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FLUCTUATIONS IN ABUNDANCE OF COLUMBIA RIVER CHINOOK SALMON (*ONCORHYNCHUS TSCHAWYTSCHA*) 1935-45

By Ralph P. Silliman

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By RALPH P. SILLIMAN, *Aquatic Biologist*

The United States Fish and Wildlife Service is charged by statute with the responsibility of reviewing plans for all water-use projects of the Federal Government, in order to determine their effect on populations of fish and to provide for the protection of these populations. Where runs of anadromous fish in the Columbia River Basin are concerned, the function has three primary aspects: (1) the determination of the species and size of the particular runs affected; (2) the ascertainment of the types of fish protective devices, if any, needed and the economic feasibility of these; and (3) the evaluation of the success of fish protective devices by comparison of the size of the runs before and after construction of dams and other such works. The present study is concerned with the most abundant of the Columbia River anadromous fish, the chinook (spring or king) salmon, *Oncorhynchus tschawytscha.*

In brief, the purposes of this report are to (1) present a detailed description of a method of calculating catch-per-unit-of-effort, for use in extending the present series of data both forward and backward; (2) indicate a method of deriving from the calculated catch-per-unit values a measure of abundance; and (3) make a preliminary appraisal of the importance of the various factors affecting abundance.

During the years in which the Fish and Wildlife Service and its predecessor the Bureau of Fisheries have carried on studies of Columbia River salmon, an enormous mass of statistical data on fish production has been accumulated, covering deliveries of 4 species of salmon and the steelhead trout to some 100 receiving stations along the commercial fishing zone of the river, and extending in time from 1897 through 1945. It is obvious that one worker (the author), with limited assistance, could gain useful information from such an accumulation of material only by limiting strictly the scope of the investigation. The study was, therefore, much restricted as to period covered, the area of the river included, the number of receiving stations within that area, the number of fishermen whose records were used, and the types of gear covered.

In relation to period of time, the most recent information is of course always of the greatest interest. The source data available in 1946 (when the study was started) ended with the 1940 fishing season; further original records were subsequently obtained bringing the series up to the most recent season for which the material was available, 1945. Calculations were carried backward as far as time available for calculations permitted—to the season of 1935.

As to area, the study was limited to deliveries made to those receiving stations of one large cannery which were located in statistical zone 1 (as established by the States of Washington and Oregon) of the commercial fishing area. This statistical zone (figure 1) includes the lowermost waters of the Columbia, opposite Pacific County, Wash., and contains the river's greatest concentration of fishing effort. It is subject to large tidal influence, and in reality is more of an estuary than a section of the river proper.

Gill nets (drift) constitute the most important form of gear on the Columbia; landings from this gear formed two-thirds of the total catch landed in the river during the decade 1935 through 1944. Because of the previously mentioned necessity for restricting the scope of the study, therefore, all calculations were based on gill-net data. Furthermore, the analysis was confined to the most consistent fishermen among the group delivering to the selected stations (this is explained in greater detail in the section, Selection of Fishermen, under the Computation of Catch-per-Unit-of-Effort).

The general effect of the above restrictions is to confine the study to a measure of the size of the runs of chinook salmon as they enter the Colum-

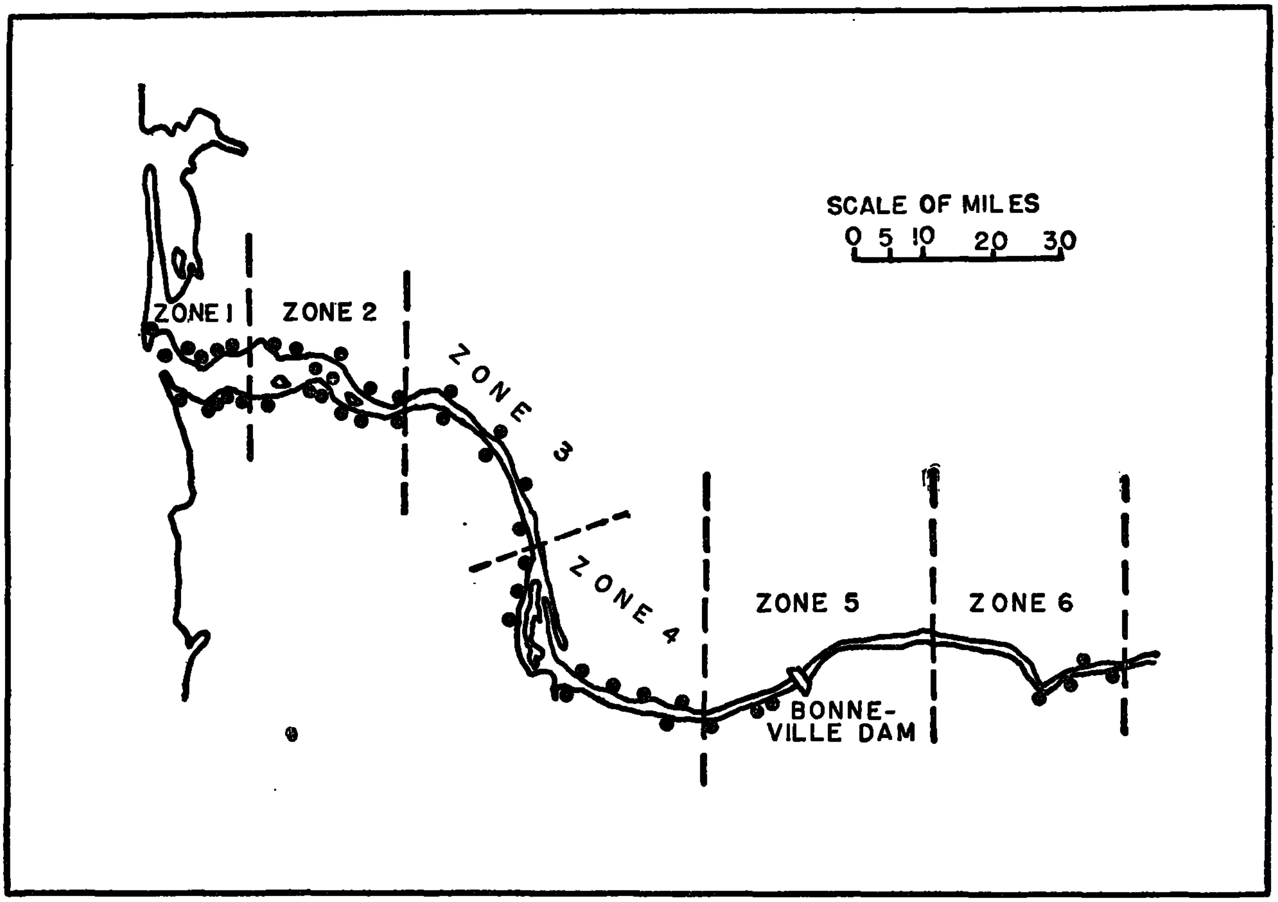

FIGURE 1.—Commercial fishing area of the Columbia River, statistical zones, and some fish-receiving stations (round dots).

bia River. It is important to recognize here that any effect of the currently (1949) large, ocean troll-fishery will have taken place before the measure occurs. This troll fishery is considered at length in another report (Silliman 1948), but it will suffice here to remark that in general its intensity seems to parallel that of the river fishery. To the extent that this seeming parallelism represents the true state of affairs, the river catch-per-unit will represent accurately the relative abundance of the runs as they enter the river, and it is relative abundance with which this study is chiefly concerned. The measurement of absolute abundance, of course, will require the addition to the river measurement of some estimate (such as that made in Silliman, loc. cit.) of the troll catch.

Many members of the Fish and Wildlife Service, both present and former, have helped me with this study. These include Harlan E. Johnson, John I. Hodges (now with the Oregon Fish Commission), Harold A. Gangmark, and Leonard A. Fulton, all of whom performed compilations and calculations; Floyd G. Bryant, who furnished information about the fishery; Mitchell G. Hanavan, who gave freely of advice on many phases of the biology of the salmon; and Elizabeth Vaughan, who counseled me on statistical matters.

I am grateful to the various canning companies on the Columbia River for their cooperation in making available to me the records of their operations, to the Fisheries Departments of Oregon and Washington for commercial catch data, and to William E. Ricker of Indiana University for review of the section on Estimation of Total Abundance.

COMPUTATION OF CATCH-PER-UNIT-OF-EFFORT

SOURCE DATA

Type of Record

The original records upon which the analysis was based consisted of cannery ledgers in which were entered the daily deliveries of individual gill-net fishermen. These fishermen (a more complete description of the gill-net fishery is given in Craig and Hacker 1940: 165, 182) operate gasoline-powered boats of characteristic type about 30 feet long. They set their nets alone or with one assistant, and are usually aided by a power-driven roller or net puller. The nets are of two types. Floater nets (used mostly near the mouth of the river) are simple walls of webbing constructed to float at the surface. Diver nets (the most efficient and popular form) are constructed to just touch the bottom, and usually are equipped with trammels of very large mesh through which the fish push the main net and get themselves caught in a bag. Both types are about 1,500 feet long and 20 feet deep, and are set at right angles to the direction of the current and allowed to drift with it.

Most of the fishing is done at night, the fisherman leaving in the evening (the exact time depending on the tidal stage) and returning in the morning to deliver his catch. Thus, each delivery record normally represents one night's fishing.

Selection of Season and Time Unit

Prior to 1943, fishing in the river was permitted the year-round except during March and April, and from August 25 to September 10. During the years 1943 through 1945, an additional closed period, May 20 to June 10, was in effect. In the trade the period from May 1 to August 25 is known as the spring season, and after September 10 as the fall season. Besides these closed seasons, there is a weekly closed period from 6 p. m. Saturday to 6 p. m. Sunday, during the spring season.

Most of the season's catch (95 percent for the period of this study) is landed during the months of May through September; in order to save time and to eliminate straggling season's-end catches, the analysis was limited to those 5 months.

Because of the Sunday closure during the spring season and because of a weekly cyclic fluctuation in the catches (Rich 1942: 128) it is desirable to subdivide the season into weekly time units. Rich (*loc. cit.*) has established a series of 7-day periods beginning with May 1, and this series will be used herein. The May–September fishing season contains 22 such periods (table 1), No. 22 ending on October 1 (the day October 1 has been included in all calculations in order to make the last period complete).

TABLE 1.—*List of 7-day periods used as time-units in the catch-per-unit-of-effort calculations*

Period No.	Dates included	Period No.	Dates included
1	May 1–May 7.	12	July 17–July 23.
2	May 8–May 14.	13	July 24–July 30.
3	May 15–May 21.	14	July 31–Aug. 6.
4	May 22–May 28.	15	Aug. 7–Aug. 13.
5	May 29–June 4.	16	Aug. 14–Aug. 20.
6	June 5–June 11.	17	Aug. 21–Aug. 27.
7	June 12–June 18.	18	Aug. 28–Sept. 3.
8	June 19–June 25.	19	Sept. 4–Sept. 10.
9	June 26–July 2.	20	Sept. 11–Sept. 17.
10	July 3–July 9.	21	Sept. 18–Sept. 24.
11	July 10–July 16.	22	Sept. 25–Oct. 1.

In contradistinction to the legal fishing seasons noted, certain large and obvious fluctuations in the catch during the fishing season have been recognized by fishery biologists and have led them to speak of at least three separate chinook-salmon runs. These are more readily apparent for data from early seasons, before certain of the runs were reduced in abundance, and can be seen in the graph of daily average gill-net catches delivered to one large cannery during the years 1926 through 1930 (fig. 2). Divisions have already been established (Rich 1942, table 13) between these, and are indicated on the graph.

The first mode or run apparently passes its peak into the river during the April closed season. Then, about the middle of June, a small peak occurs. Finally, there is the large run whose peak normally seems to occur during the August 25 to September 10 closed season. These three runs are ordinarily called "spring run," "summer run," and "fall run"; they will be so referred to herein. Incidentally, the May 20 to June 10 closed period referred to above was imposed to protect the spring run and summer run.

In the present analysis the following arbitrary divisions of the data have been made: spring run, weekly periods 1–4 (May 1 through May 28); summer run, periods 5–13 (May 29 through July 30); fall run, periods 14–22 (July 31 through October 1). The May 28 and July 30 division dates conform to those of Rich's (*loc. cit.*) table 12.

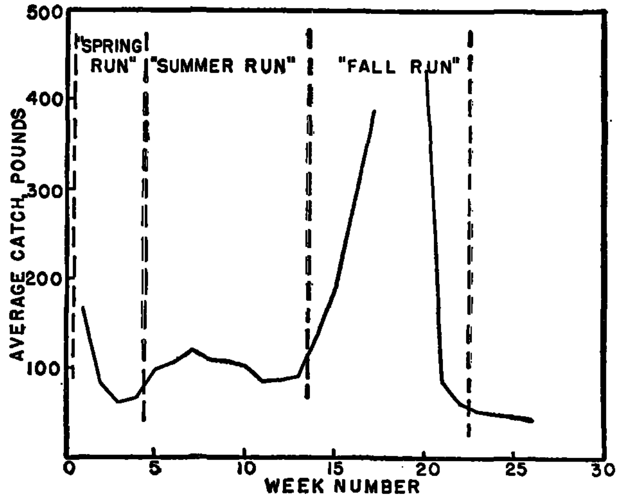

FIGURE 2.—Weekly average size of daily delivery of chinook salmon to a number of Columbia River receiving stations, 1926–30, by gill-net fishermen (for dates included in weekly periods (table 1)).

Selection of Fishermen

The aim in selecting fishermen whose records were to be used in the analysis was not to obtain a representative sample of the population of fishermen, but rather to choose fishermen whose catches would constitute a representative sample of the population of chinook salmon. Obviously, the most consistent fishermen would be most likely to obtain the best sample of the population (inconsistent fishermen tend to fish only during good fishing periods, and thus to oversample the most abundant parts of the run). The criterion of consistency was that a fisherman must have made, during each of a given pair of years, at least one landing during each month of the spring season or at least one landing during the fall season, and must not have made any landings outside of zone 1.

It is evident from the above that two groups of fishermen were selected, one for the spring season and the other for the fall. This was done purposely, since the fishery tends to change character between the two seasons. Many spring fishermen do not fish in the fall, and vice versa.

When the arbitrary criterion was applied to the available data, it was found that the number of fishermen so selected varied from 27 to 117 for the spring and from 30 to 92 for the fall season (table 2). In setting up the criterion the objective had been to keep the sample size between 30 and 100; a sample of 30 is considered the smallest to which large sample variability will apply, while 100 appeared to be a fully adequate sample size for the data used. Unfortunately, the number for the spring season of the 1944–45 comparison fell to 27, due to a change in the method of making entries in the cannery ledger. It was not deemed worthwhile, however, in view of the small size of the deficiency, to introduce nonuniformity by using a different criterion for 1944–45, or to change the criterion for the entire series of seasons to bring the sample size up for this one comparison.

TABLE 2.—*Numbers of fishermen selected by the arbitrary criterion of consistency (see p. 368 for explanation of criterion) and numbers whose records were used in the calculations*

Seasons compared [1]	Spring season		Fall season	
	Selected	Used	Selected	Used
1935–36	46	46	30	30
1936–37	117	97	55	46
1937–38	106	94	43	39
1938–39	85	85	45	45
1939–40	74	74	84	84
1940–41	55	55	68	68
1941–42	49	49	79	79
1942–43	48	48	92	92
1943–44	34	34	72	72
1944–45	27	27	66	66

[1] Method of comparison is described in the section, Use of Chain-Link Method.

As indicated in table 2, the sample size moved upward above 100 for the 1936–37 and 1937–38 spring comparisons. To save time in calculation, the number was reduced by discarding a sufficient number of fishermen at random to bring it below 100. In order not to disturb the natural relationship between spring and fall seasons, an equivalent proportion of the number of fishermen was discarded from the fall sample for the two comparisons. The actual sample sizes used are shown in table 2.

USE OF THE CHAIN-LINK METHOD

As indicated under Type of Record there are two major types of gill nets in use for catching chinook salmon in the lower Columbia River. There are innumerable variations of these, however, depending on the ideas and resources of the individual fishermen; boats also vary considerably as to size, power of engine, hull form, and equipment. Finally, fishing abilities, localities, and habits vary widely among the group of selected fishermen.

It is thus well-nigh impossible to set up a unit-of-effort of uniform and unvarying catching ability. However, since the attributes of a single fisherman tend to be relatively constant from one season to the next, it is possible to largely overcome the difficulty by comparing the performance of each fisherman in a given 7-day period of one season with his own performance in the corresponding 7-day period of an adjacent season. This is the method of chain linkage or link relatives familiar to economists; full descriptions are given in such statistical works as Croxton and Cowden (1943: 616).

ESTIMATION OF ZERO CATCHES

As mentioned above, the catch of a fisherman in a certain week of season *A* is compared in the present study with his catch during the corresponding week of season *B*. This is tantamount to calculating his catch per unit of effort for each of the two weeks, since it is implicitly assumed that the amount of effort expended is the same for both weeks. It seems reasonably safe to thus assume that, on the average, fishermen have put forth the same amount of effort during corresponding weeks of adjacent seasons, providing they made one or more catches during such weeks. There are not, however, any records of unsuccessful fishing trips, so that the data are not applicable to the situation where a fisherman made one or more catches during a certain week of one season, but did not make any catches during the corresponding week of an adjacent season. The question immediately arises, are such situations to be expected in significant numbers? In other words, is the number of zero catches great enough to be considered?

Examination of the frequency distributions of numbers of deliveries per week throws light on the above question. For instance, it is seen that during week 3 of the 1940 spring season (fig. 3), more than one-third of the fishermen who caught anything at all made only one delivery, with the occurrence of higher numbers of catches decreasing regularly as the number increases. Under such circumstances it seems practically certain that there were some fishermen who fished and caught nothing; it becomes necessary then to estimate the number of such cases. Such an estimation might be based on some assumed relation between the number of single and zero deliveries, but such a method would not be useful in connection with our method of comparing the adjacent-season performance of individual fishermen. We need to know not only how many fishermen fished during a given week, but which fishermen.

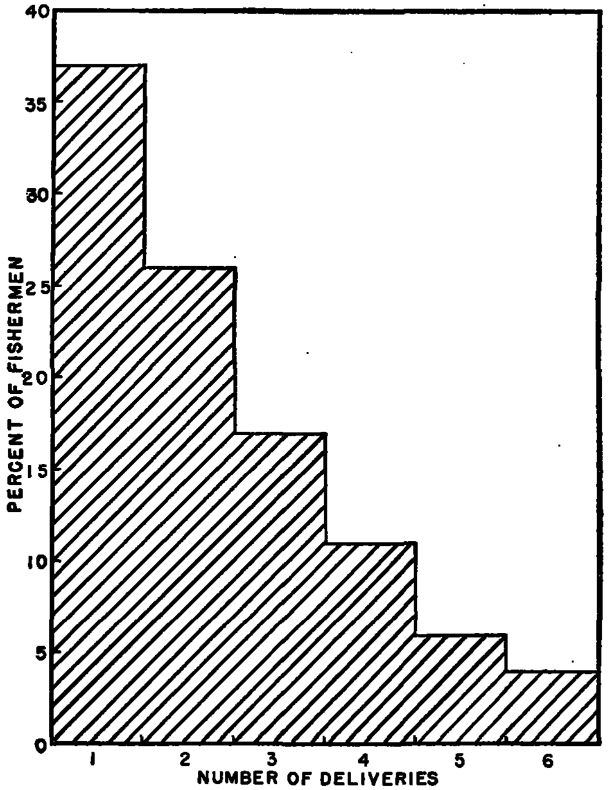

FIGURE 3.—Percentage distribution of numbers of deliveries of chinook salmon made by 54 Columbia River gill-net fishermen during week 3 (May 21–27) of the 1940 fishing season.

In setting up a rule for deciding which fishermen fished each week, a helpful assumption may be made. We may assume that it is extremely unlikely that any fisherman would fish as many as three successive weeks without a catch; under such circumstances he would probably drop out of the fishery until fishing conditions had improved. Taking this assumption as a basis we can list the weekly catches of all of the fishermen of the group considered and make the rule that a fisherman will be assumed to have been fishing during a given week even though he made no catches, if he made one or more deliveries during the preceding or succeeding week. To this we may add the requirement that at least 10 percent of the fishermen making deliveries during the week in question have made only one delivery. This is based on the idea that if 90 percent or more of the fishermen made at least two deliveries, it is improbable that there was a significant number of completely unsuccessful fishermen. We have, then, the following rule: A fisherman is considered to have fished during a given week even though he made no deliveries, if he made one or more deliveries during the preceding or succeeding week, and at least 10 percent of the fishermen making deliveries during the given week made only one delivery.

This rule was adopted with the full realization that its use provides an approximate method only, and introduces some error. Nevertheless, the method should be sufficiently accurate where averages only are dealt with (as is the intention in the present analysis), even though in the cases of individual fishermen wrong decisions are occasionally made. Further, the method is certainly superior to completely disregarding zero catches, and appears to be about the best practicable procedure applicable to the available data.

When the actual calculations were being made it was seen that application of the rule to the data for the fall season would lead to highly erroneous results. The reason for this lies in the fact that near the end of the season fishermen are rapidly dropping out of the fishery. Examination of the data leads to the conclusion that in the fall the fishermen stop fishing for chinook salmon as soon as the catches begin to decrease markedly, so that there is little likelihood of any significant number of fishermen fishing as much as a week without making catches. In view of this finding it was decided not to attempt any estimation of zero fishing weeks during the fall season (weeks 20–22).

CALCULATION OF INDICES

Using the criterion of consistency and the method of estimating zero catches described in the preceding sections, it is possible to make a series of individual fisherman-week comparisons for each of the pairs of seasons used in the chain from 1935 to 1945. As an example, the tabulation for the 1935–36 spring run comparison is presented in table 3. The sum of the four totals for 1935 is 50,942 pounds and for 1936 it is 47,462. Dividing the latter sum by the former gives 0.9317 as the ratio of 1936 to 1935 catch-per-unit-of-effort. Calculations were similar for all other seasons, except that no estimate of zero catches was included for the fall season comparisons, as mentioned under Estimation of Zero Catches (p. 370). A summary of the resulting ratios is given in table 4.

In order to calculate from the above ratios a series of indices of catch-per-unit, the year 1940 was selected as a "base year." The actual catch-per-fisherman-week was calculated for each part of the season in this base year, and the corresponding parts of the other seasons were linked to 1940 by means of the ratios in table 4; the resulting index values are given in table 5, and are shown graphically in figure 4.

The catch-per-unit index, although not a direct measure of abundance as will be brought out below, is roughly indicative of broad changes. The

TABLE 3.—*Individual fisherman-week comparisons for the 1935–36 pair of adjacent spring-run seasons. Zeros indicate weeks in which fisherman was assumed to have fished even though he made no catches (as described in text under "Estimation of Zero Catches")*

[Catches in parentheses are deleted because there were no catches in the corresponding weeks of the adjacent seasons with which to compare them]

Fisherman No.	Catches in pounds during week							
	1 (May 1–7)		2 (May 8–14)		3 (May 15–21)		4 (May 22–28)	
	1935	1936	1935	1936	1935	1936	1935	1936
1	653	680	334	496	61	204	216	364
2	693	630	883	253	438	310	895	405
3	-------	-------	(0)	-------	57	0	246	37
4	2,698	1,702	1,900	528	478	392	947	424
5	759	988	121	186	202	51	143	223
6	1,185	1,643	609	584	414	158	513	668
7	0	585	216	212	431	191	847	99
8	665	1,180	496	261	231	174	425	466
9	-------	(0)	0	152	52	74	42	89
10	77	40	0	103	83	0	22	85
11	1,128	1,594	38	360	188	21	36	501
12	857	688	166	475	237	275	248	186
13	0	263	138	636	0	216	142	162
14	463	393	95	560	376	348	793	0
15	-------	(211)	-------	(295)	0	48	175	149
16	526	1,094	581	251	387	279	702	233
17	26	76	(0)	-------	-------	-------	0	0
18	-------	(28)	-------	-------	(0)	-------	26	0
19	251	230	50	125	0	44	0	80
20	-------	-------	-------	-------	0	0	31	17
21	(154)	-------	(0)	-------	-------	(0)	0	140
22	215	212	47	188	143	0	299	34
23	478	487	146	215	0	55	143	305
24	1,065	543	160	245	83	209	464	275
25	-------	-------	-------	-------	0	100	562	470
26	-------	-------	-------	-------	0	0	114	83
27	533	493	231	292	80	0	73	62
28	1,252	749	532	658	493	417	663	626
29	536	561	279	312	97	81	150	147
30	462	807	111	137	286	70	241	129
31	-------	(0)	-------	(396)	0	362	669	289
32	-------	(68)	0	61	51	123	239	155
33	805	1,175	534	194	313	187	573	323
34	951	1,233	387	55	169	77	564	726
35	143	131	117	27	209	143	294	307
36	526	762	212	272	142	335	405	186
37	(149)	-------	(0)	-------	-------	(0)	0	170
38	-------	(0)	0	137	418	38	0	305
39	23	87	54	158	0	8	180	88
40	0	556	46	115	190	30	174	133
41	(73)	-------	(23)	-------	183	36	349	474
42	62	832	467	174	141	273	616	366
43	1,159	1,617	480	510	497	200	829	0
44	142	0	0	171	301	0	428	231
45	215	218	471	63	173	27	160	38
46	(362)	-------	(79)	-------	179	0	72	241
Total [1]	18,548	22,249	9,901	9,166	7,783	5,556	14,710	10,491

[1] Exclusive of strike-outs.

TABLE 4.—*Catch-per-unit of effort ratios between fishing seasons (season n/season n–1)*

Seasons compared	Spring, May 1–28	Summer, May 29–July 30	Fall, July 31–Oct. 1	Season,[1] May 1–Oct. 1
1936–35	0.9317	0.7424	0.5901	0.6943
1937–36	1.1878	.8714	1.3822	1.2029
1938–37	.7721	.7571	.7851	.7766
1939–38	.7943	1.2613	1.2169	1.1729
1940–39	.1905	.4498	1.0503	.8184
1941–40	3.2106	1.7588	2.0217	2.0088
1942–41	.7513	.9294	.9796	.9687
1943–42	2.2384	.8888	.4693	.5276
1944–43	.5311	1.0324	1.5408	1.4049
1945–44	2.1024	.3996	.9791	.9495

[1] Obtained by adding the linked catches for the entire season before dividing.

season curve in figure 4 does not indicate any marked trend upward or downward; although the trend for spring and summer is generally downward, the reverse is true for fall. Insofar as the spring runs are concerned this finding is in agreement with the statement of Rich (1942) that the spring runs have declined to a much greater extent than the fall runs. His analysis of total catches, however, indicated some decline in the fall also;

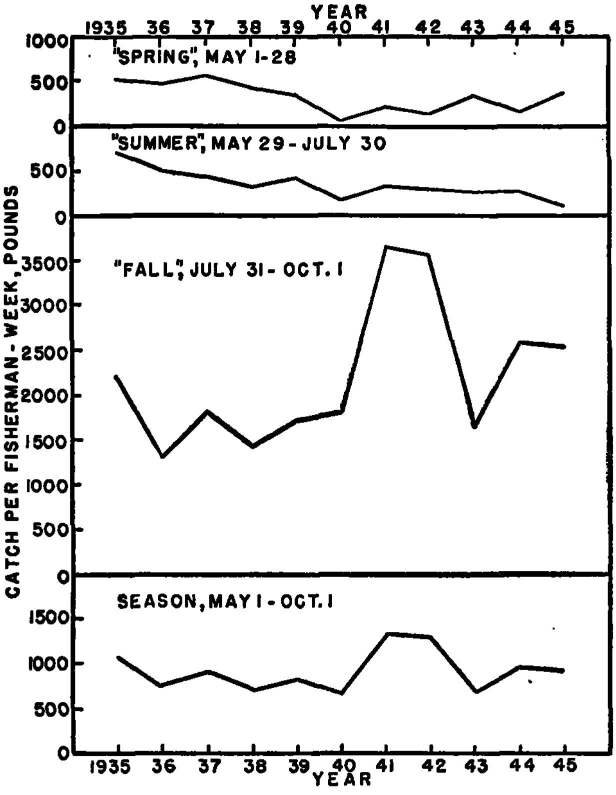

FIGURE 4.—Index of catch-per-unit-of-effort in zone 1 gill-net fishery for Columbia River chinook salmon.

the discrepancy may well be due to the difference in method of calculation.

FACTORS INFLUENCING ACCURACY OF INDEX

Changes in Efficiency of Gear

Although the chain-link method used in the above analysis eliminates the effect of variations in fishing efficiency among fishermen, it does not of course eliminate the effect of an increase in efficiency of an individual fisherman from one year to the next. Since most fisheries are undergoing some improvement in gear efficiency, the question of the magnitude of the effect of such improvement always arises in considering the accuracy of catch-per-unit indices like the present one.

TABLE 5.—*Values of catch per fisherman-week index, Columbia River chinook-salmon gill-net catches*

Year	Pounds per fisherman-week for—			
	Spring May 1–28	Summer May 29–July 30	Fall July 31–Oct. 1	Season May 1–Oct 1
1935	518	717	2,214	1,082
1936	483	532	1,307	751
1937	574	464	1,806	903
1938	443	351	1,418	701
1939	352	443	1,725	823
1940	67	199	1,812	673
1941	215	350	3,664	1,352
1942	162	326	3,589	1,310
1943	362	290	1,684	691
1944	192	299	2,595	971
1945	404	119	2,541	922

On this point, I think that the increase in efficiency of gill-net operations on the lower Columbia River from 1935 to 1945 was relatively slight. Although the selected fishermen did undoubtedly make minor improvements in their nets and boats, the only betterments of any significance were the increasing use of powerful, high-speed automotive-type boat engines in place of the old slow-speed low horsepower marine engines, and installation of power rollers on some of the 74 percent (Craig and Hacker 1940) of the boats which did not have them in 1935. To offset this, some of the 64 percent (*loc. cit.*) two-man boats undoubtedly changed to one-man operation (because it was more economical).

Because of the peculiar nature of the Columbia River gill-net fishery in zone 1, the extra speed gained by the installation of more powerful engines does not increase efficiency as much as it might in other fisheries. The many fish-receiving stations are so situated (fig. 1) that the fisherman moors his boat and delivers his fish only a few miles from where he catches them, so that the time spent in straight (full speed) running or "driving" to and from the fishing spot is relatively small in relation to the length of the fishing night. The only other driving is done between sets of the net or drifts. On two separate fishing nights observed by me, only 21 percent of the total time of absence from port was spent in driving.

The effect of an increase in fishing intensity during the period covered by the study would be to make the catch-per-unit in the latter years higher than it should be relative to the early years. In view of the considerations mentioned above, however, I do not feel that the effect could have been large enough to seriously modify the results.

Ocean Troll Catch

The effect of the omission of high seas troll catches from the analysis has been mentioned in the introduction, and will be referred to again in Discussion and Conclusions. It is noted here only for emphasis.

Weighting of Data

Those statistically inclined will have noted that the method of calculating arithmetical averages used in obtaining the catch-per-unit index automatically weights the means according to the amount caught during each part of the season. On the whole this seems preferable to a system of equal weights, since in general the largest catches are made when the largest runs are passing through the fishery. In other words, it would not appear to be desirable to give the small summer run equal weight in determining the season's index to that accorded the heavy fall run. Any number of complicated systems for weighting data from different parts of the season in various ways could be devised, but in the absence of sufficient justification for using them they have not been tried.

Short Weeks

Weekly periods adjacent to closed seasons do not in all cases contain 7 days (for instance, period 17 actually contains only the 5 days August 21–25) and, therefore, do not always contain a Sunday. Thus every 6 years (not 7 because of leap years) there is one comparison for which week 17 of the first year will have 5 days and week 17 of the second year will have 4 days. However, also once every 6 years, there is a comparison in which the reverse is true; thus tending to compensate for the error introduced.

It should be noted in this connection that Rich (1942: 128) points out that the Sunday closed period is offset to a large extent by increased catches during the early days of the week.

Sources of Error

To recapitulate, changes in efficiency of gear, fluctuations in the ocean troll catch, weighting of data and unequal lengths of short weeks all have some influence on the accuracy of the catch-per-unit index. Of these, the troll fishery is the only one I feel to be important, as the others tend to be insignificant or compensatory in effect. Unfortunately, data are not now available by which the effect of the troll fishery on the index can be appraised. Even if it should prove to have an important effect, we still have a measure of catch-per-unit from the runs as they enter the river, and this is valuable in itself.

CALCULATION OF EFFORT EXPENDED

The application of modern methods of estimating abundance requires data on the amount of fishing effort expended each season. This can readily be calculated once an index of catch-per-unit-of-effort is available simply by dividing the total catch (table 6) by the catch-per-unit. The resulting statistics will be in terms of the unit used in the catch-per-unit calculation, or gill-net-fisherman-weeks of the 1940 season in the present study.

Since the catch-per-unit analysis was confined to waters inside the mouth of the Columbia, only the inside catches have been used in calculating effort expended. The total amount of effort so obtained actually includes that expended by traps, seines, set nets, and dip bag nets; it is nevertheless all expressed in gill-net units, just as the power of a gasoline engine may be expressed in units of horsepower.

In table 7 and figure 5 are given the calculated amounts of effort expended (in the above mentioned units) for each of the parts of the fishing season, and for the entire year. The graphs of figure 5 indicate that in general the trend of fishing effort was downward during the period covered. This is contrary to the widespread impression that fishing effort has been steadily increasing. It is of course possible that increases in efficiency of gear might offset some of the apparent decline, but it hardly seems reasonable that they would be sufficient to nullify the 16 percent decrease from the average of the first 6 years to that of the last 5.

TABLE 6.—*Landings of chinook salmon inside the Columbia River*

[Thousands of pounds]

Year	Spring, May [1]	Summer, June–July [1]	Fall, August–September [1]	Entire year
1935	2,483	4,904	7,596	15,172
1936	2,093	3,661	9,815	15,998
1937	1,608	2,927	11,760	18,604
1938	1,708	2,222	8,315	12,598
1939	1,660	3,420	8,384	13,701
1940	657	1,998	10,721	13,770
1941	852	2,113	19,376	23,617
1942	951	1,496	15,954	19,061
1943	1,154	929	9,021	11,547
1944	647	1,254	11,749	14,308
1945	920	546	10,757	13,287

[1] Catch data were obtained from the fisheries departments of the States of Oregon and Washington, which sum them by calendar months. The months indicated vary only a few days from the actual periods used in the catch-per-unit analysis (table 5).

TABLE 7.—*Calculated amount of fishing effort expended toward the capture of chinook salmon inside the Columbia River, in units of 1940 gill-net fisherman-weeks*

[Thousands of pounds]

Year	Spring [1]	Summer [1]	Fall [1]	Entire year
1935	4,793	6,840	3,431	14,022
1936	4,333	6,882	7,510	21,302
1937	2,801	6,308	6,512	20,602
1938	3,856	6,330	5,864	17,971
1939	4,716	7,720	4,860	16,648
1940	9,806	10,040	5,917	20,461
1941	3,963	6,037	5,288	17,468
1942	5,870	4,589	4,445	14,550
1943	3,188	3,203	5,357	16,711
1944	3,370	4,194	4,528	14,735
1945	2,277	4,588	4,233	14,411

[1] See table 6 for explanation of these seasons.

The year 1940, particularly in the spring and summer seasons (table 7), is anomalous, and it was thought at first that this might be an artifact resulting from the method of estimating zero catches. In order to explore this possibility, the entire analysis for the spring and summer runs was recalculated, eliminating the estimation of zero catches. The recalculated data, however, still showed 1940 to represent as much of an anomaly as it did in the original figures, and it must be concluded that the unusually high amount of effort indicated for that year represented a real increase.

As mentioned previously, a May 20 through June 10 closed season was imposed beginning with the year 1943, in order to protect the spring run and summer run. It reduced the number of fishing days in spring by about 30 percent and in summer by about 20 percent. Actually there was a drop from 1942 to 1943 in fishing effort expended for both spring and summer (fig. 5). It is also evident from figure 5, however, that equally sharp drops had occurred previously, so that there is some question as to whether the reduction in effort was really accomplished by shortening the season. From the biological standpoint, of course, the closed season may well afford a measure of protection to the very meager runs of May 20–June 10, and if so is justifiable on this basis alone.

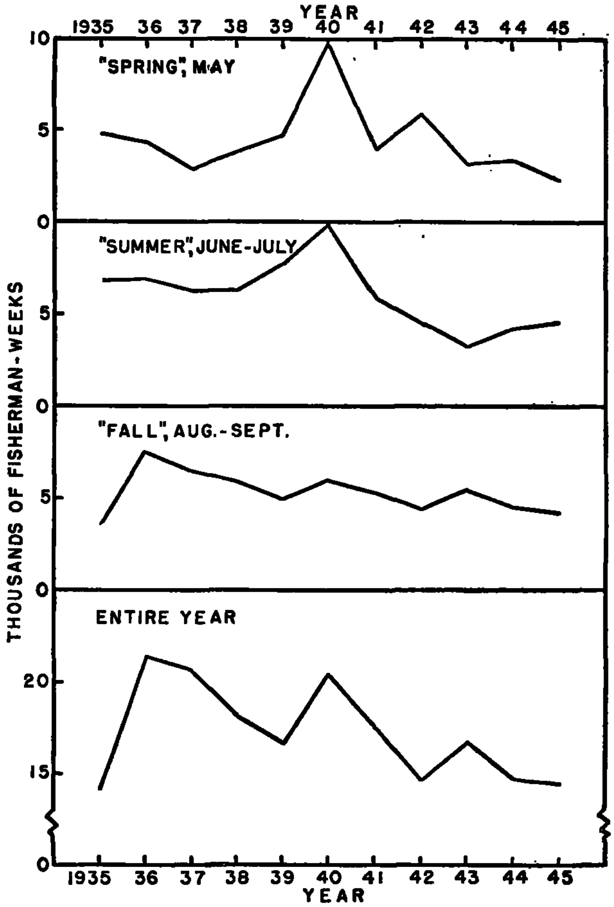

FIGURE 5.—Estimated fishing effort expended toward capture of Columbia River chinook salmon inside the river, in units of 1940 gill-net fishermen-weeks.

ESTIMATION OF TOTAL ABUNDANCE

Formulae and Assumptions

It has been very clearly demonstrated by various workers, particularly Ricker (1940, 1944), that a catch-per-unit-of-effort index is not ordinarily a direct measure of abundance of a fish population. In order to proceed from catch-per-unit to abundance it is necessary to make certain calculations, the type of calculation depending on the type of fishery. The type of fishery under consideration here is analogous to Ricker's (1944) type IA, in which there is assumed to be no significant natural mortality during the fishing season. In this type, providing absolute abundance is known for one of a pair of years, and total catch and total effort are known for both, it is possible to calculate the size of the stock for the second year by Ricker's (1940) formula (19):

$$\frac{f_2}{f_1} = \frac{\log\ (1-m_2)}{\log\ (1-m_1)}$$

where f = amount of effort expended and m = rate of exploitation or percentage of the stock taken by the fishery during the fishing season. In a later report (1944) Ricker shows this formula to be equivalent to an earlier one proposed by Baranov (1918).

$$\frac{f_2}{f_1} = \frac{p_2}{p_1}$$

where p is the instantaneous exploitation rate corresponding to the seasonal rate m.

Regarding the applicability of these formulae to anadromous fisheries, Ricker says in his 1940 paper:

> Such a fishery can be shown to conform to relationship (19) * * *, given the assumptions of (*a*) unchanging amount of fishing gear in use within each fishing season, and its uniform efficiency (or a reasonable approximation to these conditions); and (*b*) a uniform pattern of arrival and departure of the fish, between successive years * * *

As to (*a*), this can hardly be said to be true of the Columbia River fishery for chinook salmon. Data from table 6 show that the average numbers of fisherman-weeks expended during the 1935–45 period were 4,452 for spring, 6,066 for summer and 5,268 for fall. Since the respective average numbers of fishing weeks in these parts of the season were 3.7, 8.5, and 7.7 during 1935–45, the average numbers of units of gear (in terms of 1940 gill nets) in use for each were 1,203, 714, and 684, respectively. Whether or not these figures represent a reasonable approximation to uniformity is questionable, but it will be shown later that the calculation does yield more consistent results than the simple use of catch-per-unit. As far as assumption (*b*) is concerned, the data available (a series of detailed catches and counts at Bonneville Dam for the years 1938–43) indicate that, although there is some variation in migration pattern, it is relatively constant.

As stated above, we must have a measure of absolute abundance for at least 1 year in order to use the formula. Fortunately, it is not necessary to make a completely blind guess. In the year 1945 we have the Bonneville Dam (fig. 1) count and a reasonably accurate measure of the commercial river catch below Bonneville Dam (obtained by dividing the recorded catch in pounds by average weights based on samples taken throughout the season and in the various parts of the river, as see Silliman, Rich, and Bryant, 1948). It is only necessary to add to the sum of these an estimate of the number of fish spawning below Bonneville Dam, of which we have no count. Such an estimate has been made, based on actual stream observations of trained biologists and egg takes at hatcheries; a summary of the data is given in table 8. It would be preferable, in the abundance calculations, to deal entirely with numbers of fish, but this would preclude the extension of the series to years earlier than 1939, the earliest season for which adequate data on average weights (for converting catches from pounds to numbers) are available. The average weights of catches are therefore applied to escapements and counts, as set forth in table 8, thereby effecting a conversion of all data to pounds.

TABLE 8.—*Estimate of return of chinook salmon to the Columbia River in 1945*

Segment of return	Number of fish	Average weight of fish (pounds)	Pounds of fish
Catch below Bonneville Dam [1]	569, 556	21.0	11, 956, 000
Estimated escapement below Bonneville Dam	70, 000	[2] 21.0	1, 470, 000
Bonneville count	297, 488	[3] 14.1	4, 196, 515
Total	937, 044	18.8	17, 622, 515

[1] Exclusive of high seas troll catch.
[2] Assumed to be same as average weight of catch below Bonneville.
[3] Assumed to be same as average weight of catch above Bonneville.

The estimate of 1945 escapement below Bonneville Dam is admittedly subject to error, and this matter will be discussed further.

Calculations and Results

Although the data up to this point in the report have been dealt with by sections of the season corresponding to spring run, summer run, and fall run, the treatment hereafter will be confined to summaries for the entire year. It is felt that the determinations of abundance are not sufficiently precise to warrant their application to periods shorter than a full year.

The first step in the calculations is to obtain the seasonal rate of exploitation or fishing intensity, m, for 1945. Rounding the estimate from table 8, the total return is 17,600,000 pounds; the catch from table 6 is 13,287,000 pounds. Dividing catch by return gives 75.5 percent as the seasonal rate of exploitation. By means of tables such as those of Ricker (1944, table 1; 1948, appendix) such rates of exploitation can be converted to instantaneous mortality rates (this is done under the assumption that natural mortality is negligible during the salmon fishing season). The instantaneous mortality rate p corresponding to the seasonal rate of 75.5 percent is 1.41; it is used to facilitate the succeeding calculations. Such an instantaneous rate corresponds to n times the proportion of fish dying in one-nth of a season, when n is a very large number (actually p is the limit approached as n approaches infinity); in the present instance approximately 0.141 percent of the fish would die in 1/1000 of the season.

TABLE 9.—*Estimated seasonal rate of exploitation and return of Columbia River chinook salmon*

Year	Lower estimate		Median estimate		Upper estimate	
	Seasonal rate of exploitation, percentage	Return, 1,000 pounds	Seasonal rate of exploitation, percentage	Return, 1,000 pounds	Seasonal rate of exploitation, percentage	Return, 1,000 pounds
1935	81.6	18,600	74.6	20,300	68.6	22,100
1936	92.3	17,300	87.5	18,300	82.8	19,300
1937	91.7	20,300	86.6	21,500	81.7	22,800
1938	88.6	14,200	82.6	15,300	77.2	16,300
1939	86.6	15,800	80.2	17,100	74.6	18,400
1940	91.5	15,000	86.3	16,000	81.6	16,900
1941	87.9	26,900	81.7	28,900	76.3	31,000
1942	82.8	23,000	75.8	25,100	69.9	27,300
1943	86.7	13,300	80.4	14,400	74.8	15,400
1944	83.1	17,200	76.3	18,800	70.5	20,300
1945	82.5	16,100	75.5	17,600	69.6	19,100

By use of the formula $f_2/f_1=p_2/p_1$ given above, the value of p for 1944 can be calculated. Thus from table 7, the amounts of effort expended, 14,411 and 14,735 fisherman weeks for 1945 and 1944 respectively, give $f_2/f_1=1.0225$ (1944 is considered season number 2 in this calculation). Multiplying the 1945 value of p (1.41) by 1.0225 gives 1.78 as the 1944 value of p. By a series of similar calculations the series of p values is extended back to 1935. By the use of the aforementioned Ricker's tables these values of p are converted to values of m (percentage take of the fishery). Applying the values of m to the inside catches from table 6 gives a series of estimated poundage returns (median estimate) of chinook salmon to the Columbia River (table 9).

As noted previously, the estimate of 1945 escapement below Bonneville Dam is subject to error; we can, however, establish certain reasonable limits within which we can feel reasonably sure the true value lies. The lower limit is fixed, since the escapement cannot have been less than zero. There is, of course, no theoretical upper limit, but I feel that the accuracy of the estimated escapement is such that the actual escapement would not be greater than twice the estimated. The reasonable limits of error therefore can be established by using zero, or twice the estimate, for the escapement below Bonneville Dam. In the former instance we subtract the estimated below Bonneville escapement for 1945 (table 8) of 1,500,000 pounds from the estimated 17,600,000-pound total return to obtain a lower estimate of 16,100,000 pounds. In the latter instance the "below Bonneville" estimate is added instead of subtracted, giving a 19,100,000-pound upper estimate. The lower estimate and upper estimate were extended back to 1935 in the same manner as described above for the median estimate.

All three estimates are given in table 9 and figure 6. It is readily apparent from the figure that any one of the three estimates would lead to similar conclusions insofar as fluctuations in relative abundance are concerned, and it has been mentioned previously that relative abundance is the chief concern of this study. Because it uses the best available estimate of escapement below Bonneville, the median estimate series can be considered to contain the most probable estimates of return, and it will be used in the subsequent treatments of this report.

It was noted under Formulae and Assumptions that Ricker's (1940) postulate "(a)" of unchanging amount of gear during the season does not strictly hold for the Columbia River chinook fishery. This raises the question of the applicability of the formulae used in the calculations above. If the abundance estimate represents any improvement at all over the raw catch-per-unit index, then its use is justified. Such an improvement would be demonstrated if the abundance estimate were correlated more highly than the catch-per-unit index with a natural variable affecting the reproduction of salmon. A variable of this type, stream flow in the brood season, will be discussed below; it is pertinent to note here that the coefficient of its correlation with abundance estimate is 0.520, while with catch-per-unit index it is only 0.305. Thus, in addition to the logic of using the abundance estimate, there is the additional justification of improved correlation with a natural variable known to affect salmon spawning.

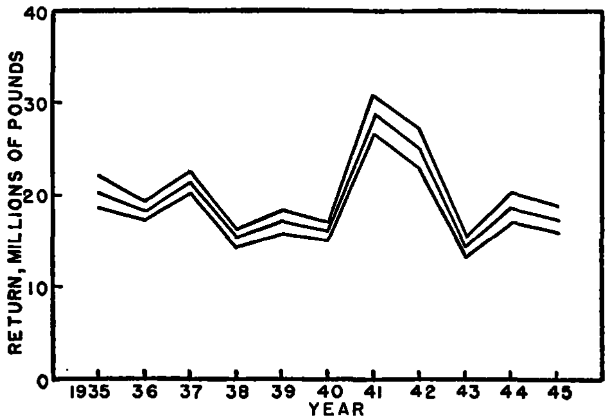

FIGURE 6.—Lower, median, and upper estimates of returns of chinook salmon to the Columbia River, derived as explained in the text.

FACTORS AFFECTING ABUNDANCE

Escapement and the Fishery

The escapement of mature salmon to the spawning beds is usually thought to be one of the major variables affecting the subsequent return; most salmon-fishery regulations are based on this idea. There have been few quantitative demonstrations of such a relationship, however, and beyond the recognized fact that there must be some seeding of the gravel beds to get any return, most of the remainder is conjecture. For the years of the present study an estimate of escapement is easily calculated by subtracting from the estimated returns in table 9 the inside catches in table 6; the resulting calculated escapements are given in table 10.

Since Columbia River chinook salmon are predominantly 4 years old when they return to the river, the return of any given year is linked to the escapement 4 years earlier. The data so linked are plotted as points on the scatter diagram of figure 7. Because of the 4-year lag in return, the 11 seasons of the analysis yield only 7 points. It is obvious from the figure that, within the range of escapements from 1935 to 1941, there was no close relationship between escapement and return. This does not, of course, mean that there is no relationship. We know, for instance, that at zero escapement there would be zero return, and that at some high escapement level the return must begin to decline. Apparently other factors affecting the return, and possible inaccuracies of measurement, obscure the true relation. The matter of the effect of other factors will be taken up again below under Stream Flow and Temperature.

TABLE 10.—*Estimated spawning escapement of chinook salmon in the Columbia River obtained by subtracting entire year catches in table 6 from median estimate of return in table 9*

Year	Escapement (thousands of pounds)	Year	Escapement (thousands of pounds)
1935	5,128	1941	5,283
1936	2,302	1942	6,039
1937	2,896	1943	2,853
1938	2,702	1944	4,492
1939	3,399	1945	4,313
1940	2,230		

It was shown in table 9 that the fishing intensities or rates of exploitation during 1935–45 were high, ranging from 75 to 88 percent, with a mean of 81 percent (median estimate), indicating a profound influence of the fishery on the escapement. Unfortunately, as shown above, the range of escapement covered in the present study is not great enough to indicate the relationship between escapement and return; therefore no relation (if such there be) between the fishery and return is demonstrable. It seems reasonably certain that if the calculations were carried backward to the earlier years of the fishery, such a relation could be shown to exist, because of the much wider range of fishing intensities that would be covered.

Since the escapement did not vary significantly during the period of study, as far as any demonstrable relation between escapement and return is concerned, the analyses below will be carried on as if the escapement were constant. This simplifies the calculations and permits the use of 11 instead of 7 pairs of observations in the correlations.

Stream Flow and Temperature

Stream flow is one of the natural variables known by direct observation to affect salmon reproduction. Its effect is felt in several ways.

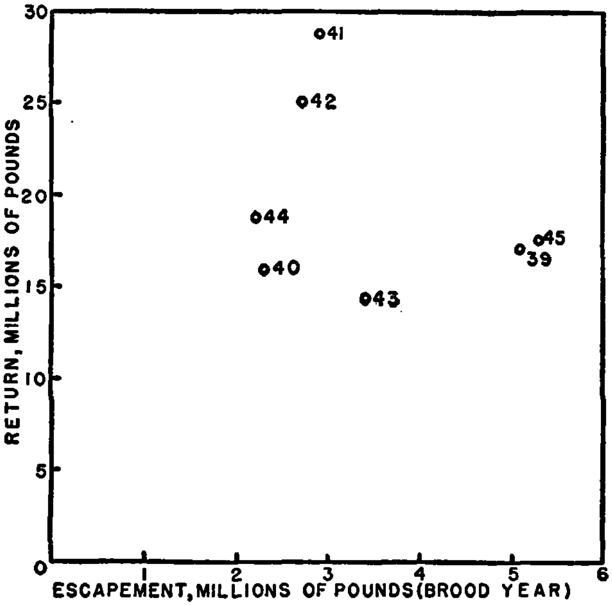

FIGURE 7.—Scatter diagram of estimated (median estimate) return against estimated escapement in the brood year (4 years before year of return). Numbers refer to year of return.

First, the upstream migrating salmon have much easier access to good gravel for spawning beds during years of high stream flow; many falls, and stretches of river affected by dams, are serious obstacles during low but not during high water. Second, high flows dilute polluted waters (such as those of the Willamette River near Portland) which during low water constitute barriers to both upstream and downstream migrants. Finally, high water during the hatching period is more favorable than low water to the escape of the fry from the gravel and their subsequent downstream migration.

In this study, therefore, we are not trying to determine whether or not there is any effect of stream flow. Salmon have actually been seen blocked during low-water periods. The purpose, then, is rather to attempt to assess the relative importance of this variable as compared with others known to affect salmon reproduction and survival.

TABLE 11.—*Stream-gaging stations whose records were used in calculating weighted mean run-off in the Columbia River chinook-salmon spawning areas*

Drainage	Estimated percentage of escapement [1]	Rivers	Gaging stations	
			Name	Number [2]
Grays River and Washington tributaries other than those listed below.	12	Cowlitz	Castle Rock, Wash.	1
Lewis and Kalama Rivers.	8	Lewis	Ariel, Wash	2
Lower Oregon tributaries	4	Sandy	Bull Run, Oregon (near).	3
Willamette River	10	Willamette	Salem, Oregon	4
Klickitat and Wind Rivers.	2	Klickitat	Pitt, Wash. (near).	5
Little and Big White Salmon Rivers.	6	White Salmon	Husum, Wash	6
Deschutes and John Day Rivers and Upper Oregon tributaries.	2	Deschutes	Moody, Oreg	7
Snake and Main Columbia Rivers.	51	Snake	Riparia and Clarkston, Wash.[3]	8, 9
Yakima River	2	Yakima	Cle Elum, Wash.	10
All tributaries above Rock Island Dam.	3	Wenatchee	Peshastin, Wash.	11

[1] Estimated on basis of stream surveys, counts at dams, and takes of eggs at hatcheries.
[2] Refers to map, fig. 8.
[3] Riparia to September 1935; Clarkston after September 1935.

A number of measures of stream flow are used, but the most convenient for the present study has been found to be the annual run-off in acre feet. This measure of total volume of flow is recorded by monthly units in the Surface Water Supply of the United States, papers of the United States Geological Survey. The data for the Columbia and its tributaries are contained in part 12, Pacific Slope Basins in Washington and Upper Columbia River Basin, and part 14, Pacific Slope Basins in Oregon and Lower Columbia River Basin. The records are available for a great number of stream-gaging stations, and some selection is necessary.

Gaging station records for this study were selected on the basis of continuity of record over the required period, and on adequate representation of the important salmon-spawning drainages. A total of 10 such stations was selected: Their location in relation to the estimated distribution of the chinook salmon escapement is indicated in table 11 and figure 8.

The selection of the "flow season" used was based on the facts of chinook-salmon life history. Mature adults of this species begin to enter the Columbia River tributaries around May 1, spawning takes place in the summer and fall, incubation in the fall and winter, and most of the down-stream migration into the main river is complete by April 30. Thus the flow season, May 1 through April 30, has been chosen for the calculation of seasonal run-off. The annual May–April run-off was determined for each of the stations in table 11, the sums weighted by the estimated percentage escapements also given in table 11, and the weighted mean calculated; results are given in table 12.

TABLE 12.—*Weighted mean run-off, season May 1–Apr. 30, Columbia River chinook-salmon spawning streams*

Season	Run-off (thousand of acre-feet)	Season	Run-off (thousand of acre-feet)
1931–32	14, 890	1937–38	18, 678
1932–33	19, 946	1938–39	20, 956
1933–34	24, 692	1939–40	16, 861
1934–35	13, 219	1940–41	14, 785
1935–36	17, 002	1941–42	18, 483
1936–37	15, 860		

The weighted seasonal run-offs were paired with the estimated returns from table 9, 4 years later, that is, the 1931–32 run-off season was paired with the 1935 return; this was because, as mentioned above, chinook salmon are predominantly 4 years

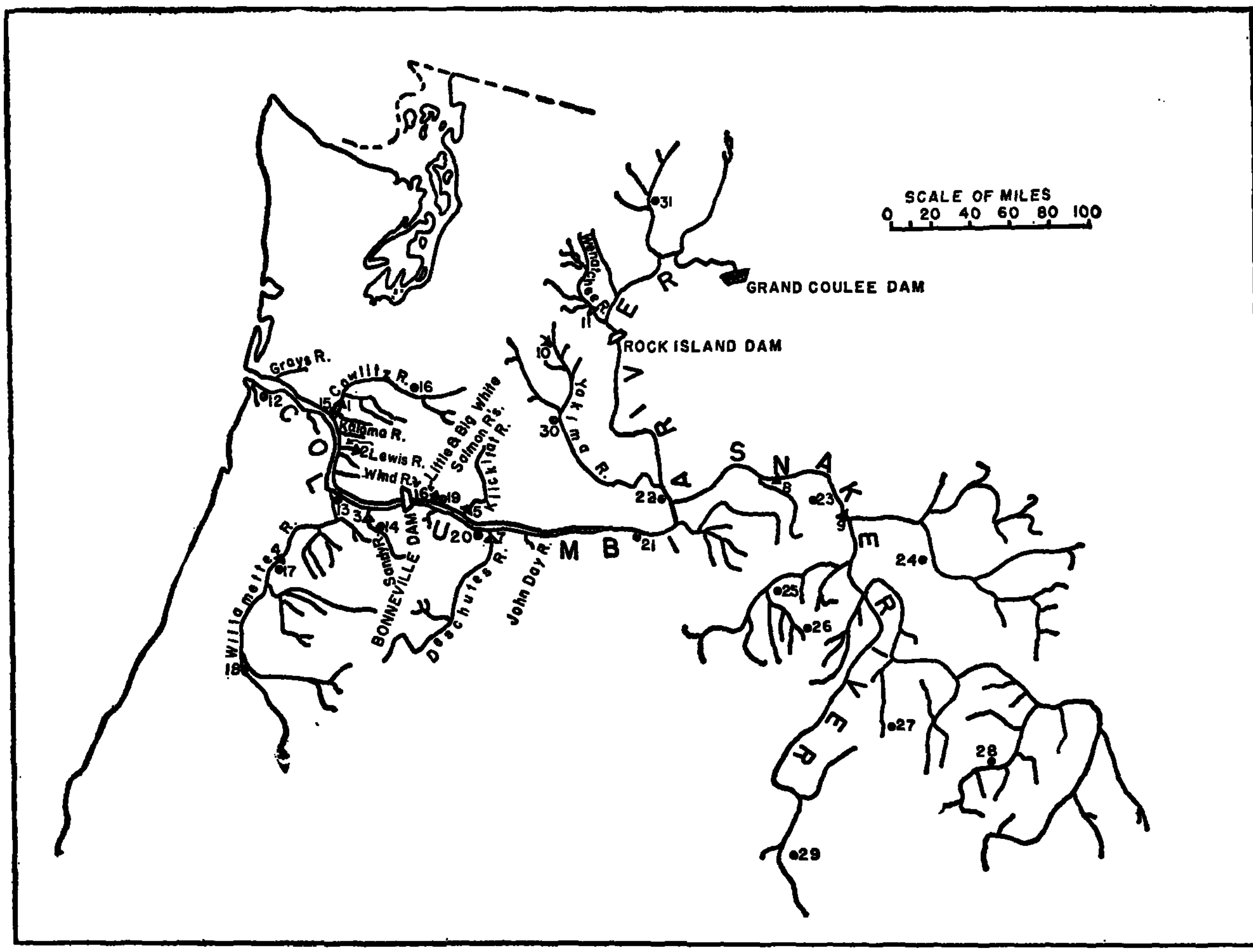

FIGURE 8.—Available (1944) salmon-spawning streams of the Columbia River showing location of stream-gaging (triangles) and temperature-observation (round dots) stations from which records were used in calculating weighted mean run-off and winter temperature. Numbers 1–11 refer to table 11, and 12–31 to table 13. Shows only parts of streams actually available for spawning.

of age (starting from egg deposition) when they return to the river. In figure 9 return is plotted against run-off, and the line of least-squares fit is shown. The coefficient of correlation is 0.520, and with 9 degrees of freedom the value of P is 0.1.

The above value of P would not ordinarily be considered to indicate a significant correlation. However, as stated, the purpose of the regression is to indicate relative rather than absolute effect. Statisticians consider that in a correlation the square of the coefficient indicates the proportion of fluctuations in the dependent variable associated with those in the independent variable; on this basis 27 percent of the fluctuations in return are associated with those in stream flow. The actual effect of flow on return is probably much greater than this, however, since the true relationship is obscured by such disturbing elements as variation in time and place of spawning, inaccuracies introduced by variable marine survival, and deviation from the 4-year spawning cycle. In regard to the last item, an analysis of the 2,677 returns from a marking experiment of Harlan B. Holmes showed that only about two-thirds of the returning fish were 4-year olds; the remaining one-third consisting of two-, three-, five-, and six-year olds.

Although winter temperatures are known to affect survival of salmon eggs (the possibility of

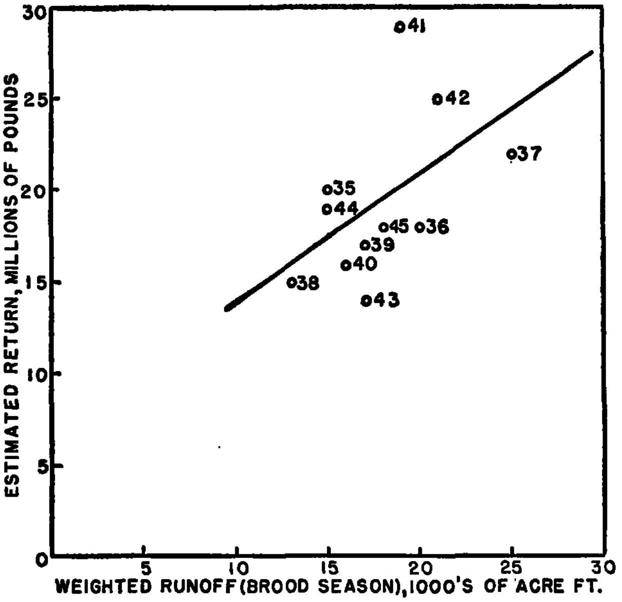

FIGURE 9.—Regression of estimated (median estimate) return on weighted May-April run-off in the brood season (4 years before year of return). Line shown is least-squares fit. Numbers refer to year of return.

such an effect on sockeye-salmon eggs in the Fraser River is pointed out by Rounsefell and Kelez 1938: 778), the relation is even more complicated than is the case with regard to stream flow. In general, severe winters result in some freezing of eggs. This effect is dependent to some extent, however, on the amount of protection afforded the spawning-nests or redds by snow cover. Also, in winters of alternate severe freezes and rapid thaws, there is damage to the redds through the scouring effect of the large ice cakes as they pass downstream. The net result of such effects is to obscure to a considerable extent any relation between winter temperatures in the brood season and the return 4 years later.

TABLE 13.—*Stations whose temperature records were used in calculating weighted mean winter temperature for Columbia River chinook salmon spawning areas*

Drainage	Estimated percentage of escapement [1]	Station	
		Name	No. [2]
Columbia River below Bonneville Dam, other than Willamette and Cowlitz Rivers.	14	Astoria, Oreg.	12
		Portland, Oreg.	13
		Headworks, Oreg.	14
Cowlitz River	10	Longview, Wash.	15
		Kosmos, Wash.	16
Willamette River	10	Salem, Oreg.	17
		Eugene, Oreg.	18
Little, Big White Salmon, and Snake Rivers, and the main Columbia River between Bonneville Dam and Rock Island Dam.	57	White Salmon, Wash.	19
		The Dalles, Oreg.	20
		Umatilla, Oreg.	21
		Kennewick, Wash.	22
		Pomeroy, Wash.	23
		Nezperce, Idaho	24
		Cove, Idaho	25
		Joseph, Oreg.	26
		New Meadows, Idaho	27
		Challis, Idaho	28
		Parma, Idaho	29
Tributaries between Bonneville and Rock Island other than Snake, Little, and Big White Salmon Rivers.	6	Yakima, Wash.	30
Main Columbia River and tributaries above Rock Island Dam.	3	Winthrop, Wash.	31

[1] Estimated on basis of stream surveys, counts at dams, and quantities of eggs taken at hatcheries.
[2] Refers to map, fig. 8.

Nevertheless, such a relation is of interest, and the appropriate data have been analyzed. Monthly average temperatures are given in the annual summaries of the series Climatological Data issued by the United States Weather Bureau. A total of 20 representative stations listed in the Oregon, Washington, and Idaho sections of the summaries was selected; criteria of selection were the same as mentioned for stream-gaging stations. A list of the stations is given in table 13, and their location is shown in figure 8. Simple averages of the December through February means were calculated (table 14); weighting in accordance with estimated percentage distribution of chinook salmon escapement was achieved by making the numbers of stations in each drainage proportional to such percentage.

TABLE 14.—*Weighted average winter (December through February) temperatures for Columbia River chinook salmon spawning areas*

Winter	Temperature (° F.)	Winter	Temperature (° F.)
1931–32	31.1	1937–38	37.3
1932–33	30.3	1938–39	34.9
1933–34	40.8	1939–40	37.4
1934–35	36.4	1940–41	37.0
1935–36	30.9	1941–42	32.7
1936–37	28.4		

Pairing of winter temperature seasons with return years was done in the same manner as with stream flows (described above) and a regression of return on temperature was made (fig. 10). The coefficient of correlation (0.337) for the least-squares line shown does not indicate significance in the statistical sense. Here again, however, the true nature of the relation has been obscured by other variables. In addition to those mentioned in connection with stream flows, and in the paragraph before the preceding one, there are many other minutiae of the relationship which cannot be recognized in a general, over-all treatment like the present.

Obviously, more detailed study of the effects of both stream flow and temperature would be necessary for an accurate appraisal. About all the studies presented herein accomplish is to indicate the relative importance of the two variables. Taking the squares of the correlation coefficients (0.270 for stream flow and 0.114 for temperature), it would appear that stream flow is about twice as important as temperature in affecting fluctuations in return, within the range of flows and temperatures experienced during the period of the analysis. Because of the rough nature of the relationships found, they were not combined into a multiple regression for the purpose of more precisely determining relative effect of the two independent variables.

If the relations of return with stream flow and temperature could be more exactly defined, it would probably be found that they were curvilinear rather than rectilinear, and that a leveling off occurred at both high waters and high winter temperatures. The reason for expecting this lies in the fact that once streams are high enough to prevent blockage of fish, and once winters are warm enough to avoid freezing of eggs, there is little or no improvement from further increases. It is entirely possible, in fact, that at high enough temperatures and flows reproduction of the salmon would actually be impaired, so that the curves would have a descending as well as an ascending limb.

It was mentioned above under Escapement and the Fishery that such variables as flow and tem-

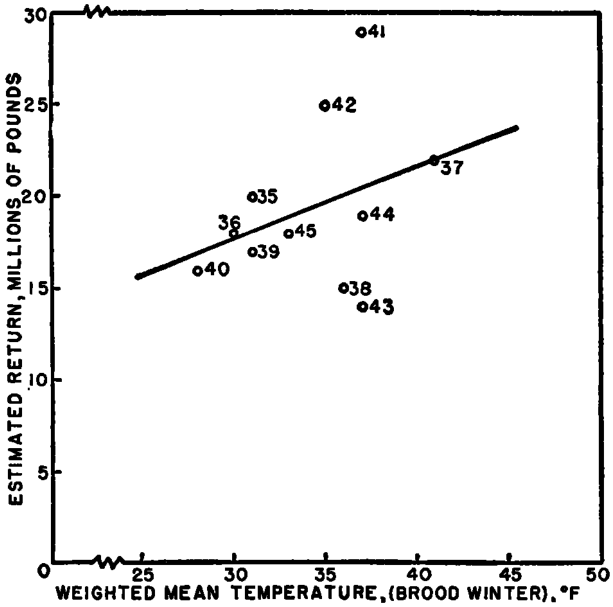

FIGURE 10.—Regression of estimated (median estimate) return on weighted winter temperature in the brood winter (4 years before year of return). Line shown is least-squares fit. Numbers refer to year of return.

perature might obscure the relation between escapement and return. By use of the regression lines of figures 9 and 10, it is possible to make an adjustment of the return data which will partially eliminate the effect of variations in stream flow and temperature. This is done by computing the deviation from mean return of the points on each of the regression lines corresponding to each yearly flow and temperature, and subtracting these deviations from the original "raw" returns.

The calculated weather adjustments, along with the unadjusted and adjusted returns, are given in table 15, covering the return years of the scatter diagram of figure 7. A new diagram of escapement-return relation, using the adjusted returns, is shown in figure 11. Obviously an insufficient proportion of the disturbance of extraneous variables has been removed to bring out the real nature of the relationship; a significant escapement-return relation has still not been demonstrated.

Dams

As a result of the completion in recent years of such huge structures as Bonneville Dam and Grand Coulee Dam, and the imminent construction of several others of similar proportions, much controversy has arisen as to the effect of such projects on the runs of salmon. Although the loss of spawning ground above Grand Coulee Dam has been compensated for by transference of runs to other streams (Fish and Hanavan 1948), there have been claims that Bonneville Dam, despite the fishways in operation there, has caused a decline in the runs. Indeed, Harlan B. Holmes has reported some loss of juvenile salmon as they pass downstream over the dam and through the turbines, but the ultimate effect of this on the returns is not yet clearly understood.

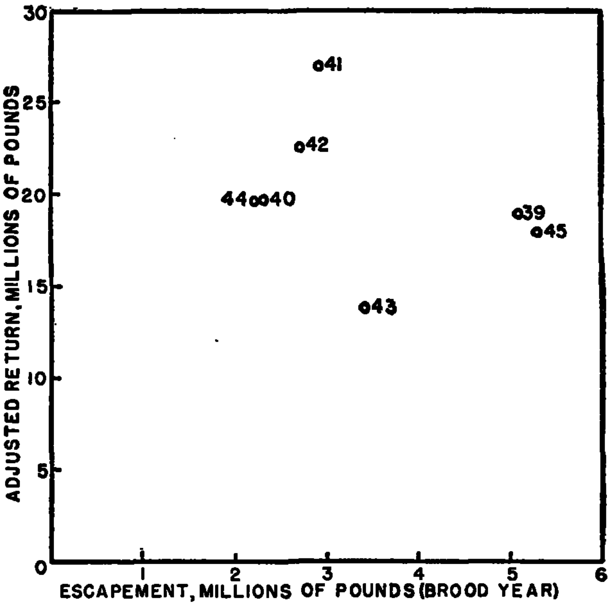

FIGURE 11.—Scatter diagram of estimated (median estimate) return, adjusted for effect of stream flow and temperature, against estimated escapement in the brood year (4 years before year of return). Numbers refer to year of return.

TABLE 15.—*Adjustment of median estimate returns for effect of stream flow and temperature*

[All data are in millions of pounds]

Year of return	Unadjusted returns	Adjustment for stream flow	Adjustment for temperature	Adjusted returns
1939	17.1	+0.6	+1.3	19.0
1940	16.0	+1.3	+2.4	19.7
1941	28.9	−.8	−1.1	27.0
1942	25.1	−2.2	−.3	22.6
1943	14.4	+.6	−1.1	13.9
1944	18.8	+2.0	−1.1	19.7
1945	17.6	−.1	+.5	18.0

Some light might be thrown on the question by comparing the returns of chinook salmon to the Columbia River before and after 1942 (Bonneville Dam was completed in 1938, and the chinook salmon return predominantly as 4-year fish). From table 9 the average median estimate return for the years 1935–41 is 19,600,000 pounds, while for 1942–45 it is 19,000,000 pounds. This slight decrease is shown by Student's (Fisher 1941) t test not to be significant ($P=0.8$).

Perhaps a better way to appraise the effect of Bonneville Dam, although it is sacrificial of data, is to analyze the ratios of returns from escapements before and after completion of the structure. The comparable returns and escapements, and the ratios between them, are given in table 16. The mean ratio of return for 1935–37 escapements is 6.75, and for 1938–41 it is 6.32. Here again Student's t test shows the small difference not to be significant ($P=0.8$).

Thus, as far as the present study is concerned, no significant effect of Bonneville Dam can be demonstrated. The loss of downstream migrants alluded to above, however, indicates that there must have been some effect; it is no doubt obscured in the data of this report by the effects of other variables.

TABLE 16.—*Estimated escapements and returns, for corresponding years, of Columbia River chinook salmon, and ratios of return to escapement*

[All data are in millions of pounds]

Year of escapement	Escapement	Year of return	Return	Ratio, return escapement
1935	5.13	1939	17.1	3.33
1936	2.30	1940	16.0	6.96
1937	2.90	1941	28.9	9.97
1938	2.70	1942	25.1	9.30
1939	3.40	1943	14.4	4.24
1940	2.23	1944	18.8	8.43
1941	5.28	1945	17.6	3.33

Anomalous Seasons

Throughout the various regressions studied above, two fishing seasons more than any others have failed to conform to the indicated relationships; 1941 has been invariably "high" and 1943 invariably "low" (figs. 9 and 10). If these seasons were eliminated from the regressions the correlations would be greatly improved. Such elision, however, is not justifiable unless it can be supported on valid *a priori grounds*. In the present instance no such grounds could be found, and the anomalous years were of necessity included with the rest of the seasons in the regressions. Further detailed study of the survival conditions in the corresponding brood seasons (1937–38 and 1939–40) should be made in order to determine the reasons for the anomalously high and low returns.

A suggestion as to the direction which such a study might follow has been made by Dr. L. A. Walford. He has pointed out to me that there is a general correspondence between salinities off California, as reported in his study of the relation between salinity and year-class strength in the sardine (Walford 1946), and the returns of salmon two years later. It is particularly noteworthy in connection with the anomalies mentioned above that the highest and lowest salinities reported in Walford's paper occur in 1939 and 1941, respectively. If the condition reflected in these salinities is coastwide, and if this condition encourages the growth of organisms on which salmon feed, a valid relationship may readily be postulated. With the present data it is not possible to obtain a significant correlation, but further study of the relationship should be made.

DISCUSSION AND CONCLUSIONS

One of the objectives mentioned in the introduction was to set forth in detail methods of calculating catch-per-unit-of-effort and of estimating abundance. It is believed that the second, third, and fourth major sections of this report present a sufficiently detailed explanation that anyone studying them can reproduce the calculations. Further, it is felt that the methods used are flexible enough so that they may be applied in other seasons and to other species of salmon.

The abundance index for chinook salmon should be extended back to the beginning of the available record at the earliest practicable moment (the writer was prevented from doing so by extraneous circumstances). When this has been done it will be possible to study the effect of changes in fishing intensity and other variables much greater than any that occurred during the 1935–45 period of the present report. Years subsequent to 1945 should also be added as soon as the data become available, in order to provide a continuing measure of abundance for current information.

The second major objective was to make a preliminary appraisal of factors influencing fluctuations in abundance. Four such variables have been considered: (1) The fishery through its effect on escapement, (2) stream flow through its effect on upstream and downstream migration, (3) winter temperature through its effect on survival of the incubating eggs, and (4) dams through their effect on upstream and downstream migration. It has been shown that the data of this study do not indicate any effect of (1) and (4) during the period covered, although there are undoubtedly effects which are obscured in the data by other variables.

Stream flow and temperature may be positively associated, but data were insufficient to establish a statistical significance. As both variables are known by direct observation to affect salmon reproduction, the correlations may be used as rough relative measures of the respective effects on fluctuations in return of adult salmon. Stream flow appeared to be about twice as important as temperature.

Regarding the course of abundance levels in general, the curves of figure 6 certainly do not indicate any well-marked trend, either upward or downward. Values of the catch-per-unit index (fig. 4) for the various parts of the fishing season (roughly indicative of broad changes in abundance level) show a decline for the spring and summer runs offset by an increase for the fall run. This finding is in keeping with current theories of fishery biologists studying the Columbia River salmon runs.

It is well in conclusion to reiterate once more the fact that this study has applied only to the chinook-salmon runs as they enter the river. The large ocean-troll-fishery takes its toll of the fish before they arrive at the locale of the analysis, and this toll may well have a considerable effect on abundance. Unfortunately, data susceptible of an abundance analysis are not available for the troll fishery for the period of this study.

SUMMARY

1. The source material of this study consists of cannery-ledger entries indicating the daily deliveries by certain selected gill-net fishermen, in pounds of chinook salmon, to receiving stations in the lower part of the Columbia River.

2. "Zero catches" were estimated on the basis that a fisherman would be considered fishing during a given week even though he made no catch, providing he made deliveries in either the preceding or the succeeding week, and providing that at least 10 percent of the other fishermen made only one catch.

3. Deliveries were summed in weekly units and compared with those of adjacent seasons, week by week and fisherman by fisherman.

4. Catch-per-fisherman-week data were linked into a series covering the 11 seasons 1935–45, using the "chain-link" method.

5. Total fishing effort expended in the Columbia River, in terms of 1940 gill-net fisherman-weeks, was computed by dividing the "inside" river catch by the catch-per-fisherman-week, for each year. In general the expenditure of effort was declining during the period of the study.

6. Catch-per-unit-of- effort index was converted to estimated size of return by use of the formula $p_2/p_1=f_2/f_1$, where f is fishing effort and p is "instantaneous rate of fishing mortality."

7. Estimated returns varied from 14.4 to 28.9 millions of pounds, with a mean of 19.4.

8. Estimated fishing intensity varied from 75 to 88 percent, with a mean of 81 percent.

9. Calculated escapements ranged for 2.23 to 6.04 millions of pounds. This range was not sufficiently great to permit the demonstration of a relationship between escapement and return.

10. Positive correlations (not statistically significant) suggested that stream flow is about twice as important as winter temperature in affecting fluctuations in return.

11. Ratio of return to escapement varied from 3.33 to 9.97, with a mean of 6.51.

12. No significant effect of Bonneville Dam could be demonstrated, either by comparing returns or by comparing ratios of return to escapement.

13. The season of 1941 was invariably high and 1943 invariably low in all regression treatments. A possible relation of these anomalies with ocean salinities is suggested.

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