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CREEL CENSUS METHODS FOR ESTIMATING THE SIZE OF FISH POPULATIONS

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Abstract

An analysis of the yield of trout per unit of fishing effort at Furnace Brook, Vermont, shows how modern statistical methods can be utilized to determine the significance of changes in the relative abundance of animal populations. The data cover the five years from 1936 to 1940, and the analysis of covariance employed shows that there was a significant decrease in the catch per unit of effort in 1939 which was attributed to the effects of severe floods caused by the hurricane in September of the previous year. This method of analysis, although useful for supplying a measure of relative abundance, fails to provide an estimate of the actual stock on hand.

Dr. D. B. DeLury has recently developed a new method for estimating the size of animal populations from data on catch and effort. His equation is as follows:

$$\log C(t) = \log (k N_o) - kE(t) \qquad \ldots\ldots\ldots\ldots (1)$$

where, $C(t)$ is the catch per unit of effort at time $\underline{t}$.

$E(t)$ is the total effort expended during the time interval $(0,t)$.

N_o is the number of individuals at $t = 0$,

and, k is a constant describing the rate at which the catch per unit of effort decreases as the effort accumulates.

The writer has developed a similar method, which would be much easier for biologists to use, based on the following formula:

$$C(t) = a - bK(t) \qquad \ldots\ldots\ldots\ldots \qquad (2)$$

where, $K(t)$ is the total catch accumulated during the time interval $(0,t)$.

a is a constant supplying the value of C when $K = 0$, $N_o = \frac{a}{b}$

b is a constant describing the rate at which the catch per unit of effort decreases as the catch accumulates, and $C(t)$ has the same meaning as in (1).

Equation (2) involves the assumptions: that there is no immigration, emigration, or recruitment in the population under investigation; that the individuals caught are selected in a representative manner; that the relation between $C(t)$ and $K(t)$ is linear; and that b, the catchability, is constant.

An example, using data from the rainbow trout fishery of Paul Lake, British Columbia, obtained in 1932, shows that both methods of estimation yield approximately the same result. The second method is being developed as an aid for fishery managers who wish to determine the size of their fish stocks. It requires that records be obtained concerning the catch per fisherman per day throughout the fishing season and that the proportion of the different age groups in the catch be determined. If sampling is used, then representative sampling methods are required.

INTRODUCTION

During the past 30 years or more biologists have developed census methods which are being used to determine the relative abundance of animal populations. Fishery biologists for instance, use the data on the number of fish caught per unit of effort to determine whether a given population is increasing or decreasing. The information is also useful for comparing the effectiveness of different management or stocking policies. Not all biologists, however, have a clear-cut idea as to how such data are to be analyzed after they have been collected. Since the intended analysis determines what facts are needed, it seems desirable to review recent developments in the methods of estimating the size of fish populations.

THE ANALYSIS OF RELATIVE ABUNDANCE

The following example will serve as an illustration of the current use of creel census data in which modern statistical methods have been employed.

The yield of trout per unit of fishing effort from the test area of Furnace Brook, Vermont, showed an apparent decline from 1936 to 1940. The data for the 5 years are shown in Table 1. The average yield per unit of effort based on the number of hours expended by the anglers was 1.76 fish per fisherman-hour; the yield for the 3 years 1936, 1937, and 1938 was above this average and the yield for 1939 and 1940 was below it. Since the heavy flood which followed the hurricane of September, 1938, may have reduced the trout population of the test area, it becomes a matter of some importance to determine if the differences

Table 1. Shows the total number of fish caught (Y) and the total number of hours expended (X) by the anglers at Furnace Brook, Vermont, for the 5 years 1936 to 1940, together with the average catch per fisherman-hour.

Year	Number of hours (X)	Number of fish (Y)	Fish per fisherman-hour
1936	3550	6995	1.97
1937	3544	6385	1.80
1938	2551	4647	1.82
1939	2103	2997	1.42
1940	2469	4063	1.64
5 years	14217	25087	1.76

in yield per unit of fishing effort before and after the flood are significant. If the differences are significant, then it may be inferred that a change has taken place in the size of the population.

A rather extensive background investigation revealed that the standard design for an analysis of covariance may be used to conduct the test provided that the original data are transformed to square-roots.

In order to provide a measure of the variability within the different years the original data were combined into 16 periods consisting of the first day and the rest of the season divided into 15 7-day periods.

The analysis of covariance, the errors of estimate, and the test of significance are shown in Table 2. The F-value, 4.045, is highly significant, indicating that there are significant differences among the mean yield for the different years, after adjustments have been made for the differences in effort.

The conclusion seems warranted that there was a significant change in the yield of trout per unit of fishing effort in the test area of Furnace Brook, Vermont. The yield was above expectation in 1936 and significantly below expectation in 1939. The sudden drop in 1939 might be reasonably ascribed to the effect of the flood which occurred in September, 1938. The yield in 1940, although below expectation, is not significantly low which seems to indicate a certain amount of recovery.

Table 2. Shows the analysis of covariance, the errors of estimate, the test of significance and the regression of the yield of trout from Furnace Brook, Vermont, for the 5 years from 1936 to 1940, where X and Y are the square-roots of the number of hours expended and the yield, respectively.

Source of variation	Degrees of freedom	Sums of squares and products		
		Sx^2	Sxy	Sy^2
Total	79	1608.52	1951.78	2808.19
Between-years	4	148.90	275.11	521.21
Within-years	75	1459.62	1676.67	2286.98

Errors of estimate

$$Sy^2 - \frac{(Sxy)^2}{Sx^2}$$

			Mean square
Total	78	439.90	
Within-years	74	360.98	4.878
For test of significance	4	78.92	19.73**

Test for significance

$$F = \frac{19.73}{4.878} = 4.045; \; n_1 = 4; \; n_2 = 74$$

Regression

$$Y = 2.263 + 1.149x$$

This example shows that the stock in the stream has changed, but it gives no indication of the magnitude of that change in terms of the number of individuals. Such information would be much more useful to the fishery manager if he knew exactly how many fish he had on hand at any particular time. Any management practice that the manager may adopt is conditioned by his estimate of the stock on hand. For example, the number of fish to be carried over from one season to the next should be gauged according to the food supply in order to permit sufficient growth.

POPULATION ESTIMATION

In an effort to get at the question of estimating the size of the stock on hand, biologists have used tagging, marking or banding methods. Knowing how many tagged individuals there are at large in the population, it is possible to estimate the total stock from the proportions of tagged individuals in the catch. This method has several shortcomings that have been discussed by others and it is not my purpose to go into them here.

During the past year a new approach has been made to the problem of estimating the size of animal populations. Last summer I renewed my interest in the problem and began experimenting with the adaptation of a graphic technique for describing the growth of animals that Dr. L. A. Walford had developed. Several people, including R. A. Fisher, D. B. DeLury, C. P. Winsor, Marion Sandomire and others, contributed suggestions which have served to refine the idea. Meanwhile, Dr. DeLury,

working independently, developed a mathematical formulation for the estimation of biological populations using the relation between catch and effort. His equation is as follows:

$$\log C(t) = \log (kN_o) - kE(t) \quad \ldots\ldots\ldots \quad (1)$$

where, $C(t)$ is the catch per unit of effort at time $\underline{t}$,

$E(t)$ is the total effort expended during the time interval $(0,t)$,

N_o is the number of individuals at $t = 0$,

and, $\underline{k}$ is a constant describing the rate at which the catch per unit of effort decreases as the effort accumulates.

The relation between catch and effort that I had developed may be expressed by the following equation, using Dr. DeLury's notation:

$$C(t) = a - bK(t) \quad \ldots\ldots\ldots \quad (2)$$

where, $K(t)$ is the total catch accumulated during the time interval $(0,t)$,

$\underline{a}$ is a constant supplying the value of C when $K = 0$; when $K = 0$, $N_o = \frac{a}{b}$

$\underline{b}$ is a constant describing the rate at which the catch per unit of effort decreases as the catch accumulates, and $C(t)$ has the same meaning as in (1).

An attempt was made to use these methods for estimating the size of the Furnace Brook population, but it became evident in the course of the investigation that recruitment was taking place throughout the season and it was impossible with the data in hand to disentangle the components of depletion and recruitment.

In order to illustrate the use of the two equations, creel census data that I obtained at Paul Lake, British Columbia, in 1932 have been selected. At this lake about two-thirds of the fish are caught by anglers using boats from a single boat livery. The proprietor of the boat livery kept records of the number of fish caught per boat each day throughout the fishing season. Samples of the fish were selected from time to time from which scales for age determinations were taken. It was thus possible to divide the population into two parts: the yearlings, some of which begin to reach legal size in July, and which steadily increase in the catch until October; and the fish two years old and older which are completely available to the fishery from May 1 to October 31. The latter group is thus exposed to depletion at all times during the 26-week fishing season. The data for 1932 compiled on a 7-day basis showing the number of boat-days, the total catch, and the number of fish caught in the group two years old and older are shown in table 3. The values calculated therefrom which are needed for estimating the constants in equations (1) and (2) are also given. The data have been plotted in figures 1 and 2.

Fitting these data by least squares equation (1) now becomes:

$$\log C(t) = 0.6552 - .001382E(t) \quad \ldots\ldots\ldots \quad (3)$$

from which, $k = .003183$ and $N_o = 1420$

and, equation (2) becomes:

$$C(t) = 4.353 - .002866K(t) \quad \ldots\ldots\ldots \quad (4)$$

from which, $N_o = \frac{4.353}{.002866} = 1519$

Table 3. The number of boat-days and the number of rainbow trout over two years old caught at Paul Lake, British Columbia in 1932 arranged by weeks. The catch per unit of effort (C), the accumulated catch (K), the logarithm of 10 C, and the accumulated effort (E) are given.

Week No.	No. boat days	No. fish	C	K	Log. 10 C	E
1	15	49	3.27	49	1.515	15
2	11	53	4.82	102	1.683	26
3	27	104	3.85	206	1.585	53
4	35	144	4.11	350	1.614	88
5	21	48	2.29	398	1.360	109
6	33	85	2.58	483	1.412	142
7	30	51	1.70	534	1.230	172
8	27	69	2.56	603	1.408	199
9	16	40	2.50	643	1.398	215
10	16	58	3.63	701	1.560	231
11	16	46	2.88	747	1.459	247
12	37	112	3.03	859	1.481	284
13	22	49	2.23	908	1.348	306
14	16	41	2.56	949	1.408	322
15	21	27	1.29	976	1.111	343
16	23	19	0.83	995	0.919	366
17	13	17	1.31	1012	1.117	379
18	14	23	1.64	1035	1.215	393
19	12	17	1.42	1052	1.152	405
20	14	14	1.00	1066	1.000	419
21	15	13	0.87	1079	0.940	434
22	14	11	0.79	1090	0.898	448
23	7	5	0.71	1095	0.851	455
24	8	11	1.38	1106	1.140	463
25	7	7	1.00	1113	1.000	470
26	11	9	0.82	1122	0.914	481

In order to determine the size of the stock on hand at any time from equation (3) values may be substituted in the following formula:

$$N(t) = 1420e^{-.003183(t)} \quad \ldots\ldots\ldots\ldots \quad (5)$$

In the case of equation (4) the stock on hand at any given time may be obtained by subtracting the accumulated catch to that date from 1519. Equation (4) is much simpler to use than equation (5).

A rough estimate of the size of the population may be obtained by plotting the values of C(t) against K(t) and fairing a line through the points as shown in figure 2. Extrapolating beyond the data to the point where the faired line cuts the K(t) axis yields the required estimate of N_o. It tells what the size of the catch would be if the catch per unit of effort were reduced to zero. Rough methods such as this may be sufficiently accurate for management purposes.

Both equations place the estimate of the number of fish available to the livery boats at about 1500. This figure seems to be a little low judging from information derived from other sources, such as the count of the number of fish surviving to spawn in subsequent years. It may be that the record keeper failed to note a few of the catches. However, the estimate seems to be reasonable enough to place considerable confidence in the method.

The data in table 4 were obtained by applying the method of equation (2) to the records for the succeeding years from 1933 to 1936. The estimate of the catch of two-year and older fish is also given. The increase in the population is the result of a change in the stocking policy which was initiated in 1931. The effect of this change first

Table 4. The population estimate of the stock of two-year and older fish available to the Paul Lake boat-livery fishery and the recorded catch arranged by years.

Year	Population Estimate	Catch
1932	1,500	1,100
1933	4,200	3,100
1934	4,500	3,700
1935	9,000	8,000
1936	8,400	- 1/

1/ No data available on age of fish.

became evident in the fall of 1932 when the yearlings began to enter the fishery. The increasing stock on hand and the increased catches which resulted from this stocking policy are evident from the data in the table.

The methods of estimating the size of fish stocks described above appear to have great promise as an aid to fishery management. Some preliminary work has indicated that they would be equally useful for estimating the size of populations of other animals that are subject to harvesting.

There are certain assumptions underlying the methods which should be pointed out. The most important of these are the assumptions that:

(i) the population is closed, i.e. that there is no immigration, emigration or recruitment;

(ii) the individuals in the catch are selected in a representative manner;

(iii) the catchability as represented by $\underline{k}$ or $\underline{b}$ does not change, and the relation between $C(t)$ and $K(t)$ is linear.

The validity of these assumptions can usually be judged if the investigator has a thorough knowledge of the biology of the population under study.

Before listing the items that should be included in a creel census that is designed to provide an estimate of the size of a fish population, I should like to draw attention to two statistical problems that remain to be solved. No attempt has been made to provide estimates of error for N_o. This question should be explored.

In experimenting with the data from a physical model and with data from a few actual situations it has become evident that the relation between catch and effort is not necessarily a linear one. It also seems evident that the relation between catch and effort may be different in different situations. One case indicated that when the fishing is good, or when weather conditions are favorable, a greater number of fishermen turn out. This leads to a parabolic relation between catch and effort. In other cases, particularly the stream-fishing in the heavily populated areas of the East, there is a great turn-out of fishermen at the beginning of the season when the stocks in the streams are high. At this time there is a greater proportion of unskilled anglers and intense competition for favorable locations. This type of situation produces an entirely different relation between catch and effort. Consequently some attention must be directed toward the fundamental relation between catch and effort before C(t) is calculated.

CREEL CENSUS METHODS

The discussion of creel census methods may be divided into two parts. The first deals with the situation where the total effort and total catch is obtained. The second is concerned with the case where sampling must be used.

In the case of total coverage the census-taker must obtain records of the number of fish caught by each fisherman throughout the season. In addition he must be able to cope with the requirements of the three assumptions listed above. The question of recruitment can be settled by obtaining data on the relative proportions of the different age groups in the population. This can be accomplished by various devices

well-known to fishery biologists. In addition the value of the data may be greatly increased, if observations on conditions that affect the yield per unit of effort are also made.

The estimating power of the data may be greatly improved if adjusted for weather conditions, season, the method of fishing and the skill of the fisherman. The unit of effort should be standardized. It could be merely the catch per trip, or it might be defined more exactly as the number of hours actually spent in fishing. The latter measure is undoubtedly superior, if such data can be obtained.

In the case of sampling, the same factors as those for total coverage must be considered. In addition the problem of obtaining representative data must be dealt with. An investigation has shown that restricted, stratified random sampling should be used if the criteria of representativeness, adequacy and cost are to be met efficiently. The essential point is to be able to reason from the sample selected to the total population with a determinable degree of accuracy.

I should like to add a practical example of the way the method might be used by a fishery manager. I shall use the 1932 data from Paul Lake. Assume that the following facts have been ascertained:

1. From May 1 to June 30 all of the fish in the catch are two years old or older. Hence there is no recruitment during this period.
2. Until May 15, those fish that are mature migrate out of the lake into the tributary stream where they are counted through a fish trap. About the middle of June they begin to return to the lake. Until May 15, about 200 fish have been caught by anglers and 500 have migrated out of the lake.

3. In the period from the middle of May to the end of June, there is a steady drain on the lake population by fly-fishermen and trollers. The fish remain near the surface which provides a fairly constant catchability.

4. An investigation has been made of the type of the fishery, and it has been found that the relation between catch (Y) and effort (X), is best described by the equation:

$$Y = X^2 \qquad \ldots\ldots\ldots \qquad (6)$$

hence,

$$C(t) = \frac{Y}{X} \qquad \ldots\ldots\ldots \qquad (7)$$

5. Plotting C(t) against E(t) in the manner developed above, and fairing a line through the points as in figure 3, it is found that the population available to the boat-livery fishery in the lake amounts to 900 fish.

6. The total stock of two-year and older fish on May 1, therefore, amounted to:

Catch prior to May 15	200
Spawning migration	500
At large in the lake on May 15	900
Total stock on May 1	1600

Thus, by the middle of June the fishery manager is in a position to estimate the size of the population in the lake. This value can then be used in guiding his management practices.