Trophy Largemouth Bass Abundance and Harvest in a Central Virginia Impoundment: Implications for Restrictive Slot Limits

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Abstract: Briery Creek Lake is a 342-ha impoundment in central Virginia that has become widely recognized as having Virginia's premier trophy largemouth bass *(Micropterus salmoides*) fishery. We estimated largemouth bass density (fish/ha) using a multiple census mark-recapture technique along a 3.2-km section of shoreline and by using the Leslie catch-depletion technique in a 4.1-ha cove. An access point creel survey was conducted in 1999 and 2000 to estimate angler catch and harvest. We used a dynamic pool model to simulate the effects of a newly imposed 356–610 mm protected slot limit with respect to size structure, harvest, yield, and abundance of trophy (≥560 mm) largemouth bass. The mark-recapture study estimated largemouth bass density to be 44 fish/ha and the number of trophy largemouth bass in the lake to be 318. The Leslie catch-depletion technique estimated the density of largemouth bass to be 43 fish/ha and the number of trophy fish to be 397. The number of largemouth bass harvested in 1999 and 2000 was 2,698 and 2,353 fish, respectively. The average time required to catch a trophy largemouth bass from 1999–2000 was 142 hours. Anglers harvested 139 and 122 trophy largemouth bass in 1999 and 2000, respectively. Modeling indicated that a 356–610 mm slot limit would result in 2–3 times more trophy largemouth bass in the population, decreased yield and no change in the number of fish harvested.

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Largemouth bass are an important component of freshwater fisheries in Virginia. In 1986, the Virginia Department of Game and Inland Fisheries (VDGIF) began work on creating the first trophy largemouth bass fishery in the state (Wilson and DiCenzo *in press*). Briery Creek Lake, located in southcentral Virginia, was impounded in 1986 and stocked with Florida largemouth bass and northern largemouth bass (3:1 ratio) in 1986 and 1987 (Hoover et al. 1997). Additionally, standing timber was left in most of the lake and the fishery opened with a 457-mm minimum length limit and a 2-fish creel limit (Wilson and DiCenzo *in press*). Briery Creek Lake succeeded in becoming a trophy largemouth bass lake, and by 1995 it dominated

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VDGIF's Angler Recognition Program (for largemouth bass ≥3.63 kg or ≥560 mm length). Between 1993 and 2000, 24 of the 25 heaviest largemouth bass entered into the Virginia Angler Recognition Program were from Briery Creek Lake. The current lake record is 7.34 kg and was caught in 1995.

Harvest restrictions are typically based on data collected by standard electrofishing surveys (Betsill 1996). Information obtained from these surveys can include length at age, growth, mortality, and recruitment information as well as assessment of year-class strength. These data can be augmented with estimates on effort, catch, and harvest from creel surveys. Analysis of this information can give reasonable estimates of largemouth bass population characteristics. However, estimating exploitation and population density may be needed on heavily fished or unique populations to ensure current harvest levels meet management objectives. These metrics are often overlooked due to the difficulty of obtaining valid data. The cost of these as well as the numerous assumptions that must be met preclude population and exploitation estimates from typical fisheries assessments.

In this study, we used multiple-census mark recapture and catch-depletion methods to estimate the population size of stock-length (≥200 mm) and trophy length (≥560 mm, minimum length required to participate in Virginia's Angler Recognition Program) largemouth bass in Briery Creek Lake, Virginia. We combined this information with a 2-year creel survey to estimate largemouth bass exploitation and to simulate the effects of a newly imposed trophy largemouth bass regulation. The objectives of this study were to: 1) determine the density of largemouth bass ≥200 mm and ≥560 mm, 2) estimate angler effort, catch, and harvest, and 3) compare largemouth bass size structure, harvest, yield, and abundance of trophy fish under a 356–610 mm slot limit and a 304–381 mm slot limit.

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Methods

Briery Creek Lake is a 342-ha mesotrophic reservoir located in south-central Virginia and is owned by the VDGIF. Full pool elevation is 122 m and water levels typically fluctuate less than 0.3 m annually. Mean depth is 4.0 m and secchi depth transparencies during summer average 2.0 m. Quality habitat is abundant in the lake. Standing timber is found in about 80% of the lake and aquatic vegetation [eelgrass *(Vallisneria americana)*, watershield *(Brasenia schreberi)*, elodea *(Elodea sp.)*, and pondweed *(Potamogeton sp.)*] is present along 90% of the shoreline. Largemouth bass, bluegill *(Lepomis machrochirus)*, and redear sunfish *(L. microlophus)* are the predominate fish species present in the lake. In addition, blueback herring *(Alosa aestivalis)* were found in April 2000.

Population Estimate

We used 2 techniques to estimate the population size of largemouth bass. First, a multiple census mark-recapture procedure was used along a 3.2-km section of shoreline between 9 and 12 April 2001. Approximately half of this section was along the main channel of the lake while the other half was in a large cove. The habitat in this section is representative of the lake. A 4.9-m pulsed DC electrofishing boat was used to collect largemouth bass during daylight hours. Water temperature was 18 C. We electrofished for approximately 600 seconds, and all largemouth bass were measured for total length (mm), fin clipped (left pectoral fin), and released. Population density (with 95% confidence limits, CL) was determined using the Schnabel multiple census estimate (Schnabel 1938, Van Den Avyle 1993). The assumptions of this technique are: (1) marked fish do not lose their marks prior to the recapture period, (2) marked fish are not overlooked in the recapture samples, (3) marked and unmarked fish are equally vulnerable to capture, (4) there is no mortality, (5) following release, marked and unmarked fish are randomly mixed, and (6) there are no additions to the population during the study interval. Largemouth bass density was expressed as number of fish per km of shoreline and expanded by the length of the entire shoreline (27.4 km) to estimate the number of largemouth bass in the lake. We estimated the number of trophy largemouth bass (≥560 mm) in the lake by multiplying the percentage of trophy fish by the population estimate. The shoreline distance was calculated by utilizing global positioning units (GPS) and plotting data on digital software (Maptech Terrain Navigator 1998).

On the night of 11 April 2001, we electrofished a 4.1-ha cove and used the Leslie catch-depletion method to estimate largemouth bass density (Leslie and Davis 1993, Maceina et al. 1995). The assumptions of this technique are: (1) there is no immigration or emigration, (2) all individuals have equal probability of capture, and (3) there is constant probability of capture among sample periods. Electrofishing was conducted along the shoreline and adjacent to standing timber in deeper water. Water temperature was 18 C. The maximum water depth was 4 m. Habitat within the cove consisted of dense stands of timber which precluded the use of a block net. To minimize emigration and immigration, we conducted 3 consecutive electrofishing runs which reduced the amount of time that fish had to enter and/or leave the cove (the entire sample required about 2.0 hours to complete). All captured largemouth bass were measured for length, fin clipped (right pectoral fin), and released in the back of the cove. Population density was determined by least-squares linear regression of catch-per-effort against cumulative catch lagged for one unit of effort (Maceina et al. 1995). The number of largemouth bass in the cove was estimated by dividing the regression intercept by the slope. We estimated the number of trophy (≥560 mm) largemouth bass in the lake by multiplying the percentage of trophy fish in the cove by the population estimate.

For both techniques, we estimated the number of stock length largemouth bass (≥200 mm). Largemouth bass are recruited to the electrofishing gear at this size and, based on creel survey data, this is the minimum length that is typically considered harvestable by anglers.

Creel Survey

A stratified, 2-stage access point creel survey with non-uniform probabilities was conducted between February and November 1999 and March and May 2000. The 1999 creel survey encompassed the entire fishing year. Funding and manpower limitations during 2000 did not allow for an annual creel survey; consequently, a spring survey was conducted (March, April, and May). We then used the ratio of fishing effort that occurred during spring 1999 to the total estimate for that year to expand data collected during spring 2000 to an annual estimate for 2000. Catch rates and harvest rates were then used to estimate the number of fish caught and harvested for the entire 2000 fishing year.

Fishing days, the primary sampling unit, were classified as either weekdays or weekend days (including holidays) and were assigned probabilities of 60% and 40%, respectively. Day length was defined as sunrise to 1 hour after sunset. Each fishing day was divided into 2 sampling periods (AM and PM), and 1 sample period was randomly chosen per sample day. In 1999, 20 days per month were sampled and in 2000, 10 days were sampled per month.

Five access points were used as secondary sampling units in 1999. Three access points were randomly chosen for each half-day sampling period and an equal amount of time was spent at each. The amount of time spent at each access point ranged from 1.5 to 2.3 hours, depending upon day length. Three of the areas were used little in 1999. Consequently, in the spring 2000 creel survey, 2 access points were used as secondary sampling units, 1 of which was randomly chosen each fishing day.

Anglers were interviewed at the conclusion of their trip. Data obtained from anglers included species sought, trip length, and number of fish harvested and released. Harvested fish were measured for total length (mm) and anglers were asked to recall lengths of fish released. KGN Consultants (St. George Island, Fla.) conducted creel survey analysis and monthly and annual estimates of effort, catch, harvest, catch-per-effort, and harvest-per-effort were computed.

Population Simulations

We used Fishery Analyses and Simulation Tools (FAST) software (Slipke and Maceina 2000) to simulate the largemouth bass population under different harvest restrictions. Using a dynamic pool model (Ricker 1975), we evaluated a 304–381 mm protected slot (the regulation that was in effect from 1990–2000) and a 356–610 mm protected slot (the regulation that went into effect on 1 January 2001).

Length-at-age (using otoliths) and weight-to-length relations were computed from electrofishing samples collected in April 2000. Age data from largemouth bass >age 10 were minimal from electrofishing. We supplemented growth data with otoliths from 9 trophy largemouth bass obtained from taxidermists. Mean length-at-age data were fit to a von Bertalanffy growth model, holding L_{inf} constant at 710 mm (the longest largemouth bass to have been harvested during the creel survey). We used Pauly's (1980) length-converted catch-curve procedure to estimate the instantaneous mortality rate (Z) for largemouth bass ages 2 to 9. This method regresses the logarithm of the number of fish in a length interval against the relative age (t_i) of fish in that length interval. The relative age is defined as:

$$t_i = -\log_e(1 - L_{mid}/L_\infty), \text{ where}$$

L_{mid} is the midpoint of the i^{th} length interval and L_α is from the von Bertalannfy growth equation. The slope (b) of this equation represents 1–Z/k; therefore, the instantaneous mortality rate (Z) is:

$$Z = k(1-b), \text{ where}$$

K is from the von Bertalannfy growth equation. Annual survival was estimated as $S = e^{-Z}$. Exploitation (u) was computed by dividing the number of largemouth bass harvested from creel surveys (average of 1999 and 2000 estimates) by the estimated population size (average of mark-recapture and catch-depletion techniques). The instantaneous rate of fishing mortality (F) was estimated as $F = u{*}Z/(1-S)$ and conditional fishing mortality (cf) was computed as $cf = 1-e^{-F}$. The instantaneous rate of natural mortality was equal to Z–F and conditional natural mortality was computed as $1-e^{-M}$. For both regulations, we modeled at conditional natural mortality rates of 0.10 and 0.25, conditional fishing mortality rates from 0.1–0.5 (0.1-increments), and fixed recruitment of 5000 age-1 fish. We set the maximum age of the population at 17 which corresponds to the maximum age of largemouth bass previously noted in several Virginia reservoirs (Table 4). Finally, we compared size structure indices (PSD, RSD-38, RSD-51, and RSD-56), number of largemouth bass harvested, yield, and the abundance of fish ≥ 560 mm between the slot limits.

Results

Population Estimate

A total of 521 stock length largemouth bass were marked during the 4-day multiple-census mark recapture study (Fig. 1). On days 2, 3, and 4, a total of 15, 21, and 33 largemouth bass were recaptured (Table 1). The resulting population estimate was 1,781 largemouth bass in the 3.2-km section (95% CL 1,441–2,331) or 553 fish/km of shoreline (95% CL 450–728). Therefore, the estimated number of stock length largemouth bass in Briery Creek Lake was 15,126 (95% CL 12,330–19,947) or 44 fish/ha (95% CL 36 – 58 fish/ha). The standing stock (density*average weight) of largemouth bass was 17 kg/ha.

Approximately 2.1% of the largemouth bass collected during the mark-recapture study were ≥560 mm (Fig. 1). Therefore, we estimated there were about 319 trophy largemouth bass in Briery Creek Lake using the mark-recapture technique.

We obtained a significant negative relation ($P < 0.01$, $r^2 = 0.96$) between catch-per-hour and cumulative catch with 3 electrofishing samples in the catch depletion cove (Fig. 2). This conferred a population estimate of 177 stock-length largemouth

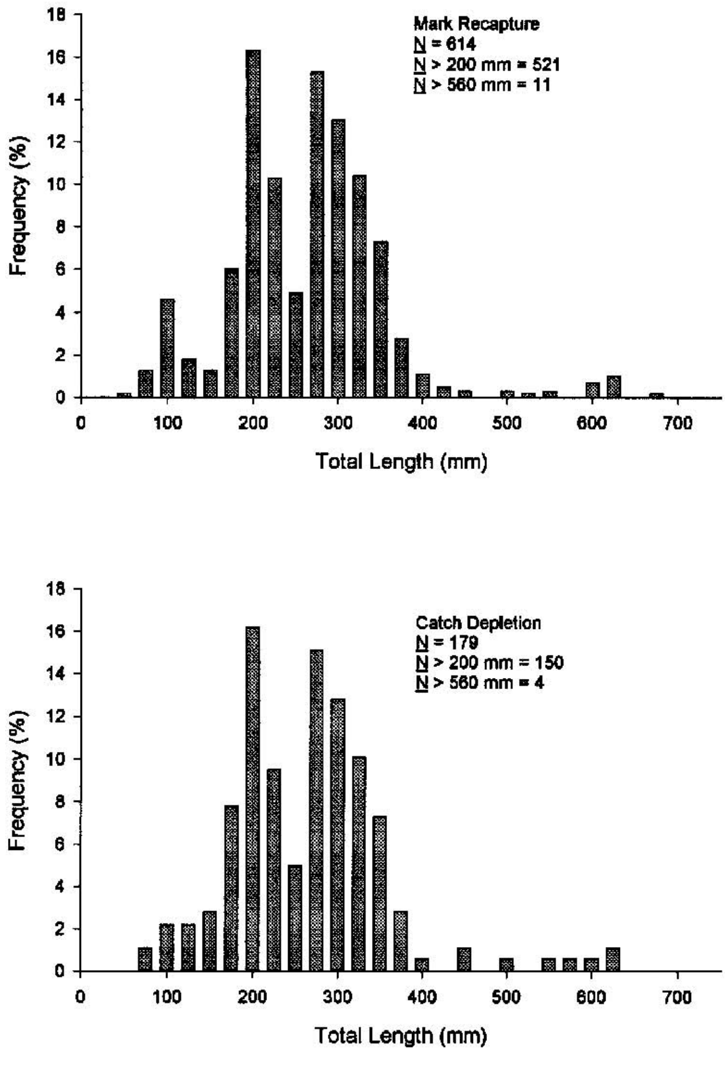

Figure 1. Length frequency distributions for largemouth bass from Briery Creek Lake, Virginia, April 2001.

bass in the cove. Therefore, the population estimate was 14,706 fish lakewide or 43 fish/ha. Confidence limits were wide because there was only 1 degree of freedom; however, the density estimate from the catch depletion was nearly identical to that of the mark recapture.

Approximately 2.7% of the largemouth bass collected in the catch-depletion cove were greater than 560 mm (Fig 1). Therefore, we estimated that there were

Table 1. Results of the multiple-census mark recapture study conducted for largemouth bass (>200 mm) at Briery Creek Lake, Virginia, between 9 and 12 April 2001.

	N of fish captured			*N* marked fish at large prior to sample (M)
Day	Marked (R)	Unmarked	Total (C)	
1	0	141	141	0
2	15	133	148	141
3	21	145	166	274
4	33	102	135	419

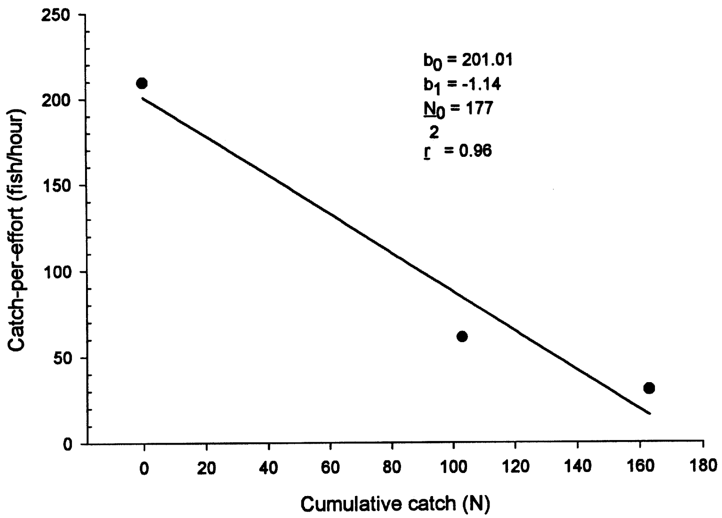

Figure 2. Regression of catch-per-effort (fish/hour) versus cumulative catch *(N)* for largemouth bass ≥200 mm in a 4.1-ha cove at Briery Creek Lake, Virginia. N_0 is the estimated number of fish in the cove. Regression intercept (b_0), regression slope (b_1), and the coefficient of determination (r^2) are given.

about 397 trophy largemouth bass in Briery Creek Lake using the catch depletion technique.

Creel Survey

Data collected during the 1999 survey indicated that 56% of the annual effort directed at largemouth bass occurred during the spring. Overall, 37% of the largemouth bass catch and 33% of the harvest occurred during the spring as well. Additionally, 78% of the annual catch and 50% of the annual harvest of trophy bass occurred at this time.

Directed effort at largemouth bass was high and consistent during 1999 (148 hours/ha) and 2000 (167 hours/ha, Table 2). During 1999, 102 largemouth bass/ha were caught, of which 8/ha were harvested. Similar results were obtained during 2000 when an estimated 89 fish/ha were caught, and 7/ha were harvested. Anglers harvested largemouth bass below (<304 mm) and above (>381mm) the protected slot limit (Fig. 3). The number of hours needed to catch a trophy largemouth bass averaged 142 for both years but was only 103 during the spring. For both years combined, approximately 34% of the trophy fish caught were harvested.

Table 2. Creel survey results for largemouth bass from Briery Creek Lake, Virginia, in 1999 and 2000.

	1999		2000	
Metric	Annual	Spring	Spring	Annual
Directed effort (hours)	50,496	28,388	32,193	57,487
N caught	35,043	13,040	17,385	30,568
N harvested	2,698	879	481	2,353
N released	32,345	12,161	16,904	28,215
Catch rate (fish/hour)	0.59	0.42	0.38	0.53
N trophy caught	407	316	278	358
N trophy harvested	139	70	41	81
N trophy released	268	246	237	277
Trophy catch rate (hours/fish)	124	90	116	160

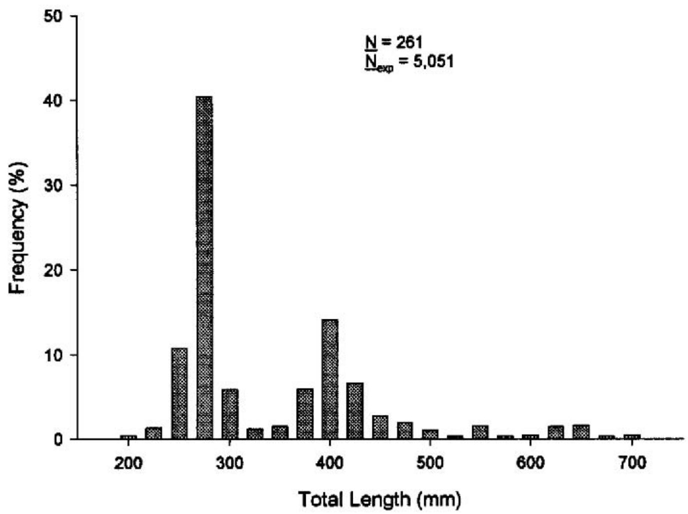

Figure 3. Length frequency distribution for largemouth bass harvested from Briery Creek Lake, Virginia. Data from 1999 and spring 2000 were pooled. *N* is the number of fish measured by the creel clerk and N_{exp} is the number of fish expanded for the entire lake for both years. Fish were protected from harvest with a 304–381 mm protected slot limit.

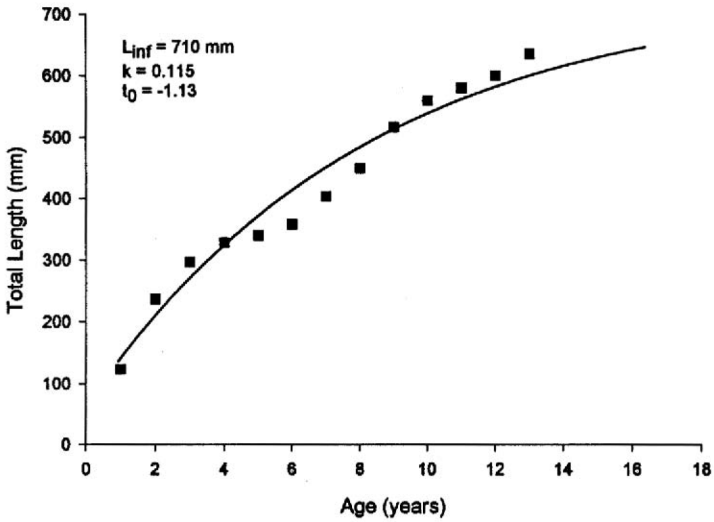

Figure 4. Mean length-at-age (squares) for largemouth bass from Briery Creek Lake, Virginia. All fish were aged using otoliths. The line is the von Bertalanffy growth relation.

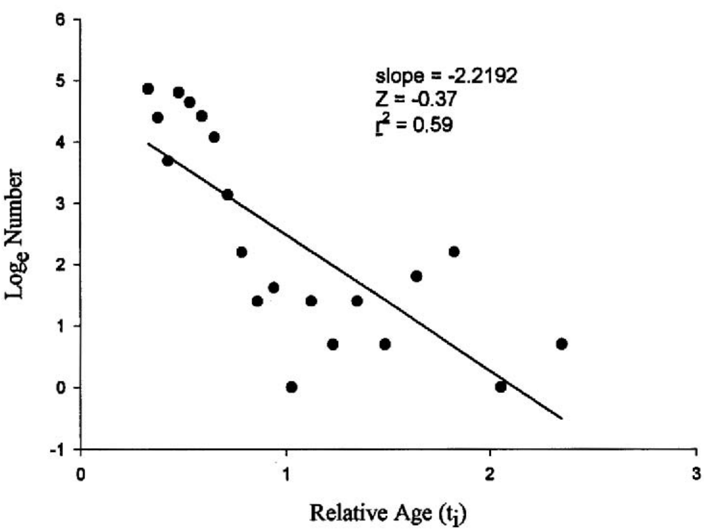

Figure 5. Length frequency based catch-curve regression (Pauly 1984) to estimate instantaneous mortality for largemouth bass from Briery Creek Lake, Virginia. Log_e number is the number of fish in each 25-mm length interval and t_i is the relative age of fish in each 25-mm length interval.

Population Simulations

In 2000, we collected 168 largemouth bass that ranged in age from 1 to 9. Fish reached lengths of 200, 300, 380, and 610 mm in 1.7, 3.5, 5.2, and 13.5 years, respectively (Fig. 4). The average number of largemouth bass harvested in 1999 and 2000 was 2,526 and the average number of stock length largemouth bass in 2001 was 14,984. This conferred an exploitation rate of 17%. The instantaneous mortality rate was 0.37 (Fig. 5) and annual survival was 69%. Instantaneous fishing mortality and natural mortality rates were 0.20 and 0.17, respectively. Conditional fishing mortality and conditional natural mortality rates were 0.18 and 0.16, respectively.

For both slot limits, we predicted no change in the number of fish harvested and large changes in yield at lower rates of conditional fishing mortality (Fig. 6). At a conditional fishing mortality rate of 20%, the number of bass harvested decreased 12% (natural mortality of 10%) and increased 5% (natural mortality of 25%) with a 356–610 mm slot limit (Table 3). Conversely, we predicted decreased yields of 23% (natural mortality of 10%) and 36% (natural mortality of 25%) with a 356–610 mm slot limit (Table 3).

The PSD and RSD-P values varied little between the 304–381 mm slot limit and the 356–610 mm slot limit when modeled at conditional natural mortality rates of 10% and 25% (Table 3). However, the RSD-M and RSD-T increased 2–3 times with a 356–610 mm slot limit at either natural mortality rate.

We predicted greater production of trophy largemouth bass with a more restrictive slot limit at conditional fishing mortality rates ranging from 10%–50% (Fig. 6). At natural mortality rates of 10 and 25%, we estimated that Briery Creek Lake would have 311 and 42 trophy largemouth bass, respectively, with the 304–381 mm slot limit and a fishing mortality rate of 20% (Table 3). Conversely, with the 356–610 mm slot limit, we predicted 807 and 110 trophy largemouth bass at natural mortality rates of 10% and 25%, respectively (Table 3).

Discussion

The 2 techniques used to estimate largemouth bass density in this study provided similar results. Largemouth bass density derived from the Schnabel estimate (conducted over a 4-day period) may have been influenced by fish movement into or out of the study area which likely could have affected the population estimate. The catch-depletion technique was subjected to similar assumptions, but we believe they were not influential on this population estimate because the time interval between sample runs left little time for fish to move into or out of the sample area. Additionally, the results from this estimate are similar to those found by other researchers. Maceina et al. (1995) estimated the number of largemouth bass >250 mm at 25/ha during samples conducted in 1992 and 42/ha in 1993 on 10 coves in Lake Guntersville, Alabama. Maceina (1995) also estimated 37 fish >250 mm/ha in Joe Wheeler Reservoir, Alabama. Largemouth bass population estimates are rarely done for reservoir largemouth bass populations. Given the utility of these data, future studies should seek to refine these techniques.

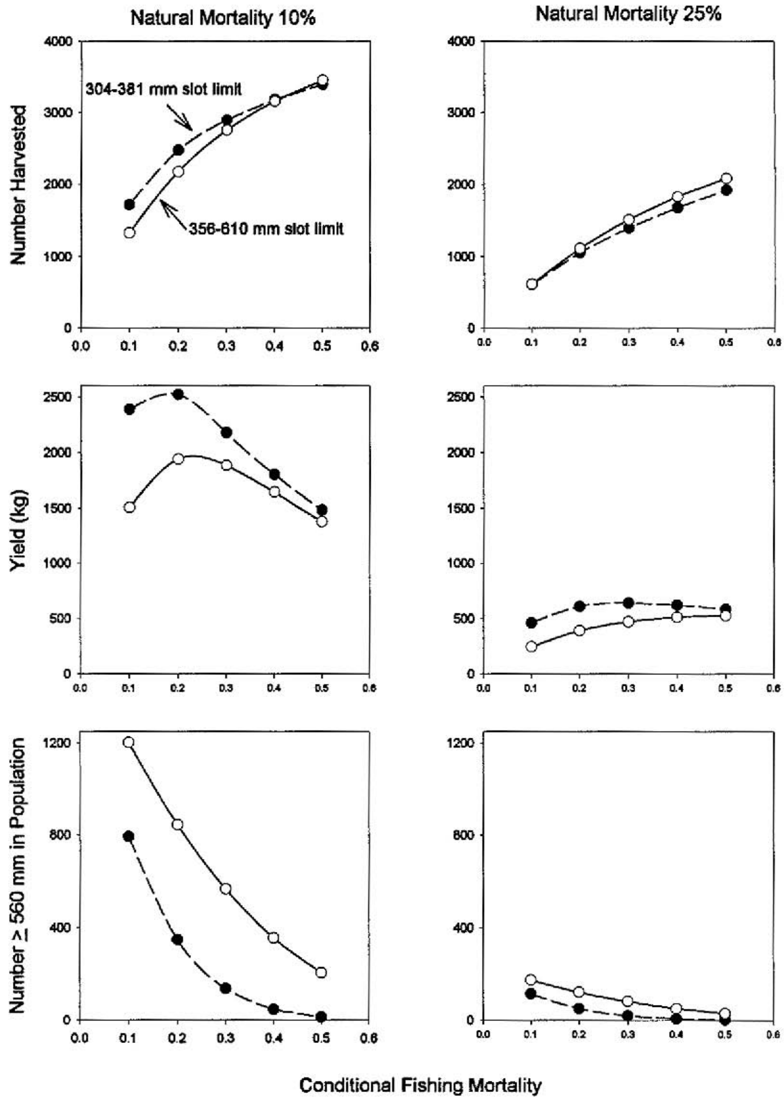

Figure 6. Simulated number harvested, yield, and abundance of trophy largemouth bass in Briery Creek Lake, Virginia, modeled at conditional natural mortality rates of 10% and 25% and slot limits of 304–381 mm (dark circles-dashed lines) and 356–610 mm (open circles-solid lines).

Table 3. Results of dynamic pool models for largemouth bass from Briery Creek Lake, Virginia, simulated with a 20% conditional fishing mortality rate.

Slot limit (mm)	PSD	RSD-38	RSD-50	RSD-56	*N* harvested	Yield (kg)	Number ≥560 mm in population
			10% Conditional natural mortality				
304–381	57	31	9	3	2,476	2,519	311
356–610	58	33	18	8	2,176	1,942	807
			25% Conditional natural mortality rate				
304–381	43	18	3	1	1,048	610	42
356–610	42	17	6	2	1,108	391	110

Table 4. The population parameters used to simulate largemouth bass from Briery Creek Lake using a dynamic pool model and the FAST modeling software.

Parameter	Definition
Recruitment	Long-term average of 5,000 age-1 fish recruited annually
Growth	Von Bertalannfy growth equation coefficients: L_{inf}=710 mm, k=0.115, t_0=−1.127 $Log_{10}TL–Log_{10}WT$ regression coefficients: Slope=3.225, y-intercept=–5.443
Maximum age	17 years
Natural mortality	Conditional natural mortality rates of 10 and 25% per year after age 1
Fishing mortality	10–50% per year at 10% intervals
Size structure	Minimum lengths of 200, 300, 380, 510, and 560 for stock, quality, preferred, memorable, and trophy fish

Variables used to model largemouth bass populations under 2 different slot limits included recruitment, growth (length-at-age and weight to length relation), and mortality (fishing and natural). Based on annual electrofishing samples, recruitment (catch-per-effort of age-2 fish) in Briery Creek Lake is relatively consistent (VDGIF, unpubl. data). Length-at-age data for largemouth bass ages 1 to 9 were easily obtained, and fitting those data to a von Bertalannfy growth model (holding L_{inf} constant at 710 mm) produced realistic results. Estimating mortality for largemouth bass between ages 2–17 was problematic. The lack of age structure data for older largemouth bass precluded the use of catch-curve regression to estimate Z because using only ages 2–9 and applying it for the entire life span of the population overestimated Z. Use of Pauly's (1980) length-converted catch-curve regression provided a practical method to approximate mortality for largemouth bass between ages 2 and 17 using data that were readily available. Traditionally, exploitation estimates are derived from tagging studies, but often these studies suffer from high non-reporting rates of harvested fish (Larson et al. 1991, Maceina et al. 1998). We were able to estimate exploitation of largemouth bass by combining 2 different sampling techniques.

Using total and fishing mortality rates, we were able to estimate natural mortality (M=Z–F) and this provided similar results to many of the methods commonly used to approximate natural mortality (Pauly 1980, Hoenig 1983, Peterson and Wroblewski 1984, Jensen 1996). Therefore, results of FAST models in this study should provide a reasonable idea of changes in the largemouth bass fishery under the 356–610 mm slot limit.

Trophy largemouth bass are the primary management objective for Briery Creek Lake. However, producing 2 to 3 times the number of fish with the 356–610 mm slot limit, as predicted by the population simulations, may not be realistic. Briery Creek Lake was impounded in 1986, stocked in 1986 and 1987 and opened to fishing in 1989. Many of the trophy largemouth bass caught during the mid-late 1990s were likely from original stockings. The 1986 and 1987 year classes exhibited fast growth and high survival (LaRoche 1987, Kittrell 1990) likely because of low fish density and the trophic upsurge typical of new reservoirs (Kimmel and Groeger 1986). However, in spring 2000 and 2001, we aged a total of 9 trophy largemouth bass, and 8 were from the 1990 and 1991 year classes suggesting that Briery Creek Lake should continue to produce trophy fish even as the lake ages and productivity declines. Data on growth, trophy fish abundance, and angler catch of trophy fish are needed to address the effectiveness of the 356–610 mm slot limit.

We found that largemouth bass density and harvest estimates were useful in managing for trophy fish in Briery Creek Lake. Although the 2 methods used to estimate density in this study provided similar results, use of the Leslie catch-depletion technique as recommended by Maceina et al. (1995) better met the assumption of a closed population. Further, multiple coves can be sampled in the time it takes to conduct a mark-recapture study which may provide a better measure of precision. Spring creel surveys have become an important tool for monitoring largemouth bass, particularly trophy fish (Wilson and DiCenzo *in press*). When used in conjunction with an occasional survey done for an entire year, short-term creel surveys can be a cost-effective way to monitor effort and catch and harvest rates for unique and important fisheries such as trophy largemouth bass. Finally, density and harvest information were valuable in developing models to simulate the effects and support the utility of the new protected slot limit.

Literature Cited

Betsill, R.K. 1996. Electrofishing catch of largemouth bass: spatiotemporal variation and relation to angler catch. Proc. Annu. Conf. Southeast. Assoc. of Fish and Wildl. Agencies 50:1–11.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82:898–903.

Hoover, R.S., J.J. Ney, E.M. Hallerman, and W.B. Kittrell, Jr. 1997. Comparison of Florida, northern, and intergrade juvenile largemouth bass in a Virginia reservoir. Proc. Annu. Conf. Southeast. Assoc. of Fish and Wildl. Agencies 51:192–198.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Fish. Aquat. Sci. 53:820–822.

Kimmel, B. L. and A. W. Groeger. 1986. Limnological and ecological changes associated with reservoir aging. Pages 103–109 *in* G. E. Hall and M. J. Van Den Avyle, eds. Reservoir fisheries Management: Strategies for the 1980's. Reservoir Comm., South Div., Am. Fish. Soc., Bethesda, Md.

Kittrell, W. B. 1990. Briery Creek Lake Investigations. Va. Dep. Game and Inland Fish., Fed. Aid in Sport Fish Restor. Rep., Proj. F-111, Richmond. 18pp.

LaRoche, A. L. 1987. Briery Creek Lake Investigations. Va. Dep. Game and Inland Fish., Fed. Aid in Sport Fish Restor. Rep., Proj. F-111, Richmond. 2pp.

Larson, S,. B. Saul, and S. Schleiger. 1991. Exploitation and survival of black crappies in Georgia reservoirs. North Am. J. Fish. Manage. 11:604–613.

Leslie, D.H. and D.H.S. Davis. 1939. An attempt to determine the absolute numbers of rates in a given area. J. Anim. Ecol. 8:94–113.

Maceina, M.J., P.W. Bettoli, S.D. Finley, and V.J. DiCenzo. 1998. Analyses of the sauger fishery with simulated effects of a minimum size limit in the Tennessee River of Alabama. North Am. J. Fish. Manage. 18:66–75.

______, W.B. Wrenn, D.R. Lowery 1995. Estimating harvestable largemouth bass abundance in a reservoir with an electrofishing catch depletion technique. North Am. J. Fish. Manage. 15:103–109.

______. 1995. Population assessment of largemouth bass in Joe Wheeler Lake and Lake Guntersville in 1994. Rep. to the Tenn. Valley Auth., Off. Serv. Annex 1B, Muscle Shoals, Ala. 26pp.

Maptech. 1998. Terrain Navigator Digital Mapping Technology, ed. 1 (software).

Pauly, D. 1980. On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. du Conseil Internatl. Pour l'Exploration de la Mer 39:175–192.

Peterson, I. and J.S. Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. Can. J. Fish. Aquat. Sci. 41:1117–1120.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 191. 383pp.

Schnabel, Z.E. 1938. The estimation of the total fish population Am. Math. Monogr. 45:348–368.

Slipke, J. W. and M. J. Maceina. 2000. Fishery analyses and simulation tools (FAST). Dep of Fish and Allied Aquacul. Auburn Univ., Ala. 112pp.

Wilson, D. M. and V. J. DiCenzo. 2002. Profile of a trophy largemouth bass fishery in Briery Creek Lake, Virginia. Pages 000–000 *in* M. S. Ridgeway and D. P. Phillip, eds. Black bass: ecology, conservation, and management. Am. Fish. Soc., Bethesda, Md.

Van Den Avyle, M. J. 1993. Dynamics of exploited fish populations. Pages 105–135 *in* C. C. Kohler and W. A. Hubert, eds. Inland fisheries management in North America. Am. Fish. Soc., Bethesda, Md.