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Largemouth bass population estimates from Diamond Valley Lake, Riverside County, California

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A combination of boat electrofishing and bass angling tournaments was used to estimate the 2008 population of largemouth bass (*Micropterus salmoides floridanus*) ≥300 mm TL at Diamond Valley Lake, Riverside County, California. We compared three combinations of sampling techniques to determine the most reliable method for estimating population size. A modified proportional stock density (PSD) was used to extrapolate the tournament data for legal size largemouth bass (≥380 mm TL) to population estimates for bass ≥300 mm TL. Each of the 3 mark and recapture combinations yielded different population estimates. The combination of both electrofishing and angling for mark and recapture of largemouth bass, along with the PSD extrapolation, produced the most precise estimate. Utilizing this PSD extrapolation would allow fishery managers for other waters with larger legal size restrictions to estimate population size by taking advantage of tournament data.

Key words: California, Diamond Valley Lake, largemouth bass, *Micropterus salmoides*, mark-recapture, population estimate, proportional stock density, PSD

In this study, we evaluated an alternative method for obtaining largemouth bass (LMB; *Micropterus salmoides floridanus*) population estimates at Diamond Valley Lake (DVL), Riverside County, California. Population estimates provide insight into the status of the LMB fishery at DVL. Various methods exist for estimating fish populations throughout the United States, such as angler catch (Gablehouse and Willis 1986), underwater surveys (Davis et al. 1997), creel census (Farman et al. 1982), or catch depletion techniques (Maceina et al. 1995). Estimates of LMB populations have relied primarily on mark-recapture (Hightower and Gilbert 1984, Isely and Tomasso 1998, McInerny and Cross 1999) and catch per unit of effort (CPUE) studies (Hall 1986, Buynak and Mitchell 1993, McInerny and Degan 1993, Miranda et al. 1996, Kershner and Marschall 1998). Electrofishing is the technique most frequently used to assess LMB populations (Gablehouse and Willis 1986). Prior studies at DVL evaluated changes in the LMB population using only electrofishing for marking and recapturing efforts. However, they were not intended to provide information on harvest, mortality, or movement by individual bass. We suspected that restricting the sampling to only electrofishing tended to underestimate the population size. This raised questions about the accuracy of prior estimates.

Materials and Methods

Diamond Valley Lake (33° 41' N, 117° 02' W), is an off-stream storage reservoir built by Metropolitan Water District of Southern California, and is located 6.4 kilometers (km) southwest of the city of Hemet, California. The crest elevation of the East, West and Saddle dams is 539.19 m and the maximum reservoir elevation is 535.23 m. DVL is approximately 7.24 km in length between the East and West dams and has an average width of 3.22 km. The average depth at full pool is 60.96 m, 48.77 m at the East dam, and 79.25 m at the West Dam. The lake has 40.23 km of shoreline including the three dams. At full pool, the surface area is 1,990.65 ha. DVL is projected to have annual water level fluctuations of approximately 10.7 m. The maximum drawdown to the emergency supply level is 27.43 m below full pool.

We are proposing a new method for estimating LMB population at DVL. Our population estimate is for all LMB ≥ 300 mm total length (TL) at DVL, and not the total population of LMB. For the new method we conducted multiple mark and recapture sampling over a limited time period to meet the assumptions of a closed population. We calculated both the Schnabel and Schumacher-Eschmeyer estimates for population size (Seber 1982, Krebs 1999). Prior studies at DVL sampled LMB with only boat electrofishing. In contrast, we sampled LMB with both boat electrofishing and angling tournaments. The basis of our method was a multi-gear approach with differences in gear selectivity and efficiency, which would more accurately estimate the LMB population structure (Meador et. al. 1993, Weaver et. al. 1993, Hickman and McDonough 1996). Angling tournaments have been cost-effective, particularly as a supplement to other sampling techniques (Grinstead and Wright 1973, Holbrook II 1975, Goudy 1981, Gablehouse and Willis 1986).

To find the best method for estimating bass population at DVL, we investigated three candidate methods that were various combinations of techniques selected from the following: boat electrofishing, LMB angling tournaments, and proportional stock density (PSD). The techniques will be described first, and then the methods.

The initial 2008 electrofishing marking effort occurred during 10-13 March, with three additional mark and recapture efforts during 7-10 April, 5-7 May, and 2-6 June, 2008. We conducted the boat electrofishing sampling using a Smith-Root SR-18 boat electrofisher with a 75 hp Mercury outboard motor and sampling crew. The crew consisted of 2 forward netters and 1 boat operator. We sampled around the perimeter of DVL at the beginning of each month during March-June of 2008. Pulsed 60 cps DC current (8-12 amps) put the fish into electro-narcosis. On some occasions, we increased productivity with 2 electrofishing boats and crews. We netted and placed the stunned LMB ≥300mm TL into the boat livewell for processing. We measured, marked, and recorded LMB into 2 size categories, LMB 300-379 mm TL and LMB ≥380mm TL. For the first 100 LMB ≥300 mm, we also weighed them on a certified A&D HL-3000WP digital scale. In 2008, we marked all bass with a left pelvic fin clip (removal) and a hole punched into the rear third of the 2nd dorsal fin; clipping is the most basic and efficient marking procedure (Guy et al. 1996).

We sampled all LMB angling tournaments that occurred between the first and last of the 4 electrofishing efforts between March and June, 2008. A total of 12 tournaments were sampled in 2008. During tournaments, staff at a live release boat processed angler caught LMB. Processing involved measuring LMB to verify the total length was ≥380 mm, checking for recaptures, and marking if not previously caught. Staff processed only LMB ≥380 mm that were in suitable condition to be released. We recorded the total number of newly marked LMB and recaptures for each tournament. Any marked bass not in suitable condition to be released was recorded and deducted from the total number marked. We then released the processed LMB at random locations throughout the lake with the live release boat.

In prior population estimates for DVL, only electrofishing was used to mark and recapture bass and focused on LMB ≥300 mm. In our study, we retained the ≥300 mm criterion for population estimation, since 300 mm is the general minimum legal size for LMB in most California waters. Since DVL has a legal size limit of ≥380 mm for angling tournaments, our study had to account for the bass between 300 and 379 mm that were ineligible for tournament capture. For this purpose, we calculated a modified proportional stock density (PSD), which is the percentage of LMB of stock length that are also of quality length. We calculated proportional stock density (Anderson 1976) as: PSD = (number of fish ≥ minimum quality length) / (number of fish ≥minimum stock length) x 100.

For this study, we defined the stock length as LMB ≥300 mm TL, as contrasted with the customary 200 mm TL (Anderson 1976). We defined bass of quality size to be ≥380 mm, compared with ≥300 mm in the literature (Anderson 1976). Fishery managers developed the PSD index for electrofishing data, because they seldom knew the population size structure (Gablehouse and Willis 1986). We estimated PSD as the mean of 4 electrofishing samplings (March-June of 2008), since the mean of 4 values was more accurate than a single value (Fleiss 1986).

If a method utilized the PSD, we first calculated the Schnabel and Schumacher-Eschmeyer population estimates (N) using the formula $N = (c)(n)$, where c = the multiplicative factor that accounted for the LMB 300-379 mm in the population ($c = 100/m$, where m = the mean PSD from electrofishing), and n = the population estimate for LMB ≥380 mm obtained from the Schnabel and Schumacher-Eschmeyer estimates. N is a product of n and c (a multiplicative factor); thus, we calculated the 95% *CI*s for LMB ≥300 mm as (c)(L) and (c)(H), respectively, where L and H are the lower and upper limits of *CI*s for bass ≥380 mm obtained from the Schnabel and Schumacher-Eschmeyer estimates.

To determine the most reliable combination of sampling techniques, we investigated 3 candidate methods (Table 1). We included Combination 1 to mimic the sampling method of prior studies at DVL, which utilized only electrofishing. In Combination 1, we marked LMB from both electrofishing (4 monthly efforts) and tournament angling (12 efforts total).

Table 1.—Summary of largemouth bass population estimation sampling methods for Diamond Valley Lake, Riverside County, California.

Method	Marking	Recapture	PSD
Pre-2008 surveys	electrofishing only	electrofishing only	not used
Combination 1	electrofishing & angling	electrofishing only	not used
Combination 2	electrofishing & angling	electrofishing & angling	used
Combination 3	electrofishing & angling	angling only	used

We obtained recapture information from only the 4 monthly electrofishing efforts (Table 1). If we recaptured marked LMB ≥380 mm during the angling tournaments, we discarded that information. Hence, the PSD expansion was not necessary. We calculated both the Schnabel and Schumacher-Eschmeyer estimates of population size and 95% *CI*s for LMB ≥300 mm.

In Combination 2, we determined if electrofishing and tournament angling in tandem for mark and recapture improved the estimates. Similar to Combination 1, electrofishing (4 monthly efforts) provided both mark and recapture data. In contrast to Combination 1, the 12 angling tournaments yielded recapture data in addition to marked bass (Table 1). Thus, we obtained recapture data from both the electrofishing and angling tournaments. Since the angling tournaments only provided recapture data for LMB ≥380 mm, we calculated the Schnabel and Schumacher-Eschmeyer estimates and *CI*s for LMB ≥380 mm. We then extrapolated to the population estimates and 95% *CI*s for LMB ≥300 mm with the mean PSD.

In Combination 3, we attempted to maximize the number of LMB marked and available for sampling by tournament angling. This combination relied on both electrofishing (4 monthly efforts) and angling (12 tournaments) for marking. We then obtained recapture data from only the 12 angling tournaments. In contrast to Combination 2, electrofishing did not yield recapture data (Table 1). We calculated the Schnabel and Schumacher-Eschmeyer estimates and *CI*s for LMB ≥380 mm. The expansion with PSD provided population estimates and 95% *CI*s for LMB ≥300 mm.

Density estimates, number of LMB/ha, and weight of LMB/ha are utilized in the literature for evaluating standing crop at various waters in North America. We compared our LMB densities/ha with what is "expected" for a fishery of DVL's caliber. In order to compare our density estimates with those in the literature, for each combination we converted our population *CI* for LMB ≥300 mm to density *CI*. We calculated the 95% *CI* for LMB count/ha by dividing the 95% *CI* for population by the surface area of DVL at the start of sampling. We then calculated the 95% *CI* for weight (kg)/ha by multiplying the 95% *CI* for LMB count/ha by the mean weight (kg) of LMB ≥300 mm TL caught in the initial electrofishing sample.

In estimating the population of LMB in DVL, we considered the population to be "closed", an assumption for some mark-recapture estimates (Seber 1982, Anderson and Neumann 1996, Krebs 1999). In a closed population the population size is constant, without recruitment or mortality during the study. It also assumed that fish remain within specific size classes during the sampling period. Delayed tournament mortality and fish growing into different size classes could have violated the closed population assumption. However, we conducted this study during a limited time period to minimize these violations (Seber 1982). We did not utilize methods for an open population, such as Jolly-Seber, due to the increased cost, undesired marking requirements, and fin clip marking complications from previous years.

Results

We collected a total of 6,893 LMB ≥300 mm TL by electrofishing to calculate the PSD. The PSD values ranged from 36 to 51 over the 4 monthly electrofishing efforts. The mean PSD derived from the 4 electrofishing efforts was 40. The population estimates using the 3 combinations were as follows.

For Combination 1, between March and June, 2008 we collected a total of 7,242 LMB ≥300 mm by electrofishing and tournament angling for marking. The Schnabel estimate for LMB ≥300 mm TL was 20,056 (95% *CI*=17,576-23,351). The Schumacher-Eschmeyer estimate for LMB ≥300 mm was 20,001 (95% *CI*=16,666-25,005) (Table 2).

TABLE 2.—Population estimates and density CIs of largemouth bass ≥300 mm from candidate approaches of multiple mark/recapture sampling conducted at Diamond Valley Lake, Riverside County, California, 2008.

	Schnabel ≥300mm (95% CI) *CI Length*	Schumacher-Eschmeyer ≥300mm (95% CI) *CI Length*	Population density per hectare (≥ 300 mm) 95% CI	Weight density per hectare (≥ 300 mm) 95% CI
Combination 1 E-fish / Angling mark E-fish recapture only	20,056 (17,576-23,351) *5,775*	20,001 (16,666-25,005) *8,339*	9 – 13 LMB / hectare	9.52 – 13.75 kg / hectare
Combination 2 E-fish / Angling mark & recapture	34,907 (31,745-38,767) *7,022*	34,524 (27,636-45,986) *18,350*	15 - 25 LMB / hectare	15.87 – 26.45 kg / hectare
Combination 3 E-fish / Angling mark Angling recapture only	65,860 (55,958-80,021) *24,063*	68,007 (58,945-80,360) *20,415*	30 - 43 LMB / hectare	31.74 – 45.49 kg / hectare

For Combination 2, we collected a total of 3,541 LMB ≥380 mm for marking by electrofishing and tournament angling. We applied the mean PSD of 40 for the extrapolation. The Schnabel estimate for LMB ≥380 mm was 13,789 (95% *CI*=12,541-15,314). The extrapolated Schnabel population estimate for LMB ≥300 mm was 34,907 (95% *CI*=31,745-38,767). The Schumacher-Eschmeyer estimate for LMB ≥380 mm was 13,638 (95% *CI*=10,917-18,166). The extrapolated Schumacher-Eschmeyer estimate for LMB ≥300 mm was 34,524 (95% *CI*=27,636-45,986) (Table 2).

For Combination 3, we collected a total of 1,282 LMB ≥380 mm by tournament angling for observation and application of marks. We again applied the mean PSD of 40 for the extrapolation. The Schnabel estimate for LMB ≥380 mm was 26,344 (95% *CI*=22,383-32,008). The extrapolated Schnabel estimate for LMB ≥300 mm was 65,860 (95% *CI*=55,958-80,021). The Schumacher-Eschmeyer estimate for LMB ≥380 mm was 27,203 (95% *CI*= 23,578-32,144). The extrapolated Schumacher-Eschmeyer estimate for LMB ≥300 mm was 68,007 (95% *CI*=58,945-80,360) (Table 2). We also calculated the densities (LMB count/ha) and weight (LMB kg/ha) and associated *CI*s (Table 2).

DISCUSSION

We suspect that previous LMB population estimates at DVL, based on only electrofishing for mark and recapture of LMB, underestimated the population size. Previous studies sampled only shallower littoral waters adjacent to the shoreline, where electrofishing is effective; electrofishing is ineffective for sampling deeper than about 3 m. Previous sampling efforts did not account for the LMB residing in deeper waters. The sampling by electrofishing likely collected only male LMB repeatedly. The male LMB make nests in shallow water during the spring and do not leave the shallow water, which will bias the results downward. Goudy (1981) observed that larger catchable bass resided in deeper water away from the shoreline and were not as susceptible to electrofishing as smaller bass. He verified his findings through creel surveys, and reported that most anglers caught their bass in water 4.5 to 6 meters deep. Department staff at DVL found that anglers caught LMB during tournaments at similar or greater depths on a consistent basis.

The previous 2006 electrofishing survey at DVL sampled half of a set of quarter-mile transects established along the perimeter of the lake using stratified random sampling. Electrofishing did not occur in deeper waters away from the littoral zone. The estimate was then adjusted to account for the areas not sampled. This and prior estimates were deemed conservative and had broad *CI*s, which made them unreliable (Table 3). A similar

Table 3.—Population estimates of largemouth bass ≥300 mm using electrofishing for marking and recapture, Diamond Valley Lake, Riverside County, California..

Year	Schnabel (95% CI)	Schumacher-Eschmeyer (95% CI)
2004	14,030 (11,328-18,424)	14,560 (9,031-37,568)
2005	11,420 (9,331-14,714)	12,235 (8,434-22,274)
2006	19,232 (14,701-27,797)	19,966 (13,493-38,371)
2008 (Combination 1 w/angling marks)	20,056 (17,576-23,351)	20,001 (16,666-25,005)

sampling method conducted on Eufaula Reservoir, Oklahoma resulted in a conservative estimate (Grinstead and Wright 1973). Since the prior estimates at DVL were conservative and unreliable, an alternative sampling method was needed. Accounting for the LMB that reside in deeper water and are unavailable to electrofishing sampling was then attempted using tournament angling in our sampling, since anglers were not limited to shallower littoral waters. Thus, they could effectively sample LMB that resided in deeper water. Goudy (1981) utilized electrofishing and trap nets to mark and recapture bass and included angler caught LMB data. He narrowed his confidence intervals by 29% by including angler catch data. To improve our methodology, we included LMB tournaments in our sampling methods. However, DVL has a 380 mm TL minimum size regulation. This limits the estimate obtained using angling to LMB ≥380 mm. In order to compare our estimates with previous population estimates of LMB ≥300 mm, we used the PSD to account for the smaller sized LMB not available in tournament angling. We believe that the mean PSD calculated from electrofishing data represented the LMB population structure well.

Compared with the most recent, prior population estimates of 2006, which sampled with only electrofishing, the added tournament data of Combination 1 in 2008 resulted in a population estimate increase of 4% over the Schnabel estimate of 2006 and an increase of 0.17% over the Schumacher-Eschmeyer estimate of 2006 (Table 3). In addition, our *CI*s in 2008 were narrowed by 56% from the Schnabel *CI* of 2006, and by 66% from the Schumacher- Eschmeyer *CI* of 2006 (Table 3).

However, the 7,242 marked LMB ≥300 mm represented 36% of the population estimate of about 20,000 LMB for Combination 1. From the estimated PSD of 40 and the estimate of about 20,000 for LMB ≥300 mm, we inferred that about 8,000 LMB (≥380 mm) would be available for harvest in angling tournaments. Therefore, given that we marked 3,541 LMB ≥380 mm, roughly half of the catchable population should have been marked and available for recapture at tournaments toward the end of tournament sampling. Nonetheless, near the end of sampling, we obtained a low recapture rate of about 10% from the tournaments.

The lower-than-expected number of recaptures from tournaments was not likely due to a poorly estimated PSD. Since we calculated the mean PSD from 4 monthly surveys, averaging would partially compensate for sampling error. This low recapture rate from tournaments indicated that Combination 1, which collected recapture data from only electrofishing, underestimated the population size. Including marked LMB from tournaments to supplement electrofishing data narrowed the confidence intervals in 2008 relative to those in 2006. However, Combination 1 still underestimated the population size, and it was undesirable as a method of population estimation. Of the three methods, Combination 1 had the narrowest *CI*s for LMB ≥300 mm, with lengths of 5,775 and 8,339 for the Schnabel *CI* and the Schumacher-Eschmeyer *CI*, respectively (Table 2). Nevertheless, as described previously, Combination 1 did not produce realistic estimates. Thus, the confidence intervals from Combination 1 might not have covered the true population size, even if they were narrower. Of the other two methods for LMB ≥300 mm, Combination 2 had the narrower *CI*s, with lengths of 7,022 and 18,350 for the Schnabel *CI* and the Schumacher-Eschmeyer *CI*, respectively (Table 2). In contrast, Combination 3 had broader *CI*s with lengths of 24,063 and 20,415 for the Schnabel *CI* and the Schumacher-Eschmeyer *CI*, respectively(Table 2).

The comparison of our estimated LMB count/ha to what is "expected" for a fishery of DVL's caliber is as follows. For Combination 1, the 95% *CI* for count/ha was approximately 9 to 13 LMB/surface-ha (Table 2). The entire density interval was lower than an expected 25 LMB/surface-ha for this relatively young reservoir. The 95% *CI* for Combination 2 was 15 to 25 LMB/per surface-ha (Table 2). Combination 3 had a 95 % *CI* of 30 to 43 LMB/ surface-ha (Table 2). A study at Mildred Lake, Wisconsin, where the dominant predatory species were smallmouth bass and LMB, estimated 27.75 bass ≥200 mm/ha (Kubisiak 2006). McInerny and Degan (1993) reported unbiased densities of LMB ≥200 mm TL ranged from 4.0 to 45.9 LMB/surface-ha in Lake Norman and Lake Wylie, North Carolina. Another study on LMB larger than 254 mm TL reported 22.5 to 125 LMB/ha in Michigan lakes (Goudy 1981). Wagner (1988) reported from 2.5 to 100 LMB/ha in smaller (<32 ha) lakes, with an average of 38.25 LMB/ha. Based on these results, the density of LMB ≥300 mm TL at DVL was expected to be about 25 bass/surface-ha. As a new LMB fishery, DVL lacked a standard. Consequently, we adopted this density for evaluation. The expected population size was also needed to determine the number of fish to mark for mark-recapture studies (Robson and Reiger 1964).

At full pool, DVL occupied 1,967.6 surface-ha, which produced an expected population of 49,190 LMB. The lake measured 1,846.4 surface-ha in early March, 2008, at the beginning of the study and fell to 1,798.8 surface-ha by early June 2008, which produced an expected population of about 46,160 LMB at the time of initial marking. This number determined the appropriate number of LMB to mark and the number of LMB to inspect for marks.

For the weight/ha, the 95% *CI*s for Combinations 1, 2, and 3 were 9.52 to 13.75 kg, 15.87 to 26.45 kg, and 31.74 to 45.49 kg per surface-ha, respectively (Table 2). Emig (1966) reported standing crops of LMB populations varied from 7.49 to 26.9 kg per surface-ha. Bennett (1971) reported the mean standing crop of 17.01 kg/surface-ha in North American lakes and reservoirs. Standing crop was likely a function of trophic status, with lower standing crops for oligotrophic waters and higher standing crops for eutrophic waters. DVL is both newly created and mesotrophic. Therefore, we expected that DVL would have a standing crop of intermediate value, about 26.44 kg/surface-ha based on the expected number and average weight of LMB ≥300 mm sampled (25 LMB at 1.058 kg each). Our results were within the range reported for North American waters (Combinations 1 and 2), but results from Combination 3 fell outside the range.

For Combination 3, the estimated LMB population was larger than expected, based on reported weight density per surface area from the literature (Emig 1966, Bennett 1971). Another study conducted on Eufaula Reservoir, Oklahoma, with only tournament recapture data yielded overly large population estimates, which were attributed to the small number of recaptures (Grinstead and Wright 1973). We examined 1,282 LMB for marks by tournament angling, which was much higher than the minimum recommended by Robson and Reiger (1964). This reduced the bias associated with a small sample size; however, there were 64% fewer LMB examined for recapture than Combination 2. For Combination 3, our estimate for weight density was larger than those reported in the literature and there were the fewest LMB sampled for recapture. Therefore, we question the population estimates generated by Combination 3.

Electrofishing was limited to areas near the shoreline <3 m deep and this likely affected the population estimates. However, electrofishing is the predominant method used by fishery managers because it can yield large numbers of bass for generating population estimates. In contrast, anglers can fish anywhere in the water column and they can distribute themselves throughout the lake to catch bass. Thus, anglers could capture LMB not vulnerable to electrofishing. Tournament anglers may not distribute themselves in a truly random manner, since they will attempt to catch fish where they are, or have been, successful. However, they were able to fish for LMB at locations deeper than are accessible to electrofishing. They were also required to release LMB alive and in good condition in order to avoid tournament penalties. Thus, they were a valuable resource for sampling.

A limitation of tournament angling was that anglers had catch limits, which could yield fewer LMB kept for use in generating population estimates. We discounted angler sampling bias due to fish size, since all tournament anglers had to abide by the 380 mm minimum size restriction. In addition, all bass ≥380 mm TL were within the size range for our study. Possible drawbacks from including tournament caught fish were: high grading or culling, a limit on the maximum number of LMB that could be retained, and potential release of marked or unmarked LMB. There was likely some "high grading" that occurred during the tournaments, but not all anglers were able to catch their limit. All fish that met the legal size criterion were kept and brought to the weigh-in by these anglers. Selecting for larger fish had little effect, since all fish ≥380 mm TL had equal value in our study.

Tournament participants were limited in the number of LMB they could retain. Thus, the sample size was a function of angler participation in each tournament. Since tournaments provided easy, cost-effective opportunities to collect LMB, we accepted any bias that might have occurred, just as we accepted the bias in electrofishing. By combining multiple sampling methods, we tried to partially offset any biases that existed. When we estimated population size with both the electrofishing and tournament angling, each technique compensated for the deficiencies of the other. We believe that this resulted in a more accurate estimate and narrower *CI*s.

Plausibly, Combination 3 properly estimated the population of LMB when compared with findings in the literature. However, the elimination of electrofishing from the recapture data reduced the overall sample size. Larger sample sizes would reflect the characteristics of a population more accurately (Brown and Austen 1996). The smaller sample size of Combination 3 reduced our confidence in its estimates. Our study showed that Combination 2, which utilized electrofishing and tournament angling for both mark and recapture, along with the PSD expansion, gave the most precise estimates for LMB at DVL. The inclusion of angler tournament data increased the sample size and increased the area sampled by including locations farther from shore away from the littoral zone (Table 4).

Table 4.—Summary of advantages and disadvantages of the sampling and estimation methods for the largemouth bass population at Diamond Valley Lake, Riverside County, California.

Method	Advantages	Disadvantages or Problems
Pre 2008 surveys (electrofishing only)	• Efficient • Widely accepted sampling method • Collects statistically valid numbers	• Highly conservative estimates with broad confidence intervals • Biased sampling in only littoral water misses fish in deeper water
Combination 1	• Efficient • Increases sample size for electrofishing • Marking additional angler caught bass • Decreased CI range	• Electrofishing recapture underestimates population • Fish in deeper water inaccessible to recapture
Combination 2	• Efficient • Increased sample size/multiple recapture methods • Marked angler & electrofishing caught fish available for recapture • Decreased CI range • Able to sample littoral & non-littoral water for recapture • Decreased CI range • Estimates within number/area & kg/area reported in literature • Most LMB checked for recapture	• Dependent on fishing tournament participation • Possible high grading of LMB • Estimate dependent upon accurate PSD value, if used
Combination 3	• Efficient • Marked angler & electrofishing caught bass available for recapture • Cost effective recapture method • Least capital involved in sampling for Resource Agency	• Dependent on fishing tournament participation • Possible high grading of LMB • Estimates of number/area & kg/area larger than reported in literature. • Fewer LMB checked for recapture • Limitation of bag limit which could reduce number available for marking or being checked • Large CI range

Using the modified PSD is not a requirement for sampling. However, with the minimum size of 380 mm for tournament angling at DVL, the modified PSD allowed us to include data from tournaments in our estimates. We increased the precision of the population estimate of LMB ≥ 300 mm, since we obtained a narrower *CI*. Using the length of the *CI*s, the expected number of LMB/ha, and the weight of LMB/ha reported in the literature as criteria, Combination 2 produced the most plausible estimates (Table 4). We suggest that the mark-recapture method utilizing both electrofishing and tournament angling may be useful at other lakes where fishing tournaments occur.

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Literature Cited

Anderson, R. O. 1976. Management of small warm water impoundments. Fisheries 1(6):5-7, 26-28.

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. Second edition. American Fisheries Society, Bethesda, Maryland, USA.

Bennett, G. W. 1971. Management of lakes and ponds. Second edition. Van Nostrand Reinhold Company, New York, New York, USA.

Brown, M. L., and D. J. Austen. 1996. Data management and statistical techniques. Pages 17-59 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques. Second edition. American Fisheries Society, Bethesda, Maryland, USA.

Buynak, G. L., and B. Mitchell. 1993. Electrofishing catch per effort as a predictor of largemouth bass abundance and angler catch in Taylorsville Lake, Kentucky. North American Journal of Fisheries Management 13:630-634.

Davis, C. L., L. M. Carl, and D. O. Evans. 1997. Use of a remotely operated vehicle to study habitat and population density of juvenile lake trout. Transactions of the American Fisheries Society 126:871-875.

Emig, J. W. 1966. Largemouth bass. Pages 332-353 *in* A. Calhoun, editor. Inland Fisheries Management. California Department of Fish and Game, Sacramento, USA.

Farman, R. S., L. A. Nielsen, and M. D. Norman. 1982. Estimating largemouth bass abundance using creel census and tournament data in the fishing success method. North American Journal of Fisheries Management 2:249-256.

Fleiss, J. L. 1986. The design and analysis of clinical experiments. John Wiley and Sons, New York, New York, USA.

Gablehouse, D. W., and D.W. Willis. 1986. Biases and utility of angler catch data for assessing size structure and density of largemouth bass. North American Journal of Fisheries Management 6:481-489.

Goudy, G. W. 1981. The exploitation, harvest and abundance of largemouth bass populations in three southeastern Michigan Lakes. Fisheries Research Report 1896. Michigan Department of Natural Resources, Lansing, USA.

Grinstead, B .G., and G. L. Wright 1973. Estimation of black bass, *Micropterus.* spp., population in Eufaula Reservoir, Oklahoma with discussion of techniques. Proceedings of the Oklahoma Academy of Science 53:48-52.

Guy, C. S., H .L. Blankenship, and L.A. Nielsen. 1996. Tagging and marking. Pages 355-358 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques. Second edition. American Fisheries Society, Bethesda, Maryland, USA.

Hall, T. J. 1986. Electrofishing catch per hour as an indicator of largemouth bas density in Ohio impoundments. North American Journal of Fisheries Management 6:397-400.

Hickman, G. D., and T. A. Mcdonough. 1996. Assessing the reservoir fish assemblage index: a potential measure of reservoir quality. American Fisheries Society Symposium 16:85-97.

Hightower, J. E., and R. J. Gilbert. 1984. Using the Jolly-Seber model to estimate population size, mortality, and recruitment for a reservoir fish population. Transactions of the American Fisheries Society 115:633-641.

Holbrook II, J. A. 1975. Bass fishing tournaments. Pages 408-415 *in* R.H. Stroud and H. Clepper, editors. Black bass biology and management. Sport Fishing Institute, Washington, DC, USA.

Isely, J. J., and J. R. Tomasso. 1998. Estimating fish abundance in a large reservoir by mark-recapture. North American Journal of Fisheries Management 18:269-273.

Kershner, M. W., and E. A. Marschall. 1998. Allocating sampling effort to equalize precision of electrofishing catch per unit effort. North American Journal of Fisheries Management 18:822-831.

Krebs, C. J. 1999. Ecological methodology. Second edition. Addison Wesley Longman Educational Publishers, Menlo Park, California, USA.

Kubisiak, J. 2006. Comprehensive fisheries survey of Mildred Lake, Oneida County Wisconsin during 2005. Wisconsin Department of Natural Resources, Madison, USA.

Maceina, M. J., W. B. Wrenn, and D. R. Lowery. 1995. Estimating harvestable largemouth bass abundance in a reservoir with an electrofishing catch depletion technique. North American Journal of Fisheries Management 15:103-110.

Mcinerny, M. C., and T. K. Cross. 1999. Comparison of three mark-recapture sampling designs for estimating population size of largemouth bass in Minnesota lakes. North American Journal of Fisheries Management 19:758-764.

Mcinery, M. C., and D. J. Degan. 1993. Electrofishing catch rates as an index of largemouth bass population density in two reservoirs. North American Journal of Fisheries Management 13:223-228.

Meador, M. R., T. F. Cuffney, and M. E. Gurtz. 1993. Methods for sampling fish communities as part of the national water quality assessment program. U.S. Geological Survey Paper OFR03-04. U.S. Geological Survey, Raleigh, North Carolina, USA.

Miranda, L. E., W. D. Hubbard, S. Sangare, and T. Holman. 1996. Optimizing electrofishing sample duration for estimating relative abundance of largemouth bass in reservoirs. North American Journal of Fisheries Management 16:324-331.

Robson, D. S., and H.A. Reiger. 1964. Sample size in Petersen mark-recapture experiments.

Transactions of the American Fisheries Society 93:215-226.

SEBER, G. A. F. 1982. The estimation of animal abundance and related parameters. Second edition. The Blackburn Press, Caldwell, New Jersey, USA.

WAGNER, W. C. 1988. Largemouth bass in Michigan's Upper Peninsula lakes. Fisheries Research Report 1945. Michigan Department of Natural Resources, Ann Arbor, USA.

WEAVER, M. J., J. J. MAGNUSON, AND M. K. CLAYTON. 1993. Analyses for differentiating littoral fish assemblages with catch data from multiple sampling gears. Transactions of the American Fisheries Society 122:1111-1119.

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