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Zane Scheftel

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ZANE SCHEFTEL
Minnesota Department of Conservation, St. Paul

ZOOLOGY

Statistical Sampling Techniques As Applied to Fish Populations

The estimation of fish populations in a given body of water is of major concern to fishery research workers. In many instances the evaluation of management techniques rests upon valid and reliable population estimates. It is often the case that the worker in the field cannot obtain independent evidence of the validity of his estimates but any sound experimental design should contain within itself a good estimate of its reliability. The worker can get little help however from experimental designs useful in other biological investigations because most often he can not control randomness and independence of the observations as necessary to such designs. The difficulty arises, of course, in the impossibility of defining a sampling area of either known or constant size. Fishery workers have therefore turned to indirect methods which depend ultimately upon the introduction of a known number of identifiable fish into a closed body of water and subsequently capturing a sample of fish (both marked and unmarked) from this closed system. An estimate of the total population is taken from the relationship between the number of fish captured, the number of these which are marked, and the known number of marked fish in the body of water. With this basic idea, fishery research workers have developed two lines of approach, the relative merits of which are discussed below.

THE NATURE OF THE PROBLEM

It might be well to discuss here some aspects of fish populations which must be taken into account in designing a procedure useful in the estimation of fish populations.

1. *Individuals of the population are not randomly distributed.* Fish will tend to distribute themselves so that they are in greater abundance in habitat more favorable to their life processes. Further-

more the criteria of favorable habitat varies through time so that fish populations are not static but will redistribute themselves in relation to factors which constitute favorable habitat at the time. Fish in and about a place of favorable habitat may tend to arrange themselves in rather compact schools. Unfortunately, the pertinent habitat conditions are largely unknown or do not lend themselves to evaluation by the investigator and so he will be unable in general to design his estimating procedure to take them into account.

2. *Individuals of the population may tend to have a home ground.* A captured fish will tend to return to the place of capture after release. Hasler found in working with white bass in Lake Mendota that these fish exhibited a marked tendency to return to the ground (spawning bed) from which they were captured. (Arthur D. Hasler, unpublished paper, Mid-west Wildlife Conference-1957.) It follows that fish captured and released at the point of capture will tend to remain in the area of their home ground.

3. *The catchability of fish vary through time.* The sampling devices available to the fishery investigator are for the most part entrapment gear which depend for their operation upon the activity level of the fish for their action. There is good reason to believe that the activity of fish is a function of water temperature and other factors which depend upon the seasonal climatic variation. In north temperate latitudes they are more active during the spring and fall than at other times of the year.

THE ESTIMATION OF FISH POPULATIONS

Two different methods of fish population estimation have been developed by fishery research workers which depend upon the introduction of a known number of marked fish into the population. A method introduced by Petersen (1896) is very simple in concept. A known number of marked fish are introduced into a body of water and then a sample of fish are captured from that body of water. The estimation is given by:

$N = nX/x$ Where N=Population estimate

n=Number in sample

With the variance: X=Known number of marked fish

$$\frac{x(1-x)}{n}$$ x=Captured marked fish

A second approach to the problem (Schnabel, 1938) is somewhat more complex in its operation and uses the method of least squares. Here the sampling effort is broken up in such a way that the fish are captured in successive sampling and each time the captured fish are all marked and returned to the population. Fish which were marked in a prior sample and then recaptured are not again marked.

The number of marked fish then which are available to each unit of sampling effort is known.

The estimation equation is given by:

$$N = \Sigma n_i X_i / \Sigma x_i$$

With a variance:

$$(m\text{-}1)\, s^2 = \Sigma \frac{(x_i)^2}{n_i} - \frac{\left[\dfrac{\Sigma\, x_i X_i}{n_i}\right]^2}{(\Sigma X_i)^2}$$

It should be noted that the above equations are the result of standard regression theory. Maximum likelihood theory would suggest that the various n_i and x_i be weighed as the reciprocal of the variance, but general practice seems to be that the formula is used as it stands. Schnable (1938), Delury (1951) and others have shown that the estimating equation yields an unbiased estimate subject to the restriction of course that the sampling is random.

EVALUATION OF THE TECHNIQUES

It might appear that the second approach is superior because the precision of the estimate is dependent upon the number of degrees of freedom available to the estimate rather than upon the total number of fish caught and in many cases it might be a difficult matter to obtain a large number of fish. But it can be easily demonstrated if the characteristics of fish populations are as given in the preceding section that the Schnable method can lead to population estimates which are very seriously in error.

Consider the design of a Schnable type experiment: a closed body of water is fished with a number of entrapment devices which are positioned about the lake in a random fashion. The unit of effort which can be of any duration is usually 24 hours. That is, the nets are lifted once every 24 hours, the total number of fish found in the nets (both marked and unmarked) are recorded, the unmarked fish are marked, and all fish are returned to the lake. Good practice indicates that an attempt at randomization be made by either releasing the fish at random locations or by relocating the nets in a random fashion. But even if these safeguards are taken, the population estimate can be seriously in error because if fish tend to return to their home ground, the ratio of marked to unmarked fish in the various habitat clusters which have been fished will not be as $\frac{X}{N}$, the true ratio in the population, but will always be greater to the extent of this tendency. Therefore if the nets are moved to the new unexploited territory, $\frac{\Sigma x_i}{\Sigma n_i}$ will be smaller than $\frac{X}{N}$ and the estimate will tend to be too high. Conversely, if the nets are left stationary $\frac{\Sigma x_i}{\Sigma n_i}$ will be larger than $\frac{X}{N}$ and the estimate will tend to be too low.

The Petersen method under the same non-random conditions supposed in the preceding paragraph may be considered. Non-random conditions mean that the fish originally marked have not distributed themselves in the same manner as the unmarked population. With this condition it becomes apparent that the equation given for the variance of the estimate becomes inappropriate. However, if netting locations are chosen at random the estimate is still unbiased. The Petersen method lends itself to intensive sampling effort since newly marked fish need not be continuously introduced into the population. The condition of independence can thus be approximately met. If the fish can be considered to be stationary during the netting effort and if the sampling locations are drawn at random, the ratio of marked to unmarked fish found in a net can be considered an independent variable from an infinite population of such variables. Then, if this ratio is weighted by n_i (the total number of fish found in the net), an unbiased estimate of $\frac{x}{n}$ and its variance can be obtained.

A good estimate of the variance might then be given by the familiar formula for random sampling suitably overhauled with x and n as random variables.

Such a formula might be.

$$V\left(\frac{x}{m}\right) = \frac{n_i 2 \left(x_i - \frac{x}{n} \right) 2}{\bar{n}^2 m \left(m\text{-}1 \right)}$$

The x_i and n_i are the individual observations in the m nets and x and n represent the sum of these observations and $\bar{n}$ is the average number of fish per net.

As may be seen, it is not possible with the methods commonly used in fishery research to obtain a random sample of individual fish, but sampling points within a body of water can certainly be selected at random. The Peterson method incorporating a sound estimate of variance is thus perhaps a more profitable approach to the problem of estimating fish populations.

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