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AN ANALYSIS OF SILVER SALMON COUNTS AT BENBOW DAM, SOUTH FORK OF EEL RIVER, CALIFORNIA[1]

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INTRODUCTION

Each year the Bureau of Fish Conservation of the Department of Fish and Game counts the salmon and steelhead which ascend the fishway at Benbow Dam, on the South Fork of Eel River near Garberville, Humboldt County. This long-range project was inaugurated by Messrs. A. C. Taft and Leo Shapovalov, and the counts have been made annually since the season of 1938-39. Summaries of the counts have been issued in mimeographed form at yearly intervals. However, as with many similar projects, it has been necessary to await the completion of several salmonid cycles before detailed analyses of the data would prove fruitful. The first of these analyses, a preliminary one of the counts at this and other stations for the counting seasons 1938-39 through 1949-50, has been presented in another paper (Murphy and Shapovalov, 1951).

In the present paper the counts of a single species, the silver salmon (*Oncorhynchus kisutch*), are given in detail for the seasons 1938-39 through 1950-51. A method is given for calculating the absolute number in each age class at the end of the first season of ocean life; for calculating the percentage of each age class that returned as grilse (males with one season in fresh water and one season in the ocean); and for calculating the percentage of mortality during the final year of life of the silver salmon. In addition, an attempt is made to explain fluctuations in the population by use of correlation analysis.

METHODS OF COUNTING

Counts are made of fish passing the fishway over Benbow Dam. A white board 24 inches in length is placed on the wall separating two pools and the fish either jump or swim over the board. An observer is stationed about eight feet above and slightly downstream from the board. Counts are made during daylight hours only.

Silver salmon are segregated as grilse, males, and females. All judged to be 24 inches or less in length (by comparing them with the board) are classed as grilse. Benbow Dam is located about 80 miles upstream from the ocean, and by the time that the salmon have reached the dam they have generally assumed most of their secondary sexual characteristics

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TABLE 1

Silver Salmon Counts at Benbow Dam

Counting season	Males	Females	Grilse	Total
1938-39	3,194	2,344	1,832	7,370
1939-40	2,572	2,861	3,196	8,629
1940-41	3,540	4,698	2,835	11,073
1941-42	4,068	5,184	4,442	13,694
1942-43	4,415	6,674	3,948	15,037
1943-44	4,351	6,363	2,316	13,030
1944-45	7,137	8,022	3,150	18,309
1945-46	6,392	7,729	2,610	16,731
1946-47	4,972	5,840	3,297	14,109
1947-48	9,708	11,583	3,998	25,289
1948-49	5,032	5,824	2,016	12,872
1949-50	2,527	2,963	2,005	7,495
1950-51	4,292	4,609	3,149	12,050

For this reason identification of males and females is usually easy. At times, though, the sexes are not so readily distinguishable. Some confusion of silver salmon with steelhead, particularly in the grilse counts, may also have taken place. The counts just described for the counting seasons 1938-39 to 1950-51 are given in Table 1. It should be noted that considerable numbers of silver salmon also spawn in the reaches below Benbow Dam.

INTERPRETATION OF THE COUNTS

A. C. Taft and Leo Shapovalov (unpublished data), working with marked silver salmon at Waddell Creek, California, found without exception that they spent one year in fresh water, one season in the ocean if they returned as grilse, and two seasons if they returned as adults. Other workers (Marr, 1943; Pritchard, 1936 and 1940) have found slight variations of this pattern, but these studies were conducted without the benefit of marked fish. Because of the regular life history pattern evinced by the silver salmon, at least in California, we can use the data in Table 1 to calculate the number of fish in each age class at the end of the first season of ocean life (when the grilse migrate to fresh water). The following formula is first solved for the survival of each age class during its last year of ocean life, in which *s* is survival, *n* any particular counting season, and *n*-1 the previous counting season.

$$s = \frac{♀\, n - ♂\, n}{♂\, n\text{-}1}$$

The numbers of males and females in the numerator are the numbers of three-year-olds counted at year *n*, and the denominator, grilse counted at year *n*-1. Once the survival, *s*, is known it can be divided into the number of females at year *n* to give the total number of females in the ocean at year *n*-1. The number of males at year *n*-1 (before the grilse migration) is assumed to equal the number of females. Once the number of fish at age *n*-1 is known it is a simple matter to calculate the percentage of males that return as grilse. These calculations can be made for the runs of 1939-40 to 1950-51, and are given in Table 2.

TABLE 2

Calculated Statistics on Benbow Dam Silver Salmon

Year (*n*)	Calculated numbers at year *n*-1			Percentage	
	Males	Females	Total	Survival during last ocean year	Males running as grilse
1939-40	13,184	13,184	26,368	21.7	10.1
1940-41	12,977	12,977	25,954	36.2	24.6
1941-42	13,157	13,157	26,314	39.4	21.5
1942-43	13,138	13,138	26,276	50.8	33.8
1943-44	12,476	12,476	24,952	51.0	31.6
1944-45	21,000	21,000	42,000	38.2	11.0
1945-46	18,229	18,229	36,458	42.4	17.3
1946-47	17,538	17,538	35,076	33.3	14.9
1947-48	20,357	20,357	40,714	56.9	16.2
1948-49	29,414	29,414	58,828	19.8	13.6
1949-50	13,718	13,718	27,436	21.6	14.7
1950-51	29,171	29,171	58,342	15.8	6.9
Mean				35.6[1] 33.0[2]	18.0[1]

[1] Arithmetic mean.
[2] Geometric mean.

We should note that certain assumptions must be made in accepting the operations in Table 2. They are:

1. A one to one sex ratio in downstream migrating silver salmon.
2. Equal mortality of males and females in the ocean and in the stream until they pass the counting station.

The first assumption is probably met whenever large numbers of migrants are concerned. It might not be met when dealing with small numbers of fishes, but on the other hand could be readily tested for any group of downstream migrants. The second assumption is not readily susceptible to test, but I know of no data indicating contrariwise.

In addition to possible failure to meet these basic assumptions, there are two other potential sources of error. Straying rates may vary between grilse and adults from the same brood. This error should not be serious, since the amount of straying among silver salmon is relatively small. Sexing of adults may not be accurate. For instance, the calculated number at *n*-1 for the 1950-51 run would be only 37,000 if only 100 of the females for that year were misclassified as males, without a compensating error in the other direction. This sort of error may affect the Benbow Dam counts, but it does not invalidate the method. A final source of error would be mortality among grilse on their fresh-water migration to the counting station. There is no commercial fishery in the Eel River and sportsmen apparently do not capture many silver salmon grilse, so this error is probably slight in the data under consideration. As pointed out above, failure to correctly sex the migrants can lead to serious error in the calculations. The first year's count had an excess of males over females.

This was probably due to misidentification, although there is no substantiating evidence. Referring to Table 2, the following correlations are obtained:

1. Total n-1 population and percentage of survival during the last year in the ocean. ($r = -.426$, $p > 5$ percent)
2. Survival in the last ocean year and percentage of males running as grilse. ($r = .682$, $p < 5$ percent)
3. Total n-1 population and percentage of males running as grilse. ($r = -.617$, $p < 5$ percent)

The most likely appearing explanation of these correlations is misclassification of the adults at the counting station. For example, if in a given year too many fish are counted as females, then the percentage grilsing and the survival are too high and the n-1 population too low. If the degree of inaccuracy varies from year to year, the three aforementioned correlations would result.

There is no reason to presume a systematic bias in the misclassification of males and females from year to year, and if the errors are random, their only effect will be to make the mortality rate and grilsing rate more variable. The mean of the 12 sets of data may then very closely approximate the true mean over the 12 years. The arithmetic mean of the grilsing rate is 18.0 percent and of the survival rate over the last year of life 35.6 percent.

Using the geometric mean of the survival rate during the last year in the ocean (33.0 percent) as the best estimate of survival each year, the n-1 population was recalculated, and from this the percentage of grilsing recalculated for each year. The new grilsing percentages range from 9.4 to 22.7, with an arithmetic mean of 17.1 percent. This treatment, then, has lessened the grilsing variability, believed due in part to misclassification of the sexes. Or, paraphrased, since misclassification of sexes leads to variation in calculated survival rates, and this in turn to variation in calculated grilsing, utilizing a mean survival rate inherently introduces a mean ratio of males to females, and results in what might be regarded as an improvement in the estimate of variability of grilsing.

Another procedure is to utilize a constant rate of grilsing (17.1 percent) and calculate a new set of n-1 population estimates by multiplying the n-1 grilse by $1/.171$. From these, new survival estimates can be calculated. This might be desirable if one assumed rate of grilsing was relatively constant from year to year, with most or all of the variation due to misclassification of the sexes. The new estimates of percentage of survival range from 24.9 to 59.2, with an arithmetic mean of 36.3.

It is obvious from the discussion above that the methods presented offer the possibility of following a group of marked hatchery fish very precisely. The number and sex ratio of the downstream migrants could be known; the ocean mortality due to the fishery could be estimated from the catch of marked fish; the size of the population after the first season of ocean life and total survival and mortality during that year could be calculated; and finally the nonfishing mortality during the last year in the ocean could be calculated.

FACTORS RESPONSIBLE FOR FLUCTUATIONS IN THE SIZE OF THE POPULATION

The life history of the silver salmon can be divided into ocean and fresh-water phases. The question might be asked, "What factors are responsible for fluctuations in the runs?" One tool for exploring this question is correlation. If some factor that reason or ecological knowledge leads us to believe can control the population is significantly correlated with the measured population fluctuations, we can conclude that that factor is responsible for part of the fluctuation in that particular population at that particular population level.

In part due to lack of knowledge of the ocean ecology of silver salmon, we cannot apply correlation analysis to the ocean phase of its life. The fresh-water life is more susceptible to analysis. Such a study is handicapped by the limited number of years for which observations are available. A factor that does control the run to a moderate extent might give a parameter correlation coefficient of only .40. Such a correlation would not be significant at the 5 percent level unless 25 paired sets of observations were available. With only 13 seasons of records available for Benbow Dam, we must either locate factors that are strongly controlling the population or tentatively accept correlations that are not significant in the statistical sense.

Other workers, such as McKernan, Johnson, and Hodges (1950), have not had great success in locating factors significantly correlated with the size of the runs. Part of their difficulty may have been due to inexactness of their measure of abundance and spawning escapement (the commercial catch). This does not apply to the Benbow Dam data.

We would expect to find the best correlations with fresh-water factors by relating them to the numbers of downstream migrants. The next best might be obtained from the numbers in the ocean after one season of life, and the poorest by relating them to the spawning escapements. This is obvious, since factors operating in the ocean are probably independent of stream factors. Counts of downstream migrants are not available for Benbow Dam. The other two measures are available, so both were related to the factors being tested. Further, it was felt that if improvement in the correlations resulted from using the calculated n-1 populations, it would indicate reliability of the method and accuracy of the calculations in Table 2. Four factors were selected for analysis because measurements are available and because they could reasonably affect the relative size of the population. No factors were studied and later rejected. These factors are: number of eggs deposited, i.e., number of spawning females; total runoff during November and December (the spawning period); total runoff during September (the critical low flow month); and total runoff during January and February.

The correlations obtained are given in Table 3. Flow data are from the main Eel River at Scotia, but flows there are almost an exact reflection of relative flows in the entire Eel River basin. Flows in November and December, the principal spawning months, should operate by controlling the amount of spawning beds available, by influencing the upstream penetration of the fish, and by influencing the dispersal of the young fish

TABLE 3

Correlations of Population Size and Various Factors

Factors related	Period included	Number of seasons	Coefficient of correlation	Probability of significance
n[1] females—parent females (*n*-3)	1941-42 to 1950-51	10	.043	$>.05$
n-1 population—parent females (*n*-3)	1941-42 to 1950-51	10	.820	$<.01$
n females—Nov. Dec. flow (*n*-3)	1938-39 to 1950-51	13	.292	$>.05$
n-1 population—Nov. Dec. flow (*n*-3)	1939-40 to 1950-51	12	.283	$>.05$
n females—Sept. flow (*n*-2)	1938-39 to 1950-51	13	.068	$>.05$
n-1 population—Sept. flow (*n*-2)	1939-40 to 1950-51	12	.415	$>.05$
n females—Jan. Feb. flow (*n*-2)	1939-40 to 1950-51	12	.353	$>.05$
n-1 population—Jan. Feb. flow (*n*-2)	1939-40 to 1950-51	12	—.226	$>.05$
n females—Nov. Dec. flow (*n*-3)	1941-42 to 1950-51	10	.300	$>.05$
n-1 population—Nov. Dec. flow (*n*-3)	1941-42 to 1950-51	10	.411	$>.05$
n females—Nov. Dec. flow (*n*)	1941-42 to 1950-51	10	.027	$>.05$
n females—Nov. Dec. flow (*n*-3) and parent females (*n*-3)	1941-42 to 1950-51	10	.302	$>.05$
n-1 population—Nov. Dec. flow (*n*-3) and parent females (*n*-3)	1941-42 to 1950-51	10	.915	$<.01$

[1] *n* is the year the adult 3-year-old females returned to Benbow Dam.

during their year in fresh water. Flows in September should operate on the young fish by controlling the temperatures, the amount of stranding, and the amount of crowding in the streams. The manner of operation of egg deposition (number of spawning females) is obvious. January and February flows should affect the size of the hatch, i.e., excessively high flows might destroy redds and sweep newly risen young into unfavorable ecological sites or merely out of their parent streams.

In addition to the simple correlations one multiple regression involving the *n* and *n*-1 populations versus the egg deposition and the November-December flow was calculated. Others were not attempted because the reduction in degrees of freedom with only 10 matching sets of data forces the level of statistical significance impossibly high.

Turning to Table 3 we see that the only significant coefficients are the *n*-1 populations versus egg depositions (probability less than 1 percent) and the multiple correlation (probability less than 1 percent). Correlations for some other factors that might influence the sizes of the populations are interesting but not statistically significant. From Table 3 we could conclude that 67 percent of the variation in the *n*-1 population was due to variation in egg deposition, and that 85 percent was due to a combination of egg deposition and flow at the time of spawning.

It is worth noting that if the true correlation between egg deposition (escapement) and the *n*-1 population is .820, this population of silver salmon is being held at an inefficient level, presumably by commercial and sport fishing. As already noted an r of .820 indicated that 67 percent of the variation in the *n*-1 population is due to variation in spawning escapement. It follows that there is a very good chance of increasing the population available for exploitation by increasing the escapement.

As indicated in Table 3, four paired sets of correlations were calculated. Each pair consists of a factor or set of factors correlated with the *n* females and the same factors correlated with the *n*-1 populations.

(Females were used to represent the *n* population or spawning escapement, since they are unaffected by grilsing.) Though many of the correlation coefficients are not significant, in each instance the *r* was improved by using the calculated *n*-1 population instead of the *n* population (improved in that the correlation changed in the direction indicated by prior reasoning). For instance, the correlation involving January and February flows and the *n* population was .353; when the *n*-1 population was used the *r* became —0.226. If the *n*-1 calculations are essentially correct this might be expected, and if the figures in Table 2 do not represent the populations at *n*-1, the observed improvement in the four sets of coefficients has a probability of occurring by chance of only 6 percent. This line of reasoning, then, tends to lend confidence in the data shown in Table 2, even though the calculated statistics are probably too variable.

SUMMARY

Silver salmon (*Oncorhynchus kisutch*) have been counted at Benbow Dam, Humboldt County, California, from 1938 through 1950. During each of the 12 seasons the fish were segregated as grilse (males with one year in fresh water and one season in the ocean) and male and female adults (fish with one year in fresh water and two seasons in the ocean). Because a known number of fish of one sex (the grilse) are withdrawn from the ocean population at the end of the first ocean season it was possible to utilize the numerical sex differential in the three-year-old fish to estimate the survival during any particular year class' last season in the ocean by dividing the excess of females over males of any particular counting season by the number of grilse counted during the previous season.

This method was applied to each year class and from the survival the absolute size of the *n*-1 population and the percentage of grilsing were calculated.

The estimated survivals ranged from 15.8 to 56.9 percent, with a mean of 35.6 percent. The best estimated grilsing rates ranged from 6.9 to 33.8 percent with a mean of 18 percent. Some of the variability in survival and grilsing rates is believed to be due to inaccurate sex classification of the adults.

By correlation analysis the effect of the following factors on the population was studied: total egg deposition; runoff during the spawning season; runoff during the late incubation and hatching season; and runoff during the dry season. These four factors were related to both the observed number of females and the calculated population at the end of one ocean season for the same year class. Statistically significant correlation coefficients were obtained for egg deposition and size of the population after one ocean season and a multiple correlation of spawning season runoff and egg deposition versus the population at the end of one ocean season. Other correlation coefficients were not statistically significant, but with few sets of data available only strong controlling factors would be expected to show statistical significance.

In each instance the correlation coefficient was improved in the expected direction when the calculated population after one ocean season was used instead of the observed counts of females at the dam. This is in line with prior expectation, since mortality over the final season in the ocean should be independent of stream factors. This observation lends credence to the calculated populations at the end of one ocean year.

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LITERATURE CITED

Marr, John C.
1943. Age, length, and weight studies of three species of Columbia River salmon (*Oncorhynchus keta, O. gorbuscha, and O. kisutch*). Stanford Ichthyological Bulletin, vol. 2, no. 6, p. 157-197.

McKernan, Donald L., Donald C. Johnson and John I. Hodges
1950. Some factors influencing the trends of salmon populations in Oregon. Fifteenth North American Wildlife Conf., Trans. p. 427-449.

Murphy, Garth I. and Leo Shapovalov
1951. A preliminary analysis of Northern California salmon and steelhead runs. Calif. Fish and Game, vol. 37, no. 4, p. 497-507.

Pritchard, A. L.
1936. Facts concerning the coho salmon (*Oncorhynchus kisutch*) in the commercial catches of British Columbia as determined from their scales. Pacific Biol. Station and Pacific Fisheries Exp. Station, Progress Repts., no. 29, p. 16-20.
1940. Studies on the age of the coho salmon (*Oncorhynchus kisutch*) and the spring salmon (*O. tschawytscha*) in British Columbia. Roy. Soc. Canada, Trans., ser. 3, vol. 34, sect. 5, 1940, p. 99-120.

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