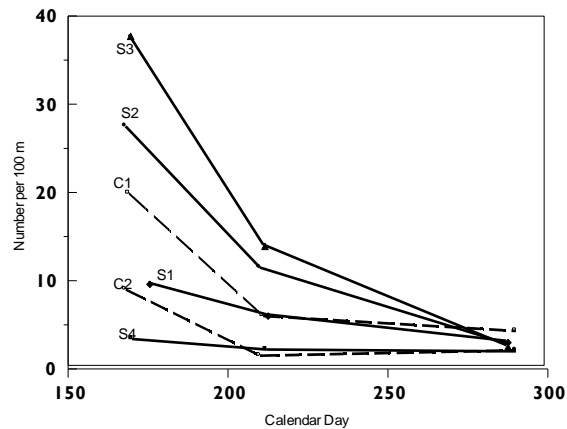
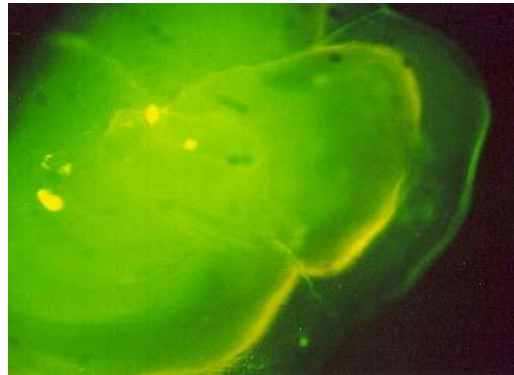


Fisheries Report 03-25

RECRUITMENT VARIABILITY, STATUS OF LARGEMOUTH BASS POPULATIONS, AND STOCKING EFFICACY IN TENNESSEE RIVER IMPOUNDMENTS



A Final Report Submitted to

Tennessee Wildlife Resources Agency

By

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U.S. Geological Survey
Tennessee Technological University
Cookeville, TN 38505

December 2003

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EXECUTIVE SUMMARY

- 1) There were no statistical relationships between largemouth bass year-class strength and reservoir discharge or hydraulic retention in Kentucky Lake or Chickamauga Lake. However, trends were similar to what had been previously reported. Specifically, year-class strength decreased as reservoir discharge increased and retention time decreased. When one outlier was removed, the relation between retention and year class-strength was significant. ($P = 0.028$).
- 2) Annual mortality of largemouth bass in Kentucky Lake increased and size structure indices decreased since 1994. Conversely, mortality of largemouth bass in Chickamauga Lake decreased and structural indices increased slightly since 1994.
- 3) Adjusted mean weights of largemouth bass longer than 300 mm total length in each reservoir were similar, as were measures of proportional stock density. The fact that the two populations were very similar in 2002 is noteworthy because they were dissimilar in 1994, when the Kentucky Lake population had lower mortality, better measures of proportional stock density, and higher relative weights than fish in Chickamauga Lake.
- 4) In May 2002, hatchery-reared largemouth bass fingerlings ($n = 128,265$) were treated in-transit with 500 mg/L of oxytetracycline (OTC) for 6 h and stocked in four embayments of Chickamauga Lake. Two embayments were stocked with the Florida subspecies of largemouth bass, one received F1-hybrids, and one received the Northern subspecies. Two other embayments were not stocked and served as control sites. OTC mark-retention was 100%.
- 5) Age-0 largemouth bass were sampled with hand-held electrofishing gear at approximately 20, 60, and 140 d post-stocking. The catch of age-0 largemouth bass was linked to habitat. Percent coverage of cobble substrate was a positive predictor and slope was a negative predictor of catch rates.
- 6) The mean catch of age-0 largemouth bass (stocked and wild fish combined) differed among stocked and control embayments on the first sampling date. By October 2002, the mean catches in each embayment were similar.
- 7) Initial contribution of stocked fish to the age-0 cohort along electrofishing transects was high (26-29%) in two of four embayments within 20 d post-stocking; however, the percent contribution of stocked fish was low (9%) at 140 d post-stocking and only 2% in April 2003.
- 8) The cost of the stocking program increased from ~\$0.35/fish at stocking to nearly \$8.00/fish by October 2002. The cost per age-1 recruit was estimated to be in the range of several hundred dollars per fish.
- 9) Much better survival of stocked fish will have to be achieved to meet the goal of introgressing the Florida bass genes into the largemouth bass population in Chickamauga Lake. Additional sampling is required to determine whether repeated stockings of Florida bass fingerlings will eventually result in biologically significant introgression. The efficacy of stocking larger (~100–200 mm TL) fingerling bass to improve survival should be investigated.

FOREWORD

This final report is based on a thesis prepared by the first author in partial fulfillment of the requirements for a Master of Science degree in Biology at Tennessee Technological University. This report is divided into two chapters.

Chapter 1 reports on the status of largemouth bass populations in Kentucky and Chickamauga Lakes in 202 and compares them to their status in 1994. Chapter 1 also explored year-class strength of largemouth bass as a function of reservoir hydrology.

Chapter 2 evaluated the ecology and contribution of stocked age-0 largemouth bass in Chickamauga Lake.

All literature citations referred to in the text of each chapter are listed together at the end of this report.

ACKNOWLEDGEMENTS

Primary funding for this research was supplied by Tennessee Wildlife Resources Agency. The Tennessee Cooperative Fishery Research Unit, and the Center for the Management, Utilization, and Protection of Water Resources at Tennessee Technological University supplied additional funding.

We thank the biologists with the Tennessee Valley Authority and TWRA who cooperated with us during both phases of this project and graciously provided logistical support and electrofishing data that they collected in 2002. In particular, we thank Tim Churchill, Mike Jolly, Tim Broadbent, and Mike Smith (TWRA biologists) and Al Brown, Donny Lowery, and Kurt Lakin (TVA biologists).

We would also like to thank Jason Henegar for his help with sampling and processing fish. This report benefited from comments on an earlier draft provided by Drs. Brad Cook and Lenly Weathers, Tennessee Technological University.

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CHAPTER 1

RECRUITMENT VARIABILITY AND STATUS OF LARGEMOUTH BASS POPULATIONS IN THE TENNESSEE RIVER

ABSTRACT

Largemouth bass were sampled in Kentucky Lake and Chickamauga Lake, TN, using boat-mounted electrofishing gear in Spring 2002 to assess the populations and to investigate recruitment variability. All largemouth bass were measured and weighed and sagittal otoliths were removed from a subsample of 130 largemouth bass from Chickamauga Lake and 124 largemouth bass from Kentucky Lake. Age-length keys were constructed to assign ages to all fish in Kentucky Lake ($n = 1,663$) and Chickamauga Lake ($n = 1,312$). Robson and Chapman Maximum Likelihood estimates of annual mortality were nearly identical in Kentucky Lake ($54\% \pm 2$) and Chickamauga Lake ($52\% \pm 3$). Year class strength tended to vary inversely with reservoir discharge, similar to findings in 1994. However, the relationships between residuals from catch-curve regressions and average June-July discharge or hydraulic retention were not statistically significant ($P \geq 0.20$). Removing one outlier improved the fit of both models and the hydraulic retention model was significant ($P = 0.028$). Length-weight relationships for adult largemouth bass were similar in each reservoir ($P = 0.927$), as were adjusted mean weights of fish longer than 300 mm total length ($P = 0.413$), and measures of proportional stock density. The fact that the two populations were very similar in 2002 is noteworthy because they were dissimilar in 1994, when the Kentucky Lake population experienced lower mortality, better measures of proportional stock density, and higher relative weights than fish in Chickamauga Lake.

INTRODUCTION

Largemouth bass *Micropterus salmoides* sport fisheries are important nationwide. In 1996, approximately 44% of the freshwater anglers in the USA and over 50% in Tennessee fished for black basses (U.S. Department of Interior 1996). Sport fish populations can be highly variable; therefore, it is critical for fishery managers to understand factors that regulate sportfish recruitment. Recruitment can be defined as the number of individuals coming into the exploited portion of a population. Largemouth bass recruitment has been linked to hydraulic conditions (Martin et al. 1981; Raibley et al. 1997; Maceina and Bettoli 1998; Sammons et al. 1999), type and hatch date of prey (Davies et al. 1982; Allen et al. 1999), parental stock size and condition (Miranda and Muncy 1987; Goodgame and Miranda 1993), and size of age-0 fishes entering their first winter (Gutreuter and Anderson 1985; Garvey et al. 1998).

In many systems, water level fluctuations regulate largemouth bass recruitment. High water in the spring increases available nursery habitat and survival of age-0 largemouth bass, which often increases recruitment (Ploskey 1986; Raibley et al. 1997). In tributary impoundments of the Tennessee River that are steep-sided and deep (e.g., Normandy Reservoir), spring floods and full-pool conditions through the summer resulted in better largemouth bass recruitment (Sammons et al. 1999). In Normandy Reservoir, wet conditions in spring and summer produced strong year classes that hatched early, grew fast, and survived well; drought conditions produced opposite results. High water levels strongly influenced hatch date of largemouth bass in Normandy Reservoir and average hatch date was positively correlated with the first day at full-pool and the number of days the reservoir remained over full-pool (Sammons et al. 1999). Largemouth bass that hatched early grew faster than those hatched later in the spring, which was similar to other findings (e.g., Goodgame and Miranda 1993). Fast growth allows age-0 largemouth bass to reach larger sizes, which results in better first-winter survival (Aggus and Elliot 1975; Gutreuter and Anderson 1985). Kohler et al. (1993) did not find relationships between spring water level fluctuations and largemouth bass recruitment in two Illinois reservoirs. Garvey et al. (1998) suggested that winter survival

of age-0 largemouth bass might be regulated by first-summer growth, availability of winter refuge, and availability of prey from fall to spring.

Largemouth bass populations were investigated in the Tennessee River system in 1994 (Maceina and Bettoli 1998). Recruitment was positively linked to drought conditions in the summer in mainstream impoundments of the Tennessee River, such as Kentucky Lake and Chickamauga, in contrast to what Sammons et al. (1999) described for a tributary reservoir in Tennessee. A multiple-regression model that included a term for summer discharges explained 73% of the variation in largemouth bass recruitment in four mainstream reservoirs on the Tennessee River, including Kentucky and Chickamauga Lakes (Maceina and Bettoli 1998). Largemouth bass year-class strength was positively related to average June-July retention and inversely related to average June-July discharge. Chickamauga Lake largemouth bass populations exhibited slow growth, average body condition, and average survival rates. Conversely, Kentucky Lake largemouth bass exhibited fast growth, excellent body condition, and high survival.

Drought conditions in the mid-to-late 1980's produced strong cohorts of largemouth bass and subsequent electrofishing surveys in Kentucky Lake had high catch rates (Broadbent 2000). In Kentucky and Chickamauga Lakes, the 1989 year-class was extremely weak, most likely due to high summer discharges (Buynak et al. 1991; Maceina and Bettoli 1998). Although the exact mechanisms are unknown, largemouth bass are better adapted to lentic waters (Stuber et al. 1982) and high discharges resulted in riverine conditions in Kentucky and Chickamauga Lakes. High discharges during the summer months in the Tennessee River probably reduced primary production. In Alabama reservoirs, high flushing rates limited phosphorus availability and reduced primary production by phytoplankton (Maceina et al. 1996). In Kentucky and Chickamauga Lakes, high discharges throughout the summer increased turbidity and may have limited phosphorus availability to phytoplankton. Young largemouth bass may have been adversely affected due to the high discharges that reduced production at lower trophic levels. In contrast, drought conditions during summer months produced strong year classes in Kentucky Lake because of the higher trophic state (Buynak et al. 1991). Drought conditions in the Tennessee River valley in 1999 and 2000 should have resulted in strong largemouth bass year-classes.

The objectives of this project were to: (1) describe population characteristics of largemouth bass in Kentucky and Chickamauga Lakes; (2) compare data collected on current largemouth bass populations with historical data collected in 1994; (3) quantify relationships between environmental variables and recruitment variability for largemouth bass populations in Kentucky and Chickamauga Lakes.

METHODS

Study Area

Kentucky and Chickamauga Lakes are mainstream impoundments of the Tennessee River regulated by the Tennessee Valley Authority (Figure 1). Kentucky Lake, impounded in 1944, is a eutrophic impoundment that covers 64,870 ha with a volume of 350,298 ha-m and a mean depth of 5.4 m. Water levels usually fluctuate about 1.5 m between winter and summer pools. Tennessee Valley Authority (TVA), Tennessee Wildlife Resources Agency (TWRA), and Tennessee Technological University (TTU) biologists collected electrofishing data from multiple sites in Kentucky Lake (Figure 2). Chickamauga Lake, impounded in 1940, is a eutrophic impoundment that covers 14,330 ha with a volume of 78,815 ha-m and mean depth of 5.5 m. The water level fluctuates approximately 2.3 m between summer and winter pools. TVA, TWRA, and TTU biologists collected bass from multiple sites in Chickamauga Lake (Figure 3).

Fish Collection

Largemouth bass collections were coordinated with annual samples collected by TVA and TWRA biologists. Largemouth bass were collected using boat-mounted electrofishing gear in the spring of 2002. All bass were dipped, measured (total length, TL) and weighed (g). Sagittal otoliths were removed from a subsample of fish in 25 mm length groups and age-length keys were constructed to assign ages to all fish that were sampled (Bettoli and Miranda 2001). At the beginning of sampling in each reservoir, a subsample of fish shorter than 150 mm were aged and shown to be age-1; in subsequent samples fish shorter than 150 mm TL were not sacrificed and assumed to be age-1.

Otoliths were dried, stored, and processed using the methods of Hoyer et al. (1985) and Maceina (1988). Otoliths were read in whole view and any otolith displaying three or more annuli was cracked, polished with 600-grit sandpaper, and illuminated with a fiber-optic wand.

Data Analysis

Mortality rates and 95% confidence limits were calculated using the Robson and Chapman Maximum Likelihood method (Ricker 1975). Reservoir levels and discharge data were acquired from the TVA and were averaged by day. Residuals from catch-curve regressions were modeled against average June-July discharge and retention time (Maceina 1997) to test the empirical model developed by Maceina and Bettoli (1998). Maximum change in water level during the spawning season (April-May) was also related to the catch-curve residuals. Body condition and size-structures of each population were evaluated using relative weights and stock indices (Anderson and Neumann 1996). Body conditions in 1994 and 2002 were compared using analysis of covariance.

RESULTS

Recruitment Variability

The combined TVA, TWRA, and TTU sample represented nearly 3,000 largemouth bass (Kentucky Lake: $n = 1,663$; Chickamauga Lake: $n = 1,312$). Otoliths were examined from a subsample of 130 fish from Chickamauga Lake (Table 1) and 124 fish from Kentucky Lake (Table 2). Age 10 was the oldest age-class in Chickamauga Lake and age 9 was the oldest in Kentucky Lake (Figure 4); however, some of the largest and perhaps oldest fish collected in both lakes ($n = 19$) could not be sacrificed due to public relations concerns.

The 1996 year-class was very weak in Kentucky Lake, but it was above average in Chickamauga Lake. In general, year class strength was directly related to retention

time and inversely related to discharge. However, there were no significant relationships ($P \geq 0.20$) between the pooled residuals from the catch-curves and the corresponding average June-July discharges or retention times (Figure 5). When one outlier was removed, the relation between retention and residuals was significant. ($P = 0.028$). The relation between discharge and residuals (after removing the same outlier) was still not significant ($P = 0.13$).

Mortality, Size Structure, and Robustness

Robson and Chapman Maximum Likelihood estimates of annual mortality rates were nearly identical for largemouth bass in Kentucky Lake (54%, ± 2) and Chickamauga Lake (52%, ± 3). Largemouth bass longer than 400 mm TL represented a larger proportion of the sample in Kentucky Lake than Chickamauga Lake. For largemouth bass longer than 300 mm TL, the slopes of the length-weight regression were similar ($P = 0.93$) and the adjusted mean weights were also similar ($P = 0.41$); thus, robustness of adult bass was the same in each reservoir. Proportional stock densities were 55% for both reservoirs (Table 3). Kentucky Lake had a higher relative stock density (RSD) for preferred-size fish (20%) than Chickamauga Lake (10%), but both RSD's were within the acceptable range of 10-40%. Kentucky Lake and Chickamauga Lake had similar RSD's (1-2%) for memorable-size fish. Kentucky Lake largemouth bass stock indices decreased since 1994, when the PSD was 70%, RSD-P was 38%, and the RSD-M was 10%. Conversely, the PSD and RSD-P for Chickamauga Lake largemouth bass increased between 1994 and 2002. The RSD-M in Chickamauga Lake did not change between 1994 (2%) and 2002 (1%). The length-frequency distribution for Chickamauga Lake largemouth bass was bimodal in 2002 (Figure 6) and was similar to what was observed in 1994. The length frequency distribution for Kentucky Lake largemouth bass was distinctly bimodal in 2002 (Figure 6), but it was trimodal in 1994. Mean relative weights of stock, quality, preferred, and memorable bass in Kentucky Lake and Chickamauga Lake were slightly below 100 (Table 4). Mean relative weights for Chickamauga bass increased for stock and quality size fish and decreased for preferred and memorable size

fish since 1994 (Table 5). Mean relative weights of Kentucky Lake largemouth bass in the stock, quality, preferred, and memorable size groups declined since 1994 (Table 5).

The slopes of the \log_{10} length- \log_{10} weight regression lines for all largemouth bass longer than 200 mm TL in Kentucky Lake were similar in 1994 and 2002 ($P = 0.19$). The adjusted mean weight of Kentucky Lake bass declined slightly (2%; $P = 0.0159$) between 1994 (590 g) and 2002 (577 g). Annual mortality of Kentucky Lake largemouth bass increased from 41 % (± 3) in 1994 to 54% (± 2) in 2002. The slopes of the \log_{10} length- \log_{10} weight regressions for all largemouth bass larger than 360 mm TL in Chickamauga Lake were similar ($P = 0.39$) and the adjusted mean weights were also similar ($P = 0.83$) in 1994 and 2002. Annual mortality of Chickamauga Lake largemouth bass decreased from 67% (± 1) in 1994 to 52% (± 3) in 2002.

DISCUSSION

Recruitment Variability

There were no significant relationships between year-class strength and June-July reservoir discharge or retention time; however, the trends were similar to what Maceina and Bettoli (1998) described for mainstream impoundments of the Tennessee River. In general, year-class strength varied inversely with reservoir discharge and directly with retention time. The exception was the 1996 year-class, which was weak in Kentucky Lake but above average in Chickamauga Lake. The summer discharges in 1996 were intermediate; however, a weak year-class was produced in Kentucky Lake. One explanation for why the 1996 year-class was weak in Kentucky Lake and strong in Chickamauga is that the average June-July discharge the following summer (when the 1996 year-class was age 1) increased 114% in Kentucky Lake (9,572 ha-m in 1996 and 20,561 ha-m in 1997), but only increased 36% in Chickamauga Lake. High summer discharges could have negatively affected production at lower trophic levels (Maceina and Bettoli 1998) and possibly affected age-1 fish growth and survival.

The study by Maceina and Bettoli (1998) included two other mainstream reservoirs on the Tennessee River that are located between Chickamauga Lake and Kentucky Lake, which nearly doubled the number of observations in their study. We

might have detected relationships between year-class strength and reservoir hydrology if data from the other two reservoirs were included in the analysis. Also, the relationships between reservoir hydrology and year-class strength described by Maceina and Bettoli (1998) were driven by extremely high summer discharges and completely missing year-classes, which were not observed in the present study.

There were no significant relationships between year-class strength and maximum change in stage during the spawning season, which has been identified as a possible source of variation in year-class strength (Raibley et al. 1997). Rapidly fluctuating water levels during the spawning season can cause largemouth bass to abandon their nests and delay spawning, which can negatively affect year-class strength. Earlier hatched fish typically survive better and contribute more to year-class strength than fish hatched later (Gutrueter and Anderson 1985; Goodgame and Miranda 1993).

Studies elsewhere identified factors that may be influencing recruitment of largemouth bass in the Tennessee River system. First summer growth of largemouth bass may be affected by hatch date (Goodgame and Miranda 1993) and availability of prey (Garvey et al. 1998). The accumulation of lipids during the first summer can decrease the chance of starvation during the winter (Miranda and Hubbard 1994a). Also, availability of prey and refuge from predation during the winter can be important for survival of young largemouth bass in some systems (Miranda and Hubbard 1994b). Although these factors were not addressed specifically in this study, they may be affecting year-class formation along with reservoir discharge and retention.

Mortality, Size Structure, and Robustness

Structural indices for largemouth bass in Kentucky Lake decreased between 1994 and 2002, which has concerned fishery managers and anglers. However, the 2002 indices were indicative of a balanced population (Gablehouse 1984). In 1994, largemouth bass in Kentucky Lake grew fast, experienced low mortality, and the abundance of large fish was high following the drought years in the mid-to-late 1980's. Since 1994, mortality rates have increased and condition of largemouth bass has decreased slightly. The size structure also shifted towards smaller fish in 2002. Largemouth bass in Kentucky Lake

were heavier than similar-size largemouth bass in Chickamauga Lake in 1994, but weights were similar in 2002. Whereas the quality of the Kentucky Lake population has decreased since 1994, the largemouth bass population in Chickamauga Lake improved and was in better condition and experienced lower mortality in 2002.

Fluctuations in largemouth bass recruitment were found to be synchronous throughout the Tennessee River during the late 1980's and early 1990's (Maceina and Bettoli 1998); however, population structure and condition of largemouth bass differed among reservoirs. Thus, there were other factors accounting for the differences in population structure among reservoirs. Restrictive size limits, fishing pressure, and prey availability are examples of factors that affect population structure and these factors need to be investigated to determine which factors impact the populations the most. The Tennessee Valley experienced drought conditions from 1999 to 2001, which should have promoted strong year classes. It remains to be seen whether the year-classes produced in those years will be strong enough to improve the quality of the fishery in the coming years. Based on our catch curves, the 1999 and 2000 year-classes were strong in Kentucky Lake and average in Chickamauga Lake; additional sampling is needed to determine the strength of the 2001 year class in each reservoir.

Table 1. Age-length frequency for largemouth bass collected from Chickamauga Lake, Tennessee, April 2002.

Size Class (mm TL)	<u>Year Class</u>											
	Total	01	00	99	98	97	96	95	94	93	92	Unknown
75 - 100	1	1										
101 - 125	6	6										
126 - 150	30	30										
151 - 175	92	92										
176 - 200	140	140										
201 - 225	121	121										
226 - 250	70	56	14									
251 - 275	97	10	87									
276 - 300	201		186		15							
301 - 325	211		146	49	16							
326 - 350	135		58	48			29					
351 - 375	95			40	32	8	15					
376 - 400	39			15	20	4						
401 - 425	29			3	17			6	3			
426 - 450	18					18						
451 - 475	11							3	5		3	
476 - 500	4							1	3			
501 - 525	6								2		4	
526 - 550	5											5
551 - 575	1											1
Totals	1312	456	491	155	100	30	48	16	3	3	4	6

Table 2. Age-length frequency for largemouth bass collected from Kentucky Lake, Tennessee, May 2002.

Size Class (mm TL)	Year Class										
	Total	01	00	99	98	97	96	95	94	93	Unknown
75 - 100	3	3									
101 - 125	11	11									
126 - 150	85	85									
151 - 175	141	141									
176 - 200	109	109									
201 - 225	58	25	33								
226 - 250	75		75								
251 - 275	184		184								
276 - 300	289		289								
301 - 325	229		183	46							
326 - 350	135		54	81							
351 - 375	72			31	41						
376 - 400	62			48	14						
401 - 425	50			38	12						
426 - 450	46					23			12	11	
451 - 475	50					10		30	10		
476 - 500	31					5	5		10	11	
501 - 525	20					10			10		
526 - 550	10										10
551 - 575	3										3
Totals	1663	374	818	244	67	48	5	30	42	22	13

Table 3. Largemouth bass mortality rates and stock indices in 1994 and 2002 for Chickamauga and Kentucky Lakes, Tennessee, 1994 and 2002. PSD is the proportional stock density of fish greater than 200 mm TL, RSD-P is the relative stock density of preferred-sized fish (380 – 509 mm TL), and RSD-M is the relative stock density of memorable-sized fish (≥ 510 mm TL).

Parameter	<u>Kentucky</u>		<u>Chickamauga</u>	
	1994	2002	1994	2002
Mortality rate (%)	41	52	67	54
PSD (%)	70	55	47	55
RSD-P (%)	38	20	8	10
RSD-M (%)	10	2	2	1

Table 4. Relative weight by size group for largemouth bass collected in Chickamauga and Kentucky Lakes, Tennessee, Spring 2002.

Lake	Statistic	<u>Size Groups (mm, TL)</u>			
		Stock (200-299)	Quality (300-379)	Preferred (380-509)	Memorable (510-629)
Chickamauga	Mean	98	99	99	97
	SE	0.52	0.57	1.47	3.87
	N	475	465	96	9
Kentucky	Mean	98	99	98	97
	SE	0.41	0.44	0.6	1.79
	N	590	463	232	29

Table 5. Relative weight by size group for largemouth bass collected in Chickamauga and Kentucky Lakes, Tennessee, Spring 1994 and 2002. Data from 1994 is reported in Bettoli (1994).

Lake	Year	Size Groups (mm, TL)			
		Stock (200-299)	Quality (300-379)	Preferred (380-509)	Memorable (510-629)
Chickamauga	2002	98	99	99	97
	1994	89	93	102	103
Kentucky	2002	98	99	98	97
	1994	100	100	104	107

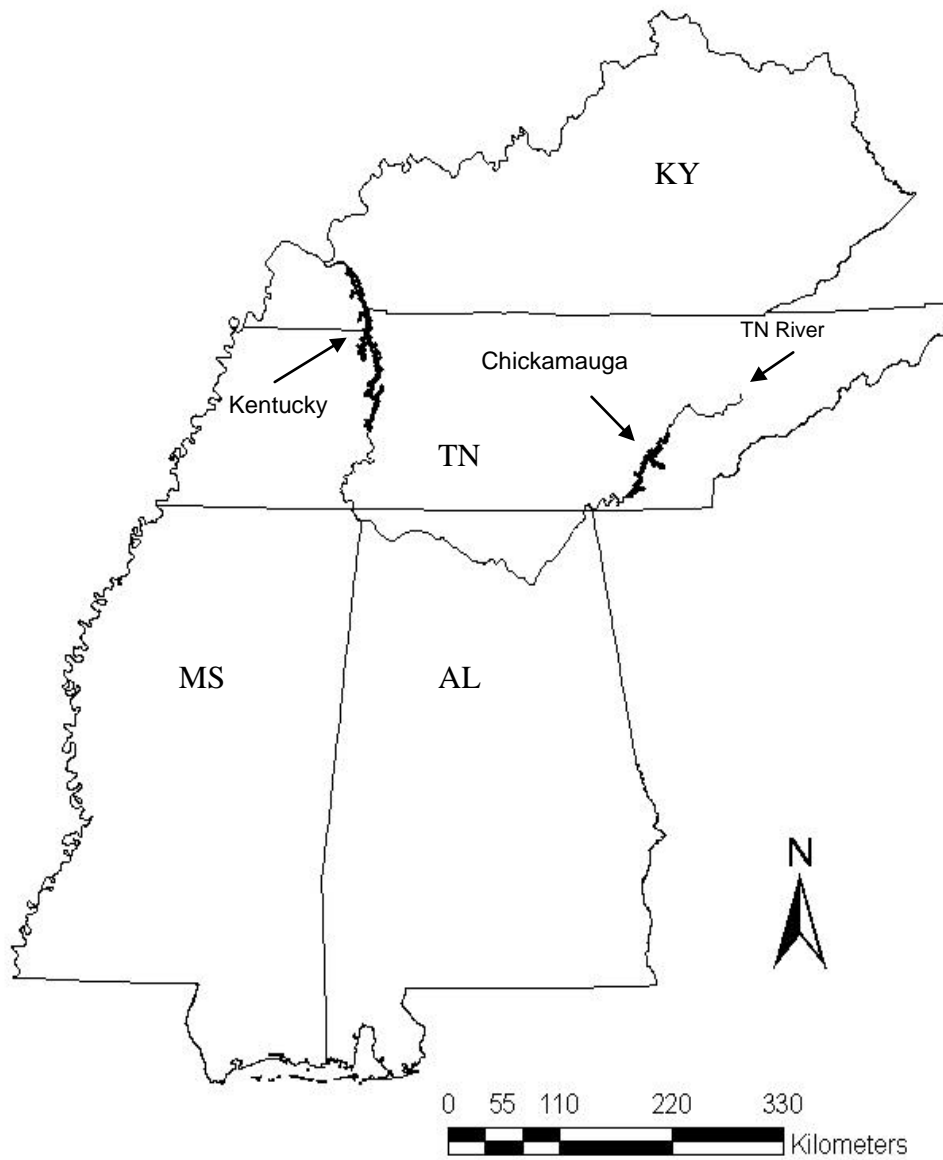


Figure 1. Kentucky and Chickamauga Lakes, mainstream impoundments of the Tennessee River, Tennessee.

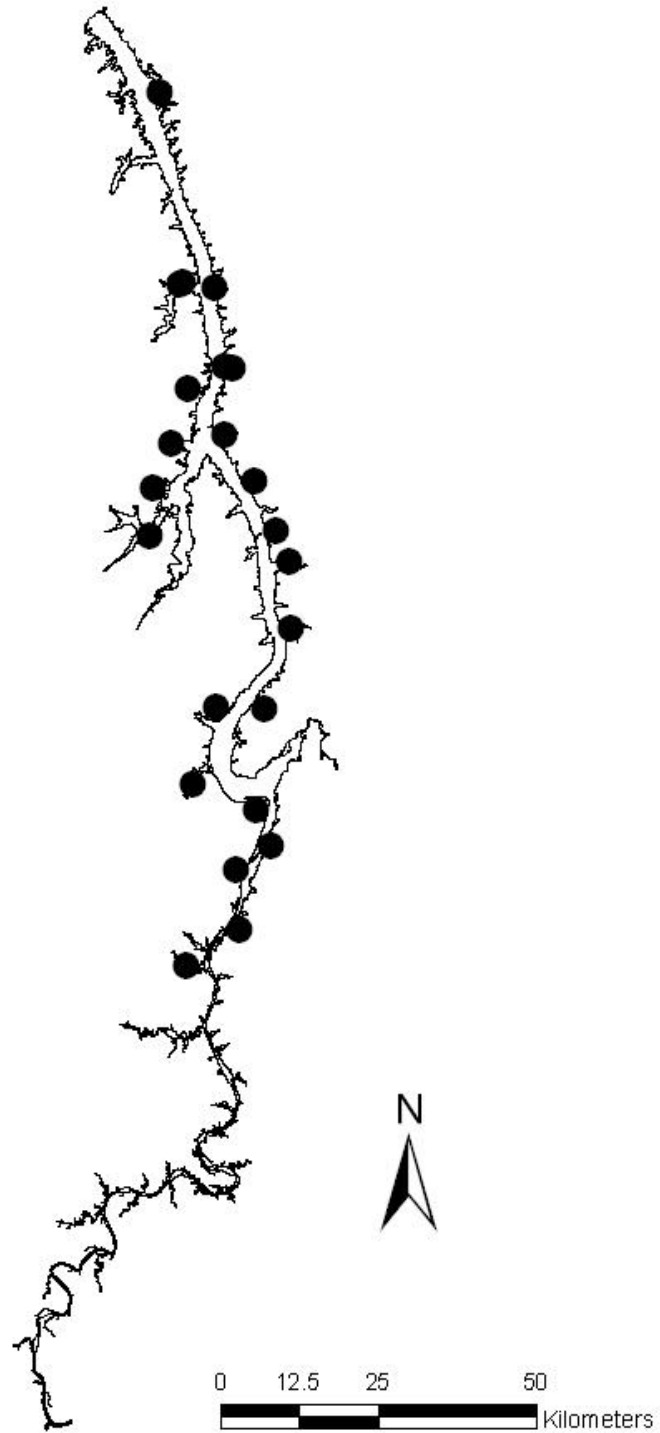


Figure 2. Electrofishing sites on Kentucky Lake, Tennessee, 2002.

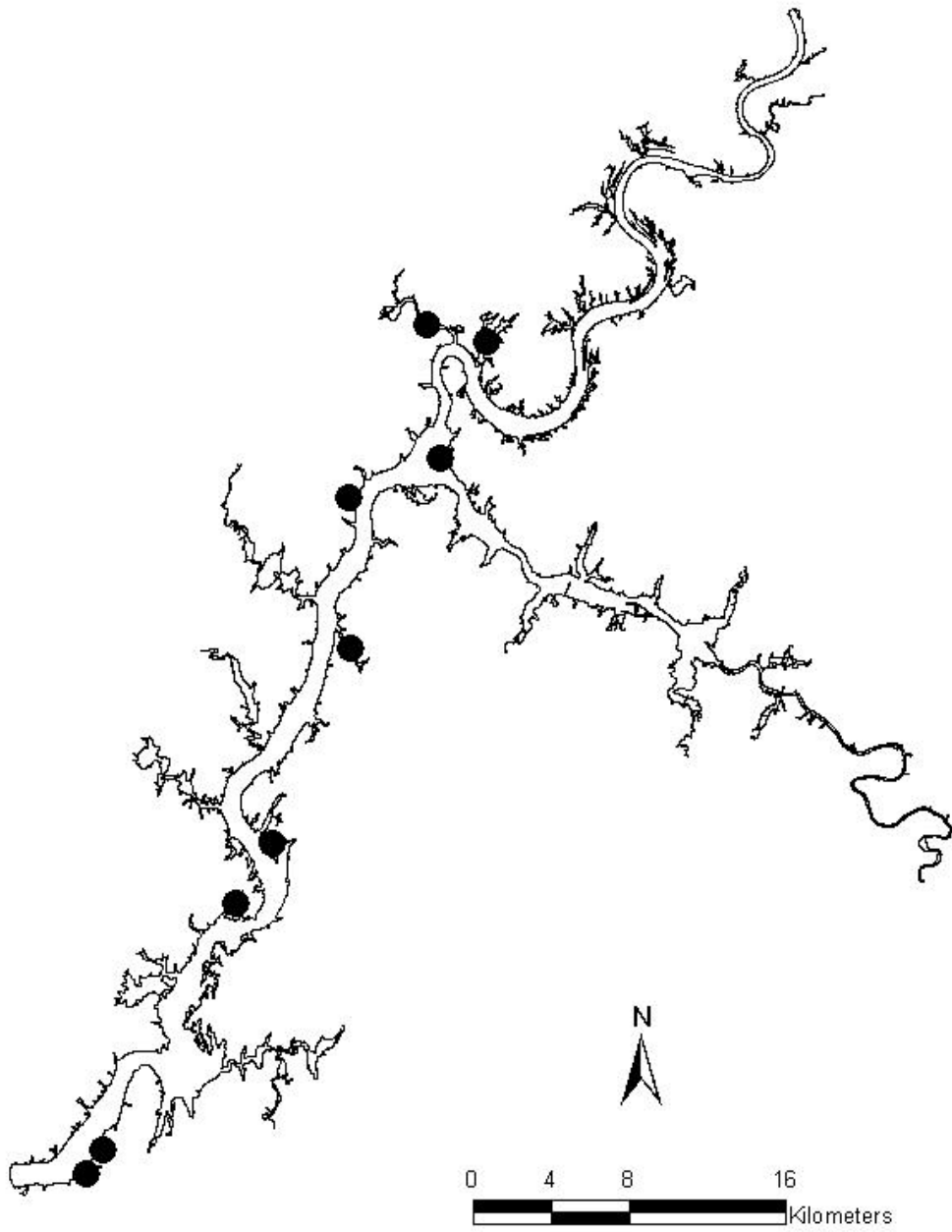


Figure 3. Electrofishing sites on Chickamauga Lake, Tennessee, 2002.

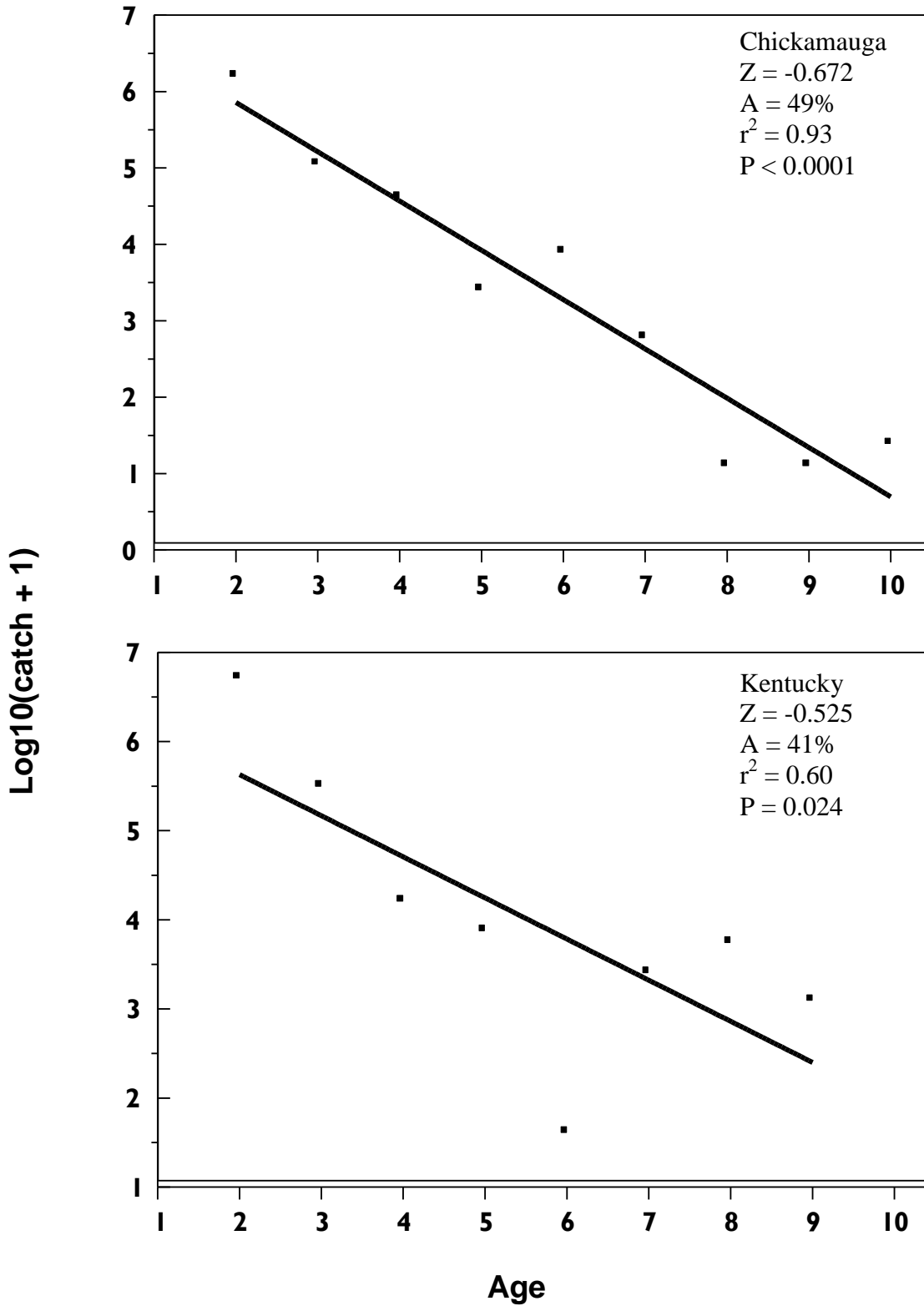


Figure 4. Catch-curves for Chickamauga and Kentucky Lakes, Tennessee, 2002. Instantaneous mortality rates (Z) and annual interval mortality (A) rates for each reservoir are displayed.

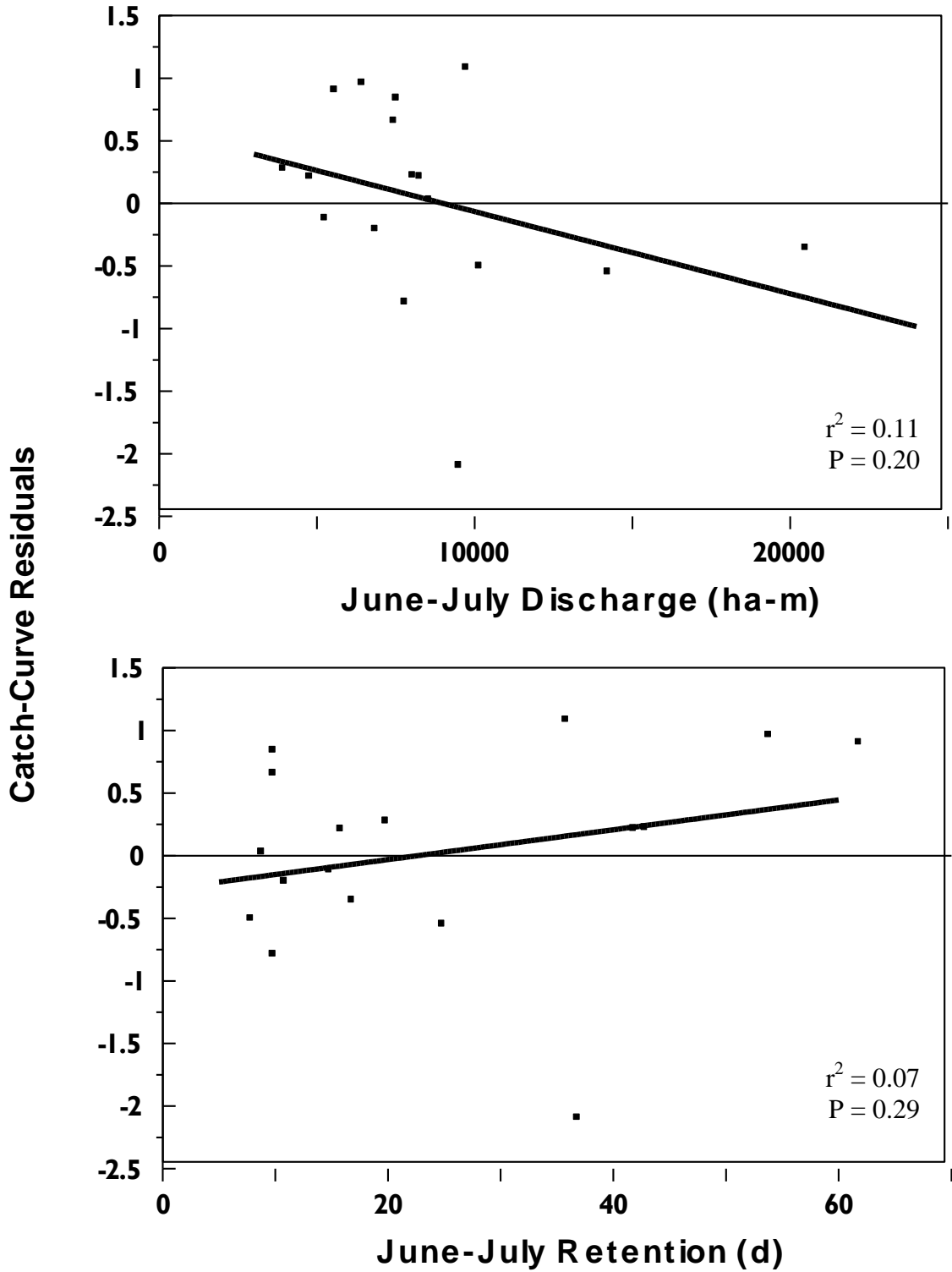


Figure 5. Catch-curves residuals plotted against corresponding June-July discharge and June-July retention for Chickamauga and Kentucky Lakes, Tennessee, 2002.

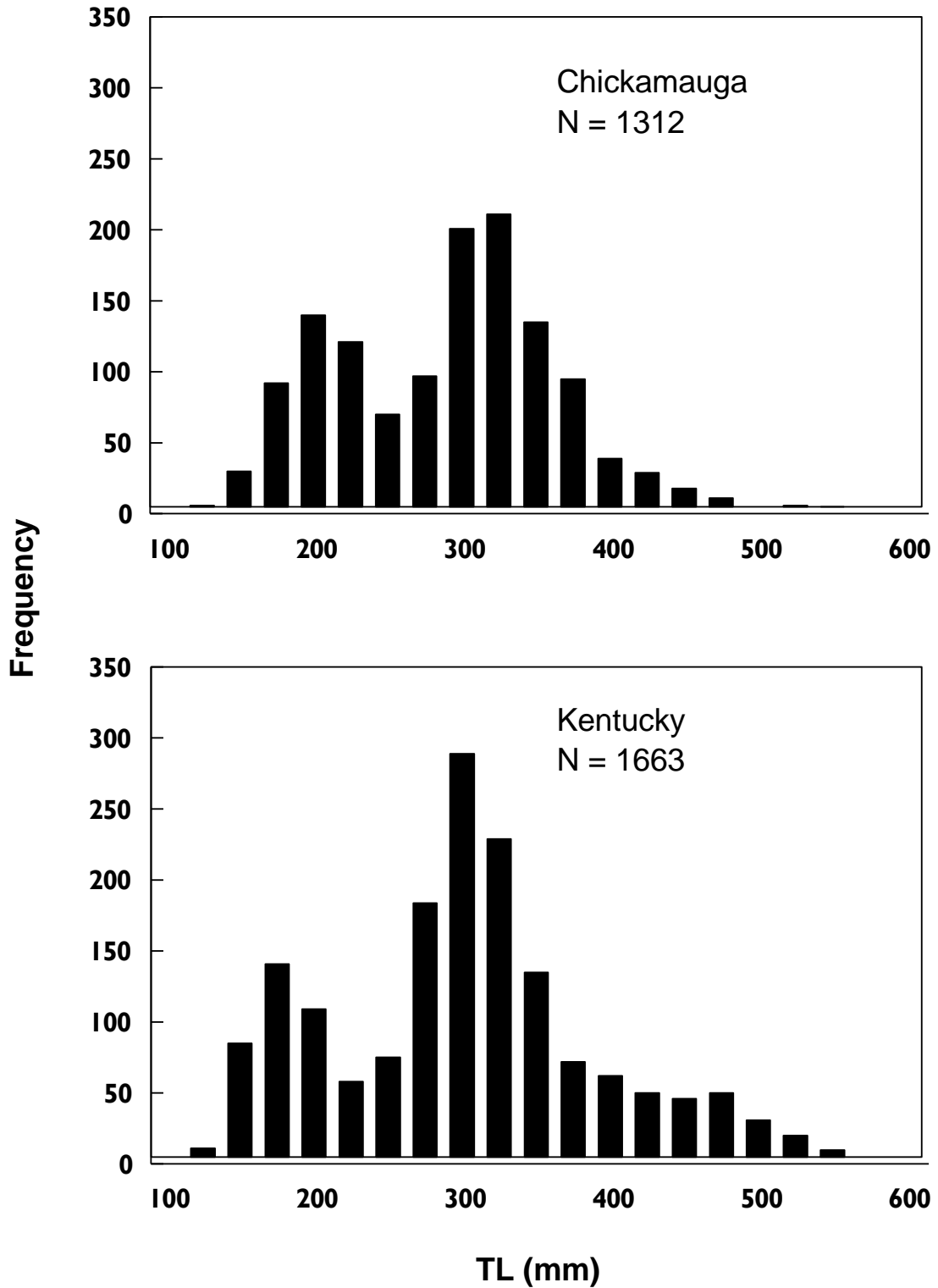


Figure 6. Total length-frequency distributions of largemouth bass in electrofishing samples taken in Chickamauga and Kentucky Lakes, Tennessee, spring 2002.

CHAPTER 2

EFFICACY OF STOCKING LARGEMOUTH BASS USING OXYTETRACYCLINE MARKING TECHNIQUES

ABSTRACT

Over 128,000 largemouth bass fingerlings were stocked into Chickamauga Lake in May 2002. Fish were marked in transit with 500 mg/L of oxytetracycline (OTC) for 6 h. The OTC marks were visible on 100% of 240 treated bass held for 30 d. Two embayments were stocked with the Florida subspecies of largemouth bass, one received F1-hybrids, one received the Northern subspecies, and two embayments were not stocked and served as control sites. Largemouth bass fingerlings were sampled approximately 20, 60, and 140 d after stocking along fixed transects within 1 km on each side of the stock sites in each embayment using DC electrofishing gear and a hand-held anode. Rapid dispersal was observed in all embayments. After 20 days, 31% of all recaptures occurred more than 600 m from the nearest stocking site. Shoreline slope and substrate characteristics explained about 50% of the variation in age-0 largemouth bass catch rates. More age-0 largemouth bass were caught along shallow shorelines with cobble substrate and fewer were caught on steep shorelines with gravel substrate. Stocked fish were larger than wild fish at time of stocking and grew faster (0.5 mm/d) than wild fish (0.4 mm/d). Mean catch in the first sample was highest in the embayment that received the largest number of stocked fingerlings and mean catches in the six embayments were positively related to the number of fish stocked ($P = 0.08$). However, the positive effects of stocking did not persist. By 140 d post-stocking, catch rates of all age-0 largemouth bass were similar among embayments ($P = 0.46$). First summer survival rates of stocked and wild age-0 largemouth bass were comparable and low (4.5% - 6.8%) in the two embayments stocked with the Florida subspecies. In the other two stocked embayments, stocked fish survived at much lower rates (0 - 4.4%) than wild fish (33.7 - 50.0%). Survival between June and October differed ($P = 0.05$) for the six cohorts of age-0 wild fish (mean = 21% ; SE = 7.2) and four cohorts of stocked fish (mean = 4.0% ; SE = 1.4). Although instantaneous mortality of wild fish tended to increase with the number of fingerlings stocked, the linear model was not significant ($P = 0.17$). Compensatory growth was not evident; instantaneous growth was actually positively correlated

($r = 0.86$, $P = 0.03$) with initial mean catch. The feeding ecology of wild and stocked age-0 bass was similar in terms of the percentage of fish with empty stomachs and percentages of fish that had fish or invertebrates in their stomachs. Logistic regression models accurately predicted the presence of fish in the stomachs of age-0 bass as a function of their total length and several habitat variables. The predicted length at which most age-0 largemouth bass assumed piscivory ranged from 53 mm in an unvegetated embayment to 85 mm in the most heavily vegetated embayment. In the first three samples we collected 1,024 age-0 largemouth bass in the stocked embayments and recaptured 147 stocked fish. The percent contribution of stocked fish was low in October 2002 (9%) and April 2002 (2 of 91 fish, or ~ 2%). Electrofishing samples in 2002 encompassed only 2 km of shoreline in each embayment, and less than 6 km of shoreline were sampled in each embayment in 2003; therefore, percent contributions on an embayment-wide scale were miniscule. Cost per fingerling increased from \$0.35 at stocking to \$7.80 per recruit at 120 days post-stocking and over \$700 per recruit on April 1, 2003. Much better survival will have to be achieved to meet the goal of introgressing the Florida bass genes into the largemouth bass population in Chickamauga Lake. Additional sampling is required to determine whether repeated stockings of Florida bass fingerlings will eventually result in biologically significant introgression. The efficacy of stocking larger (~100 –200 mm TL) fingerling bass should be investigated.

INTRODUCTION

The largemouth bass is the most popular sportfish in the United States and any decline in its abundance concerns fishery managers and anglers. Factors that affect year-class strength have been well documented; however, specific factors vary among systems. In order to enhance weak year-classes, fishery managers have used strategies such as stocking fish, managing aquatic plants, manipulating water levels, and altering habitat. In many cases, more than one of these management practices is used concurrently. In some reservoirs, management of water levels to enhance largemouth bass fisheries may be more important than aquatic plant management or habitat enhancement (Sammons and Bettoli 2000). For instance, aquatic plant management and habitat enhancement at whole-lake levels can be very costly and labor intensive in large reservoirs such as Chickamauga Lake, Tennessee. In contrast, Copeland and Noble (1994) suggested localized management of shoreline habitat in embayments within large reservoirs. Largemouth bass rarely moved out of the embayments into which they were stocked; when bass did move, it was from embayments with low quality habitat to nearby high quality habitat (Noble et al. 1994). Therefore, aquatic habitat enhancement could be implemented in embayments that lack high quality habitat, followed by supplemental stockings of hatchery fish. Unfortunately, stocking sites are often chosen for their accessibility to hatchery trucks and not for the quality of habitat (Noble et al. 1994). Ideally, largemouth bass should only be stocked into embayments with good habitat to increase survival of the hatchery fish.

Stocking programs are often initiated to produce results at whole-lake levels instead of at embayment-specific levels; consequently, the impacts of stocking programs are often underestimated (Copeland and Noble 1994). Not surprisingly, largemouth bass stocking programs have reported mixed results.

In some situations, largemouth bass are stocked to augment natural recruitment and increase the population of catchable fish. For instance, fingerling largemouth were stocked into two Tennessee reservoirs in 1993 with the goal of increasing year class strength (Bettoli 1997). Over the following year, none of the stocked fish (which were microtagged) were recaptured in Center Hill Lake, but stocked fish represented 18% of the cohort in one embayment on Tims Ford Lake. Buynak and Mitchell (1989) stocked advanced fingerling (~ 100 mm total length [TL]) largemouth bass into a small Kentucky Reservoir and concluded that the program boosted

angler catch rates, but only as long as the stocking program continued. Lee et al. (1993) microtagged and stocked more than 240,000 fingerling Florida and northern largemouth bass into two California reservoirs over four years to augment natural recruitment and improve fishing. In subsequent electrofishing samples, tagged fish represented only 1% of all sampled bass and only 0.1% of all the largemouth bass weighed-in at 79 fishing tournaments were tagged.

Fishery managers frequently stock the Florida subspecies of largemouth bass because some studies have shown that these fish grow larger than the northern subspecies of largemouth bass (i.e., Maceina et al. 1988). Florida largemouth bass grow bigger and faster than northern largemouth bass in some locales, especially in Gulf Coast states where the subspecies is adapted to the climate and the habitat. However, the Florida subspecies does not always grow faster or survive better when stocked outside its native range (Isely et al. 1987; Philipp and Whitt 1991). Terre et al. (1993) reported that Florida largemouth bass stocked in three Texas reservoirs at a rate of 30 to 200 fish/ha contributed 1 - 45% to each cohort one to three years after stocking. The contribution of stocked fish varied inversely with largemouth bass recruitment in each reservoir. The contribution of Florida largemouth bass stocked into two other Texas reservoirs was 16% after two or three years (Maceina et al. 1988). The percent contribution to year class strength was initially low, but the frequency of Florida and hybrid alleles increased in subsequent years. Florida, northern, and F1-hybrid largemouth bass were simultaneously stocked into a newly created 420 ha reservoir in Oklahoma (Wright and Wigtil 1980) and the Florida bass and hybrid bass initially grew faster and survived better than the northern strain of fish. These examples demonstrated somewhat successful stockings of Florida largemouth bass.

For each successful stocking of Florida largemouth bass, there are just as many unsuccessful efforts documented in the literature. Florida largemouth bass stocked into a Texas reservoir at rate of 62 fish/ha contributed only 4% to cohort strength after 150 d (Buckmeier and Betsill 2002). Dispersal of the stocked fish stabilized within one month of stocking and the majority of the stocked fish remained within 2 km of the stocking site the first summer. Stocked fish maintained a length advantage over wild fish until 125 d post-stocking. Florida largemouth bass were stocked into two other Texas reservoirs at rates of 2.8 and 8.8 fish/ha and the percent contribution was nil in both systems after 2 to 3 years (Ryan et al. 1996). In a 3-year pond experiment in Illinois, northern largemouth bass experienced higher overwinter survival than Florida largemouth bass; the hybrids had intermediate survival (Philipp and Whitt 1991). The

northern subspecies also grew faster than the Florida subspecies in 2 of 3 years; again, the hybrids had intermediate growth rates. Northern largemouth bass grew faster than Florida largemouth bass in a Tennessee pond (Smith and Wilson 1980). Philipp et al. (2002) recommended discontinuing all stocking programs using Florida largemouth bass that were outside its native range due to concerns over outbreeding depression. In pond experiments they conducted at different latitudes, the native subspecies out-competed the introduced subspecies and F₁-hybrids in terms of survival, growth, and reproductive success. Despite concerns over rearing and introducing non-native stocks of largemouth bass into new habitats, such stocking programs persist to increase the trophy bass potential of specific bodies of water.

In order to judge the efficacy of any stocking program, stocked fish must be distinguished from wild fish and many techniques have been developed to mark hatchery fish. Microwire tagging is a useful technique to permanently mark hatchery fish; however, initial equipment expenditures can be costly and manual tagging is time consuming. Fin-clipping is a technique widely used to mark fish, however, it is also time consuming and the technique requires mutilation of the fins, which might affect survival (Coble 1971). Oxytetracycline (OTC) immersion has been used to mark several species of fish, including American shad (Lorson and Mudrak 1987), walleye (Kayle 1992; Brooks et al. 1994), red drum (Bumgaardner 1991), yellow perch (Brown et al. 2002), and crappie (Conover and Sheehan 1996; Isermann et al. 1999). There are no reports in the primary literature of using oxytetracycline to mark largemouth bass. Oxytetracycline is an antibiotic of the tetracycline family, which binds with calcium molecules during osteogenesis (Weber and Ridgway 1962). Otoliths are commonly removed and examined for OTC marks, which requires that the fish be sacrificed; however, large numbers of fish can be easily marked.

Declines in the largemouth bass stocks in Chickamauga Lake in the mid-to-late 1990's prompted the supplemental stocking of hatchery-reared fingerlings by the Tennessee Wildlife Resources Agency (TWRA). This stocking program was initiated at the urging of local anglers, who partially funded the costs of purchasing fingerling bass from an Alabama fish producer. The TWRA set a goal of stocking 175,500 fingerling Florida largemouth bass each spring between 2000 and 2004. Florida largemouth bass were stocked in hopes of introgressing those alleles into the population and subsequently producing trophy fish. The TWRA feels that such a stocking program, if successful, will enhance quality sport fishing opportunities in Tennessee (Churchill

and Reeves 2001) and create destination fisheries that are known to have significant economic impacts elsewhere (e.g., Lake Fork, Texas; Hunt and Ditton 1996). Florida bass stocking programs receive broad support from anglers across the country. Despite public pressure, TWRA is conservative and restricts such stockings to reservoirs below the 37⁰ parallel where the heating degree days are less than 1,900. One embayment in Kentucky Lake was stocked with Florida largemouth bass for several years and the percent contribution of Florida alleles was high (39%; TWRA, unpublished data). The TWRA collected largemouth bass before the Chickamauga stocking program commenced and there was a low percentage of Florida largemouth bass alleles before stocking and 2 years post-stocking (Epifanio 2003). The goal of this stocking program is for 15% of the bass genome to be represented by Florida bass genes. If the contribution of Florida genes to the bass genome in a stocked reservoir does not exceed 5% after four years, the stocking program is critically reevaluated.

The objectives of our study were to (1) determine the contribution of stocked largemouth bass using oxytetracycline-marking techniques, (2) describe dispersal and estimate growth and mortality of stocked fish, (3) investigate predation as a source of initial mortality on stocked fish, (4) examine the diet of age-0 largemouth bass, and (5) build multiple regression models to relate the catch of fingerlings to the shoreline habitat in Chickamauga Lake.

STUDY AREA

Chickamauga Lake is a eutrophic reservoir impounded in 1940 that covers 14,330 ha, has a volume of 78,815 ha-m, and a mean depth of 5.5 m. The water level fluctuates about 2.3 m between summer and winter pools. Four embayments were stocked in 2002 with 128,265 largemouth bass (Figure 1), which included northern, Florida, and F-1 hybrid largemouth bass because not enough Florida largemouth bass could be obtained. Embayment S1 near Booker T. State Park, off Tynes Road, was stocked with 14,825 northern largemouth bass on 17 June 2002. The Dayton Boat Dock embayment (S2) received 23,440 Florida largemouth bass on 30 May and about 75,000 Florida largemouth bass were stocked 31 May at the boat ramp where Highway 58 Bridge crosses the Hiwassee River embayment (S3). Wolftever Creek embayment (S4) was stocked on 31 May with 15,000 F1-hybrid largemouth bass. All sites were separated by at least

17 km of shoreline. Two additional embayments (C1 and C2) that were not stocked served as control embayments (Figure 1).

METHODS

Oxytetracycline Marking

Largemouth bass were marked in-transit with 500 mg/l of OTC (Terramycin-343; Phizer Animal Health, Inc.) and 300 mg/l of sodium phosphate dibasic buffer for 6 h. The OTC and buffer came in powder form and were mixed in buckets using the water from the hatchery tanks. When the solution was mixed and the pH stabilized, the solution was poured back into the hauling tanks of the hatchery truck. Each embayment was stocked at one site. When each truckload of fish were stocked, a random sample of fish was removed and held in the lab for 30 d for subsequent verification of an OTC mark. Otoliths were mounted on microscope slides using a cyanoacrylate glue (Secor et al. 1991). Otoliths were viewed under a microscope with a 100-W halogen light source, a 450-490 nm excitation filter, a 515 nm barrier filter, and a 510 nm dichroic mirror (Isermann et al. 1999).

Fish Collection

Ten 100-m transects were established to the right and left ($N_{\text{total}} = 20$) of each boat ramp where fish were stocked. All sampling during the first summer was within 1 km on each side of each stocking site, based on the finding by Jackson et al. (1993) that most age-0 largemouth bass did not move more than 1 km after they were stocked in a North Carolina reservoir. Age-0 largemouth bass were sampled using hand-held electrofishing gear (Jackson and Noble 1995), which consisted of a 2000 W generator, a converter box that delivered 260 V of straight DC, and a handheld anode fitted with a triangular net. Age-0 bass were sampled approximately 20, 60, and 140 d after stocking, except for one embayment (S1) that was sampled 7, 60, and 140 d post-stocking. All sampling was conducted in shallow water (< 1.5 m) near the shoreline at night. Eight transects were sampled in each embayment per sampling date, except S1 where only six transects were sampled per date. Sagittal otoliths were removed from all age-0 largemouth bass and examined for OTC marks. The two embayments not stocked with fingerlings were also

sampled for age-0 largemouth bass at the same time stocked embayments were sampled. Boat-mounted electrofishing gear was used to sample potential predators (e.g., adult largemouth bass) 2 to 10 h post-stocking at three of the stocking sites to assess initial mortality due to predation.

Largemouth bass in the four stocked and two control embayments were sampled using boat-mounted electrofishing gear in April 2003 to index recruitment to age-1. At each embayment, one transect was sampled adjacent to the boat ramp where fish were stocked (if it was a stocked embayment) and at 1 km and 2-3 km on each side of the ramp (i.e., 5 transects per embayment). Each transect amounted to approximately 10-minutes of pedal time. Otoliths were removed from all fish less than 275 mm TL. Otoliths of all age-1 fish were mounted and viewed under a microscope with an epifluorescent light source (as described above) to determine the percent contribution of stocked fish.

Habitat

The shoreline habitat was described at all electrofishing transects in all six embayments during the winter of 2001-2002. Shoreline habitat data was collected by extending a 100-m tape along the electrofishing transects at the water line and visually estimating substrate within a 1 x 1 m frame every 10 m. Substrate was visually classified using a modified Wentworth scale (Cummins 1962) and grouped into fines (0.059 to < 2 mm), gravel (2 to < 16 mm), cobble (16 to < 256 mm), and boulder (> 256 mm). Slope was measured every 20 m by extending a 2-m rope from a vertical pole perpendicular to the waterline. The rope was equipped with a level and the location of the leveled rope on the pole was recorded as the height. Percent coverage of aquatic vegetation was also visually estimated in a 1 x 1 m plot approximately every 10 m along all 100-m transects in early August 2002. Aquatic vegetation was classified as floating leaf, submergent, or emergent.

Data Analysis

The percent contribution of stocked fish on each sample date was simply the ratio of stocked age-0 fish to wild age-0 fish in the electrofishing samples. Catch data for age-0 largemouth bass (wild and stocked fish combined) were \log_{10} -transformed and averaged per

embayment and sampling date, and compared using analysis of variance (ANOVA). Those same catch data were subjected to catch curve analysis to estimate instantaneous mortality rates of age-0 bass in each embayment. Relations between mortality during the first summer and instantaneous growth, initial mean catches, and number of fish stocked into each embayment were explored using simple linear regression and correlation analyses. Mortality rates were also calculated separately for each cohort (six wild and four stocked cohorts) based on their geometric mean catches in the June and October 2002 samples. Mean survival through October 2002 of wild and stocked age-0 largemouth bass was compared using a t-test after determining that the variances of the arcsine-transformed percentage data were similar ($P > 0.10$). Growth rates of stocked and wild fish were expressed as instantaneous growth rates (mm; %/d) between sample periods. All statistics were calculated and compared using SAS program statements.

Stomach contents of a subsample of five age-0 largemouth bass per electrofishing transect in each embayment on each of the three sampling dates were examined under a dissecting scope. Prey items were grouped into either fish or invertebrates, and presence/absence of fish or invertebrates was determined. Logistic regression was used to model presence of fish in the diet as a function of length to determine when most age-0 largemouth bass switched to piscivory, which was arbitrarily defined as 60% (Bettoli et al. 1992).

Habitat data were averaged for each 100-m transect and compared between stocked and control embayments and among stocked embayments using ANOVA. Percent slope was calculated by dividing the height on the pole by the tangent of 2 (length of the rope). Percent slope was also averaged for each 100-m transect. The stepwise multiple regression procedure was not used to predict mean catch from habitat parameters because of multicollinearity among habitat variables. Multiple regression models that incorporated percent slope and percent substrate class were developed for each substrate class to determine which combination of substrate class and percent slope was the best predictor of mean catch. Habitat parameters and the total length of each fish were modeled to determine whether habitat could predict the presence of fish in the stomach of age-0 largemouth bass. All statistical tests were considered significant at $P = 0.05$.

RESULTS

Marking Efficacy

No initial mortality due to marking was observed for fish that were returned to the laboratory for the mark retention study. Also, no initial mortality due to marking was observed by TWRA hatchery personnel when fish were released. One reader correctly identified 97% of the otoliths as either marked or unmarked in a blind test, which consisted of 18 control fish and 22 OTC-immersed fish. There was one omission of a marked fish, but the mark was detected on subsequent review of the second otolith. Marks were visible on 100% of the fish ($n = 240$) that were held for 30 d and marks were clearly visible as early as 7 d post-immersion. Autofluorescence of the otolith did not affect the ability of the reader to detect the oxytetracycline mark.

Dispersal

Rapid dispersal was observed at 20 d post-stocking, where 35 of 111 (32%) recaptures were within 100 m of the stocking sites and 31% of the recaptures were greater than 600 m from stocking sites. The distance moved by each subspecies was similar (ANOVA; d.f. = 3, 107; $F = 0.76$; $P = 0.52$). At 60 d post-stocking, 13 of 30 (44%) recaptures were within 200 m of stocking sites and 30% of the recaptures were greater than 600 m from the stocking sites. Similarly, at 140 d post-stocking (October 2002), two of six recaptures were within 200 m of the closest stocking site and two others were captured more than 600 m away from the nearest stocking site. The proportions of stocked fish found at different distances were similar on the first three sample dates, indicating that dispersal of stocked fish stabilized by 20 d post-stocking.

Growth, Abundance, and Mortality

In the first sample (7-20 d post-stocking), stocked fish were longer on average ($n = 111$, $\bar{x} = 56.3$, $SE = 0.26$) than wild fish ($n = 867$, $\bar{x} = 45.8$, $SE = 1.04$) in all six embayments ($t = -12.77$; d.f. = 977, $P < 0.0001$). The stocked fish maintained their length advantage over

wild fish and were 26 mm longer on average than wild fish by the third sample, 140 d post-stocking ($t = -1.82$; d.f. = 112; $P = 0.07$). Only six stocked fish were recaptured in that October 2002 sample and they displayed a wide range in lengths (76-156 mm). Stocked fish grew faster on average (0.5 mm/d) than wild fish (0.4 mm/d). In April 2003, mean TL of age-1 bass (wild and stocked fish combined) differed among embayments (ANOVA; $F = 6.07$; d.f. = 5, 156; $P < 0.0001$). Age-1 bass were shortest in stocked embayment S1 (mean = 150 mm TL) and longest in control embayment C1 (mean = 176 mm TL).

The catch of age-0 largemouth bass (wild and stocked fish combined) varied an order of magnitude among embayments in the first (June 2002) electrofishing sampling (ANOVA; d.f. = 5, 40; $F = 8.63$; $P < 0.0001$; Table 1). Mean catch was highest in the embayment which received the largest number of stocked fingerlings (S3; 75,000 fish; Figure 2); initial mean catches in the six embayments were positively related to the number of fish stocked (linear regression; $F = 5.6$; d.f. = 1,4; $r^2 = 58\%$; $P = 0.0779$). However, the effects of stocking did not persist. By 140 d post-stocking, catch rates of all age-0 largemouth bass were similar among embayments (ANOVA; d.f. = 5, 40; $F = 0.94$; $P = 0.4651$).

First summer survival of stocked and wild age-0 largemouth bass was comparable, but low (4.5% - 6.8%), in the two embayments stocked with the Florida subspecies (S2 and S3; Table 2). In the other two stocked embayments, stocked fish survived at a much lower rate (0 – 4.4%) compared to wild fish (33.7 – 50.0%). Mean survival between June and October for the six cohorts of wild fish and four cohorts of stocked fish averaged 21% (SE = 7.2) and 4.0% (SE = 1.4), respectively, and the means differed (t-test; d.f. = 8; $P = 0.0536$).

Stocking fingerling bass did not appear to affect the mortality of wild age-0 largemouth bass. Although instantaneous mortality of wild fish tended to increase with the number of fingerlings stocked, the linear model was not significant ($F = 2.85$; d.f. = 1,4; $P = 0.1666$). Our failure to reject the null hypothesis of “no effect” does not mean survival of wild fish was unaffected by the stocking program. Instead, if there was an effect, it was too small (or the variation was too high) to detect with a sample size of only six observations (i.e., statistical power was low).

Compensatory mortality was evident because instantaneous mortality was positively correlated ($r = 0.95$, $P = 0.003$) with initial mean catch of all age-0 largemouth bass (Figure 3). Thus, cohorts with high initial abundance (wild and stocked fish combined) experienced high

mortality, and vice-versa. Compensatory growth was not evident because instantaneous growth of all age-0 fish was positively correlated ($r = 0.86$, $P = 0.029$) with initial mean catch (Figure 4).

Predation

Age-0 largemouth bass that were recovered from stomachs of predators could not be identified as either stocked or wild fish because too little time had elapsed between when fish were stocked and when they were recovered from predator stomachs (i.e., the OTC mark would be on the margin of the otoliths of treated fish and undetectable). Predators were collected 2-10 hours post-stocking and an OTC mark is not detectable that soon after immersion. However, at least one age-0 bass was consumed by 34% of the 87 potential predators that were collected and 83 age-0 bass were recovered from the predator stomachs. The only other prey items found in the predator diets were crayfish and sunfish (*Lepomis* sp.). Also, 39 of the 87 predators that were sampled had empty stomachs; if these fish were excluded, 63% of the predator stomachs with food contained at least one fingerling bass. The most common predator of fingerling bass was largemouth bass longer than 200 mm TL; 41% (24 of 58) of the largemouth bass examined had at least one fingerling bass in their stomach. Other predators of fingerling bass were spotted bass *Micropterus punctucatus*, green sunfish *Lepomis cyanellus*, warmouth *L. gulosus*, and hybrid striped bass *Morone saxatilis* x *Morone chrysops*. Potential predators that did not have a fingerling bass in their stomach were spotted gar *Lepisosteus oculatus*, flathead catfish *Pylodictis olivaris*, sauger *Stizostedion canadense*, yellow perch *Perca flavescens*, white crappie *Pomoxis annularis*, and black crappie *P. nigromaculatus*.

Diet

The percentages of stocked and wild age-0 largemouth bass that had empty stomachs were similar ($\chi^2 = 0.52$; $P = 0.47$). Also, the percentages of stocked fish and wild fish that had fish or invertebrates in their stomach were similar ($P \geq 0.89$). Thus, data from stocked fish and wild fish were combined for analysis. After pooling the data, nearly 40% of the age-0 largemouth bass had empty stomachs, leaving 407 fish for the analysis. Total length was a good predictor of the presence of fish in the stomachs of age-0 largemouth bass (Figure 5) and the logistic model was significant ($\chi^2 = 83.19$; d.f. = 1; $P < 0.0001$):

$$\text{Logit}(P_i) = -2.527 + 0.041 (\text{TL}).$$

The predicted size at which 60% of the age-0 largemouth bass would contain a fish in their stomachs was 76 mm TL. Slope of the shoreline was included in the model, which improved the fit of the data to the model (Homer and Lemeshow Goodness-of-Fit Test; $\chi^2 = 8.88$; d.f. = 2; $P = 0.3528$). All regression coefficients were significant ($P < 0.0001$) and the model was significant ($\chi^2 = 111.35$; d.f. = 2; $P < 0.0001$):

$$\text{Logit}(P_i) = -0.6913 + 0.0473 (\text{TL}) - 0.08 (\text{Slope}).$$

Percent coverage of boulder was also modeled with TL and the model was significant ($\chi^2 = 104.27$; d.f. = 2; $P < 0.0001$). The regression coefficients were also significant ($P < 0.0001$). The model was

$$\text{Logit}(P_i) = -2.612 + 0.047 (\text{TL}) - 0.0263 (\text{Boulder}).$$

Percent slope and percent coverage of boulder substrate were significantly correlated ($r = 0.843$; $P < 0.0001$); therefore, slope and boulder were not included in the same logistic model.

The probability that stomach contents of age-0 largemouth bass would contain at least one fish was also modeled for each embayment to detect any differences among habitat types. Two embayments with disparate structural complexity were compared; S2 had a significantly greater percent coverage of aquatic vegetation than C1 (Figure 6). The predicted size at which 60% of the age-0 largemouth bass contained a fish in their stomach was 53 mm TL in embayment C1 and 85 mm TL in embayment S2 (Figure 7), indicating that fish switched to piscivory earlier where vegetation was scarcest.

Stocking Contributions

The contribution of stocked fish to the age-0 cohort in each embayment ranged from 13 to 29% after 7-20 d (Figure 8). The number of recaptures in the first sample (111) was small compared to the number stocked (128,265). Two embayments (S1 and S4) where the percent

contribution of stocked fish was highest in the initial sample yielded only one stocked fish (of 82 collected) in the two subsequent samples. The contribution of the Florida subspecies stocked in embayments S2 and S3 (both of which received the Florida subspecies) remained consistent at 10-14% through 140 d post-stocking. By October 2002, only 9% of the 70 age-0 largemouth collected in the four stocked embayments were stocked fish and most of those were in the embayment stocked with the Florida subspecies. In all, 1,024 age-0 largemouth bass were collected in the stocked embayments and of those, 147 fish were marked with OTC. Transects that were sampled for age-1 largemouth bass in April 2003 extended at least 3 km from each stocking site to account for further dispersal. In those samples we recaptured only two fish, which represented less than 2% of the total catch ($n = 91$) of age-1 largemouth bass in the stocked embayments. The two recaptures occurred in one of the embayments stocked with Florida bass (S2). No OTC-marked largemouth bass were ever collected in the two control embayments. Electrofishing samples in 2002 encompassed only 2 km of shoreline in each embayment, and less than 6 km of shoreline were sampled in each embayment in 2003; therefore, percent contributions on an embayment-wide scale were miniscule.

Habitat

Most of the electrofishing transects lacked aquatic vegetation, except for those in stocked embayment S2 (Table 3). Mean shoreline slope of the embayments ranged from 22 to 40% (Table 4). In five of six embayments, some transects were located along bridge embankments and these transects were characterized by steep slopes and boulder riprap. The one embayment that did not have transects along a bridge embankment (S1) had a mean slope of 24%. In that embayment, boat docks and seawalls were common and as a result, only the first two transects were sampled on the left side of the boat ramp. Relative to the other embayments, fines and gravel were more common and cobble and boulder less common in stocked embayment S1.

The embayment with the greatest coverage of aquatic vegetation (S2) also had the greatest coverage of fines. Some form of aquatic vegetation covered over 90% of the sample transects in that embayment. The majority of this embayment was characterized by shallow slopes, except for a few transects along a bridge embankment.

Stocked embayment S3 was comprised of two very different habitats. All of the transects on the left-side of the boat ramp ran along a bridge embankment, which was characterized by steep slopes and a high percent coverage of boulders. Transects to the right of the boat ramp had a much shallower slope and little gravel, cobble, or boulder. The shoreline to the right of the ramp did have high coverage of fines and aquatic vegetation. Emergents dominated the aquatic vegetation at S3, but the percent coverage was lower than in embayment S2.

The embayment with the greatest mean slope (S4, 40%) had a high percent coverage of boulder and fines. The first few transects to the right of the boat ramp were along a bridge embankment, which led towards the main reservoir and transects in the basin of the reservoir were dominated by a high percent coverage of fines. Steep slopes and boulders dominated the left side of the boat ramp and aquatic vegetation was scarce.

The first few transects to the right of the boat ramp in control embayment C1 were along a bridge embankment with steep slopes and boulders. The rest of the transects on the right side had lower slopes with high coverage of cobble. The first few transects to the left of the boat ramp had a high mean coverage of cobble. The rest of the transects on the left side had shallow slopes with a high percent coverage of fines and intermediate coverage of aquatic vegetation.

A low mean slope and high mean coverage of gravel characterized control embayment C2. The first few transects to the left of the boat ramp were along a bridge embankments; subsequent transects had shallower slopes with a high mean coverage of gravel. Aquatic vegetation was scarce and isolated to a few transects. The first few transects to the right of the boat ramp had shallow slopes with high coverage of gravel and the remaining transects on the right side were dominated by steep slopes and boulders.

Slope of the shoreline was a negative regressor of mean catch of age-0 largemouth bass in all sample periods. Percent gravel substrate was also a negative regressor of mean catch in all sampling periods. Slope and percent gravel were the best pair of predictors of mean catch for the first sampling period (20 d post-stocking; $r^2 = 0.40$, $P < 0.001$) and second sampling period (60 d post-stocking; $r^2 = 0.34$, $P < 0.001$). All regression coefficients were significant ($P \leq 0.0019$) and the models were:

$$\text{Sample Period 1: } \log_{10}(\text{catch} + 1) = 2.42 - 0.011(\text{Gravel}) - 0.032(\text{Slope}).$$

$$\text{Sample Period 2: } \log_{10}(\text{catch} + 1) = 1.72 - 0.014(\text{Gravel}) - 0.023(\text{Slope}).$$

Percent cobble was a negative regressor of mean catch in all sample periods. Percent coverage of cobble and shoreline slope were the best predictors of mean catch for the third sampling period (140 d post-stocking; $r^2 = 0.20$, $P = 0.0078$). The model was

$$\text{Sample Period 3: } \log_{10}(\text{catch} + 1) = 0.58 - 0.0055(\text{Cobble}) - 0.0086(\text{Slope}).$$

Average shoreline slopes were similar in control and stocked embayments ($F = 0.17$; d.f. = 1, 392; $P = 0.6771$); however, slopes differed among stocked embayments ($P < 0.0001$). Slopes were shallowest and similar in stocked embayments S1 and S2 (Table 4). Control embayments had a greater mean coverage of gravel ($F = 27.51$; d.f. = 1, 712; $P < 0.0001$) and cobble ($F = 39.19$; d.f. = 1, 712; $P < 0.0001$) than stocked embayments. Mean coverage of cobble substrate did not vary among stocked embayments ($P = 0.6966$).

DISCUSSION

Oxytetracycline immersion was a useful technique for mass marking juvenile largemouth bass in this study. It took little effort to mark the fish and we observed 100% marking efficacy, which is not always achieved using other marking techniques. Recent studies have also reported high (98-100%) oxytetracycline mark retention for black-nose crappie (Isermann et al. 1999), walleyes (Kayle 1992) and yellow perch (Unkenholz et al. 1997; Brown et al. 2002). Retention of oxytetracycline marks for up to four and five years has been reported for red drum (Jenkins et al. 2002) and sauger (Heidinger and Brooks 1998).

The oxytetracycline marks on otoliths removed from recaptured bass and fish held in the laboratory were clearly visible and auto-fluorescence of the otolith did not affect mark clarity, which is similar to what Isermann et al. (1999) reported for black crappies stocked in Tennessee. In contrast, Conover and Sheehan (1996) found that auto-fluorescence hindered the detection of OTC marks; however, they marked fish in the fall when growth may have been slower. In the present study, only one marked fish was mistaken for a control fish in the blind test, but the mark was detected upon review of the second otolith.

Stocked largemouth bass dispersed farther and faster in Chickamauga Lake than in a North Carolina reservoir (Jackson et al. 1993). For instance, after only 7 d, almost 30% of our recaptures in one embayment occurred more than 700 m from the stocking site. Dispersion appeared to stabilize by 20 d post-stocking, which is similar to what Buckmeier and Betsill (2002) reported for Florida largemouth bass stocked in a Texas reservoir. All sampling of age-0 largemouth bass in our study occurred within 1 km of each stocking site because it was assumed that stocked largemouth bass would not move more than 1 km during their first summer of life. It is possible that stocked fish dispersed further than 1 km during their first summer; however, no fish were recaptured when transects further than 1 km from each stocking site were sampled the following spring. Also, only 3% of all the age-0 recaptures occurred at transects located 900 m from the nearest stocking site.

Stocked fish in this study experienced high mortality that was likely due to factors other than handling and marking. No initial or delayed mortality was observed for treated fish that were retained for the efficacy study. Also, mortality rates of stocked fish and wild fish between 20 and 140 d post-stocking were very similar in two of four embayments. Brown et al. (2002) marked yellow perch with OTC in a similar manner and initial mortality was also low (< 1%).

Mortality rates of stocked fish were high, undoubtedly due to predation. Age-0 bass fingerlings were consumed by 63% of potential predators that had recently consumed a meal. Although age-0 largemouth bass recovered from predator stomachs could not be identified as stocked fish, most were probably stocked fish. There were very few prey items other than fingerling bass found in the stomachs of the predators, which suggests that predators were not displaying regular feeding behavior at the time they were captured. Stocking a large number of fish at one location may induce predators to feed on stocked fish. Hoxmeier and Wahl (2002) concluded that initial losses to predation (as high as 26%) could have been an important factor limiting the success of largemouth bass stockings in Illinois lakes. Initial loss of stocked fish to predation might be decreased by stocking fish in suitable habitat; however, if fish are disoriented when released from the hatchery truck (Forsberg et al. 2001), the fish may not be able to find suitable habitat and avoid predation. Similarly, bass reared under artificial circumstances (e.g., pellet-reared) behave differently than wild fish when searching for food and may be more vulnerable to predation (Heidinger and Brooks 2002). For at least 12 h after fish were stocked in our study, large schools of largemouth bass presumed to be stocked fish were observed near

the boat ramps. Although we did not measure it, intra-cohort cannibalism can reduce the survival of stocked largemouth bass in southern reservoirs (Pine et al. 2000). When we reared treated fish to verify OTC-mark retention, larger fish of the same cohort were often observed preying on smaller counterparts. The influence of predation on stocked fish survival could be addressed by sampling predators at stocked *and* non-stocked sites.

Although stocking age-0 largemouth bass tended to initially increase the abundance of fish, increased abundance was offset by higher mortality. Wild fish survived as well or better in the four stocked embayments (pooled average between June and October = 24%) as in the two control embayments (pooled average = 15%) and their mortality was not linearly related to the number of fish stocked; thus, there were no clear negative effects of the stocking program on wild age-0 largemouth bass. In contrast, Buckmeier and Betsill (2002) reported that stocked fish might have suppressed wild fish abundance. They also observed that stocked fish that survived the initial period of high mortality experienced mortality rates similar to wild fish, which we observed in two of the four embayments. Jackson et al. (2002) reported that stocked age-0 largemouth bass performed similar to wild fish in terms of survival and feeding in a North Carolina reservoir. Fingerlings stocked into Chickamauga Lake in our study also displayed similar feeding ecology as their wild counterparts.

Our stocking rates (17,000 to 75,000 fish per stocking site) were much higher than the rate used by Buckmeier and Betsill (2002), who stocked fish at a rate of 3,500-fish/site. In another Texas study, Buckmeier et al. (2003) stocked Florida largemouth bass at rates of 1,000, 10,000, and 100,000 fish per site to determine the most efficient rate to alter the genetic composition of the receiving populations. Stocking 10,000 fish per site was judged to be most efficient, despite a low ($\leq 5.4\%$) contribution of stocked fish. Close and Anderson (1992) suggested that “scatter-stocking” steelhead fry was better than single-site stocking. When largemouth bass fingerlings were stocked from a boat at regular intervals along the shoreline of another Tennessee reservoir, piscine predators attacked stocked fish as soon as they entered the water (Bettoli 1997). Dispersing fish along a shoreline instead of at a single-point may reduce fish density and intraspecific competition, but it will not eliminate mortality due to predation.

Instantaneous mortality rates were positively related to initial catch rates, which is similar to what Ludsin and DeVries (1997) described for juvenile largemouth bass in Alabama. In contrast, Sammons et al. (1999) found no significant correlation between age-0 largemouth bass

density and mortality. High spatial variation in our study was consistent with what Phillips et al. (1997) described for age-0 largemouth bass in a North Carolina Reservoir. Although annual variations in abundance were not measured in this study, variation in abundance among the embayments was likely due to spatial variability in habitat. In Chickamauga Lake, carrying capacity could have been reached by natural recruitment alone in some of the embayments, or the combination of natural recruitment and stocking fish in treatment embayments. Buckmeier et al. (2003) and Buynak and Mitchell (1999) also suggested that localized carrying capacity could have been reached when largemouth bass were stocked at high rates. Catch rates in Chickamauga Lake varied among embayments in the first samples (June 2002); however, catch rates were similar by October 2002. Density-dependent mortality of age-0 fish has also been described for smallmouth bass (DeAngelis et al. 1993), bluegill (Partridge and DeVries 1999), salmon (Egglisshaw and Shackley 1980), and steelhead (Wentworth and LaBar 1984).

Instantaneous growth rates of largemouth bass stocked in Chickamauga Lake were positively correlated with initial mean catches, in contrast to what Miranda et al. (1984) reported for age-0 largemouth bass in West Point Reservoir, Alabama-Georgia. Ridgway et al. (2002) reported a significant inverse relationship between growth and density of juvenile smallmouth bass. Sammons et al. (1999) did not find a relationship between growth rates and density of juvenile largemouth bass. In our study, smaller individuals could have died at a faster rate, which would have increased the mean total length each sampling period; thus, the estimates of growth may have been positively biased.

Stocked fish in our study maintained an initial length advantage over wild fish throughout the summer. Age-0 largemouth bass are gape-limited (Shelton et al. 1979) and larger fish of the same cohort should have more prey available than smaller individuals (Keast and Eadie 1985). Additionally, large age-0 bass will accumulate more lipids and have a better chance of surviving the winter than smaller bass (Miranda and Hubbard 1994). However, stocked fish in our study did not benefit from having a length advantage over the wild fish (i.e., they contributed poorly to the cohort). Buckmeier and Betsill (2002) also reported that largemouth bass stocked in a Texas reservoir retained a length advantage over wild fish for the most of the summer; however, stocked fish also contributed poorly to cohort strength in that study.

As expected, abundance of age-0 largemouth bass was linked to the habitat. Irwin et al. (1997) found that age-0 largemouth bass preferred shorelines with low slopes and rocky

substratum (≥ 15 mm in diameter) in the absence of vegetation. Much of Chickamauga Lake's littoral zone lacked vegetation; thus, appropriate rock substratum (16 – 256 mm) and low slopes offered the best available cover for age-0 largemouth bass. Habitat complexity affects the growth of age-0 bass (Bettoli et al. 1992) and intermediate levels of vegetative cover offer optimal habitat complexity for good growth of age-0 largemouth bass (Miranda and Pugh 1997).

Largemouth bass stocked in eight Florida lakes fed less on fish and more often on invertebrates (Porak et al. 2002). In contrast, stocked fish and wild fish in our study had similar proportions of fish and invertebrates in their diets. When data from all embayments were pooled, age-0 largemouth bass were considered piscivorous (i.e., at least 60% of fish with food in their stomachs consumed fish) at approximately 76 mm, which is intermediate to what was described for age-0 largemouth bass in a Texas reservoir before and after vegetation removal (Bettoli et al. 1992).

MANAGEMENT IMPLICATIONS

Nearly 130,000 fish were stocked into four embayments in Chickamauga Lake and their contribution to cohort strength was only 9% by fall and declined to just 2% at age 1. In terms of their contribution to the entire cohort in each embayment, those estimates are inflated because we did not sample the entire shoreline of each embayment. The success of any largemouth bass stocking program is undoubtedly influenced by when fish are stocked, not only in terms of time-of-year, but the year in which fish are stocked. At the very least, fish should not be stocked when a strong year-class exists; however, it is difficult to accurately predict the formation of weak year-classes. Additionally, even if fish are stocked on top of a weak year class, it is still impractical to stock fish in late spring if a critical period exists later in the growing season. Our results clearly showed that the number of age-0 bass early in the summer was not related to the number surviving to the end of summer; thus, stocking fish in early summer on top of a good year class (which we assume we observed in our study based on high initial catch rates) did not bolster recruitment. Sammons and Bettoli (2000) noted that water levels in August controlled recruitment by largemouth bass to age-1 in Normandy Reservoir, Tennessee; if the same phenomenon existed in Chickamauga Lake, stocking fish in late spring would not guarantee high abundance of age-1 and older bass.

We used cohort-specific mortality rates (Table 2) to estimate that only 5% ($n = 5,764$) of the 128,265 stocked fingerlings survived their first 120 d in Chickamauga Lake. Subsequently, the cost increased from \$0.35 per fingerling when they were stocked (Tim Churchill, TWRA, personal communication) to about \$7.80 per fingerling surviving 120 days. If mortality remained constant through winter, we estimate that a mere 64 stocked fish survived to April 1, 2003; thus the cost jumped to about \$700 per age-1 recruit. Although the primary objective of the stocking program was to promote introgression of the Florida bass genome into the receiving population, the chances of substantial introgression occurring are slight if few fish survive. Ongoing genetic studies are examining whether introgression of the Florida bass genome is occurring as a result of this multi-year stocking program.

If TWRA continues this stocking program, they should consider stocking fewer, but larger fish. Commercial fish farmers in the southeastern U.S. currently sell 150-200 mm largemouth bass for about \$3/fish; these fish are available each winter and spring. Three dollars per fish compares quite favorably with the estimated cost per recruit (\$700) originating from a fingerling-stocking program. For the same amount of money spent on the current stocking program (~\$45,000), about 15,000 larger fish could be purchased. Even if those larger fish experienced 90% annual mortality their first year, the number of stocked age-2 fish the following spring (~1,500) would dwarf the number of small stocked fingerlings that would survive to age-2. Similarly, the large (~100 mm TL) fingerling largemouth bass stocked by Buynack and Mitchell (1999) into a small Kentucky reservoir experienced good survival and began to contribute to the fishery within a year of stocking. Although it is not TWRA's objective to augment natural recruitment through their fingerling stocking program, and most attempts to do so elsewhere have failed, good survival is a prerequisite for impacting the genome of the receiving population. Therefore, the efficacy of stocking larger fingerlings should be investigated.

We detected significant statistical relations between various habitat variables and age-0 largemouth bass abundance; however, the models never explained more than 40% of the variation in catch. Thus, they have little utility in guiding the choice of where largemouth bass should be stocked. One recurring variable in all models was shoreline slope: wild age-0 bass tended to be most common along shorelines with shallow slopes. Enough evidence exists from

other studies to support stocking fish at multiple sites within each embayment and avoiding releasing huge numbers of fish at one boat ramp or stock site.

Table 1. Geometric mean catch (N/100 m) of age-0 largemouth bass (wild and stocked fish combined) in six embayments in Chickamauga Lake, Tennessee, 2002. Means within each sample period with the same letter were statistically similar (Tukey's test, $P > 0.05$). "S" indicates a stocked embayment and "C" refers to control (unstocked) embayments.

Sample Period	Embayment	Calendar Day	Mean Catch	95 % CI	
				LL	UL
1	S1	175	9.8 a,b,c	2.1	45.0
1	S2	168	27.5 a,b	20.1	37.5
1	S3	169	37.9 a	30.0	47.9
1	S4	170	3.4 c	1.4	8.5
1	C1	169	19.9 a,b	6.6	60.0
1	C2	168	9.0 b,c	5.6	14.5
2	S1	212	6.2 a,b	3.0	13.0
2	S2	210	11.5 a	8.5	15.7
2	S3	211	14.1 a	6.5	30.7
2	S4	212	2.2 b,c	1.1	4.4
2	C1	211	6.0 a,b	1.9	19.0
2	C2	210	1.5 c	1.0	2.2
3	S1	287	3.2 a	1.5	6.8
3	S2	287	2.9 a	1.6	5.0
3	S3	287	2.7 a	1.3	5.4
3	S4	290	2.0 a	1.1	3.4
3	C1	290	4.3 a	2.9	6.4
3	C2	290	2.1 a	1.1	3.8

Table 2. Geometric mean catch (N/100 m), instantaneous mortality rate (Z_{daily}), and survival of wild and stocked age-0 largemouth bass between the first and third samples in six embayments of Chickamauga Lake. “S” indicates a stocked embayment and “C” refers to control (unstocked) embayments. First electrofishing samples were collected June 17-24, 2003; third samples were collected October 14-17 2003.

Embayment	Mean catch first sample	Mean catch third sample	Interval (d)	Z_{daily}	Interval survival (%)
Wild Fish					
S1	6.36	2.14	112	0.0097	33.7
S2	23.23	1.59	119	0.0225	6.8
S3	31.56	1.41	118	0.0263	4.5
S4	1.92	0.96	120	0.0058	50.0
C1	18.94	3.30	120	0.0146	17.4
C2	8.01	1.07	121	0.0166	13.4
Stocked Fish					
S1	2.79 ¹	0.12	112	0.0281	4.3
S2	3.03 ²	0.19	119	0.0233	6.3
S3	4.68 ²	0.25	118	0.0248	5.3
S4	0.80 ³	0	120	-	0

¹ - Northern subspecies

² - Florida subspecies

³ - F₁ hybrid

Table 3. Mean percent cover of aquatic vegetation along 10- m transects at six embayments in Chickamauga Lake, August 2002. “S” indicates a stocked embayment and “C” refers to control (unstocked) embayments. Means in each column with the same letters were statistically similar (Tukey's test, $P > 0.05$).

Embayment	n	Floating leaf	Submergent	Emergent
S1	70	0.0 ^b	0.1 ^c	3.6 ^b
S2	150	6.1 ^a	34.1 ^a	16.8 ^a
S3	150	0.0 ^b	0.2 ^{b,c}	5.5 ^b
S4	130	0.0 ^b	0.6 ^{b,c}	0.0 ^c
C1	110	0.0 ^b	1.9 ^b	2.5 ^b
C2	130	0.1 ^b	0.2 ^{b,c}	0.0 ^c

Table 4. Average habitat parameters with 95% confidence intervals in parentheses at six embayments in Chickamauga Lake, Tennessee, 2002. “S” indicates a stocked embayment and “C” refers to control (unstocked) embayments. Means in columns with the same letters were statistically similar (Tukey's test; $P > 0.05$).

Embayment	% Slope	% Fines < 2 mm	% Gravel 2 – 15 mm	% Cobble 16 – 256 mm	% Boulder > 256 mm
S1	24.0 ^{b,c} (19.5, 28.8)	40.9 ^b (30.0, 52.2)	33.3 ^a (23.9, 43.6)	8.7 ^{b,c} (4.2, 14.8)	0.2 ^c (0.0, 0.7)
S2	22.2 ^c (20.5, 24.0)	65.2 ^a (56.9, 73.1)	6.3 ^b (4.1, 9.1)	12.7 ^b (8.9, 17.0)	1.2 ^c (0.3, 2.5)
S3	32.3 ^{a,b} (27.8, 37.0)	43.0 ^b (31.7, 54.8)	0.3 ^c (0.1, 0.7)	4.0 ^c (2.4, 6.0)	33.9 ^a (24.2, 44.3)
S4	40.0 ^a (34.3, 45.9)	24.6 ^b (15.2, 35.4)	5.3 ^b (2.5, 9.0)	10.5 ^{c,b} (6.2, 15.8)	26.0 ^{a,b} (16.6, 36.5)
C1	34.0 ^a (28.8, 39.5)	8.4 ^c (3.6, 15.0)	6.3 ^b (3.3, 10.1)	32.0 ^a (22.4, 42.4)	20.8 ^{a,b} (12.5, 30.5)
C2	23.5 ^c (19.4, 27.7)	7.1 ^c (3.8, 11.2)	35.6 ^a (27.4, 44.2)	15.7 ^b (11.2, 20.9)	10.5 ^b (5.3, 17.2)

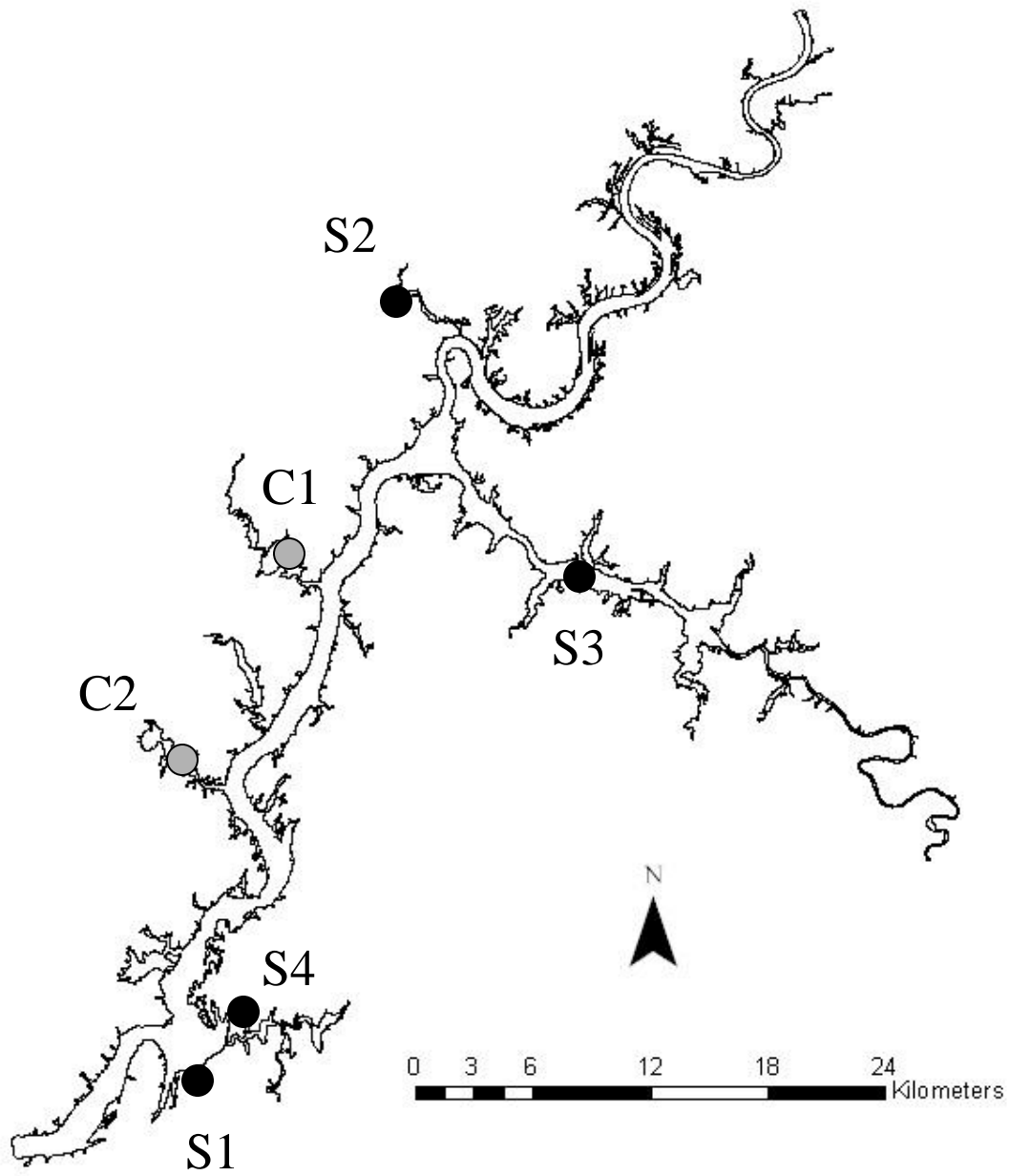


Figure 1. Stocking sites (dark circles) and control sites (gray circles) in Chickamauga Lake, Tennessee, 2002.

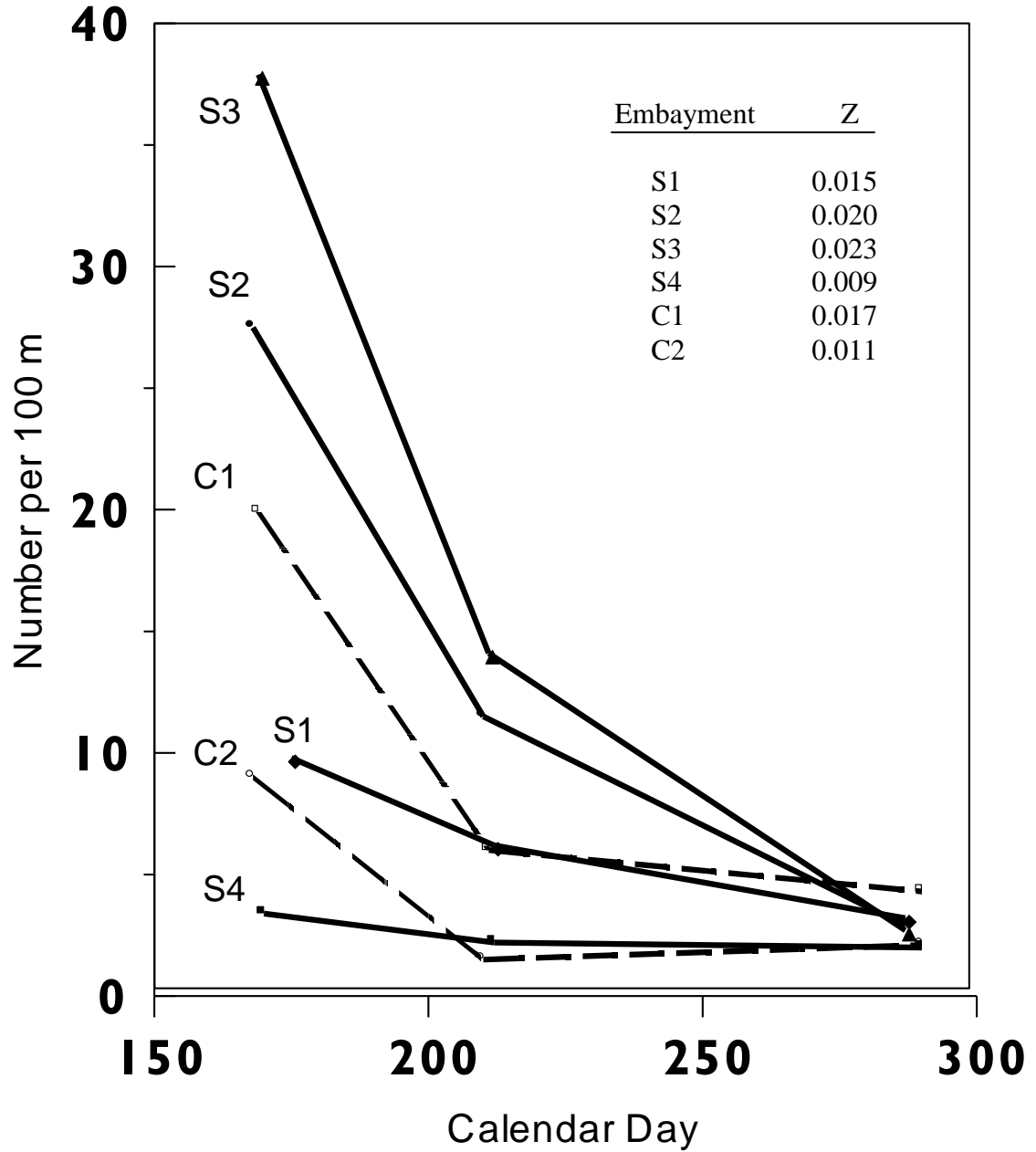


Figure 2. Geometric mean catch in electrofishing samples of age-0 largemouth bass in six embayments of Chickamauga Lake, Tennessee, 2002. “S” indicates stocked embayments and “C” refers to control (unstocked) embayments. Embayment S1 was stocked with 14,825 northern largemouth bass. Embayments S2 and S3 were stocked with 23,440 and 75,000 Florida largemouth bass, respectively. Embayment S4 was stocked with 15,000 F1-hybrid largemouth bass.

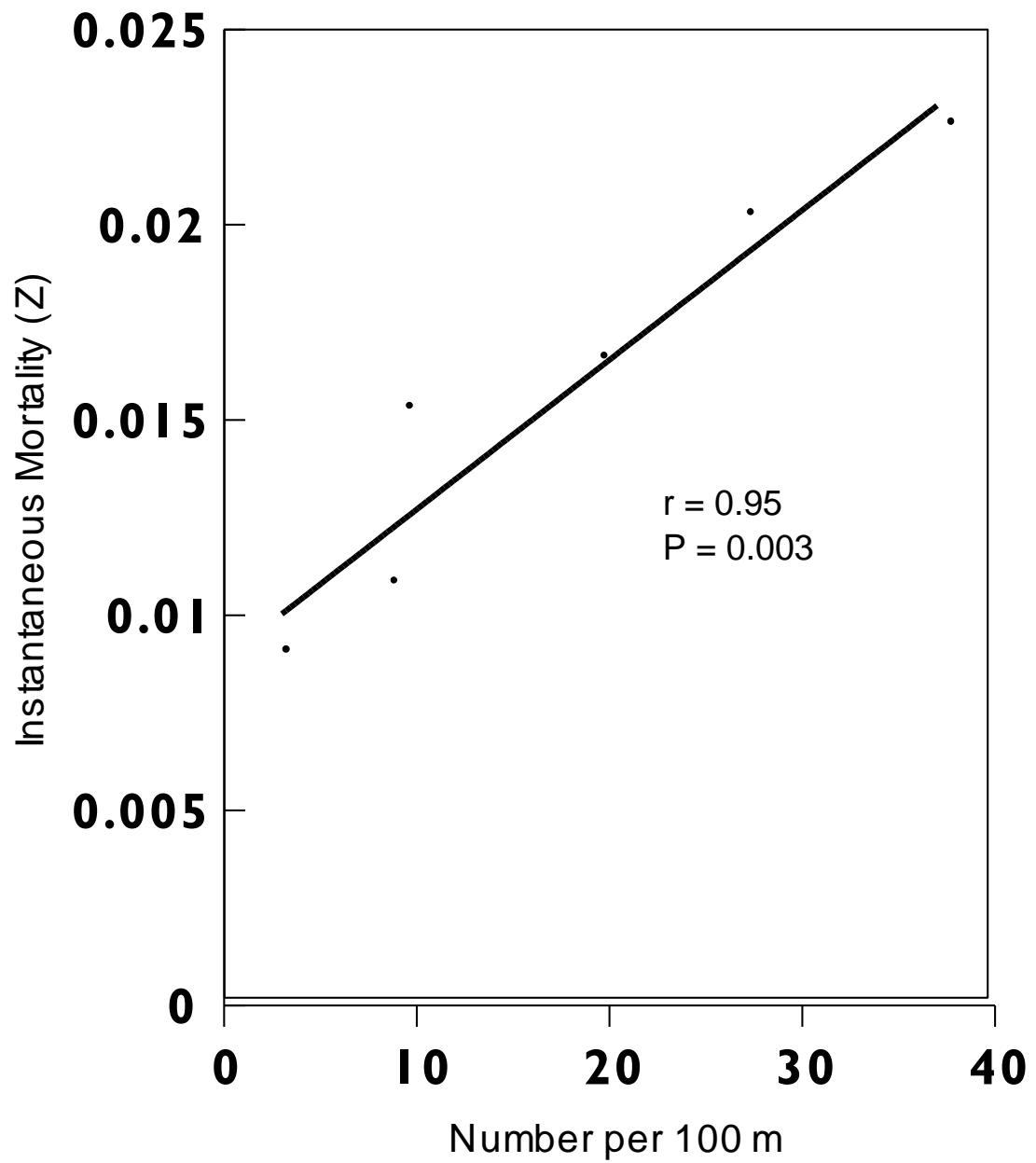


Figure 3. Instantaneous daily mortality between June and October 2002 versus initial geometric mean catch of all age-0 largemouth bass in six embayments of Chickamauga Lake, Tennessee, 2002.

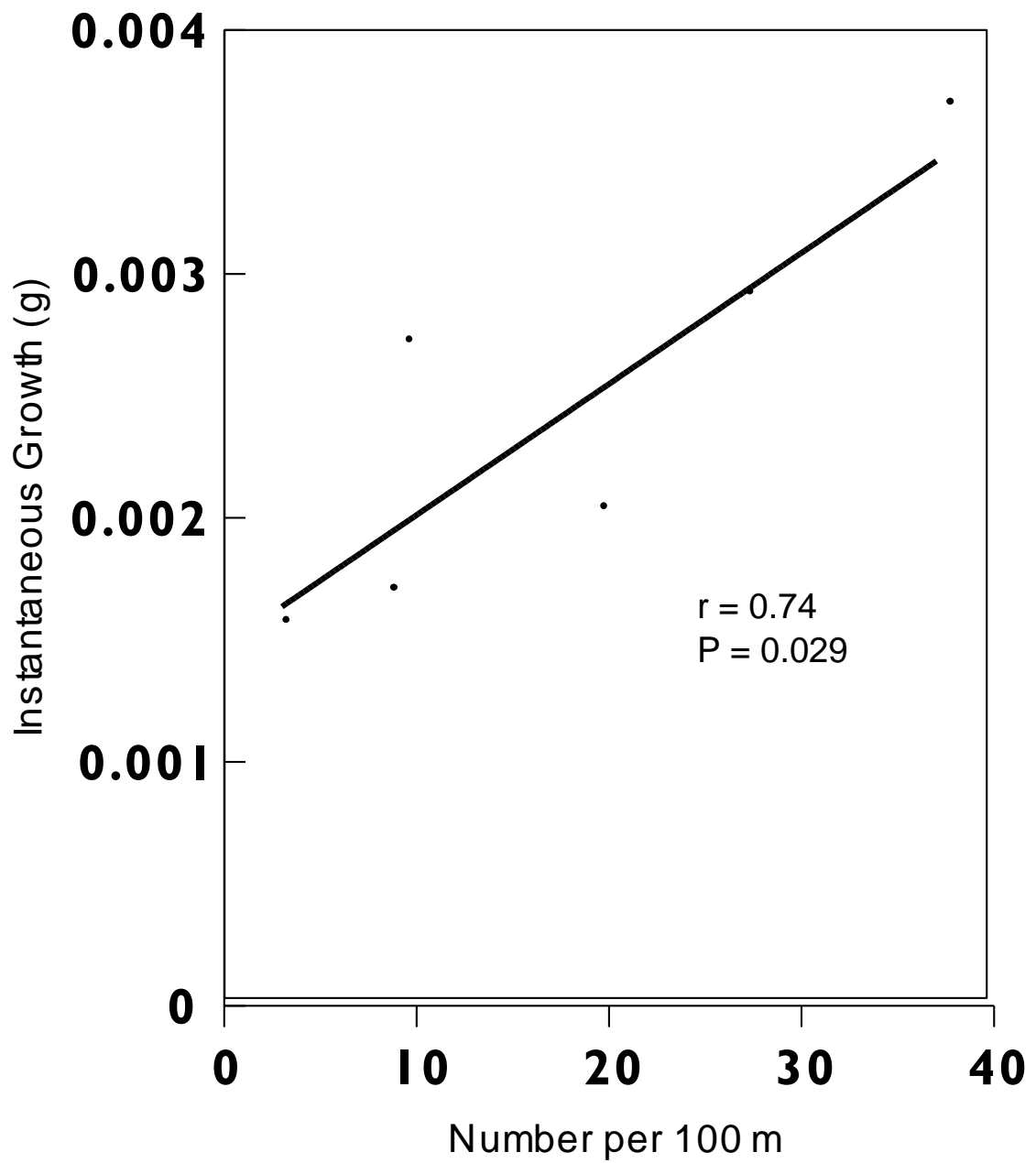


Figure 4. Instantaneous daily growth (%/d) versus initial geometric mean catch of all age-0 largemouth bass in six embayments of Chickamauga Lake, Tennessee, 2002.

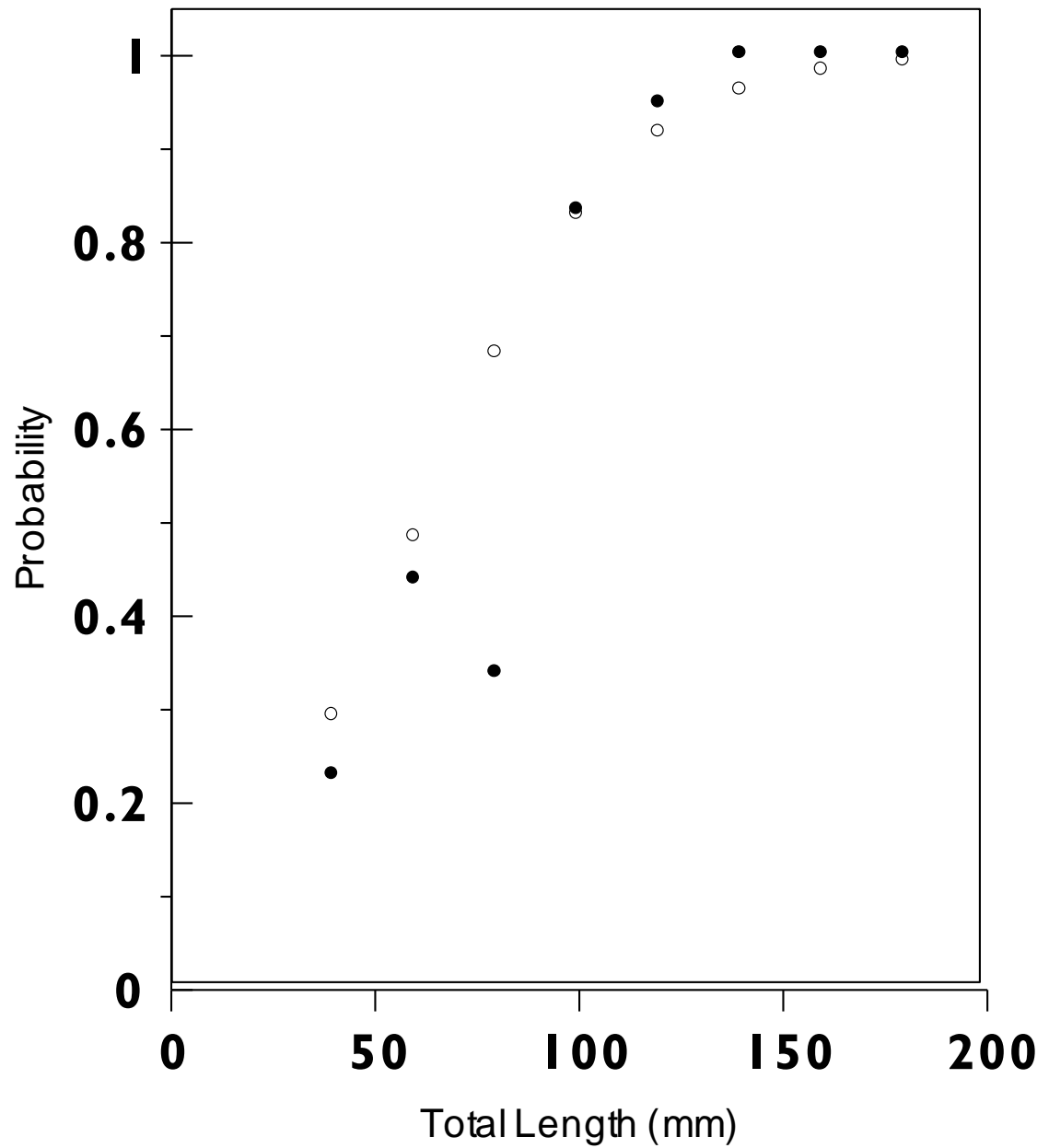


Figure 5. Probability of age-0 largemouth bass stomach contents containing at least one fish (open circles) and the observed percentage of largemouth bass that consumed a fish (dark circles), Chickamauga Lake, Tennessee, 2002.

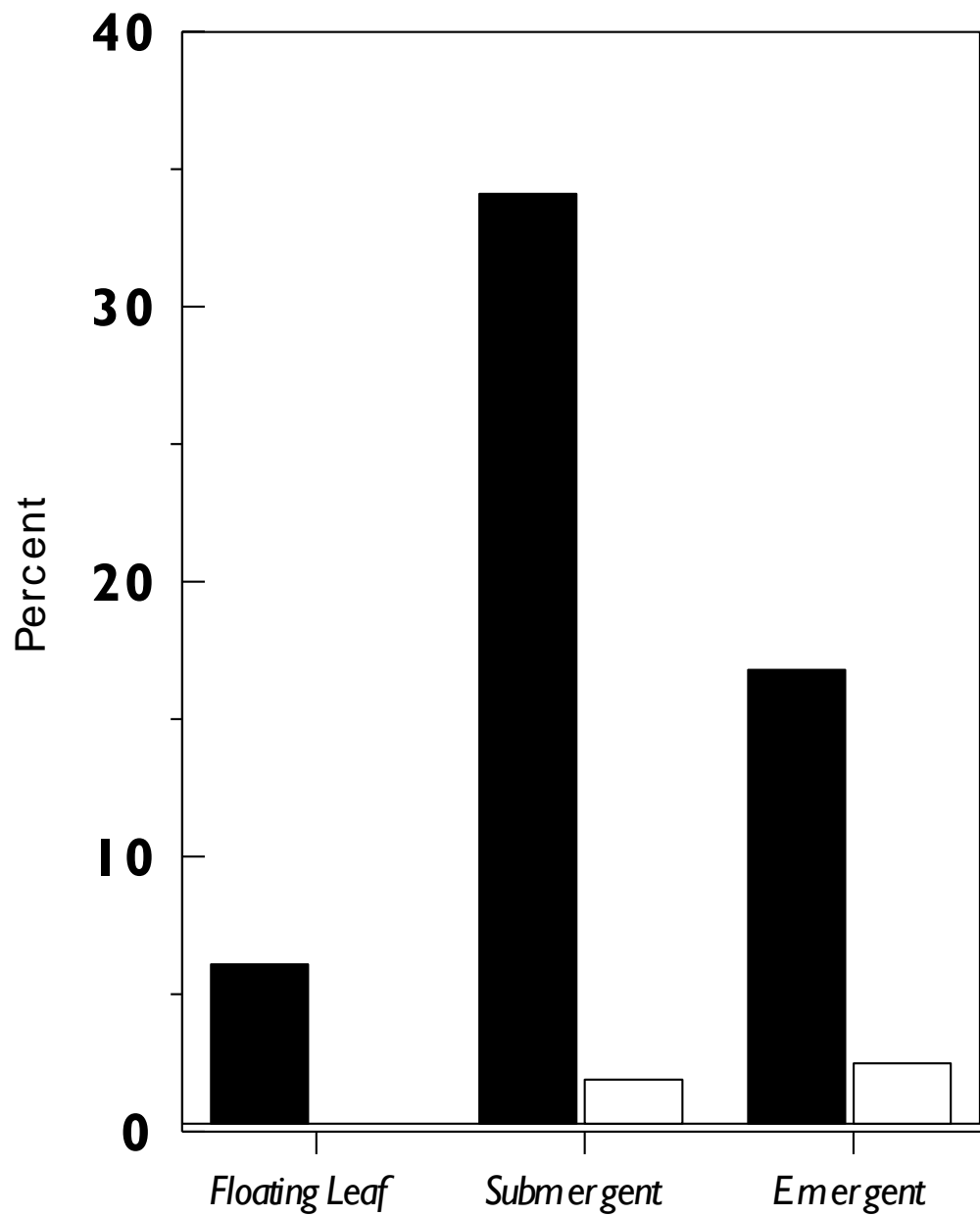


Figure 6. Percent coverage of aquatic plants in control embayment C1 (white bars) and stocked embayment S2 (dark bars), Chickamauga Lake, Tennessee, 2002.

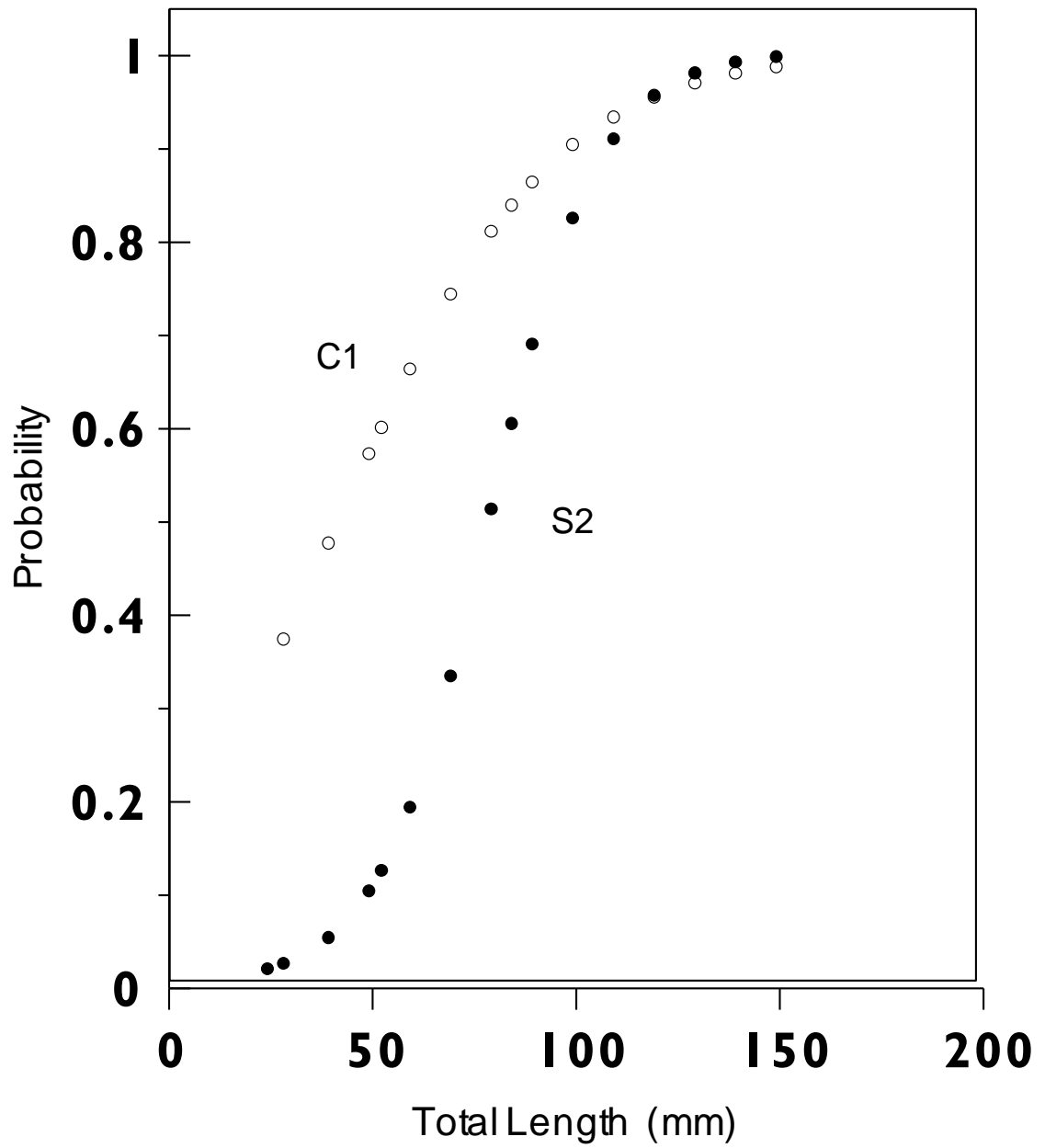


Figure 7. Probability of largemouth bass stomach contents containing a fish versus total length (mm), Chickamauga Lake, Tennessee, June - October 2002.

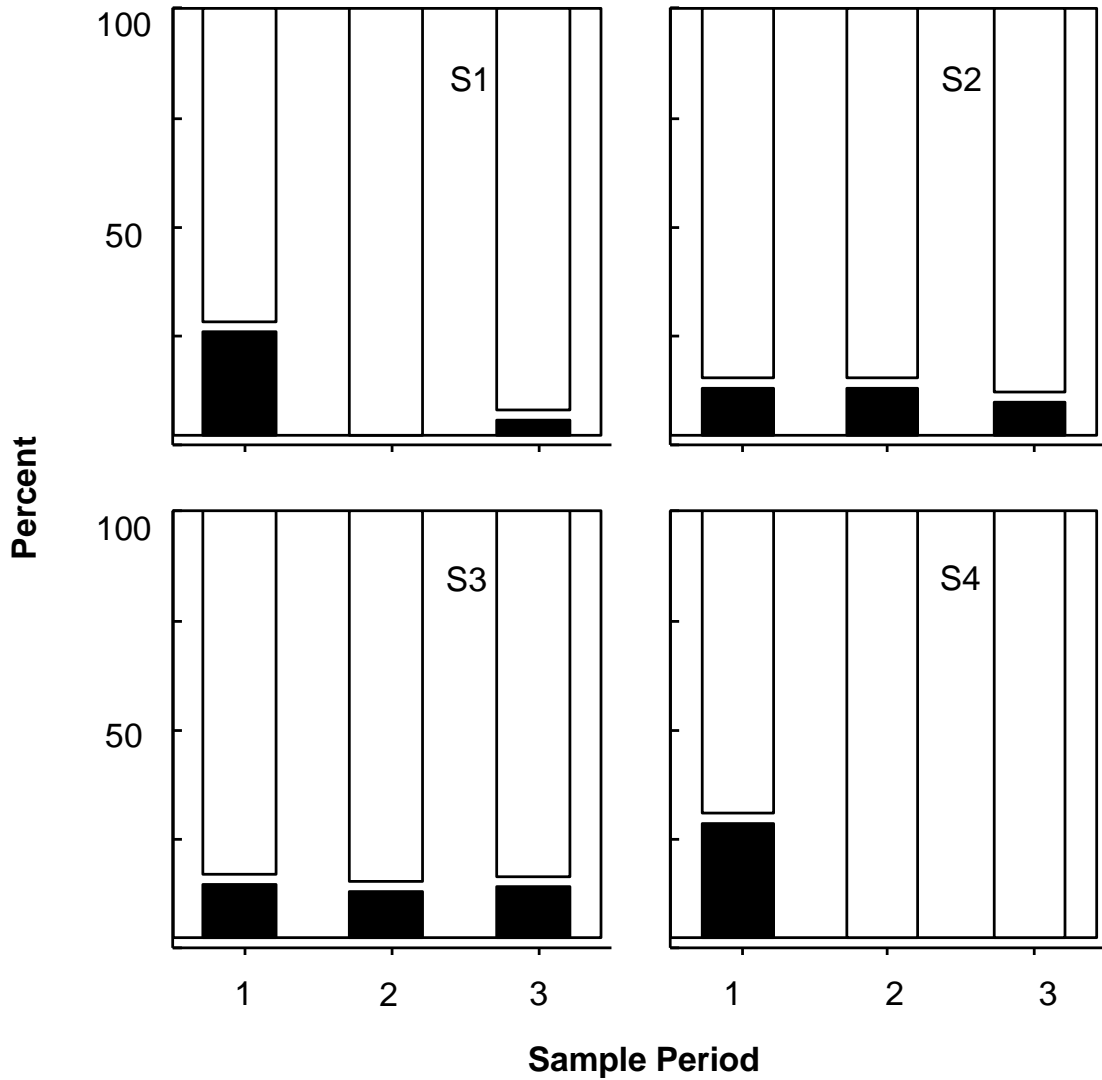


Figure 8. Percent contribution of stocked fish (dark bars) to age-0 cohort strength along transects in four embayments of Chickamauga Lake, Tennessee, 2002. The first, second, and third electrofishing samples were collected June 17-24, July 29-31, and October 14-17 2003, respectively.

LITERATURE CITED

- Aggus, L. R., and G. V. Elliot. 1975. Effects of cover and food on year-class strength of largemouth bass. Pages 317-322 *in* H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C.
- Allen, M. S., J. C. Greene, F. J. Snow, M. J. Maceina, and D. R. DeVries. 1999. Recruitment of largemouth bass in Alabama reservoirs: relations to trophic state and larval shad occurrence. *North American Journal of Fisheries Management* 19(1):67-77.
- Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* B. R. Murphy and D. W. Willis, editors. *Fisheries Techniques*. 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Bettoli, P. W., M. J. Maceina, R. L. Noble, and R. K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. *North American Journal of Fisheries Management* 12:509-516.
- Bettoli, P. W., and L. E. Miranda. 2001. Cautionary note about estimating mean length at age with subsampled data. *North American Journal of Fisheries Management* 21:425-428.
- Broadbent, T. 2000. Annual reservoir report for Kentucky Lake. Tennessee Wildlife Resource Agency, Nashville
- Brooks, R. C., R. C. Heidinger, and C. C. Kohler. 1994. Mass marking of larval and juvenile walleyes by immersion in oxytetracycline, calcein, and calcein blue. *North American Journal of Fisheries Management* 14:143-146.
- Brown, M. L., J. L. Powell, and D. O. Lucchesi. 2002. In-transit oxytetracycline marking, nonlethal mark detection, and tissue residue depletion in yellow perch. *North American Journal of Fisheries Management* 22:236-242.
- Buckmeier, D. L., J. W. Schlechte, and R. K. Betsill. 2003. Stocking fingerling largemouth bass to alter genetic composition: efficacy and efficiency of three stocking rates. *North American Journal of Fisheries Management* 23:523-529.
- Buckmeier, D. L., and R. K. Betsill. 2002. Mortality and dispersal of stocked fingerling largemouth bass and effects on cohort abundance. Pages 101-114 *in* D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, Symposium 31, Bethesda, Maryland.
- Bumguardner, B. W. 1991. Marking subadult red drums with oxytetracycline. *Transactions of the American Fisheries Society* 120:537-540.

- Buynak, G. L., and B. Mitchell. 1999. Contribution of stocked advanced-fingerling largemouth bass to the population and fishery at Taylorsville Lake, Kentucky. *North American Journal of Fisheries Management* 19(2):494-503.
- Buynak, G. L., W. N. McLemore, and B. Mitchell. 1991. Changes in largemouth bass populations at Kentucky and Barkley Lakes: environmental or regulatory responses? *North American Journal of Fisheries Management* 11:285-292.
- Churchill, T.N., and W.C. Reeves. 2001. Tennessee largemouth bass management plan for lakes and reservoirs. Tennessee Wildlife Resources Agency report, Nashville.
- Close, T. L., and C. S. Anderson. 1992. Dispersal, density-dependent growth, and survival of stocked steelhead fry in Lake Superior tributaries. *North American Journal of Fisheries Management* 12:728-735.
- Coble, D. W. 1971. Effects of fin clipping and other factors on survival and growth of smallmouth bass. *Transactions of the American Fisheries Society* 100(3):460-473.
- Conover, G. A., and R. J. Sheehan. 1996. Evaluation of oxytetracycline marks in sagittal otoliths of juvenile black crappies. *North American Journal of Fisheries Management* 16:686-688.
- Copeland, J. R., and R. L. Noble. 1994. Movements by young-of-year and yearling largemouth bass and their implications for supplemental stocking. *North American Journal of Fisheries Management* 14:119-124.
- Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. *American Midland Naturalist* 67:477-504.
- Davies, W. D., W. L. Shelton, and S. P. Malvestuto. 1982. Prey-dependent recruitment of largemouth bass: A conceptual model. *Fisheries* 7(6):15-Dec.
- DeAngelis, D. L., B. J. Shuter, M. S. Ridgway, and M. Scheffer. 1993. Modeling growth and survival in an age-0 fish cohort. *Transactions of the American Fisheries Society* 122(5):927-941.
- Egglisshaw, H. J., and P. E. Shackley. 1980. Survival and growth of salmon, *Salmo salar* (L.), planted in a Scottish stream. *Journal of Fish Biology* 16:565-584.
- Epifanio, J. 2003. Genetic analysis of Tennessee sport fisheries (2000-2003): largemouth bass, smallmouth bass, rainbow trout, and brown trout. Final report submitted to the Tennessee Wildlife Resources Agency, Nashville.

- Forsberg, J. A., R. C. Summerfelt, and B. A. Barton. 2001. Physiological and behavioral stress responses of walleyes transported in salt and buffered-salt solutions. *North American Journal of Aquaculture* 63:191-200.
- Gabelhouse, D. W., Jr. 1984. A length-characterization system to assess fish stocks. *North American Journal of Aquaculture* 4:273-285.
- Garvey, J. E., R. A. Wright, and R. A. Stein. 1998. Overwinter growth and survival of age-0 largemouth bass (*Micropterus salmoides*): revisiting the role of body size. *Canadian Journal of Fisheries and Aquatic Sciences* 55:2414-2424.
- Goodgame, L. S., and L. E. Miranda. 1993. Early growth and survival of age-0 largemouth bass in relation to parental size and swim-up time. *Transactions of the American Fisheries Society* 122:131-138.
- Gutreuter, S. J., and R. O. Anderson. 1985. Importance of body size to the recruitment process in largemouth bass populations. *Transactions of the American Fisheries Society* 114:317-327.
- Heidinger, R. C., and R. C. Brooks. 1998. Relative survival and contribution of saugers stocked in the Peoria Pool of the Illinois River, 1990-1995. *North American Journal of Fisheries Management* 18(2):374-382.
- Heidinger, R. C., and R. C. Brooks. 2002. Relative contribution of stocked minnow-fed and pellet-fed advanced fingerling largemouth bass to year-classes in Crab Orchard Lake, Illinois. D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, Symposium 31, Bethesda, Maryland.
- Hoxmeier, R. J. H., and D. H. Wahl. 2002. Evaluation of supplemental stocking of largemouth bass across reservoirs: effects of predation, prey availability, and natural recruitment. D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, Symposium 31, Bethesda, Maryland.
- Hoyer, M. V., J. V. Shireman, and M. J. Maceina. 1985. Use of otoliths to determine age and growth of largemouth bass in Florida. *Transactions of the American Fisheries Society* 114:307-309.
- Hunt, K. B., and R.B. Ditton. 1996. A social and economic study of the Lake Fork Reservoir recreational fishery. Final report to the Texas Parks and Wildlife Department, Austin.
- Irwin, E. R., R. L. Noble, and J. R. Jackson. 1997. Distribution of age-0 largemouth bass in relation to shoreline landscape features. *North American Journal of Fisheries Management* 17:882-893.

- Iseley, J. J., R. L. Noble, J. B. Koppelman, and D. P. Philipp. 1987. Spawning period and first-year growth of northern, Florida, and intergrade stocks of largemouth bass. *Transactions of the American Fisheries Society* 116(5):757-762.
- Isermann, D. A., P. W. Bettoli, and S. M. Sammons. 1999. Efficacy of identifying stocked crappies in a Tennessee reservoir through oxytetracycline marking. *North American Journal of Fisheries Management* 19:1122-1123.
- Jackson, J. R., J. R. Copeland, and R. L. Noble. 1993. Movements and growth of stocked largemouth bass in B.E. Jordan Lake. Final Report, North Carolina Wildlife Resources Commission, Raleigh.
- Jackson, J. R., R. L. Noble, and J. R. Copeland. 2002. Movements, growth, and survival of individually-marked fingerling largemouth bass supplementally stocked into a North Carolina Reservoir. D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, Symposium 31, Bethesda, Maryland.
- Jackson, J. R., and R. L. Noble. 1995. Selectivity of sampling methods for juvenile largemouth bass in assessments of recruitment processes. *North American Journal of Fisheries Management* 15:408-418.
- Jenkins, W. E., M. R. Denson, C. B. Bridgham, M. R. Collins, and T. I. J. Smith. 2002. Retention of oxytetracycline-induced marks on sagittae of red drum. *North American Journal of Fisheries Management* 22:590-594.
- Kayle, K. A. 1992. Use of oxytetracycline to determine the contribution of stocked fingerling walleyes. *North American Journal of Fisheries Management* 12:353-355.
- Keast, A., and J. M. Eadie. 1985. Growth depensation in year-0 largemouth bass: the influence of diet. *Transactions of the American Fisheries Society* 114(2):204-213.
- Kohler, C. C., R. J. Sheehan, and J. J. Sweatman. 1993. Largemouth bass hatching success and first-winter survival in two Illinois reservoirs. *North American Journal of Fisheries Management* 13:125-133.
- Lee, D.P., I.L. Paulsen, and W. Beer. 1993. Evaluation of supplemental stocking of largemouth bass fingerlings. Final performance report, Federal Aid in Fish Restoration Project F-51-R, Study Number 3, California Department of Fish and Game, Sacramento.
- Lorson, R. D., and V. A. Mudrak. 1987. Use of tetracycline to mark otoliths of American shad fry. *North American Journal of Fisheries Management* 7:453-455.

- Ludsin, S. A., and D. R. DeVries. 1997. Understanding first-year survival of a freshwater piscivore: the interdependency of life-history stages. *Ecological Applications* 7:1024-1038.
- Maceina, M. J. 1988. A simple grinding procedure for sectioning otoliths. *North American Journal of Fisheries Management* 8:123-126.
- Maceina, M. J., B. R. Murphy, and J. J. Isely. 1988. Factors regulating Florida largemouth bass stocking success and hybridization with northern largemouth bass in Aquilla Lake, Texas. *Transactions of the American Fisheries Society* 117(3):221-231.
- Maceina, M. J., D. R. Bayne, A. S. Hendricks, W. C. Reeves, W. P. Black and V. J. DiCenzo. 1996. Compatibility between water clarity and quality black bass and crappie fisheries in Alabama. Pages 296-305 *in* L. E. Miranda and D. R. DeVries, editors. *Multidimensional approaches to reservoir fisheries management*. American Fisheries Society, Symposium 16, Bethesda, Maryland.
- Maceina, M. J. 1997. Simple application of using residuals from catch-curve regressions to assess year-class strength in fish. *Fisheries Research* 32:115-121.
- Maceina, M. J., and P. W. Bettoli. 1998. Variation in largemouth bass recruitment in four mainstream impoundments of the Tennessee River. *North American Journal of Fisheries Management* 18:998-1003.
- Martin, D. B., L. J. Mengel, J. F. Novotny, and C. H. Walburg. 1981. Spring and summer water levels in a Missouri River reservoir: effects on age-0 fish and zooplankton. *Transactions of the American Fisheries Society* 110:370-381.
- Miranda, L. E., W. L. Shelton, and T. D. Bryce. 1984. Effects of water level manipulation on abundance, mortality, and growth of young-of-year largemouth bass in West Point Reservoir, Alabama-Georgia. *North American Journal of Fisheries Management* 4:314-320.
- Miranda, L. E., and R. J. Muncy. 1987. Recruitment of young-of-year largemouth bass in relation to size structure of parental stock. *North American Journal of Fisheries Management* 7:131-137.
- Miranda, L. E., and W. D. Hubbard. 1994a. Length-dependent winter survival and lipid composition of age-0 largemouth bass in Bay Springs Reservoir, Mississippi. *North American Journal of Fisheries Management* 123:80-87.
- Miranda, L. E., and W. D. Hubbard. 1994b. Winter survival of age-0 largemouth bass relative to size, predators, and shelter. *North American Journal of Fisheries Management* 14(4):790-796.

- Miranda, L. E., and L. L. Pugh. 1997. Relationship between vegetation coverage and abundance, size, and diet of juvenile largemouth bass during winter. *North American Journal of Fisheries Management* 17:601-610.
- Noble, R. L., J. R. Jackson, E. R. Irwin, J. M. Phillips, and T. N. Churchill. 1994. Reservoirs as landscapes: implications for fish stocking programs. *Transactions of the North American Wildlife and Natural Resources Conference* 59:281-288.
- Partridge, D. G., and D. R. De Vries. 1999. Regulation of growth and mortality in larval bluegills: implications for juvenile recruitment. *Transactions of the American Fisheries Society* 128(4):625-638.
- Philipp, D. P., W. F. Childers, and G. S. Whitt. 1983. A biochemical genetic evaluation of the northern and Florida subspecies of largemouth bass. *Transactions of the American Fisheries Society* 112:1-20.
- Philipp, D. P., and G. S. Whitt. 1991. Survival and growth of northern, Florida, and reciprocal F1 hybrid largemouth bass in central Illinois. *Transactions of the American Fisheries Society* 120(1):58-64.
- Philipp, D. P., J. E. Claussen, T. W. Kassler, and J. M. Epifanio. 2002. Mixing stocks of largemouth bass reduces fitness through outbreeding depression. Pages 349-363 *in* D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, Symposium 31, Bethesda, Maryland.
- Phillips, J. M., J. R. Jackson, and R. L. Noble. 1997. Spatial heterogeneity in abundance of age-0 largemouth bass among reservoir embayments. *North American Journal of Fisheries Management* 17(4):894-901.
- Pine, W. E. I., S. A. Ludsin, and D. R. DeVries. 2000. First-summer survival of largemouth bass cohorts: is early spawning really best? *Transactions of the American Fisheries Society* 129:504-513.
- Ploskey, G. R. 1986. Effects of water-level changes on reservoir ecosystems with implications for fisheries management. Pages 86-97 *in* *Reservoir Fisheries Management: strategies for the 80's*. American Fisheries Society, Southern Division, Reservoir Committee, Bethesda, Maryland.
- Porak, W. F., and seven coauthors. 2002. Factors affecting survival of largemouth bass raised on artificial diets and stocked into Florida lakes. D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, 31, Bethesda, Maryland.

- Raibley, P. T., T. M. O'Hara, K. S. Irons, K. D. Blodgett, and R. E. Sparks. 1997. Largemouth bass size distributions under varying annual hydrological regimes in the Illinois River. *Transactions of the American Fisheries Society* 126:850-856.
- Ricker, W.E. Computation and interpretation of biological statistics of fish populations. Bulletin 191, Fisheries Research Board of Canada, Ottawa.
- Ridgway, M. S., B. J. Shuter, T. A. Middel, and M. L. Gross. 2002. Spatial ecology and density-dependent processes in smallmouth bass: the juvenile transition hypothesis. D. P. Philipp, and M. S. Ridgway, editors. *Black bass: ecology, conservation, and management*. American Fisheries Society, Symposium 31, Bethesda, Maryland.
- Ryan, M. J., M. A. Webb, and T. F. Loraine. 1996. Contribution of largemouth bass reared in nursery ponds to year classes in two Texas reservoirs. *Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies* 50:131-138.
- Sammons, S. M., L. G. Dorsey, P. W. Bettoli., and F. C. Fiss. 1999. Effects of reservoir hydrology on reproduction by largemouth bass and spotted bass in Normandy Reservoir, Tennessee. *North American Journal of Fisheries Management* 19:78-88.
- Sammons, S. M., and P. W. Bettoli. 2000. Population dynamics of a reservoir sport fish community in response to hydrology. *North American Journal of Fisheries Management* 20:791-800.
- SAS Institute. 1989. *SAS/STAT user's guide, version 6, fourth edition*. SAS Institute, Inc., Cary, North Carolina.
- Secor, D. H., J. M. Dean, and E. H. Laban. 1991. *Manual for otolith removal and preparation for microstructural examination*. Electric Power Research Institute and the Belle W. Baruch Institute for Marine Biology and Coastal Research, Technical Publication, 1991-01, Columbia, South Carolina.
- Shelton, W. L., W. D. Davies, T. A. King, and T. J. Timmons. 1979. Variation in the growth of the initial year class of largemouth bass in West Point Reservoir, Alabama and Georgia. *Transactions of the American Fisheries Society* 108:143-149.
- Smith, R. P., and J. L. Wilson. 1980. Growth comparison of two subspecies of largemouth bass in Tennessee ponds. *Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies* 34:25-30.
- Stuber, R. J. F., F. Gebhart, and O. E. Maughan. 1982. *Habitat suitability index models: largemouth bass*. U. S. Fish and Wildlife Service FWS/OBS-82/10.16.

- Terre, D. R., S. J. Magnelia, and M. J. Ryan. 1993. Year class contribution of genetically -marked Florida x northern largemouth bass stocked in three Texas reservoirs. *Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies* 47:622-632.
- Unkenholz, E. G., M. L. Brown, and K. L. Pope. 1997. Oxytetracycline marking efficacy for yellow perch fingerlings and temporal analysis. *Progressive Fish-Culturist* 59:280-284.
- U.S. Department of the Interior 1996. Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census. 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Washington, D.C.
- Weber, D. D., and G. J. Ridgeway. 1962. The deposition of tetracycline drugs in bones and scales of fish and its possible use for marking. *The Progressive Fish-Culturist* 24:150-155.
- Wentworth, R. S., and G. W. Labar. 1984. First-year survival and growth of steelhead stocked as fry in Lewis Creek, Vermont. *North American Journal of Fisheries Management* 4:103-110.
- Wright, G. L., and G. W. Wigtil. 1980. Comparison of growth, survival, and catchability of Florida, northern, and hybrid largemouth bass in a new Oklahoma reservoir. *Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies* 34:31-38.