ASSESSMENT OF STRUCTURE OF LARGEMOUTH BASS STOCKS BY SEQUENTIAL SAMPLING

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Abstract: We examined the accuracy and application of sequential sampling to determine structure of fish stocks, using electrofishing data for largemouth bass (*Micropterus salmoides*) as an example. Structure of the stock was categorized with the index of Proportional Stock Density (PSD), which is the percentage of quality-size fish in the stock. Minimum stock and quality sizes for largemouth bass were defined as 20 and 30 cm, respectively. Sequential sampling is based on data evaluation during collection. An average reduction in sample size of 42% is realized when populations are sampled sequentially rather than continuing to an endpoint (n=100 fish), because sampling ends as soon as a decision is reached. Fish stocks can be categorized based on PSD, i.e. 0 to 39%, 40 to 60%, or 61 to 100%, or a point estimate of PSD with confidence limits can be calculated. The size of the sample needed to reach a conclusion about stock structure is influenced most by the true PSD of the stock and to a lesser extent by the significance level (α) chosen for the estimate.

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Sampling fish populations and communities is essential for sound management of recreational fisheries. A variety of approaches have been used to sample warmwater, coolwater, and coldwater species including direct and remote sensing, removal of water, anesthetics and poisons, hook-and-line fishing, capture by hand, concussion, electrofishing, active netting (seining, trawling), passive netting (gill and trammel nets), and impounding devices (hoop, fyke, and trap nets) (Lagler 1971). Each method has strengths and weaknesses in terms of efficiency and selectivity, given the variety of conditions a biologist can encounter.

Samples of fish are collected for a variety of reasons. A typical situation involves sampling to determine the density and length-frequency distribution of fish stocks. Lengths and weights of fish are recorded and scales are collected to calculate age, growth, and condition. Tagging experiments and food habits studies also require collecting fish.

Length-frequency distributions are easily constructed regardless of the sampling technique, and can be adjusted subjectively to account for gear selectivity. We concur with Anderson (1976) that management of recreational fisheries might best be achieved by analyzing length-frequency data, given the limited time and money available for any particular body of water. Relative numbers of fish are especially important because a variety of sizes of fish are needed to sustain a balanced population or community.

Proportional Stock Density (PSD) is a useful index of fish stock structure (relative number of various-size fish) that can be calculated with length frequency data for any

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species (Anderson 1976). The purpose is to determine the structure of fish stocks, which we define as the harvestable segment of a population. The PSD of a particular species is the result of growth, recruitment, and mortality and the structure and balance of the fish community to which it belongs.

A PSD value is calculated by dividing the number of quality-size fish by the number of fish in the stock and expressing the result as a percentage for a particular species (Anderson 1976). Stock and quality sizes are defined as about 25 and 40% of the world-record length for a species (Anderson and Weithman 1978). For example, stock and quality sizes for largemouth bass are 20 and 30 cm, respectively.

Specific management objectives can be defined in terms of PSD. A target range of PSD that defines a population as balanced depends on the species of fish and management strategies. As a rule, a desirable range of PSD for a predator is 30 to 70%, and for prey 20 to 50%. A target range of 40 to 60% for largemouth bass was recommended by Reynolds and Babb (1978) when the management objective is to provide good bass fishing from a water containing mainly largemouth bass and bluegills (*Lepomis macrochirus*). Weithman (1978) recommended a target range of 50 to 70% for largemouth bass in large impoundments with abundant prey.

Electrofishing is one of the most efficient methods for sampling centrarchids. However, the most important assumption in estimating PSD is equal vulnerability of stock-and quality-size fish. Electrofishing can be size-selective due to fish distribution and other factors (Simpson 1978). Spring and fall offer the best opportunity to acquire a representative sample of largemouth bass. Ziebell and McClain (1977) observed that bass of all sizes moved shoreward in the spring in a lake in Arizona. We believe this observation is widely applicable for estimating PSD. Therefore, collection during the spring should provide the most representative samples, although bass populations in small Missouri impoundments can also be satisfactorily sampled in the fall (Reynolds and Simpson 1978).

A frequent concern of biologists is an appropriate sample size on which to base management recommendations. Samples containing 8 to 12 stock-size largemouth bass were adequate to estimate the true PSD$\pm$10% in ponds studied by the Central States Pond Management Work Group (CSPMWG) (Reynolds and Simpson 1978). Estimates of largemouth bass PSD were made from electrofishing samples collected during 1 lap of the shoreline of small impoundments, and compared to the true PSD which was calculated after total census with rotenone. We believe the sample of only 8 to 12 fish was satisfactory for the CSPMWG ponds primarily because most of the populations were not balanced; i.e. PSD was less than 30% or greater than 70%. Even though a small sample may be a practical goal for sampling many ponds, it may be an underestimate of the sample size needed to estimate largemouth bass PSD$\pm$10% when the true PSD is between 30 and 70%.

Sequential sampling, which involves evaluation of the data as they are collected, is an approach to minimize the sample size needed for categorizing stock structure based on PSD. Sampling is terminated as soon as collections permit a stock to be classified as below, above, or within a target range of PSD. This method can be used when evaluation of the structure of the fish stock is the primary objective. Sequential sampling should permit about a 50% reduction in sample size (Wald 1957). The purpose of this paper is to discuss the application and accuracy of sequential sampling for determining the stock structure of any species of fish. We used, as an example, the index of Proportional Stock Density to determine the structure of largemouth bass stocks sampled by electrofishing.

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METHODS

The binomial distribution is the basis for estimating PSD, since stock-size fish are either (1) less than quality size or (2) of quality size. If n is the total number of stock-size fish in the sample, and v is the number of quality-size fish in the sample, then estimated PSD in decimal form (p) is equal to v/n.

In sequential sampling each fish is categorized as it is collected. The choices for largemouth bass are less than 20 cm (discarded), 20 to 30 cm (A), or over 30 cm (B). Two totals are maintained -- the number of stock-size fish (n, A + B) and the number of quality-size fish (v, B). The cumulative numbers, n and v, are constantly compared. Sampling continues until a population can be classified according to stock structure (PSD).

We propose the sequential probability ratio test (Wald 1957, p. 90) to determine a lower limit, upper limit, and middle range for a 3-celled model of stock structure based on PSD. The numbers of quality-size bass required in samples of stock-size bass can be calculated prior to sampling, once p_o, p_1, α, and β are specified, where p_o is an approximate lower limit for a target range of PSD, p_1 is an approximate upper limit for a target range of PSD, α is the probability of a type I error, and β is the probability of a type II error.

Three categories of population structure result from testing 2 sets of hypotheses simultaneously: (1) $H_0{:}p_o{=}0.35$ and $H_1{:}p_1{=}0.50$; and (2) $H_0{:}p_0{=}0.50$ and $H_1{:}p_1{=}0.65$. The PSD is either less than 35% or greater than 50% based on test 1; and the PSD is either less than 50% or greater than 65% on test 2. If H_0 is accepted in test 1, the conclusion is that the PSD is less than 40%. If H_1 is accepted in test 2, the conclusion is that the PSD is greater than 60%. If H_1 is accepted in test 1 and H_0 is accepted in test 2, the population has a PSD that is neither less than 35% nor greater than 65%. Therefore, we are nearly 90% confident that the PSD is between 40 and 60%. The exact level of confidence is unknown when 2 tests of hypotheses are involved in reaching a decision with the sequential probability ratio test.

The null hypothesis (H_o) is accepted in the test of hypotheses if the number of quality-size bass (v) in the sample is equal to a_n, where

$$a_n = \frac{\log \frac{\beta}{1-\alpha}}{\log \frac{p_1}{p_o} - \log \frac{1-p_1}{1-p_o}} + n \frac{\log \frac{1-p_o}{1-p_1}}{\log \frac{p_1}{p_o} - \log \frac{1-p_1}{1-p_o}}$$

the alternate hypothesis (H_1) is accepted if the number of quality-size bass (v) in the sample is equal to r_n, where

$$r_n = \frac{\log \frac{1-\beta}{\alpha}}{\log \frac{p_1}{p_o} - \log \frac{1-p_1}{1-p_o}} + n \frac{\log \frac{1-p_o}{1-p_1}}{\log \frac{p_1}{p_o} - \log \frac{1-p_1}{1-p_o}}$$

The middle range of 40 to 60% is accepted if v exceeds r_n in test 1 and is less than a_n in test 2.

We chose $p_o = 0.35$ rather than 0.39 in test 1 and $p_1 = 0.65$ rather than 0.61 in test 2, because this provides the best test for determining stock structure in terms of the PSD categories of 0 to 39%, 40 to 60%, and 61 to 100%. When the true PSD is less than 35% or greater than 65%, the probability that the stock will be classified as less than 35% or greater than 65%, respectively, approaches unity. Likewise, if the true PSD is close to

50%, the probability that the stock will be classified between 35 and 65% also approaches unity.

When the true PSD is 35 to 40% or 60 to 65%, it is difficult to categorize the stock. If a decision is reached, there is a much greater chance that the PSD of the stock will be classified as less than 35% rather than greater than 50%, or greater than 65% rather than less than 50%. This is an advantage because the boundaries of interest are actually 40 and 60%. The result is that when the PSD of the stock is classified as less than 35% or greater than 65%, we are at least 90% certain ($\alpha = \beta = 0.10$) that the true PSD is less than 40% or greater than 60%, respectively.

We developed 2 models for assessing stock structure of any species of fish, assuming $\alpha = \beta = 0.10$: (1) a 3-celled model with PSD categories of 0 to 39%, 40 to 60%, and 61 to 100%; and (2) a 5-celled model with PSD categories of 0 to 19%, 20 to 39%, 40 to 60%, 61 to 80%, and 81 to 100%. Numbers of quality-size bass required for stock categorization are presented for various sample sizes of stock-size fish (Tables 1, 2).

The sample size of stock-size fish need not exceed 100. Sampling should be terminated regardless of whether a decision has been reached, because the required sample size cannot practically be collected when the true PSD occurs where categories of structure overlap. Instead, a point estimate of PSD and appropriate confidence limits can be estimated as

$$\hat{p} \pm 1.645 \left\{ \frac{(\hat{p})(\hat{q})}{n - 1} \left(\frac{N - n}{N} \right) \right\}^{\frac{1}{2}},$$

where p and n are as previously defined, $q = 1 - p$, and N is the total number of stock-size fish in the water being sampled. Since N is unknown it can be estimated, or the term $\frac{N-n}{N}$ can be ignored. The term $\frac{N-n}{N}$ is important in reducing the confidence limits only when a substantial percentage of stock-size fish in a body of water is sampled.

APPLICATION OF A SEQUENTIAL SAMPLING PLAN

Hypothetical example

We set up 2 hypothetical examples of sequential sampling for largemouth bass to illustrate the approach. The 3-celled model with PSD categories of 0 to 39%, 40 to 60%, and 61 to 100% was used to determine stock structure. As each fish was captured, cumulative totals of the number of stock-size (n) and quality-size (v) bass were maintained. Sequential sampling ended as soon as the number of quality-size bass was less than or equal to the lower limit, greater than or equal to the upper limit, or within the target range of PSD (40 to 60%).

After 30 bass were sampled in the first example (A), only 9 were of quality size. We stopped sampling, knowing that it was at least 90% certain that the true PSD was less than 40% (Fig. 1). In the second example (B), sampling proceeded to $n = 70$ stock-size bass, of which 34 were of quality size. At this point we were nearly 90% confident that the true PSD was between 40 and 60% (Fig. 1).

Accuracy of sequential sampling

We used electrofishing data collected in April and May 1977 at Table Rock Lake, a 17,440-ha impoundment in southwestern Missouri, to test the accuracy of a sequential sampling plan. Samples of largemouth bass ranged from 101 to 333 fish in 20 electrofishing trials. Bass lengths were recorded as they were collected. The PSD in each sample was assumed to represent the true PSD of the stock. We were able to reach a conclusion about population structure with 90% confidence before the endpoint ($n = 100$) was reached in 18 of the 20 trials (Table 3). The average reduction in sample size was 42%

TABLE 1. Number of quality-size largemouth bass (≥ 30 cm) needed in a sample of stock-size bass (≥ 20 cm) to determine whether a population is below, above, or within the target range of 40 to 60% PSD for a given sample size (n) ($\alpha = \beta = 0.10$).

Stock-size fish sampled (n)	PSD (%)		
	0 to 39	40 to 60	61 to 100
10	0	———	10
15	2	———	13
20	4	———	16
25	7	———	18
30	9	———	21
35	11	———	24
40	13	———	27
45	15	———	30
50	17	25	33
55	19	27-28	36
60	21	29-31	39
65	23	32-33	42
70	26	34-36	44
75	28	36-39	47
80	30	38-42	50
85	32	40-45	53
90	34	42-48	56
95	36	44-51	59
100	38	46-54	62

for conclusions reached by sampling sequentially, rather than by considering each trial as an endpoint sample (n = 100). Of 20 decisions for estimates below, above, or within the target range of PSD, 17 (85%) were accurate when compared with the true PSD. Three errors were made by accepting the PSD as less than 40% when the true PSD was actually 44%, and twice by accepting the PSD as greater than 60% when the true PSD was exactly 60% (Table 3). All 3 errors were relatively minor.

DISCUSSION

Sequential sampling is an effective approach for estimating the structure (PSD) of fish stocks. The stocks can be categorized according to target ranges of structure, or the value of PSD can be presented as a point estimate with confidence limits.

Sample size required to categorize a stock based on PSD was influenced most by the true PSD of the fish population. A minimum sample size of 48 stock-size fish, of which 24 must be quality-size, is needed to categorize a PSD between 40 and 60% (balanced population). The average sample size required to reach a conclusion is 70 fish for a balanced population, and 35 for a population that is not balanced in the 3-celled model (PSD less than 40%, PSD from 40 to 60%, or PSD greater than 60%). The expected sample size required to determine stock structure is 20 fish when the true PSD is 20 or 80%, and 30 fish when the true PSD is 30 or 70%. The expected sample size increases as

TABLE 2. Number of quality-size fish required in a sample of stock-size fish (n) to establish the category of structure to which a population belongs for a given sample size (n) ($\alpha = \beta = 0.10$). For example, in a sample of 85 fish, if the number of quality-size fish is 0 to 16, PSD is <20%; if 22 to 29, PSD is 20-39%; if 40 to 45, PSD is 40-60%; if 56 to 63, PSD is 61-80%; and if 69 to 85, PSD is >80%.

Stock-size fish sampled	PSD (%)				
(n)	0 to 19	20 to 39	40 to 60	61 to 80	81 to 100
15	0	---	---	---	15
20	1	---	---	---	19
25	2	---	---	---	23
30	4	---	---	---	26
35	5	---	---	---	30
40	6	12	---	28	34
45	7	13-14	---	31-32	38
50	8	14-16	25	34-36	42
55	9	15-18	27-28	37-40	46
60	10	16-20	29-31	40-44	50
65	11	17-22	32-33	43-48	54
70	12	18-24	34-36	46-52	58
75	13	19-26	36-39	49-56	62
80	15	20-28	38-42	52-60	65
85	16	22-29	40-45	56-63	69
90	17	23-31	42-48	59-67	73
95	18	24-33	44-51	62-71	77
100	19	25-35	46-54	65-75	81

PSD approaches the range of 35 to 65% because of the difficulty in detecting whether the PSD is below, above, or within the target range.

Confidence limits for PSD estimates can be calculated after sampling is completed. We recommend expressing the PSD as a point estimate with confidence limits for endpoint samples (n = 100) or when the estimate is near a boundary between two categories of stock structure. The confidence limits for PSD estimates depend on the number of stock-size fish (n) in the sample, level of confidence chosen for the estimates, and the true PSD of the fish population (Fig. 2). Confidence limits around the estimate of PSD decrease as the sample size (n) increases, and the specified significance level is changed from 0.10 to 0.20, for example. For a given sample size at a chosen level of confidence, the confidence limits are largest for populations with a PSD of 35 to 65% and decrease symmetrically as PSD approaches 0 or 100%.

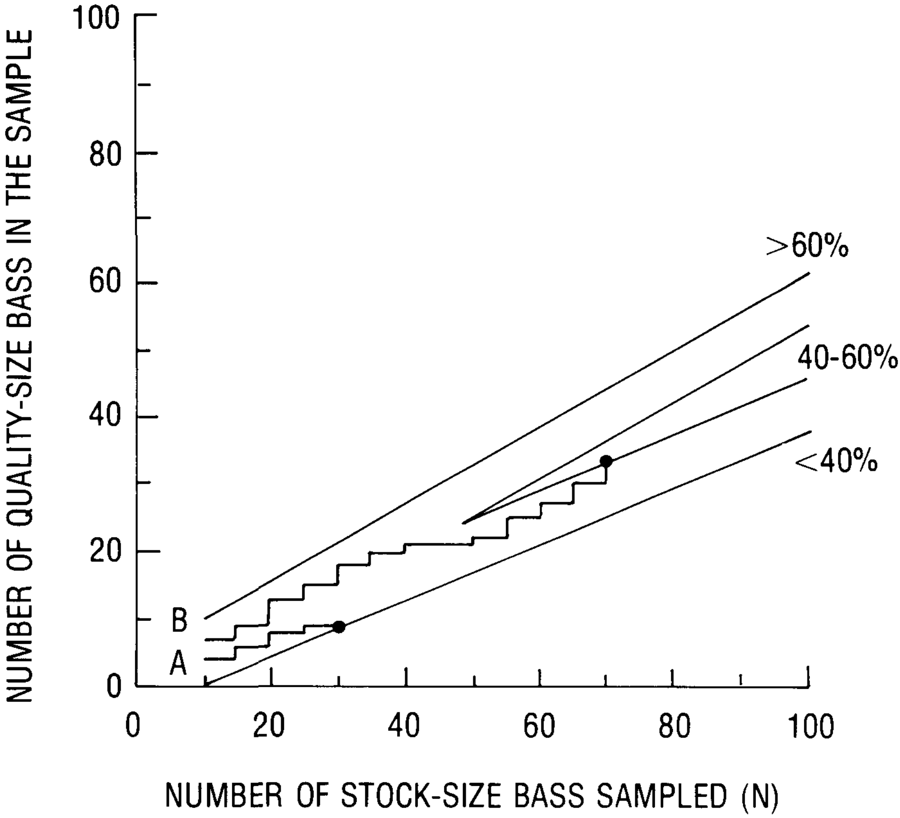

Fig. 1. Upper and lower limits, and middle range for estimating, at the 90% level of confidence, the category of structure in which a fish stock belongs. The number of quality-size largemouth bass (≥30 cm) in this sample is plotted sequentially as each stock-size bass (≥20 cm) is captured. When a boundary is penetrated a decision is reached. Population (A) is shown to have a PSD below 40% after 30 fish have been collected, and population (B) a PSD between 40 and 60% after 70 fish have been collected.

TABLE 3. Estimated accuracy of sequential samples collected by electrofishing, when the total sample was used to represent the true PSD of the largemouth bass population in Table Rock Lake, Missouri. The population in each trial was classified on the basis of PSD as: less than 40% (B); 40 to 60% (W); and greater than 60% (A). Errors in conclusions are marked by an asterisk.

Date	Total sample size	True PSD (%)	Sequential sample size	Conclusion
4/11	212	55	48	W
4/12	333	42	57	W
4/12	120	43	58	W
4/13	143	49	60	W
4/20	161	68	14	A
4/21	101	50	59	W
4/26	139	60	52	A*
4/27	254	61	57	A
5/3	102	63	23	A
5/3	109	60	49	A*
5/4	257	56	79	W
5/10	185	51	94	W
5/11	204	50	75	W
5/12	232	53	73	W
5/17	123	57	49	W
5/17	101	50	57	W
5/17	129	57	100	W
5/18	167	44	37	B*
5/19	296	61	15	A
5/24	195	56	100	W

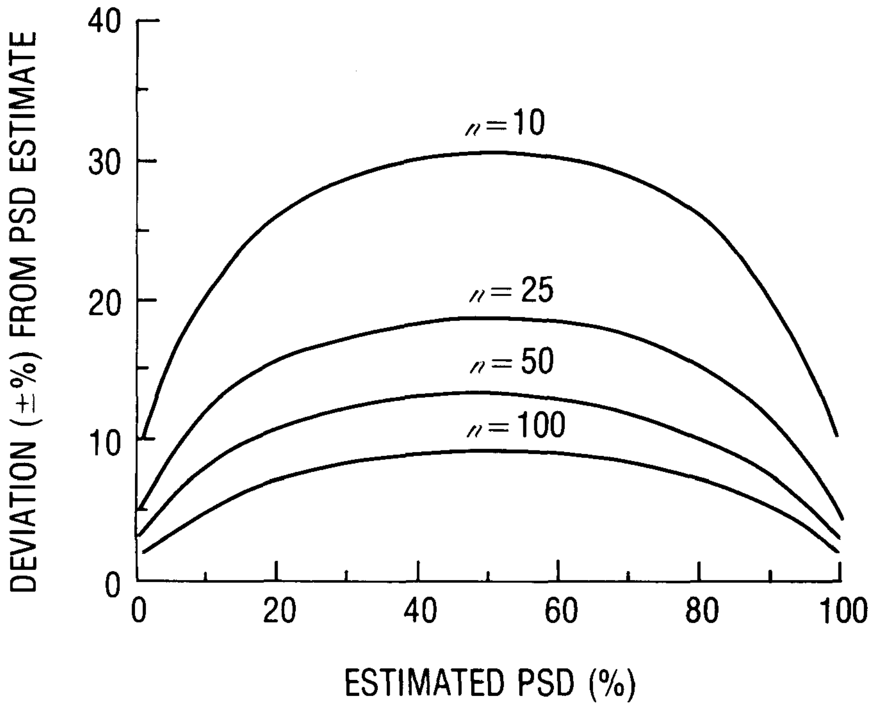

Fig. 2. Deviation (±%) from a PSD point estimate, given a significance level of $\alpha = 0.10$ and an estimate of the true PSD. A family of curves is developed for various sample sizes of fish (*n*).

The smaller samples required to detect poor stock structure, such as a PSD less than 30% or greater than 70% for largemouth bass, work to the advantage of the biologist. Correct assessment of stock structure is easiest when the PSD is extremely low or high, or right in the middle of the target range of 40 to 60%. In providing the basis for a management decision, sequential sampling allows detection of problems with a minimum of effort.

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