurred across systems for each species (Table 1; ANOVA; all $P<0.001$). Blue catfish were longest in Wheeler, followed by Mitchell, and were shortest in Millers Ferry and Seldon (Table 1). Channel catfish were longest in Wheeler, intermediate in Mitchell, and shortest in Seldon and Millers Ferry. Among-system differences in flathead catfish length varied with habitat types (Table 1); there were no among-system differences in the length of flathead catfish collected in backwater habitats, but in the main channel, fish were longest in Mitchell, and in tributaries they were longest in Millers Ferry and Seldon (Table 1).

Growth

Ages determined using AP sections agreed with ages determined using BR sections in 75% of the subsample ($N=82$ of 110 fish). Further examination of sections that differed revealed that in 72% of the differences, ages were greater using AP sections than BR sections ($N=20$ of 28). In sections that differed, we found most differences resulted from incorrect ages assigned to the AP sections, due to false checks, or difficulty in reading AP sections. We found AP sections generally more difficult to read, and agreement between readers was lower than for BR sections. Additionally, false annuli that were identified with incomplete or faint rings (Layher 1981) were easier to identify in BR sections than AP sections, where incomplete rings must be used for aging. This problem with AP sections became obvious after several of the discrepancies were noted on age I and II fish, where fish should not yet have reabsorbed any annuli (as confirmed with examination of the first annulus in relation to the central lumen on BR sections). Further, false annuli existed for many of the younger fish that were aged incorrectly using AP sections. Therefore, we used BR sections to assign catfish ages.

Lumen resorption of at least 1 annulus was found in 27% of flathead catfish, 8% of blue catfish, and 0.4% of channel catfish. Flathead catfish reabsorption of annuli was first detected in age-4 fish in all systems, with occurrence increasing with fish age. Blue catfish annuli reabsorption was first noted in age-4 fish in Mitchell and Seldon, and after age 5 in Millers Ferry, and age 13 in Wheeler. Reabsorption of annuli in channel catfish was rare, being detected only once in this study with an age-5 fish from Mitchell.

Because fish were collected throughout the year, use of length at capture would bias length at age comparisons. Thus, we backcalculated length at last annulus for comparison. Differences in length-at-age were found across systems for each species with analysis of covariance (ANCOVA). Growth of blue and channel catfish was highest in Wheeler. Blue catfish growth in Mitchell and Wheeler was higher than that in Millers Ferry and Seldon (ANCOVA; $P=0.0001$). Channel catfish growth was higher in Wheeler, Mitchell, and Millers Ferry than in Seldon (ANCOVA; $P=0.0001$). Similarly, flathead catfish growth differed across systems (ANCOVA; $P=0.0001$), being lower in Wheeler than in Mitchell, Millers Ferry, and Seldon, which all had similar growth (Fig. 3). Across systems, growth differed among species, with either flathead or blue catfish having the highest growth in each system.

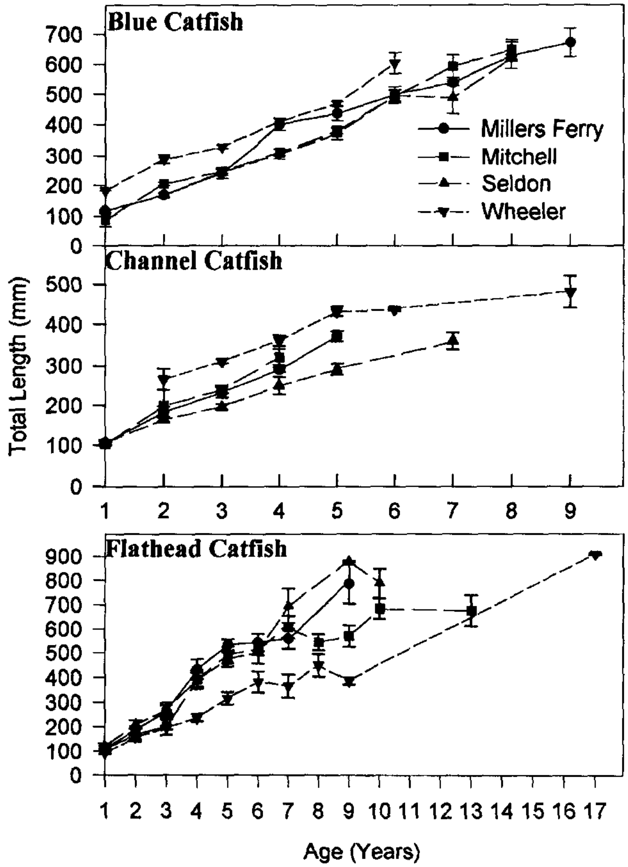

Figure 3. Mean (±1 SE) length (mm) at age of blue catfish (top panel), channel catfish (middle panel), and flathead catfish (bottom panel) in 4 Alabama systems. Because lengths were backcalculated for the last annulus for all fish, each fish contributed only 1 observation to these data.

Insufficient collection of older channel catfish and younger flathead catfish prevented the use of catch curve analysis to estimate mortality for these species. However, for blue catfish, mortality did not differ among systems (ANCOVA, $P=0.20$; Millers Ferry: $S=0.73$, $z=-0.31$; Mitchell: $S=0.44$, $z=-0.82$; Seldon: $S=0.69$, $z=-0.37$; Wheeler: $S=0.61$, $z=-0.50$).

Habitat Use

Catch rates of blue catfish were similar in all habitat types across systems (ANOVA: system × habitat type interaction effect: $F=0.30$, $df=6, 52$, $P=0.93$; habitat

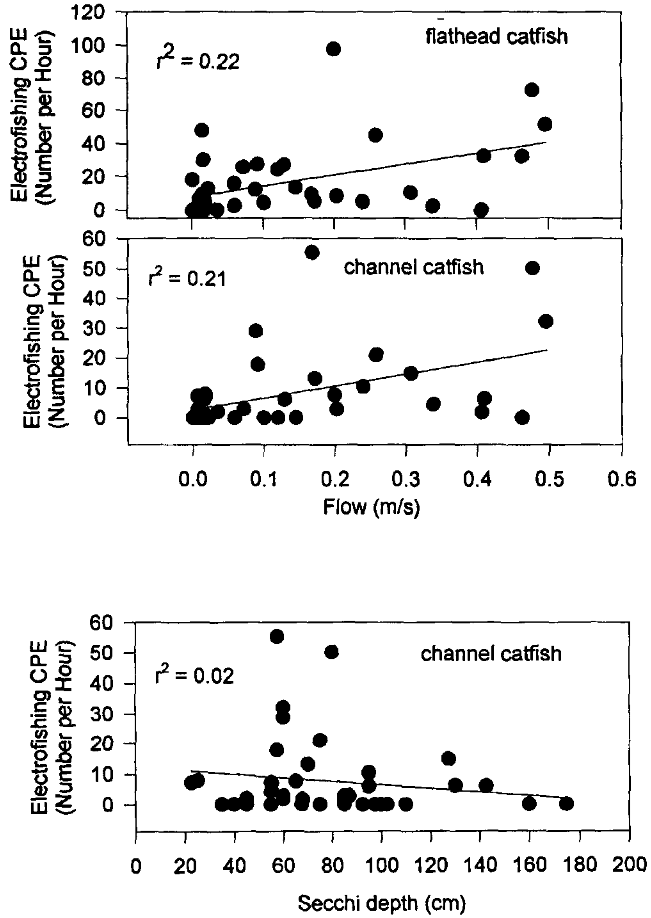

Figure 4. Relationship between flathead catfish catch-per-effort (CPE) and flow (m/sec) for fish collected in all systems (top panel), and between channel catfish CPE and flow (middle panel), and channel catfish CPE and water transparency (measured by Secchi depth, bottom panel) in all systems.

effect: F=0.58, df=2, 52, *P*=0.56) and across seasons (season × habitat type interaction effect: F=0.21, df=6, 52, *P*=0.97; season effect: F=0.30, df=3, 52, *P*=0.82). However, blue catfish length differed among habitat types (ANOVA: habitat type effect: F=13.16, df=2, 509, *P*=0.0001; system × habitat type interaction effect: F=0.36, df=6, 509, *P*=0.90), being greatest in tailrace habitats, followed by tributary and main channel habitats, which did not differ.

Similarly, channel catfish catch rates did not differ among habitat types (ANOVA; habitat and all interaction terms, all *P*>0.43). However, when comparing lengths, the system × habitat type interaction term was significant (ANOVA; *P*=0.03), indicating among-system differences in length patterns in the 3 habitat types. As such, habitat differences were tested individually for each system. Channel catfish were longer in tributaries in 3 systems (Mitchell, Seldon, Wheeler), and similar among habit types in Millers Ferry. Relative to seasonal patterns, channel catfish length did not differ across habitat types in spring, summer, or winter. In fall, however, fish were longer in tailrace and tributary habitats than in the main channel (ANOVA: habitat × season interaction term: F=2.51, df=6, 222, *P*=0.02).

Flathead catfish catch-per-effort also did not differ among habitat types and seasons (ANOVA: all *P*>0.26). Relative to length of flathead catfish across habitat types, although both the system × habitat type interaction term (F=8.84, df=6, 499, *P*=0.0001) and habitat type × season interaction term (F=9.67, df=5, 499, *P*=0.0001) were significant, no patterns were evident upon examination of the data. Overall, there was no difference in lengths of flathead catfish across habitats (F=0.51, df=2, 499, *P*=0.60).

We compared 8 habitat variables with catch rates of each species using stepwise multiple regression analysis, using F-change tests to identify variables considered most important predictors of catch rate. For flathead catfish, flow and woody debris were most important as predictors of catch rate (R^2=0.34), with flow being positively correlated with catch rate (Fig. 4) and with moderate and abundant amounts of woody debris yielding higher catch rates. Substrate was the most important predictor of blue catfish catch rate (R^2=0.28), with pebble/cobble substrates yielding increased catch rates. For channel catfish, flow (positively correlated, Fig. 4) and water transparency (negatively correlated, Fig. 4), were the most important predictors of catch rate (R^2=0.20).

Discussion

Fish Collection

We successfully collected all 3 catfish species using 3 types of sampling. Low-frequency (15 Hz–30 Hz) electrofishing yielded the best results relative to catch-per-effort and distributions. Although catch rates of blue and channel catfish did not differ between electrofishing gears, catch rates for flathead catfish were lower when the cables were used. Constraints of cable electrofishing, combined with species-specific responses to electricity may account for this difference. During cable electrofishing, the boat could be moved only in reverse to prevent tangling of the cables in the boat motor, greatly reducing both mobility and speed. Flathead catfish were more difficult to collect because they tended to remain active once stunned, often requiring pursuit for capture (particularly for larger individuals). Blue and channel catfish, on the other hand, remained stunned for longer periods.

Unfortunately, sampling with low-frequency electrofishing was only effective during spring, summer, and fall when water temperatures exceeded 18 C. While we did successfully collect catfish with gill nets during all seasons, catch rates were similarly lower in winter, likely due to reduced fish activity at low temperatures (Crawshaw 1984). As is often the case with gill nets, the lack of collection of small fish combined with our considerably lower catches reduced our ability to use gill net catch data for comparison across systems and habitats as well as for catch curve mortality estimation.

Relative Abundance and Size

Relative abundance of both blue catfish and flathead catfish was higher than that of channel catfish in all systems. Additionally, flathead catfish contributed a greater percentage of total catfish biomass and on average were larger than channel or blue catfish in 3 of 4 systems. Flathead catfish domination of the Ictaluridae in 3 of 4 systems, in addition to published accounts of their dominance, suggest their ability to dominate the catfish fauna of southeastern U.S. waters. When introduced in a Georgia stream, flathead catfish dominated all piscivores in the mainstream habitat within 10 years, displacing native ictalurids (Thomas 1993). Similarly, flathead catfish introduction in a North Carolina stream was followed by reduced ictalurid abundance (Guier et al. 1981).

Age and Growth

Basal recess sections proved superior to AP sections for aging catfish in this study. This contrasts with studies in which articulating process sections were found to be superior (Langemeier 1965, Quinn 1988). However, Crumpton et al. (1984) found ages calculated from the 2 pectoral spine regions in channel catfish did not differ. The primary advantage of the AP section is the lack of a lumen in this region of the spine. However, in our study the error associated with reading AP sections combined with the inability to backcalculate length-at-age, offset any advantage provided by the lack of a lumen. We were able to correct for error due to potential resorption of annuli by the central lumen (using the mean location of the annuli in age-1 to age-4 fish from the same system) and thus use BR sections for both aging and length backcalculation.

Based on growth data, none of our study systems provided conditions that were simultaneously best for growth of all 3 species. While growth of blue and channel catfish was highest in Wheeler and Mitchell, growth of flathead catfish was simultaneously lowest in Wheeler. Flathead catfish growth was similar across the remaining systems, suggesting similar conditions existed for growth. Blue catfish growth was lowest in Millers Ferry and channel catfish growth was lowest in Seldon.

Table 2. Blue catfish length-at-age data from the current and previous studies. Sites in the current study are Millers Ferry (Ala-MFE), Mitchell (Ala-MIT), Seldon (Ala-SEL), and Wheller (Ala-WHE), all in Alabama.

	Fish Age														
State	I	II	II	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Ala-MFE	118	168	240	401	436	499	538	628	673						
Ala-MIT	88	204	248	313	381	492	592	648							
Ala-SEL	117	167	244	307	372	495	489	620							
Ala-WHE	182	289	331	411	469	604									
Ala[a]	124	221	338	450	531	612	693	803	942						
Ky[b]	133	221	274	317	368	425	485	548	585	608	693	736	813		
Mo[c]	130	206	262	320	378	427	483	566	604	638	734	767	622	828	1148
La[d]	191	386	508	638	749	848									
Okla[e]	145	254	351	442	533	655	770	871	1026						
Tenn[f]	119	211	254	297	338	432	480	584	683	846					
Tenn[g]	141	229	287	342	401	446	501	522	551	587					

a. Kelley 1968.
b. Hale and Timmons 1989.
c. Graham 1995.
d. Kelley and Carver 1965.
e. Jenkins 1956.
f. Condor and Hoffarth 1958.
g. Hale and Timmons 1990-riverine fishes.

Table 3. Channel catfish length-at-age data from the current and previous studies. Sites in the current study are as in Table 2.

	Fish Age												
State	I	II	II	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Ala—MFE[a]	46	190	291	368	422	471	526						
Ala—MFE	105	182	233	291	372								
Ala—MIT[a]	35	120	196	243	290	349							
Ala—MIT	103	198	239	321									
Ala—SEL[a]	57	165	256	321	394	388							
Ala—SEL	106	165	196	250	291		361						
Ala—WHE		266	311	431	437				481				
Iowa[b]	74	158	216	263	295	368	422	467	433	347	477		
Mo[c]	94	173	216	267	302	353	363	391	404	422	602		597
Ohio[d]	63	166	226	268	298	328	362						
S.C.[e]	86	185	284	368	442	531	602	665	726	772	808	853	917
Tenn[f]	114	206	264	287	323	391	406	495	566	640			
Tenn[g]	99	175	272	325	373	424	457	541					

a. Wahlquist 1971.
b. Harrison 1957.
c. Graham 1995.
d. DeRoth 1965.
e. Stevens 1959.
f. Conder and Hoffarth 1958.
g. Carroll and Hall 1964.

Table 4. Flathead catfish length-at-age data from the current and previous studies. Sites in the current study are as in Table 2.

	Fish Age																
State	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
Ala—MFE	110	189	265	433	534	544	560		785								
Ala-MIT	109	168	204	391	492	517	610	545	571	684							
Ala—SEL	122	211	271	392	474	503	697		879								
Ala—WHE	93	157	199	239	318	384	367	451	387								909
Tenn[a]	132	239	351	472	589	610	737	790	841	879	947	991	1008	1013	1036	1067	
Ga[b]	203	352	497	613	710	774	833	935	1000								
Kans.[c]	164	230	316	412	517	591	700	796	837	869	894	909	926	942			
Iowa[d]	142	269	393	469	550	600	674	714									
Neb.[e]	128	210	305	383	447	518	595	623	606	760	822	858					
Okla[f]	117	246	386	508	594	658	734	823	892	973	991	1054	1087	1099			

a. Carroll and Hall 1964. b. Quinn 1988.

c. Layher 1981. d. Mayhew 1969.

e. Langemeier 1965. f. McCoy 1953.

Flathead and blue catfish had higher growth rates than channel catfish in all systems. These results were similar to previous studies examining growth of several catfish species within a system. In Missouri and Tennessee, channel catfish growth rates were lower than for blue catfish (Conder and Hoffarth 1962, Graham 1995). Similarly, in a Tennessee reservoir, flathead catfish grew faster than channel catfish (Carroll and Hall 1964).

Relative to other systems (Table 2), blue catfish in Alabama grew faster than in Missouri (Graham 1995) and slower than in Louisiana (Kelley and Carver 1965) and Oklahoma (Jenkins 1956) but similar to that in Tennessee (Conder and Hoffarth 1962, Hale and Timmons 1990), Kentucky (Hale and Timmons 1989), and in the Tombigbee River in Alabama (Kelley 1968). Length of the growing season may be responsible given that Alabama would have a longer growing season than Tennessee and Missouri but not Louisiana (and perhaps Oklahoma). In contrast, channel catfish growth in our Alabama systems was similar to that expressed in other regions (Table 3). Finally, flathead catfish length-at-age in Alabama was generally lower than that reported in previous studies (Table 4). Several previous studies were conducted on bodies of water with rapidly expanding flathead catfish populations. These studies reported exceptional rates of growth for both recently introduced populations or populations located in recently-formed reservoirs. Additionally, we found flathead catfish had the highest rate of lumen resorption. If previous studies did not adequately account for the resorption of annuli, then reported lengths-at-age would be higher than expected. Further, we did not backcalculate length-at-age as in previous studies: backcalculated lengths are subject to inflated values for early year classes particularly if growth is rapid for recently introduced populations or populations in newly-formed reservoirs.

Unfortunately, too few older channel catfish and younger flathead catfish were collected in this study to allow generation of mortality estimates via catch-curve analysis. However, our observed annual mortality for blue catfish (27%–57%) was within the range of previously reported mortality rates in exploited populations (36%–68% for blue catfish in Kentucky Lake, Tenn., Hale and Timmons 1988; 29% for blue catfish in Lake of the Ozarks, Mo., Graham 1995).

Habitat use

In this study, blue catfish did not consistently use any habitat type more than the others across systems. This contrasted with a previous study that suggested higher harvest rates of blue catfish in a Missouri tailwater were due to attraction of blue catfish to these regions (Graham 1995). In 2 rivers in the Tennessee-Tombigbee Waterway, Jackson (1995) found that blue catfish <30 cm did not prefer any habitat type, while those ≥30 cm were more abundant in main channel habitats than in tailwater habitats. While 2 previous studies in Alabama indicated that blue catfish prefer deeper, slower waters (Swingle 1952, Ala. Power Co. 1994), neither depth nor flow were significant predictors of catch rate in the present study; substrate type was the only significant predictor. The intermediate-sized pebble and cobble substrates that yielded higher catch rates may provide more suitable foraging for both invertebrates and fish prey items than smaller or larger substrates.

Overall, channel catfish catch rates did not differ across habitat types. However, our regression model indicated flow and water transparency to be the best predictors of channel catfish catch rate. The positive relationship with flow agrees with Robinson (1985) who found channel catfish preferred fast-water habitats but not with the findings of Jackson (1995) where channel catfish were more abundant in main channel habitats than in tailwaters (thought to be to avoid higher current velocities). McMahon and Terrell (1982) report that while channel catfish are abundant in reservoirs with both low and high turbidity, low to moderate turbidities are considered best for survival and growth of channel catfish.

Catch rates of flathead catfish were higher in the tailrace habitat in only 1 of 4 systems. All 4 systems had high flows in the tailrace, but only Seldon had abundant woody debris in this habitat. Results of multiple regression analysis showed flow and high amounts of woody debris to both be positively correlated with catch rate. Previous studies have indicated that flathead catfish use snags for cover, foraging, and spawning (Minckley and Deacon 1959).

Conclusions

Flathead catfish was the dominant catfish species in 3 of the 4 systems. Their higher growth rate in 3 of 4 systems, and a commercial fishery focused on blue and channel catfish likely combined to allow flathead catfish dominance over blue and channel catfish in these systems. Channel catfish populations were characterized by low abundance and small size. In Millers Ferry, Mitchell, and Seldon, most channel catfish collected appeared to be juveniles, having lengths below reported length at maturity in South Dakota, Louisiana, and Tennessee (Davis and Posey 1958, Elrod 1974, Hale and Timmons 1988).

Catch rates of both flathead and channel catfish were higher in waters associated with higher flow, with flathead catfish also being associated with woody debris while channel catfish were associated with greater water transparency. This suggests that it may be important to maintain some degree of water release from dams at all times to enhance habitat for flathead and channel catfish. Further, the addition of woody debris in portions of systems that have sufficient moving water, particularly in the tailrace, may also improve habitat quality for flathead catfish.

Literature Cited

Alabama Power Company. 1994. Jordan radiotelemetry study. Ala. Power Co., Birmingham, Ala., 1st Annu. Rep. 38pp.

Blouin, M. A. and G. R. Hall. 1990. Improved method for sectioning pectoral spine of catfish for age determination. J. Freshwater Ecol. 5:489–490.

Carrol, B. B. and G. E. Hall. 1964. Growth of catfishes in Norris Reservoir, Tennessee. J. Tenn. Acad. Sci. 39:86–91.

Conder, J. R. and R. Hoffarth. 1962. Growth of channel catfish, *Ictalurus punctatus,* and blue catfish *Ictalurus furcaturs,* in the Kentucky Lake portion of the Tennessee River in Tennessee. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 12:348–354.

Corcoran, M. F. 1979. Electrofishing for catfish: use of low-frequency pulsed direct current. Prog. Fish-Cult. 41:200–201.

Crawshaw, L. I. 1984. Low temperature dormancy in fish. Am. J. Physiology 246:479–486.

Crumpton, J. E., M. M. Hale, and D. J. Renfro. 1984. Aging of three species of Florida catfish utilizing three pectoral spine sites and otoliths. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 38:335–341.

Cunningham, K. K. 1995. Comparison of stationary and mobile electrofishing for sampling flathead catfish. N. Am. J. Fish. Manage. 15:515–517.

Davis, J. T. and L. E. Posey. 1958. Length at maturity of channel catfish *(Ictalurus lacustris)* in Louisiana. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 12:72–74.

DeRoth, G. C. 1965. Age and growth studies of channel catfish in western Lake Erie. J. Wildl. Manage. 29:280–286.

Elrod, J. H. 1974. Abundance, growth, survival, and maturation of channel catfish in Lake Sharpe, South Dakota. Trans. Am. Fish. Soc. 103:53–58.

Fisheries Information Management Systems. 1992. Recreational use and sport fishing survey Jordan dam tailwater on the Coosa River (July 1990–June 1991). Ala. Power Co., Birmingham, Ala., 82pp.

Fisheries Information Management Systems. 1993. Recreational use and sport fishing survey Jordan Dam tailwater on the Coosa River (July 1991–June 1992). Ala Power Co., Birmingham, Ala. 93pp.

Fisheries Information Management Systems. 1994. Recreational use and sport fishing survey Jordan Dam tailwater on the Coosa River Final Report (July 1992–June 1993). Ala. Power Co., Birmingham, Ala. 175pp.

Garvey, J. E., E. A. Marschall, and R. A. Wright. 1998. From star charts to stoneflies: detecting relationships in continuous bivariate data. Ecology 79:442–447.

Graham, K. 1995. A study of catfish in the tailwaters of Harry S. Truman dam and upper Lake of the Ozarks. Sport Fish Restor. Proj. F-1-R-44, Study S-38. Mo. Dep. Conserv. Perform. Rep. 18pp.

Guier, C. R., L. E. Nichols, and R. T. Rachels. 1981. Biological investigation of flathead catfish in the Cape Fear River. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 35:607–621.

Hale, R. S. and T. J. Timmons. 1988. Spawning season and maturity of blue catfish in Kentucky Lake. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 42:128–132.

——— and ———. 1989. Comparative age and growth of blue catfish in the Kentucky portion of Kentucky Lake between 1967 and 1985. Trans. Ky. Acad. Sci. 50:22–26.

——— and ———. 1990. Growth of blue catfish in the lacustrine and riverine areas of the Tennessee portion of Kentucky Lake. J. Tenn. Acad. Sci. 65:86–90.

Harrison, H. M. 1957. Growth of the channel catfish, *Ictalurus punctatus,* in some Iowa waters. Iowa Acad. Sci. 64:657–666.

Jackson, D. C. 1995. Distribution and stock structure of blue catfish and channel catfish in macrohabitats along riverine sections of the Tennessee-Tombigbee Waterway. N. Am. J. Fish. Manage. 15:845–853.

——— and J. R. Dillard. 1991. Sport fisheries exploitation in riverine sections of the Tennessee-Tombigbee Waterway. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 45:333–341.

Jenkins, R. M. 1956. Growth of blue catfish *(Ictalurus furcatus)* in Lake Texoma. Southwestern Nat. 1(4):166–173.

Kelley, J. R. 1968. Growth of blue catfish, *Ictalurus furcatus (LeSueur),* in the Tombigbee

River of Alabama. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 22: 248–255.

——— and D. C. Carver. 1965. Age and growth of blue catfish, *Ictalurus furcatus* (LeSueur), in the recent delta of the Mississippi River. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 19:296–299.

Langemeier, R. N. 1965. Effects of channelization on the limnology of the Missouri River, Nebraska, with emphasis on food habits and growth of the flathead catfish. M.S. Thesis, Univ. Mo., 156pp.

Layher, W. G. 1981. Comparison of annulus counts of pectoral and dorsal spines in flathead catfish. Prog. Fish-Cult. 43(4):218–219.

Lee, L. A. and J. W. Terrell. 1987. Habitat suitability index models: flathead catfish. U.S. Dep. Int., Fish and Wildl. Serv. FWS/OBS-82/10.152. 39pp.

Lemmons, R. P. and G. D. Schnell. 1994. Flathead catfish ecology and population structure in Oklahoma prairie streams. Okla. Dep. Wildl. Conserv. Final Rep. F-37-R(20). 60pp.

Marzolf, R. G. 1955. Use of the pectoral spines and vertebrae for determining age and rate of growth of the channel catfish. J. Wildl. Manage. 19:243–249.

Mayhew, J. K. 1969. Age and growth of flathead catfish in the Des Moines River, Iowa. Trans. Am. Fish. Soc. 98:118–121.

McElroy, M. G., T. Morrison, and R. Gouget. 1990. Age, growth, and maturity of channel catfish in two southeast Louisiana Lakes. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 44:13–19.

McCoy, H. A. 1953. Rate of growth of flathead catfish in twenty-one Oklahoma lakes. Proc. Okla. Acad. Sci. 34:47–52.

McMahon, T. E. and J. W. Terrell. 1982. Habitat suitability index models: channel catfish. U.S. Dept. Int., Fish and Wildl. Serv. FWS/OBS-82/10.2. 29pp.

Minckley, W. L. and J. E. Deacon. 1959. Biology of the flathead catfish in Kansas. Trans. Am. Fish. Soc. 88:344–355.

Moss, J. L. and W. H. Tucker. 1988. Growth and harvest of catfish in three Alabama public lakes. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 42:149–156.

Newcomb, B. A. 1989. Winter abundance of channel catfish in the channelized Missouri River, Nebraska. North Am. J. Fish. Manage. 9:195–202.

Paragamian, V. L. 1990. Characteristics of channel catfish populations in streams and rivers of Iowa with varying habitats. J. Iowa Acad. Sci. 97:37–45.

Prather, E. E. 1959. The use of channel catfish as sport fish. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 13:331–335.

Quinn, S. P. 1986. Effectiveness of an electrofishing system for collecting flathead catfish. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 40:85–91.

———. 1988. Flathead catfish abundance and growth in the Flint River, Georgia. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 42:141–148.

———. 1989. Evaluation of a length-categorization system for flathead catfish. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 43:146–152.

———. 1995. Catfish for the future. The In-Fisherman. 7:101–104.

Ricker, W. E. 1975. Compilation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. 191. 382pp.

Robinson, J. W. 1977. The utilization of dikes by certain fishes in the Missouri River. Final Rep., Study B and C, Job 3. Natl. Mar. Fish. Serv. Proj. 2-199-R. Mo. Dep. Conserv. 12pp.

———. 1985. The development of a qualitative system to evaluate populations of flathead catfish and channel catfish in the Missouri and Mississippi Rivers. Perf. Rep., Dingell-Johnson Proj. F-1-R-34 Study S-30, Mo. Dep. Conserv. 9pp.

Sneed, K. E. 1951. A method for calculating the growth of channel catfish *Ictalurus lacustris punctatus.* Trans. Am. Fish. Soc. 80:174–183.

Spencer, S. L., W. E. Swingle, and T. M. Scott. 1965. Commercial fishing in the Mobile Delta, Alabama during the period of July 1, 1963 to June 30, 1964. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 19:432–438.

Stevens, R. E. 1959. The white and channel catfishes of the Santee-Cooper Reservoir and tailrace sanctuary. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 13:203–219.

Swingle, H. S. 1952. Fish populations in Alabama rivers and impoundments. Trans. Am Fish. Soc. 81:47–57.

Thomas, M. E. 1993. Monitoring the effects of introduced flathead catfish on sport fish populations in the Altamaha River, Georgia. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 47:531–538.

Turner, P. R. 1980. Procedures for age determination and growth calculations of flathead catfish. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 34:253–262.

U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, Bureau of the Census. 1996. National survey of fishing, hunting, and wildlife-associated recreation. Publ. FHW96/AL, U.S. Fish and Wildl. Serv. 87pp.

Wahlquist, H. 1971. Age and growth of channel catfish, *Ictalurus punctatus,* in the Alabama and Tombigbee River drainage. Ph.D. Diss. Auburn Univ., Auburn, Ala. 76pp.