Yield-per-recruit Simulation Analyses for a Largemouth Bass Population in Lucchetti Reservoir, Puerto Rico

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Abstract: Minimum size limits of 279, 305, and 330 mm total lengths (TL) were evaluated using Beverton-Holt yield modeling for the largemouth bass *(Micropterus salmoides)* population in Lucchetti Reservoir, Puerto Rico. Growth, estimated from microtagged fish, was faster until maturity compared to the populations in the contiguous United States. The von Bertalanffy growth coefficient (k) was 1.44 with L_∞ estimated at 404.4 mm TL. Survival rates for adult largemouth bass (>250 mmTL), calculated from mark-recapture studies, were estimated to be 40% for 1998 and 30% for 1999. Simulations revealed that a 305-mm length limit results in higher yield when instantaneous natural mortality exceeds 0.4. Higher harvest rates would be achieved with a 279-mm length limit, whereas a 330-mm length limit would result in greater mean-fish-size at any of the instantaneous natural mortality rates addressed (0.3, 0.4, and 0.5). Since reservoirs in Puerto Rico are relatively small and therefore subject to heavy fishing pressure, fishing regulations would be feasible and beneficial management options.

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Harvest regulations for black bass *(Micropterus spp.)* were originally intended to restrict commercial fishing, but as sport fisheries became more popular the necessity to implement limits for game fish emerged (Fox 1975). Noble and Jones (1993) categorized the reasons of implementing regulations as biological, ecological, sociological, and economic. In Puerto Rico, competitive freshwater sport fishing is mainly largemouth bass oriented, demonstrating social and economic benefits of fisheries resources (Schramm et al. 1991). A daily bag limit of 12 largemouth bass was implemented for all reservoirs in 1984, but the effect of this regulation has not been assessed (Lilyestrom and Churchill 1996). An island-wide minimum size limit of 305 mm for largemouth bass is also in effect, which apparently is not strictly enforced (Waters 1999). Minimum size limits are recommended for fish populations that have low rates of recruitment and natural mortality, rapid growth rates, and high fishing mortality (Anderson 1980, Novinger 1984).

The largemouth bass population in Lucchetti Reservoir is characterized by relatively fast growth until maturity (Neal et al. 1999). Largemouth bass have been found to live as much as 23 years (Green and Heidinger 1994), whereas in Lucchetti Reservoir few fish survive to age-4 (Churchill et al. 1995), suggesting high mortality rates.

Wilde (1997) reported that minimum-length limits for largemouth bass did not increase the proportion of larger fish, nor did they increase the number and weight of fish harvested in the 40+ water bodies across the United States. However, the length limits implemented for largemouth bass in the United States often were not intended to increase yield or harvest but rather to protect the spawning stock or to increase the catch rates. Novinger (1984) suggested that size limits could improve the quality of fishing for largemouth bass if they were applied properly. He also reported that there were few published results available to managers to determine if a size limit is needed, what length limit would be appropriate, and whether changes after imposing length limits were the results of the regulation.

The main objective of this study was to determine if the island-wide 305 mm minimum length limit for largemouth bass was beneficial in Luchetti Reservoir in terms of yield, harvest rate, and catch size. Moreover, different size limits and rates of fishing efforts were analyzed to determine if different regulation alternatives could result in a more desirable largemouth bass fishery for this fast-growing and short-living population.

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Methods

Lucchetti Reservoir, completed in 1952, is a 108-ha impoundment in the mountain region of southwestern Puerto Rico. With a drainage area of 45.1 km^2, Lucchetti Reservoir is divided into 4 embayments, corresponding to its 4-river confluence. The basin of the reservoir is located in a subtropical moist forest, where annual precipitation averages about 198 cm. Water retention time is about 0.66 years, which is above the average for reservoirs in Puerto Rico. Mean depth of the reservoir was about 11.6 m with a maximum design depth of 54.3 m at the spill level of 174 m above the sea level (Churchill et al. 1995). However, Neal et al. (1999) found the maximum depth to be less than 22.3 m, suggesting heavy siltation since impoundment.

Water levels vary over a range of 17 m annually, resulting in dramatic changes of the shoreline distance and surface area. These extreme water level changes result in low aquatic macrophyte production. The productivity level of Lucchetti Reservoir has been categorized as eutrophic (Perez-Santos 1994). A creel survey conducted by Corujo Flores (1991) in Lucchetti Reservoir indicated that the main target fish of boat anglers (81%) was largemouth bass, whereas most of the shore anglers (88%) had no targeted species.

Largemouth bass survival data were obtained from annual Petersen mark-recapture population estimates (Ashe et al. 1998). Adult largemouth bass were captured with a boom-mounted electrofishing boat from the entire shoreline, and fish exceeding 250 mm TL were marked with a fin clip, released in January, and recaptured in February from 1996 to 2000. Recaptures continued until the sample size of largemouth bass >250 mm TL was sufficient to obtain a precision level of 25% for the population estimate (Robson and Regier 1964). All fish captured were measured (mm) and weighed (g). Fins marked were alternated each year as left pelvic and right pelvic.

Instantaneous fishing (F) and instantaneous natural mortality (M) estimates of largemouth bass for the yield-per-recruit simulation were obtained from a telemetry study conducted in Lucchetti Reservoir (Waters 1999). Instantaneous fishing mortality rates were estimated as 0.58 and 0.69 for the years 1998 and 1999, respectively. Instantaneous natural mortality estimates were 0.31 for 1998 and 0.47 for 1999. For simulation purposes 3 different rates of M were used: 0.3, 0.4, and 0.5, which cover the range of the estimated mortality rates from the telemetry study. Fishing mortality rates from 0.1 to 0.9 were used for the overall estimates of the yield modeling, but the more realistic values of 0.5, 0.6, and 0.7 were used in the detailed analyses for more appropriate management decisions.

In order to check the accuracy of the telemetry mortality estimates, survival rates (S) were estimated from the independent population estimate study. From the population estimate study (Table 1) we estimated S with Ricker's method (Ricker 1975):

$$S_1 = \frac{R_{12}M_2}{M_1R_{22}}$$

where S_1 is the survival rate from time of marking in year 1 to time of marking in year 2, M_1 is the number of fish marked at the start of the first year, M_2 is the number of fish marked at the start of the second year, R_{12} is the number of recaptures of first-year marked fish in the second year, and R_{22} is the number of recaptures of second-year fish in the second year.

Juvenile largemouth bass population characteristics were obtained through

Table 1. Marking data used for the survival (S) estimate of adult largemouth bass in Lucchetti Reservoir. M is the number of fish marked (>250 mm), and R_1 and R_2 are the recaptures of the previous and current years, respectively.

Year	M	R_1	R_2	S
1998	962			40
1999	650	31	52	30
2000	771	14	55	

timed. nighttime electrofishing efforts using a 260-volt DC hand-held probe (Jackson and Noble 1995) every 6 weeks from 1996 to 1999. Saggital otoliths were removed and daily rings were counted using the procedure described by Miller and Storck (1982).

Because annuli cannot be distinguished on adult largemouth bass in Puerto Rico (Neal et al. 1997), growth curves were developed from microtagged fish. A total of 5,666 hatchery largemouth bass fingerlings were tagged with binary-coded wire microtags and released in Lucchetti Reservoir in May 1996 and April 1997. Total length ranged between 47 and 66 mm (mean=55.3 mm) in 1996 and between 43 and 75 mm (mean=54.8 mm) in 1997. Microtagged fish were collected during targeted electrofishing approximately one month following stocking, during the periodic electrofishing for juvenile largemouth bass, and during the population estimate studies from 1997 to 2000. Ages of the microtagged fish at the time of stocking were estimated from the otolith readings obtained from juvenile largemouth bass in 1996 and 1997 (Neal et al. 1999). Average ages of the juvenile largemouth bass with similar length distributions to the microtagged fish were 95 days in 1996 and 92 in 1997. The time elapsed since stocking plus the estimated age at stocking and the total lengths at the time of recaptures were used to estimate parameters of the von Bertalanffy growth equation.

A weight-length relation, defined as $W = aTL^b$ was constructed for pooled data for 1996–2000, where W is weight in g, a is the intercept, TL is the total length in mm, and b is the exponent.

Parameters for the weight-length relationship were calculated using data from juvenile largemouth bass during 1996–1999, and the adult population estimate studies from 1996–2000.

Yield was calculated with the Jones' modification of the Beverton and Holt equilibrium yield model (Ricker 1975) using the software program Statistical Analysis System (SAS Inst. 1988) described by Maceina et al. (1998):

$$Y = \frac{FN_0 e^{Fr} W_\infty}{K} (\beta[X,P,Q]);$$

where Y is yield in weight; F is the instantaneous rate of fishing mortality; N_0 is the hypothetical number of individuals that reach the hypothetical age t_0; $r = t_R - t_0$; t_R is the age of recruitment to the fishery; t_0 is the age at zero length; W_∞ is the average asympotic weight of fish; K is the Brody growth coefficient; β is the incomplete beta function; $X=e^{-Kr}$; $P=Z/K$; Z is the instantaneous total mortality; $Q=b+1$; and b is the exponent in the population weight-length relationship.

We used 100 individuals for N_0 in the yield simulation analyses to avoid decimal places for the harvest rates. The asympotic weight (W_∞) was estimated by substituting TL with L_∞ in the weight-length equation. Harvest rates were computed from $(N_t{*}F)/Z$ where N_t is the number of fish entering the fishery at time t. Mean weights of harvested fish were calculated by dividing Y to the harvest rate. Mean total length of fish harvested were then back calculated from the weight-length equation.

Results and Discussion

Length and weight data from 5,854 fish collected from 1996–2000 were used to develop the weight-length relationship for largemouth bass in Lucchetti Reservoir. The intercept (a) and the exponent (b) of the weight-length equation were calculated as 0.0000075 and 3.1 respectively. Growth data were available for 211 microtag recaptures and were used to construct the von Bertalanffy growth curve (Fig. 1). The asymptotic length (L_∞) of the von Bertalanffy growth equation was estimated as 404.4 mm with a growth coefficient (k) of 1.44 and t_0 of 0.21. Beamesderfer and North (1995) reported the von Bertalanffy growth parameters ranging between 0.06 and 0.36 (with a mean of 0.21) for k, and L_∞ between 510 mm and 1264 mm (with a mean of 635 mm) for 648 largemouth bass populations from 34 different states. These results indicate that the largemouth bass population in Lucchetti Reservoir grows much faster, at least until maturity, but does not reach a total length as large as populations in the contiguous United States. After largemouth bass in Lucchetti Reservoir reached maturity (259 mm for males; 269 mm for females) (Gran 1995), growth slowed (Fig. 1). Consequently, in years when first year growth is relatively fast, age-1 and age-2 cohorts exhibit unimodal frequency length distribution (Fig. 2).

Growth rate of largemouth bass varies among years, resulting in variable size distribution of adults (Fig. 2), which could bias our results for different years. Largemouth bass start to spawn in January and cease spawning between February and June (Churchill et al. 1995), depending on the water level fluctuation pattern (Neal et al.

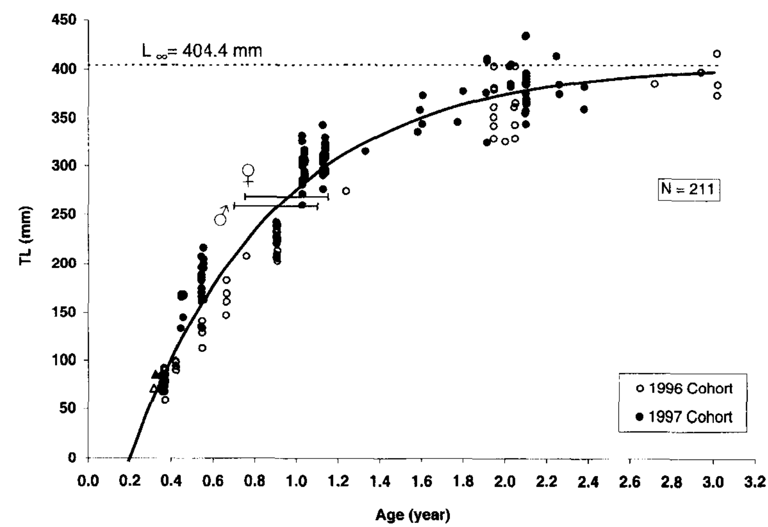

Figure 1. The von Bertalanffy growth curve estimated from the recapture data obtained from the microtagged largemouth bass in 1996 (open circles) and 1997 (closed circles). Each circle represents a captured fish. The open and closed triangles represent the mean length obtained from intensive recapture studies for the 1996 and 1997 cohorts, respectively. Male and female symbols indicate sizes at maturity (259 mm and 269 mm, respectively).

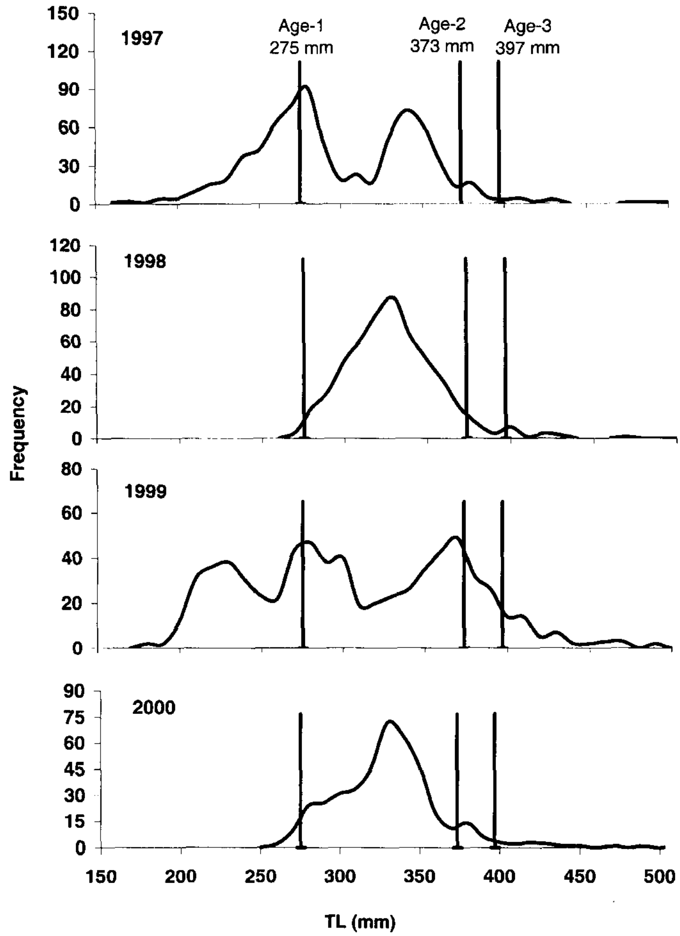

Figure 2. Estimated total lengths (TL) for age-1 to age-3 from the von Bertalanffy growth equation. Frequency distributions are from population estimate recapture surveys conducted in February each year (1997–2000).

1999). This variation in spawning period, combined with possible density dependent growth, results in differential growth rates that can not be explained only by age, which the von Bertalanffy equation assumes.

Survival rate estimates for largemouth bass from the telemetry study were 41% for 1998 and 31% for 1999 (Waters 1999). Estimates from the mark-recapture data revealed similar results with survival rates of 40% for 1998 and 30% for 1999 (Table 1). This similarity in estimates from 2 independent studies, rarely observed in fisheries data, is an indication that the overall mortality rate is fairly accurate. The bias for the fishing and natural mortality estimates could arise from the partitioning of the mortality rate. However, the different levels of F and M used in simulations considered this type of error.

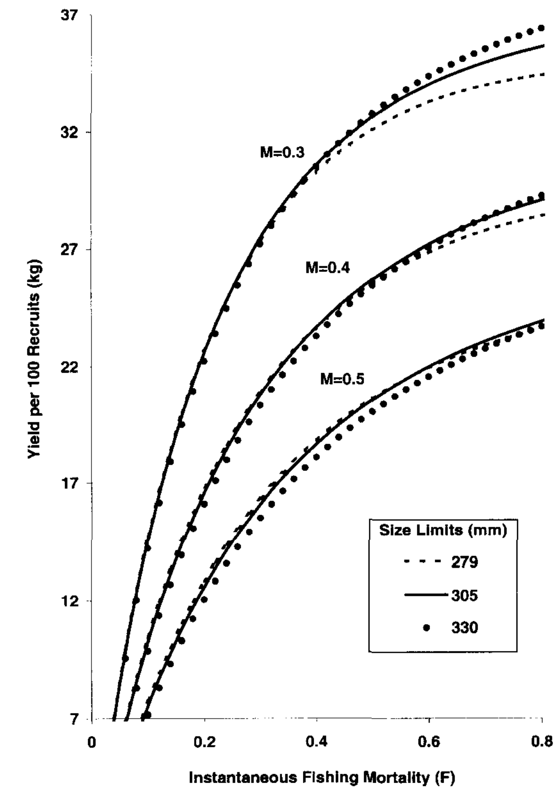

Figure 3. Yield per 100 recruits (kg) for 279 mm, 305 mm, and 330 mm length limits with instantaneous natural mortality rates (M) of 0.3, 0.4, and 0.5 for instantaneous fishing mortality rates (F) of 0.1–0.8.

The yield-per-recruit computations revealed that a 330-mm minimum size limit would result in higher yield than lower size limits only when there was a low instantaneous natural mortality rate (e.g., 0.3) and a high instantaneous fishing mortality rates (e.g., >0.4) (Fig. 3).

In cases where instantaneous natural mortality is higher than 0.3, a 330-mm size limit would result in less yield than either a 305-mm or a 279-mm size limit. A more detailed illustration (Fig. 4) shows the level of instantaneous fishing mortality, yield, and harvest rate is also illustrated. At a instantaneous natural mortality rate of 0.4, and even more pronounced at 0.5, a 330-mm size limit would potentially result in reduced yield and harvest rate. However, at any given instantaneous natural mortality rate, a 330-mm length limit would produce larger fish at the expense of harvest rate and yield. For example, the 330-mm size limit would result in a loss of about 3–4 fish and 1,000 g of yield but would gain 7–8 mm in fish length harvested (per 100 recruits at 0.4 and 0.5 instantaneous natural mortality rates, Fig. 5).

The advantages of these 3 minimum length limits in relation to one another may

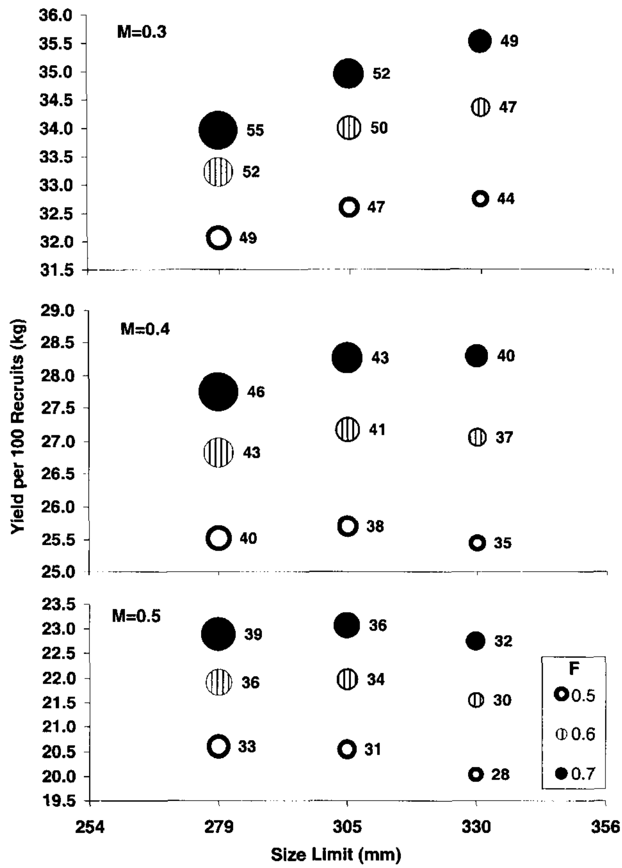

Figure 4. Estimated yield per 100 recruits (kg) for 279 mm, 305 mm, and 330 mm length limits with instantaneous fishing mortality rates (F) of 0.5, 0.6, and 0.7 and instantaneous natural mortality rates (M) of 0.3, 0.4, and 0.5. The numbers next to the points represent the number of harvest; point sizes are propotional to the harvest rates.

not seem biologically significant. However, other length limits <279 mm or >330 mm would result in higher rates of loss for the fishery, at current growth and mortality rates. Larger fish size harvested could be achieved with length limits >330 mm, but catch rates and yield would decline beyond those associated with 279-, 305-, and 330-mm size limits. Thus, depending on management objectives, one of these 3 length limits would likely result in a more satisfactory largemouth bass fishery in Lucchetti Reservoir.

Novinger (1984) suggested that more effective decisions on size limits could be made if managers develop plans with clear-cut objectives, carefully consider the influence of bass population characteristics, conduct well-designed studies, and communicate results. If the main objective is angler satisfaction, then management decisions

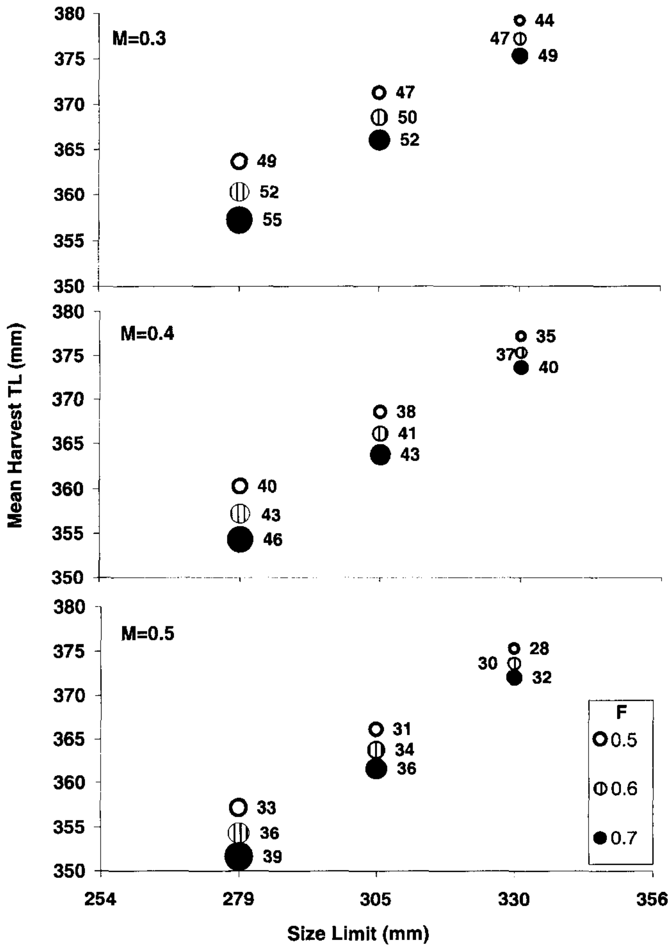

Figure 5. Estimated mean total length (TL) of harvested fish for 280 mm, 305 mm, and 330 mm length limits with instantaneous fishing mortality rates (F) of 0.5, 0.6, and 0.7 and instantaneous natural mortality rates (M) of 0.3, 0.4, and 0.5. The numbers next to points represent the number of harvest; point sizes are proportional to the harvest rates.

should incorporate anglers' opinions. Most anglers in Lucchetti Reservoir are dedicated largemouth bass anglers, and prefer catching larger fish (D. Lopez-Clayton PRDNER, pers. commun.). Since reservoirs in Puerto Rico are relatively small and subject to substantial fishing pressure, fishing regulations seem to be a viable management tool. However, success depends on angler compliance and adequate enforcement. Angler compliance is frequently related to their knowledge and input (Noble and Jones 1993). Before implementing fishing regulations, an angler survey that provides different regulation options and that explains the likely outcomes of the regulations, would probably be beneficial in obtaining angler compliance with regulations, and better public relations. Although compliance to regulations in Lucchetti Reservoir is enhanced by its single access point for boat anglers, increased enforcement for shore anglers should further contribute to compliance with regulations, and therefore, the effectiveness of regulations as a management tool.

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