Comparison of Population Estimates on a Known Largemouth Bass Population

John U. Crutchfield, Jr., *Carolina Power and Light Co., Shearon Harris Energy & Environmental Center, New Hill, NC 27562*
William J. Warren-Hicks, *Carolina Power and Light Co., Shearon Harris Energy & Environmental Center, New Hill, NC 27562*

Abstract: Population estimates were calculated for a known young-of-the-year (Y-O-Y) largemouth bass (*Micropterus salmoides*) population in a Piedmont North Carolina pond. Bass were collected by electrofishing for 6 consecutive nights. Estimates were derived using capture-recapture (Chapman, Chapman modified Peterson, Schnabel, and Schumacher-Eschmeyer) and removal (Leslie and DeLury) methods. Accuracy and bias of population estimates for each method were assessed from a statistical framework. All methods gave negatively biased estimates. Schumacher-Eschmeyer and DeLury exponential catchability models gave minimally-biased, accurate estimates within 12% to 17% of the true population. Independent Chapman estimates also gave acceptable results (known population within 95% confidence limits) when at least 56% of the known population was marked and the number of sampling occasions >4.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 39:261–268

A considerable amount of research has been conducted on estimating largemouth bass, *Micropterus salmoides*, populations over the past 4 decades (Fredin 1950, Lewis et al. 1962, Swingle et al. 1965, Bryant and Houser 1971, Zweiacker 1972, Grinstead and Wright 1973, Aggus and Rainwater 1975, Hickman and Hevel 1975, Seawell and Hevel 1978, Woodrum 1978, Harris et al. 1979, Herring 1979). Objectives of such studies were to determine: 1) the most suitable methods for developing estimates of population size ($\hat{N}$), 2) gear type(s) that gave the most accurate population estimates, 3) the most reliable methods of calculating $\hat{N}$ for different size classes relative to gear selectivity and associated bias, and 4) the most economically feasible methods in obtaining $\hat{N}$. Ultimately, the main goal of all studies was to provide insight into bass population dynamics so that management decisions (e.g., harvest restrictions and population manipulations) could be evaluated or implemented if necessary.

While most studies dealt with estimating N, an unknown finite population, particularly of one year and older members, the objectives of this study were to estimate N for Y-O-Y bass in a small pond environment with a known population size and to examine the accuracy and bias of several population estimation methods. The efficiency of electrofishing in capturing Y-O-Y year bass was also evaluated.

The authors appreciate the assistance of J. M. Swing and E. C. Weaver with the field sampling. Special thanks are due to K. A. MacPherson, W. T. Bryson, and members of the Word Processing Subunit at the Shearon Harris Energy and Environmental Center for preparation of this manuscript.

Methods

This study was conducted on a small pond (0.5 ha, 1.7 m mean depth) located in southwestern Wake County, North Carolina, approximately 40 km from Raleigh. The pond is adjacent to Carolina Power and Light Co.'s Harris Lake. Two weeks prior to stocking, the pond was treated twice within 1 week with 5% emulsifiable rotenone at a 2 mg/liter concentration to eliminate the existing fish population.

Y-O-Y bass were obtained from a private fish hatchery and transported to the stocking site via truck. Temperature and dissolved oxygen were measured at regular intervals during the trip and regulated if necessary to minimize stress. Upon arrival at the pond, the bass were netted, independently counted out in lots of 25, and acclimated to ambient water temperature for 20 minutes prior to release. A total of 250 bass were released. They were of similar size (mean total length = 135 mm, SD = 12.5) to prevent cannibalism during the study. After stocking, the pond was observed to determine any poststocking mortality. Sampling began on the third day after stocking to allow time for the bass to disperse. No dead bass were observed before or during sampling.

Bass were collected by electrofishing for 6 consecutive nights from 7–12 November 1984. A Wisconsin-designed boat was utilized with a Smith-Root Type VI-A electrofisher that supplied pulsed DC current at 280 volts and approximately 3 amperes from a 3,500-watt generator. Beginning at the dam, electrofishing was conducted twice around the entire shoreline (289 m) and over open water for 1 hour. The direction (clockwise versus counterclockwise) of shoreline electrofishing was alternated every other night to minimize any potential for sampling bias. Stunned bass were placed in a holding tank containing water treated with MS222 (100 mg/liter), Furaloid® (350 mg/liter), and $NaHCO_3$ (720 mg/liter) to minimize stress and disease. After sampling, the number of marked and unmarked bass was recorded and unmarked bass were batch-marked by clipping the left pelvic fin. The bass were then transferred to another holding tank containing freshwater, allowed to recover, and randomly released around the pond. Prior to sampling, water temperature was measured at a 1-m depth with a YSI® telethermometer.

Assuming a closed population (i.e., no losses or additions of fish), 6 different methods were used to derive $\hat{N}$: 1) Chapman modified Peterson (Chapman 1951), 2) Chapman (1952), 3) Schnabel (1938), 4) Schumacher-Eschmeyer (1943), 5) Leslie and Davis (1939), and 6) DeLury (1947). Methods 1 through 4 determine $\hat{N}$ from capture-recapture of marked bass, while methods 5 and 6 estimate $\hat{N}$ based on a proportional removal of members from the population over time. Marked bass were considered removed from the population for these last 2 methods. Ricker (1975) gives a detailed description of the underlying assumptions for all methods and equations for calculating $\hat{N}$, standard errors (S.E.), and confidence intervals (C.I.). The following symbols are used in summarizing and discussing the data:

Capture-Recapture Methods

C_t is the total sample taken in the time interval t

R_t is the total recaptures in the sample C_t

M_t is the total marked sample at the start of the time interval t

Removal Methods

N_o is the original population size

E_t is the midinterval cumulative fishing effort between 2 time intervals

q is the fraction of the population taken by 1 unit of fishing effort (slope)

f is the total fishing effort for the study period

S^f is the estimate of survival to the end of the experiment (for DeLury large catchability method)

C_t/f_t is the catch per unit effort for time interval t

Differences in catch rates of total population, as well as marked and unmarked subpopulations between the first and second shoreline sampling rounds, were tested with paired t-tests.

Results and Discussion

During the study, 65% (162) of the known bass population was captured and marked by electrofishing (Table 1). Catchability values for the total population (number of fish collected per sampling occasion/total population) ranged from 9% to

Table 1. Data summary for computations of Schnabel and Schumacher-Eschmeyer estimates for largemouth bass during November 1984 (see text for meanings of column headings).

C_t	R_t	M_t	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t
39	0	0	0	0	0	0
71	20	39	2,769	780	107,991	5.6338
60	29	90	5,400	2,610	486,000	14.0167
49	30	121	5,929	3,630	717,409	18.3673
35	19	140	4,900	2,660	686,000	10.3143
22	16	156	3,432	2,496	535,392	11.6364
276	114	162	22,430	12,176	2,532,792	59.9685

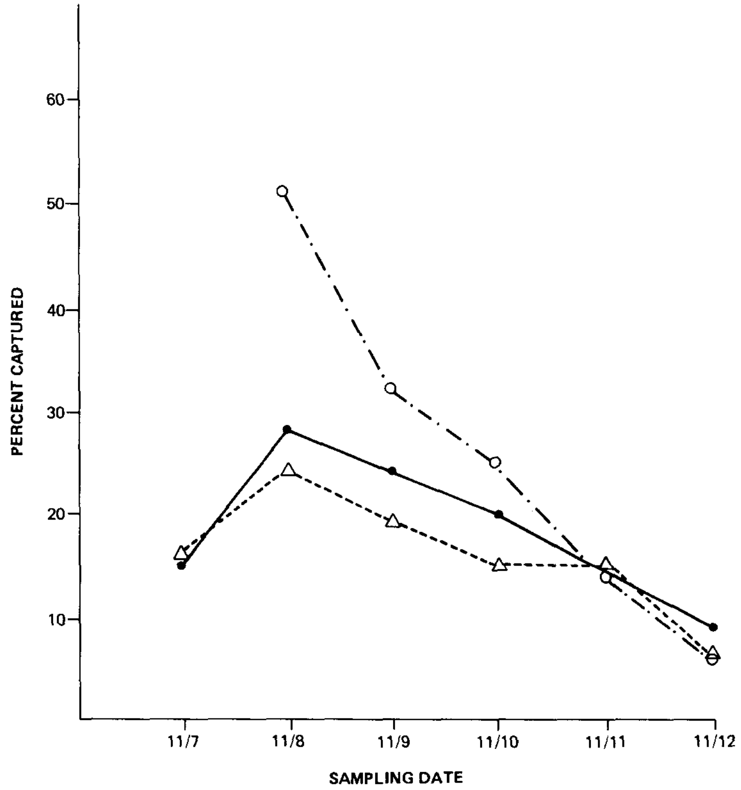

Figure 1. Catchability values (%) of the total population (•——•), marked (o-·-·-o), and unmarked (△------△) subpopulations of largemouth bass by sampling date during November 1984.

28% with a mean of 18% (coefficient of variation = 36%) (Fig. 1). Catchability values for the unmarked subpopulation (unmarked fish collected per sampling occasion/remaining unmarked) ranged from 6% to 24% with a mean of 16% (coefficient of variation = 61%). The marked subpopulation catchability values (marked fish collected per sampling occasion/total number marked) were generally higher and displayed greater variability (Fig. 1). Values ranged from 6% to 51% with a mean of 26% (coefficient of variation = 78%). Catchability of these 3 groups generally decreased over time and probably resulted from either gear avoidance, different capture probabilities of unmarked and marked bass, mortality, or a combination of these factors. The generally higher catchability rates of marked bass suggested they were more vulnerable to capture, thereby providing negatively biased estimates. In a similar study, Swingle et al. (1965) also derived negatively biased estimates and suggested that unequal capture vulnerability existed between marked and unmarked fish.

Examining capture differences between shoreline electrofishing rounds, the marked subpopulation and the total population were captured at a significantly ($P \leq 0.05$) higher rate during the first round compared to the second round. No significant differences ($P > 0.05$) were found in capture rates of the unmarked subpopulation between rounds. Marked bass were either more vulnerable to electrofishing during the first round or they responded negatively to the electrofisher by moving to deeper water during the second round. Constant capture rates of unmarked bass between rounds indicated behavior independent of electrofishing effects.

All capture-recapture and removal methods gave negatively biased population estimates (Table 2). Bias is defined here as the relative closeness of $\hat{N}$ to the true N (i.e., no bias means $\hat{N} = N$). The Chapman modified Peterson method had the poorest estimate with the calculated $\hat{N}$ of 136 (95% C.I. = 103 to 169), underestimating the true N by 46% on the second sampling occasion. The large percentage of recaptured bass on this occasion adversely affected $\hat{N}$ (Fig. 1, 2).

Independent Chapman $\hat{N}$ estimates derived for each sampling occasion gave acceptable results (known population within 95% confidence limits) when at least 56% of the known N was marked and the sampling effort (including initial marking) exceeded 4 occasions (Fig. 2). The estimated $\hat{N}$ was negatively biased on the second to fourth sampling occasions and the true N actually fell outside of the calculated 95% C.I. On the fifth and sixth sampling occasions, $\hat{N}$ was less biased with the true N lying inside the 95% C.I. Accuracy decreased over time with a predictable inverse relationship between C_t and R_t and the calculated size of the S.E. and 95% C.I. Utilizing the Chapman estimates as 1 sample ($N = 5$), a mean $\hat{N}$, S.E., and 95% C.I. was generated for the sampling distribution (Table 2). Again, the mean $\hat{N}$ of 196 was negatively biased with the true N lying outside the 95% C.I.

Schnabel and Schumacher-Eschmeyer methods yielded similarly biased $\hat{N}$ estimates which underestimated the true N by 22% and 17%, respectively. The Schumacher-Eschmeyer method gave the more accurate estimate with a smaller S.E. and narrower 95% C.I., although the true N fell inside the 95% C.I. calculated for each method (Table 2).

Table 2. Largemouth bass population estimates, 95% confidence intervals, and standard errors calculated by method for November 1984 study.

Estimator	$\hat{N}$	95% Confidence Intervals	Standard Error[a]
Chapman[b]	196	178 to 245	17.6206
Peterson	136	103 to 169	16.9600
Schnabel	195	157 to 256	0.0012
Schumacher-Eschmeyer	208	176 to 254	0.0009
Leslie	202	144 to 244	
DeLury (large catchability coefficient)	180	N/A	
DeLury (exponential catchability)	219	N/A	

[a] Standard error calculated for Schnabel and Schumacher-Eschmeyer estimates are for 1/N.
[b] Chapman 95% confidence intervals and standard error derived for "sampling distribution" of 5 estimates.

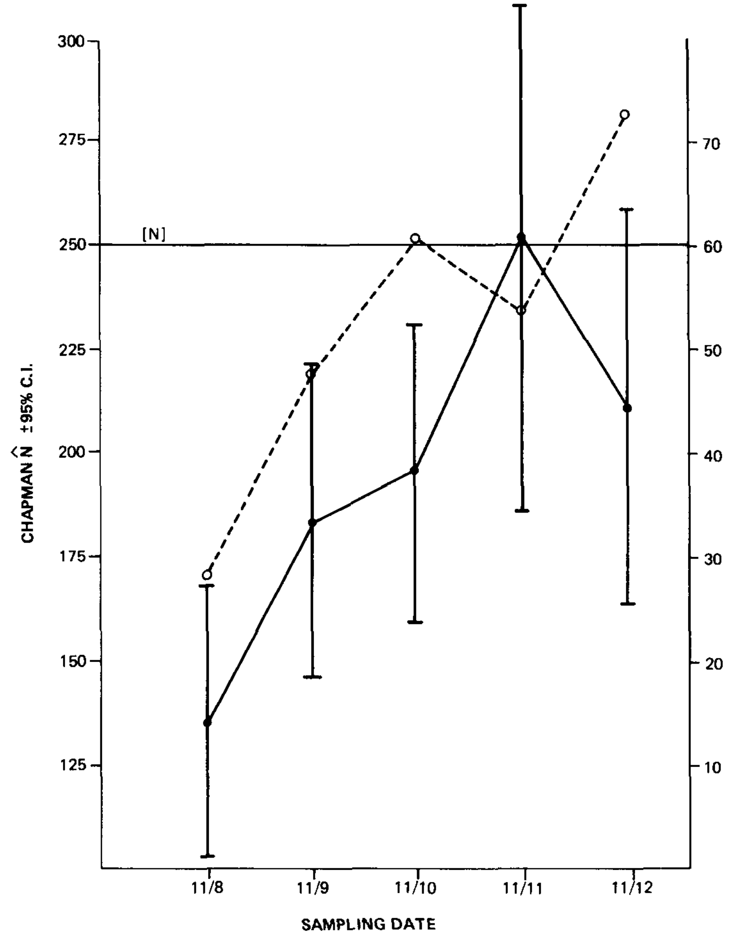

Figure 2. Chapman population estimates, 95% C.I., and % marks (o------o) in sample for largemouth bass by sampling trip during November 1984 (Note: Black dot is N̂ and brackets are 95% C.I.).

Population estimates based on removal methods of Leslie and Davis and of DeLury were also negatively biased and similar to those derived from capture-recapture methods (Table 2). Regression lines derived for each removal method showed a good fit to the data (Leslie, $R^2 = 0.75$ and DeLury, $R^2 = 0.82$). Ricker (1975) discussed 2 special cases (i.e., exponential and large catchability) of the DeLury model that are dependent upon the fraction of the stock (q) taken by a unit of effort. The exponential catchability $[\log_e (C_t/f_t) = \log_e (qN_o) - qE_t]$ should be used when q is usually ≤ 0.02, and the large catchability $[N_o = C/(1 - S^f)]$ is used when q is > 0.02. Based on actual catchability values of the unmarked population (Fig. 2), each unit of effort removed a substantial proportion ($\geq$ 6%) of N. In this situation, the large catchability case is recommended for calculating $\hat{N}$. Calculation of $\hat{N}$ showed that the exponential catchability case gave a better $\hat{N}$ ($\hat{N}$ = 219, q = 0.3808) than the large catchability case ($\hat{N}$ = 180). The Leslie $\hat{N}$ of 202 (q = 0.2424) agreed closely to the $\hat{N}$ for the former. It should be noted that the large catchability case predicted a surviving stock (S^f) of 10%, while 35% of the known stock actually remained (assuming no mortality) at the end of the experiment. Regardless, the negatively biased population estimates suggested a violation of the assumptions of no mortality or equal catchability of all members. In both the Leslie and DeLury estimates, marked bass were considered removed from the population. Competition for capture and interaction of marked and unmarked bass may have affected the assumption of equal catchability. Another possibility of bias is the questionable performance of regression methods in predicting N given good fitting data and a large percentage of N removed. In a review of removal methods, Cowx (1983) stated that population estimates derived from regression techniques should be considered minimum values of N when assessing fish populations. Mahon (1980) discussed the validity of regression methods and concluded they consistently underestimated the true N. He calculated an average error of 22% for the Leslie model. In this study, the error was 19% for the Leslie model, while the DeLury exponential and large catchability models were in error by 12% and 28%, respectively.

Conclusions

Even with the fairly controlled experimental conditions used in this study, all capture-recapture and removal methods gave negatively biased population estimates. The Schumacher-Eschmeyer and the DeLury exponential catchability models gave minimally biased, accurate estimates within 12% to 17% of the true N. Independent Chapman estimates also gave acceptable results in terms of accuracy and bias when the number of sampling occasions exceeded four. Possible reasons for the negative bias are: 1) that undetected mortality occurred within the unmarked population prior to the study, 2) that some differences existed in capture vulnerability of marked and unmarked members, or 3) that the small size of the pond sampled magnified gear avoidance behavior. Conservative or negatively biased population estimates are usually preferable to liberal, positively biased estimates, especially when making management decisions on fish populations.

Literature Cited

Aggus, L. R. and W. C. Rainwater. 1975. Estimating largemouth bass populations in reservoirs from catches in angling tournaments. Proc. Annu. Conf. Southeast. Assoc. Game and Fish. Comm. 29:106–114.

Bryant, H. E. and A. Houser. 1971. Population estimates and growth of largemouth bass in Beaver and Bull Shoals Reservoir. Pages 349–357 *in* Gordon E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc., Washington, D.C.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample census. Univ. Calif. Pub. Stat. 1:131–160.

———. 1952. Inverse, multiple, and sequential censuses. Biometrics. 8:286–306.

Cowx, I. G. 1983. Review of the methods for estimating fish population size from survey removal data. Fish. Manage. 14:67–82.

DeLury, D. B. 1947. On the estimation of biological populations. Biometrics. 3:145–167.

Fredin, R. A. 1950. Fish population estimates in small ponds using the mark and recovery technique. Iowa State Coll. J. Sci. 24:363–384.

Grinstead, B. G. and G. L. Wright. 1973. Estimation of black bass, *Micropterus* spp., population in Eufaula Reservoir, Oklahoma, with discussion of techniques. Proc. Okla. Acad. Sci. 53:48–52.

Harris, F. A., L. M. Ager, and E. Hayes. 1979. Comparison of various mark-recapture techniques for estimating abundance of largemouth bass in Barkley Lake, Kentucky. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 33:703–709.

Herring, J. 1979. Fish population estimate methods evaluated by a total drawdown. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 33:393–401.

Hickman, G. D. and K. W. Hevel. 1975. Comparisons of population estimates of largemouth bass in Forrest Lake, Missouri, utilizing a bass tournament and an electroshocker for collection of recaptures. Proc. Annu. Conf. Southeast. Assoc. Game and Fish. Comm. 29:102–105.

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

Lewis, W. M., R. C. Summerfelt, and M. E. Bender. 1962. Use of an electric shocker in conjunction with the mark-and-recovery technique in making estimates of largemouth bass populations. Prog. Fish Cult. 24:41–45.

Mahon, R. 1980. Accuracy of catch-effort methods for estimating fish density and biomass in streams. Environ. Biol. Fish. 5:343–360.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can., Bul. 191, Ottawa. 382pp.

Seawell, W. M. and K. W. Hevel. 1978. Comparison of two methods of recapturing marked fish for estimating black bass populations in a reservoir. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 32:437–445.

Schnabel, Z. E. 1938. The estimation of the total fish population of a lake. Am. Math. Monogr. 45:348–352.

Schumacher, F. X. and R. W. Eschmeyer. 1943. The estimate of fish population in lakes or ponds. J. Tenn. Acad. Sci. 18:228–249.

Swingle, W. E., R. O. Smitherman, and S. L. Spencer. 1965. Estimation of bass numbers in a farm pond prior to draining with electroshocking and angling. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 19:246–253.

Woodrum, J. E. 1978. Comparison of rotenone and electrofishing population estimates to lake draining. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies. 32: 634–638.

Zweiacker, P. L. 1972. Population dynamics of largemouth bass in an 808-hectare Oklahoma reservoir. Ph.D. Diss., Okla. St. Univ., Stillwater. 145pp.