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[Article]

Comparison of Native and Introduced Flathead Catfish Populations in Alabama and Georgia: Growth, Mortality, and Management

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Abstract.—We compared growth of flathead catfish *Pylodictis olivaris* from two native populations in Alabama (Coosa and Tallapoosa rivers) and two introduced populations in Georgia (Ocmulgee and Satilla rivers). We also compared mortality rates and potential outcomes of various management regimes (minimum length limits [MLLs]) among the populations. Total length–$\log_{10}$(age) regression slopes for introduced fish were higher than those for native fish, and von Bertalanffy growth coefficients (K) were greater for introduced fish (Ocmulgee: 0.195; Satilla: 0.201) than for native individuals (Coosa: 0.057; Tallapoosa: 0.059). Therefore, introduced flathead catfish grew more rapidly than those in their native range. Mortality (instantaneous mortality rate, Z) was higher in the Satilla River population ($Z = -0.602$) than in the Ocmulgee River ($Z = -0.227$) and Coosa River ($Z = -0.156$) populations. However, fish in the Satilla River population had been introduced for only 10 years and presumably did not reach their theoretical maximum age, potentially biasing the mortality estimate for that population. Simulation of management regimes in Fishery Analyses and Simulation Tools software predicted that maximum biomass of flathead catfish in the Ocmulgee (1,668 kg) and Satilla (1,137 kg) rivers was substantially larger than that in the Coosa (873 kg) and Tallapoosa (768 kg) populations. However, increased exploitation rates in the Ocmulgee and Satilla River populations resulted in dramatic declines in overall biomass, especially at lower MLLs (254 and 356 mm, respectively). Therefore, in systems where introduced flathead catfish represent an important recreational fishery but have dramatically reduced the abundance of native fishes through predation, minimal protection is recommended. We contend that rapid growth of introduced flathead catfish has major implications for their management and the conservation of native fishes.

The flathead catfish *Pylodictis olivaris* is primarily a riverine species that is native to the Mobile (Alabama), Mississippi–Missouri, and Rio Grande River drainages and portions of the lower Great Lakes region (Jackson 1999; Boschung and Mayden 2004). Flathead catfish are dominant predators in river systems and usually are exclusively piscivorous as adults (Jackson 1999; Jolley and Irwin 2005; Pine et al. 2005). Introduced in rivers throughout the Atlantic Slope of the southeastern USA (Guier et al. 1984; Quinn 1988; Thomas 1995; Dobbins et al. 1999; Jackson 1999), flathead catfish have negatively impacted native fish populations through predation (Guier et al. 1984; Thomas 1995). Thomas (1995) observed a decline in abundances of redbreast sunfish *Lepomis auritus* and bullheads *Ameiurus* spp. as flathead catfish rapidly expanded in the Altamaha River, Georgia. In the Altamaha River, centrarchids and ictalurids were the dominant prey items consumed by flathead catfish (Weller and Robbins 2001).

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Centrarchids were also the most common fish items consumed by introduced flathead catfish in North Carolina coastal rivers (Pine et al. 2005). Pine et al. (2005) suggested that centrarchids, such as native redbreast sunfish, that did not coevolve with flathead catfish in these systems were "naïve" to catfish and thus more susceptible to flathead catfish predation.

Most recently, substantial declines in bullhead and redbreast sunfish abundance have been observed in a section of the Satilla River, Georgia, where flathead catfish have become well established after their introduction in the mid-1990s (D.H., unpublished data). In an effort to benefit impacted native fishes in the Satilla River system, agency biologists have used boat electrofishing in an attempt to remove flathead catfish from the system (D.H., unpublished data). In addition to electrofishing removal efforts, harvest is encouraged; there is currently no minimum length limit (MLL) or daily creel limit on flathead catfish in the Satilla River. However, the level of exploitation that is required to considerably reduce population size is unknown. Before such an estimate of exploitation can be assessed, the flathead catfish population in the Satilla River must be fully characterized.

Although growth rates have been reported for flathead catfish from populations in the Southeast and other regions of the USA (Jenkins 1954; Carroll and Hall 1964; Pisano et al. 1983; Guier et al. 1984; Quinn 1989; Young and Marsh 1990; Mayo and Schramm 1999; Grabowski et al. 2004), no studies have been conducted providing a detailed comparison of characteristics (e.g., growth, survival) between introduced and native flathead catfish populations. Researchers have suggested that flathead catfish growth in introduced populations is faster than that in native populations, at least during the population expansion that occurs after introduction (Guier et al. 1984; Quinn 1989; Jackson 1999; Nash 1999; Kwak et al. 2006). However, statistical analyses have not been conducted or have been limited in full support of this assertion. Kwak et al. (2006) compared growth and mortality among three introduced populations in North Carolina, but statistical comparisons were not conducted with native populations. If substantial differences in growth rates, survival, and other parameters exist among introduced and native flathead catfish populations, implementation of management regimes (e.g., MLLs or daily creel limits) could vary considerably among introduced and native populations.

The primary goal of our study was to compare population characteristics (growth and mortality) between native flathead catfish populations in Alabama and introduced populations in Georgia. We also assessed the implementation of management regimes (i.e., MLLs) on native and introduced populations and predicted what levels of exploitation (or harvest) would substantially reduce flathead catfish biomass in an introduced population.

Methods

Flathead catfish were sampled from two native populations in Alabama and two introduced populations in Georgia. In Alabama, we collected fish from regulated river sections within the Mobile River basin, which included the lower Coosa and middle and lower Tallapoosa rivers (Figure 1). In Georgia, flathead catfish were collected from the Ocmulgee and Satilla rivers (Figure 1). Boat electrofishing (low-pulse frequency; 15 pulses/s) was our primary fish collection method; however, slat boxes were used to collect three flathead catfish (1% of the 292 fish sampled) from the Coosa River. The addition of these three data points resulted in no changes in the instantaneous mortality rate or von Bertalanffy growth coefficients for the Coosa River population.

Laboratory methods.—Flathead catfish were weighed (g) and measured (mm total length [TL]), and saggital otoliths were extracted for aging. Fish ages were estimated with methods that have been described and validated for channel catfish *Ictalurus punctatus* and used for flathead catfish (Nash and Irwin 1999; Buckmeier et al. 2002). Otoliths were the most efficient and accurate method for aging flathead catfish, especially for age-5 and older fish (Nash and Irwin 1999). Two readers aged fish independently, and any differences in age between readers were reconciled by concert reads (i.e., mutual examination; Buckmeier et al. 2002).

Statistical analysis.—Von Bertalanffy growth models ($L_t = L_\infty\{1 - e^{-k[t-t_0]}\}$, where L_t is TL at time t, L_∞ is theoretical maximum TL, e is the base of natural logarithms, and k is the growth coefficient) were computed for populations from the Coosa, Tallapoosa, Ocmulgee, and Satilla rivers. Data from the middle and lower Tallapoosa River were combined to improve the overall sample size for analyses; statistical comparisons indicated that mean TLs at age were similar between the middle and lower sections of the Tallapoosa River (*t*-tests). Analysis of covariance (ANCOVA) was used to compare slopes of TL–$\log_{10}$(age) regressions among the four populations. Analysis of covariance was also used to compare slopes of catch-curve regressions (i.e., instantaneous mortality rate, Z) among populations from the Coosa, Ocmulgee, and Satilla rivers (SAS 2001). Data were insufficient to conduct catch-curve analysis for the Tallapoosa River population, because fish were collected over several sampling years (<50 fish/year).

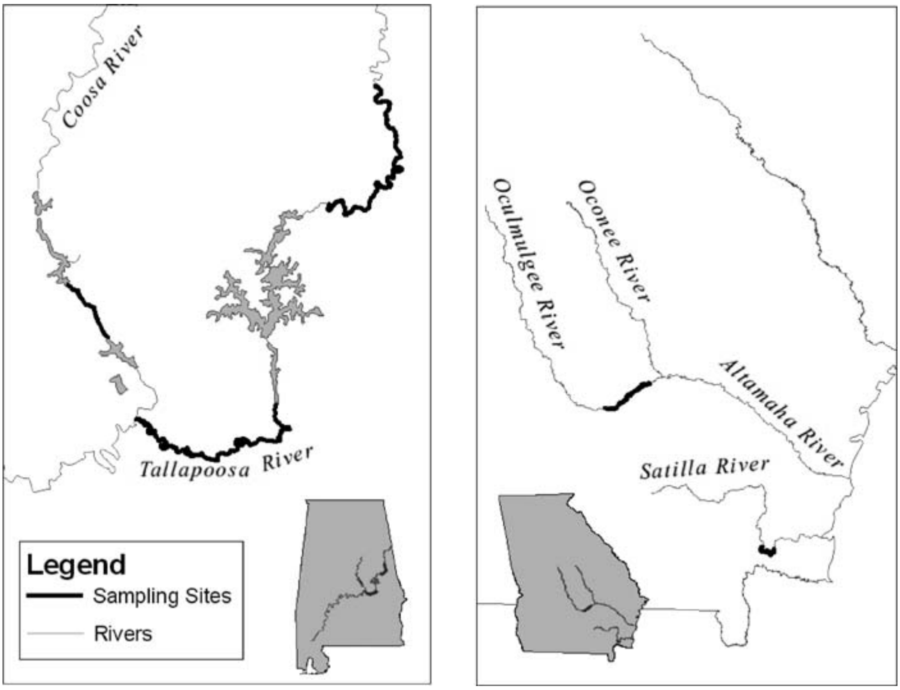

FIGURE 1.—Maps illustrating sites where four flathead catfish populations were sampled. Two native populations were located in Alabama (left panel) within the Mobile River basin: lower Coosa River below Mitchell Dam (sampled in 2001–2002) and middle and lower Tallapoosa River below Harris and Thurlow dams (1996–1997 and 2002–2004). Two introduced populations in Georgia (right panel) were from the Ocmulgee (1997) and (**B**) Satilla (2004) rivers.

Jones' (1957) modification of the Beverton–Holt equilibrium yield equation was used to predict total biomass (kg) of flathead catfish over a range of conditional fishing mortalities (C_f = 0–0.9) at five MLLs (254, 356, 432, 508, and 572 mm) for the four populations (Table 1). Predictions were made with Fishery Analyses and Simulation Tools (FAST) software (Slipke and Maceina 2001). For all simulations, the following conditional natural mortalities (C_m) were used: (1) 0.13 for the Coosa River population; (2) 0.13 for the Tallapoosa River population; (3) 0.22 for the Ocmulgee River population; and (4) 0.28 for the Satilla River population. For each population, C_m was calculated as a mean value of five estimation methods within FAST (Slipke and Maceina 2001). All simulations were conducted with fixed recruitment (1,000 recruits/year). Because flathead catfish were introduced in the Satilla River only 10 years ago, we assumed that the population had not reached its theoretical maximum age or L_∞ and that fish growth (K) had not stabilized.

To evaluate the potential of reducing the abundance of flathead catfish by boat electrofishing in the Satilla River, we predicted the number of fish at stock, quality, and preferred sizes (see Bister et al. 2000) over a range of conditional fishing mortalities (C_f = 0.0–0.9). Analyses included fish greater than 100 mm TL (i.e., modeled a 100-mm MLL), because fish less than 100 mm TL made up less than 1% of the sample and presumably were not susceptible to electrofishing gear.

Results

Maximum ages of flathead catfish from the Coosa (N = 292; range = 93–995 mm TL) and Tallapoosa (N = 140; range = 28–1,010 mm TL) rivers were 25 and 28 years, respectively. Flathead catfish in introduced populations were generally younger than native fish; maximum age was 16 years in the Ocmulgee River (N = 136; range = 48–1,074 mm TL) and 10 years in the Satilla River (N = 305; range = 87–1,035 mm TL).

Von Bertalanffy growth models predicted that an individual flathead catfish would attain preferred size (710 mm TL) in 4.8 years in the Ocmulgee River, 4.4 years in the Satilla River, 16.5 years in the Coosa River, and 19.0 years in the Tallapoosa River. After age 1, faster growth was evident for fish in the introduced populations than in the native populations (Figure 2). Slopes of TL–$\log_{10}$(age) regressions were similar between the Coosa (slope = 594.9; r^2 = 0.89) and Tallapoosa (slope = 487.6; r^2 = 0.67) populations (ANCOVA: t = 1.15, P = 0.26). In contrast, the slope

TABLE 1.—Flathead catfish population parameters used in FAST software for Jones (1957) modification of the Beverton–Holt equilibrium yield equation (L_∞ = theoretical maximum length; k = growth coefficient; t_0 = theoretical time when length equals 0; b = slope; a = intercept; C_m = conditional natural mortality; TL = total length; WT = weight).

River	Parameters	Coefficients
Coosa[a]	Von Bertalanffy growth model	$L_\infty = 1{,}137$ mm TL, $k = 0.057$, $t_0 = -0.68$
	Log_{10}(WT)–$\log_{10}$(TL) relation	$b = 3.17$, $a = -5.409$
	C_m	0.13
	Maximum age	25
Tallapoosa[a]	Von Bertalanffy growth model	$L_\infty = 1{,}010$ mm TL, $k = 0.059$, $t_0 = -1.68$
	Log_{10}(WT)–$\log_{10}$(TL) relation	$b = 3.127$, $a = -5.316$
	C_m	0.13
	Maximum age	28
Satilla[b]	Von Bertalanffy growth model	$L_\infty = 1{,}229.8$ mm TL, $k = 0.201$, $t_0 = 0.059$
	Log_{10}(WT)–$\log_{10}$(TL) relation	$b = 3.219$, $a = -5.506$
	C_m	0.28
	Maximum age	10
Ocumulgee[b]	Von Bertalanffy growth model	$L_\infty = 1{,}113.5$ mm TL, $k = 0.195$, $t_0 = -0.4$
	Log_{10}(WT)–$\log_{10}$(TL) relation	$b = 3.138$, $a = -5.316$
	C_m	0.22
	Maximum age	16

[a] Alabama populations (native fish).
[b] Georgia populations (introduced fish).

of the TL–$\log_{10}$(age) regression for the Satilla River population (slope = 875.5; r^2 = 0.96) was slightly higher (ANCOVA: t = 2.39; P = 0.03) than the slope for the Ocmulgee River population (slope = 723.8; r^2 = 0.98). The slope of the TL–$\log_{10}$(age) regression for the Satilla River population also was higher than the slopes for the Coosa (ANCOVA: t = 2.88, P < 0.01) and Tallapoosa (ANCOVA: t = 2.5, P = 0.02) populations. In addition, the slope of the regression was higher for the Ocmulgee River than for the Coosa (ANCOVA: t = 1.95, P = 0.06) and Tallapoosa (ANCOVA: t = 2.24, P = 0.03) populations; therefore, introduced fish grew more rapidly than native fish. Instantaneous mortality rates differed among populations from the Coosa (Z = –0.156, S = 86%), Ocmulgee (Z = –0.227, S = 80%), and Satilla (Z = –0.602, S = 55%) rivers (ANCOVA: t = 2.47–5.54, P < 0.02 for all analyses; Figure 3).

When populations were modeled with no fishing mortality (μ = 0), estimated maximum biomass (MB) in the Ocmulgee River (1,668 kg) was greater than biomass estimates in the Coosa (873 kg) and Tallapoosa (767.9 kg) rivers. Maximum biomass was also estimated to be greater in the Ocmulgee River than in the Satilla River (MB = 1,137.1 kg; Figure 4A–D). In the Coosa River, biomass was predicted to be reduced to less than 25% of the MB at a low exploitation rate ($\mu \approx$ 20%) when MLLs of 254 and 356 mm were implemented (Figure 4A). When the

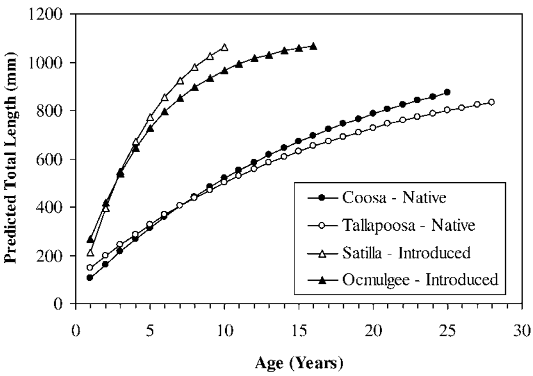

FIGURE 2.—Von Bertalanffy growth curves for introduced flathead catfish from the Satilla and Ocmulgee rivers, Georgia, and native flathead catfish from the Coosa and Tallapoosa rivers, Alabama.

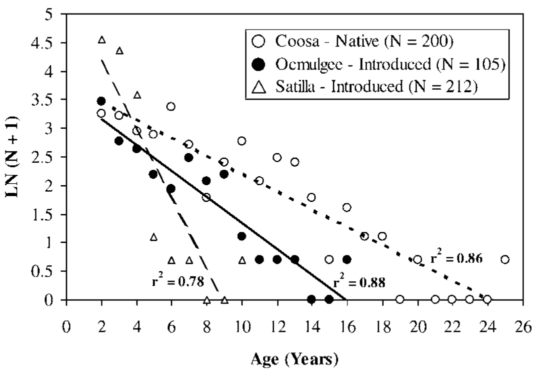

FIGURE 3.—Abundance at age for introduced flathead catfish from the Satilla and Ocmulgee rivers, Georgia, and native flathead catfish from the Coosa River, Alabama. Slopes of catch-curve regressions were different among the populations (ANCOVA: Satilla and Ocmulgee, t = 4.11, P < 0.01; Satilla and Coosa, t = 5.5, P < 0.01; Ocmulgee and Coosa, t = 2.5, P < 0.02).

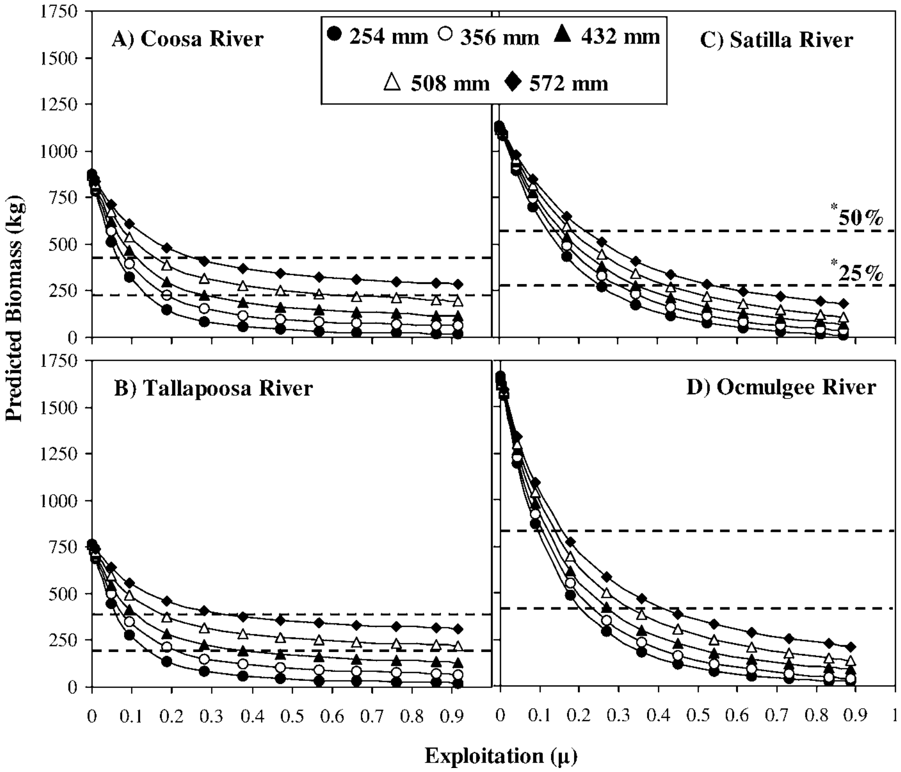

FIGURE 4.—Biomass of flathead catfish over a range of exploitation levels at five minimum length limits for native flathead catfish populations from the **(A)** Coosa and **(B)** Tallapoosa rivers, Alabama, and introduced populations from the **(C)** Satilla and **(D)** Ocmulgee rivers, Georgia. Reference lines within each figure represent 50% and 25% of the maximum biomass.

508-mm MLL was implemented in the Coosa River, high exploitation rates ($\mu > 60\%$) were required to reduce biomass to less than 25% of MB (Figure 4A). Biomass was not reduced to less than 25% of MB when the 572-mm MLL was implemented over all exploitation levels (Figure 4A). The Tallapoosa River population was less susceptible to increased exploitation than the Coosa River population; biomass in the Tallapoosa River was not reduced to less than 25% of MB when MLLs of 508 and 572 mm were implemented (Figure 4B).

The Satilla and Ocmulgee River populations were more susceptible to increased exploitation than the Coosa and Tallapoosa River populations were. Biomass was reduced to less than 25% of MB at all MLLs in the Satilla and Ocmulgee rivers at exploitation levels ranging from 20% to 70% (Figure 4C–D). In the Satilla River, substantial declines in abundance of stock, quality, and preferred sizes were predicted with increasing exploitation when boat electrofishing removal efforts (i.e., 100-mm MLL) were simulated (Figure 5). For example, a 75% reduction in the number of fish at preferred size (i.e., 710 mm TL) was predicted at a 26% exploitation rate (Figure 5).

Discussion

Our study has demonstrated that growth rates of flathead catfish were substantially faster in the introduced populations than in the native populations. In addition, we have provided evidence suggesting that introduced flathead catfish can sustain rapid growth rates for extended periods of time after introduction (i.e., >20 years). For example, although introduced flathead catfish have been present in the Ocmulgee River for approximately 30 years (Thomas 1995), they have sustained growth rates that are considerably faster than fish in their native range. In contrast, Quinn (1989) observed a decline in growth of introduced flathead catfish from the Flint River, Georgia, over a 10-year period (1976–1985; 25–35 years after introduction) and attributed this decline to increased intraspecific competition for resources (i.e., density dependence). However, to estimate growth, Quinn (1989) used back-calculated lengths at age from sections of pectoral spines (i.e., the articulating

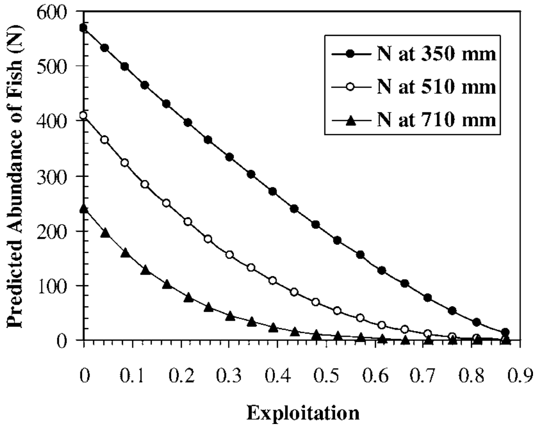

FIGURE 5.—Abundance of flathead catfish at stock (350 mm TL), quality (510 mm TL), and preferred (710 mm TL) sizes over a range of exploitation levels and subjected to a 100-mm minimum length limit to simulate the effects of population removal by electrofishing in the Satilla River, Georgia.

process), which may underestimate the ages of flathead catfish that are older than 5 years (Nash and Irwin 1999) and thus overestimate the growth rates of older fish. Growth was slightly faster in the Satilla River than in the Ocmulgee River, but we contend that the Satilla River population has not fully stabilized since its introduction 10 years ago. In general, introduced flathead catfish in Georgia grew faster than introduced fish in North Carolina coastal rivers. For example, fish in the Northeast Cape Fear River of North Carolina grew to 700 mm TL by age 7 (Kwak et al. 2006), whereas fish in the Ocmulgee and Satilla rivers exceeded 700 mm TL by age 5.

Several hypotheses may explain why introduced flathead catfish exhibit faster growth rates than native fish. For example, increased exploitation rates in association with density-dependent mechanisms may have resulted in the sustained rapid growth of flathead catfish in the Ocmulgee River. Weller and Geihsler (1999) reported that 54% of surveyed anglers had fished for flathead catfish in the Altamaha River system (which includes the Ocmulgee River). Although these anglers were not asked whether they preferred flathead catfish to other sport fishes, results of the survey indicated that recreational fishing for flathead catfish occurred within the system (Weller and Geihsler 1999). An alternative hypothesis is that flathead catfish may have been introduced in systems possessing higher primary and secondary production than is found in systems with native populations. Finally, flathead catfish in some introduced populations may have a higher inherent capacity for growth than fish in native populations.

Mortality was higher in the Satilla River population than in the Ocmulgee and Coosa River populations. Because introduced flathead catfish have been present in the Satilla River for only 10 years, they presumably have not reached their theoretical maximum age; therefore, our mortality estimate for the Satilla River population was confounded or biased because the population had not yet stabilized. Mortality was higher in the Ocmulgee River population than in the Coosa River population, and native fish appeared to have greater longevity than introduced fish, as indicated by the maximum ages of each group. Higher mortality rates in the Ocmulgee River probably resulted from high fishing mortality (Weller and Geihsler 1999) and rapid growth rates (i.e., reaching harvestable size at earlier ages). Several more years were required for flathead catfish in the Coosa River to reach harvestable size due to slower growth rates. For example, flathead catfish in the Coosa River did not surpass stock size (i.e., 350 mm TL; Bister et al. 2000) until the sixth year of life, whereas fish from the Ocmulgee River exceeded this size by the second year. The mortality rate for the Ocmulgee River ($Z = -0.227$) population was similar to rates reported for introduced populations in North Carolina (Neuse River: $Z = -0.221$; Lumber River: $Z = -0.208$; Kwak et al. 2006).

For a thorough review of flathead catfish growth and mortality throughout their native and introduced ranges, we refer readers to Kwak et al. (2006). However, the majority of past studies have used pectoral spines as aging structures (Kwak et al. 2006). Annuli in spine sections are typically lost as the central lumen expands, and basal recess sections appear to underestimate otolith age more than articulating process sections do (Nash and Irwin 1999). Researchers should consider any biases that may be associated with the use of spines for aging before interpreting differences among previously studied populations.

Modeling of various management regimes resulted in different outcomes for introduced and native flathead catfish populations. In our simulations, the biomass of flathead catfish was higher in the introduced populations than in the native populations at low exploitation levels; this finding resulted from differences in growth between the populations. However, increased exploitation rates in the Ocmulgee and Satilla River populations resulted in dramatic declines in overall biomass, especially at the lower MLLs. Therefore, in systems where introduced flathead catfish support an important recreational fishery but have dramatically reduced the abundance of native fishes through predation (e.g., the Ocmulgee River), flathead catfish populations should be minimally protected.

Because anglers will be able to harvest more flathead catfish from introduced populations, the decrease in predation from these populations may allow other fishes (e.g., redbreast sunfish) to become reestablished in the system. In contrast, native flathead catfish populations should be protected by the implementation of higher MLLs (e.g., 508-mm MLL, low daily creel limit), especially in systems where exploitation levels are substantial.

Although total removal of an introduced flathead catfish population seems improbable, our simulations predict that an intensive electrofishing removal plan coupled with minimal protection from anglers would considerably reduce the biomass of flathead catfish in the Satilla River system. In addition, our simulation of flathead catfish removal efforts (i.e., a 100-mm MLL) predicts that the abundance of large fish would decline dramatically with an increase in exploitation rate. Because flathead catfish are exclusively piscivorous as adults (Jolley and Irwin 2005), the removal of large individuals from introduced populations may have positive effects on the reestablishment of native fish populations. However, we acknowledge that our models did not incorporate density-dependent responses that may occur in the population as a result of flathead catfish removal (i.e., populations were modeled with fixed recruitment). Therefore, our predicted declines in biomass and abundance may not be as substantial in nature. Future modeling should incorporate density-dependent mechanisms.

The presence of rapidly growing, introduced flathead catfish in Atlantic Slope drainages may ultimately have major implications for the management of sport fisheries and the persistence of native fishes. Whether flathead catfish growth rates are related to environmental variables, increased exploitation, food resource availability, or genetics, the causes of sustained, rapid growth in introduced populations should be fully investigated. Impacts of introduced flathead catfish on native fishes, especially on endemic and endangered species and traditionally important fisheries (e.g., redbreast sunfish or anadromous species; Pine et al. 2005), should also be assessed. Because little is known about the stabilization of newly introduced flathead catfish populations, the population in the Satilla River should be closely monitored.

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