UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

FISH AND WILDLIFE SERVICE
Ira N. Gabrielson, Director

Fishery Bulletin 39

FLUCTUATIONS IN ABUNDANCE OF RED SALMON, *Oncorhynchus nerka* (WALBAUM), OF THE KARLUK RIVER, ALASKA

By JOSEPH T. BARNABY

From FISHERY BULLETIN OF THE FISH AND WILDLIFE SERVICE
Volume 50

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1944

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. - - - - - - - Price 20 cents

ABSTRACT

Karluk River red salmon migrate to the ocean in their first to their fifth year. The majority migrate during their third or fourth year. They mature, and return to fresh water to spawn in their third to eighth year. The 5-year age group is dominant, with the 6-year age group next in importance. In the period from 1921 to 1936, the spawning escapements have fluctuated from 400,000 to 2,533,402 with an average escapement of 1,113,594. The fluctuations in the ratio of return to escapement have been considerable, and no correlation has been found to exist between escapement and return.

Certain adverse environmental conditions in the lake and tributary streams appear to have a deleteriou effect upon the young red salmon. Insufficient amounts of phosphorus and silica present in the lake waters is one such condition. This shortage of essential chemicals indirectly affects the production of zooplankton of the lake, and thus appears to indirectly affect the growth and survival of young salmon which depend upon zooplankton for food. A marked change is occurring in the percentage of fish of a given fresh-water history in the escapement, in relation to the percentage of fish of the same fresh-water history in the return. A higher percentage of fish spend 3 years in fresh water in the escapement than in the return, and a higher percentage of fish spend 4 years in fresh water in the return than in the escapement. Unless this relationship changes, the majority of salmon in the Karluk River runs will be fish that have spent 4 years in fresh water, whereas, formerly, the dominant age group was composed of fish that had spent 3 years in fresh water.

Seaward migration takes place during the last week of May and the first 2 weeks in June. The percentage of 4-year fingerlings decreased, and the percentage of 3-year fingerlings increased during the period of migration. Growth rate affects the time of migration, as the fastest growing individuals migrate first. Marking experiments at Karluk River have shown the amputation of the adipose and right, left, or both ventral fins to be better methods of marking than those which included the pectoral fins. The fresh-water mortality of Karluk River red salmon was found to be in excess of 99 percent. The average ocean mortality was 79 percent. The older and larger 4-year seaward migrants experienced a lower ocean mortality than the 3-year migrants; the average mortality of the former was 76 percent as compared to 83 percent for the younger age-group. Returns from marking experiments on the red salmon of Karluk River have been consistently greater than returns from similar experiments in other areas.

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INTRODUCTION

One of the major problems of the Federal Government on the Pacific coast is the conservation of the Alaska salmon resources which yield more than 280 million pounds of salmon to the commercial fisheries each year. In order to conserve these resources, so as to provide for an optimum yield each season, it has been found necessary to impose certain regulations on the fishing industry. These regulations aim primarily to provide an adequate escapement of the salmon to the streams each season so that they may reproduce and maintain the supply.[1]

Knowledge of fluctuations in the abundance of salmon populations provided the basis upon which the regulations were formulated. Since the commercial catch records gave insufficient and frequently unreliable information on the abundance of salmon, picket weirs were established in a number of important salmon rivers through which the fish were counted on their upstream migration to the spawning grounds. The count of the number of salmon migrating into a river, together with the record of the commercial catch in the locality of the river, furnished information

[1] Pacific salmon spend the early part of life in fresh water, the time spent there depending on the species and locality. They then migrate to the ocean and after a varying period of time return to fresh water to spawn. Fishery Bulletin 39. Approved for publication May 6, 1940.

on the magnitude of the total run during a particular season. It was soon evident, however, that information on the fluctuations in abundance was not sufficient. A knowledge of the causes of the fluctuations was both desirable and valuable in promulgating sound and adequate regulations.

The Karluk River on Kodiak Island, Alaska, was selected as an appropriate site for the study of the causal factors responsible for the yearly fluctuations in the abundance of a single population of red salmon, *Oncorhynchus nerka* (Walbaum). This river supports a commercial red-salmon fishery of considerable importance. The area in which the Karluk River red salmon are caught is confined to a readily delineated zone near the mouth of the river within which very few red salmon from other watersheds are taken, consequently the commercial catch can be determined quite accurately. The stream bed and water flow of the river are of such a nature that a counting weir for determining the number of salmon migrating upstream can be operated successfully throughout the season. Karluk Lake, the source of the river, and its tributaries are fairly accessible. Thus, this watershed fulfills admirably the requirements essential for a study of the biological background of the red salmon.

The White Act (43 Stat. 464–467; June 6, 1924) provided that there should be a 50 percent escapement of all salmon populations. Subsequent to the passage of that act, commercial fishing in the Karluk area has been so regulated that the catch of red salmon for a season has never exceeded the escapement. Unfortunately, this restriction of the commercial catch has not increased the size of the runs of red salmon in the river to the level of abundance that existed during the early years of the fishery. Factors other than the total number of salmon spawning in the river system each season have played an important role in the abundance of the runs. In this paper a statistical review is presented of the Karluk River red-salmon fishery from its inception in 1822 to 1936, together with a report on the major biological studies carried on to date.

STATISTICAL HISTORY OF THE FISHERY

Statistics of the catch of Karluk red salmon presented in this report are not always identical with those published by Gilbert and Rich (1927) but do agree for the years 1882 to 1920 with those given by Rich and Ball (1931) as these latter statistics are considered more reliable for this period. From 1921 to 1927, the statistics of the catch given herein are not identical with those presented by Rich and Ball, who include in their figures for the Karluk catch only those fish caught between Cape Karluk and Cape Uyak, although they mentioned that a large part of the fish caught to the northeast of Karluk in later years were Karluk fish. The development of the fishery between Cape Uyak and Uganik Bay resulted in the capture of a part of the Karluk run before it reached the mouth of the Karluk River. That fish caught as far north as Uganik Bay were chiefly derived from the Karluk run was shown by a tagging experiment (Rich and Morton 1929) carried on at West Point. The Karluk area, as defined in this report, includes all of the coast line between Cape Karluk and West Point on Kodiak Island.

TABLE 1.—*Catch of Karluk River red salmon from beginning of the canning industry in 1882 to 1936*

Year	Number of fish	Year	Number of fish	Year	Number of fish	Year	Number of fish
1882	58,800	1896	2,638,976	1910	1,492,544	1924	890,839
1883	188,706	1897	2,204,425	1911	1,723,132	1925	1,323,302
1884	282,184	1898	1,534,064	1912	1,245,275	1926	2,386,335
1885	468,580	1899	1,399,117	1913	868,422	1927	714,790
1886	646,100	1900	2,594,774	1914	540,455	1928	1,000,774
1887	1,004,500	1901	3,985,177	1915	828,429	1929	227,399
1888	2,781,100	1902	2,981,112	1916	2,343,104	1930	167,091
1889	3,411,730	1903	1,319,975	1917	2,324,492	1931	751,889
1890	3,148,796	1904	1,638,949	1918	1,094,665	1932	674,407
1891	3,500,588	1905	1,787,642	1919	1,089,809	1933	845,423
1892	2,852,458	1906	3,382,913	1920	1,368,526	1934	919,200
1893	2,909,508	1907	2,929,886	1921	1,643,119	1935	654,817
1894	3,349,976	1908	1,608,418	1922	658,159	1936	1,077,831
1895	2,055,984	1909	923,501	1923	730,170		

Table 1 gives the yearly catch of Karluk red salmon from the beginning of the commercial fishery in 1882 up to and including the season of 1936. There has been a marked decline in the abundance of the run of fish. The total runs (catch plus escapement) for the past 16 years (table 19) have averaged slightly over 2,000,000 fish per year, and the average yearly run for 12 of these years was less than 1,600,000 fish, whereas for the 7-year period, 1888 to 1894, inclusive, the catch alone averaged over 3,000,000 fish per year.

In table 2 are presented, for the period 1895 to 1921,[2] the coefficients of correlation[3] between the catches during the years of escapement and the catches 4, 5, and 6 years later, together with corresponding values of P.[4]

The values of P for 4-year and 6-year intervals are such that the coefficients of correlation cannot be considered statistically different from zero. The value of P for the 5-year interval is such that the coefficient of correlation can be considered statistically significant. It can be concluded from the fact that a statistically significant correlation of over 0.6 exists between the catches at 5-year intervals and that no statistically significant correlation exists between the catches at 4-year or 6-year intervals that the runs of Karluk red salmon from 1895 to 1921, inclusive, were composed largely of 5-year fish. Such a conclusion is verified by the age determinations based on examinations of scale samples taken during 1916, 1917, 1919, and 1921.

TABLE 2.—*Values of coefficients of correlation between catches during year of escapement and catches 4, 5, and 6 years later for the period 1895 to 1921, inclusive*

Yearly interval between catches	Number of pairs of catches correlated	r [1]	z [2]	t [3]	P [4]
4	23	0.236	0.241	1.076	0.2–0.3
5	22	.644	.765	3.341	.01
6	21	.375	.394	1.669	0.1–0.2

[1] Coefficient of correlation.
[2] Transformed coefficient of correlation.
[3] Ratio of z to the standard deviation of z.
[4] Probability that z is not different from zero.

[2] The data for the years 1895 to 1921 were used in this analysis as the fishing effort was fairly constant during this period.
[3] Where the relationship between two variables is found or assumed to be linear, the coefficient of correlation r measures the proportion of the variation in one variable which is associated with the second variable. As the number of pairs of observations are relatively small the method of analysis given by Fisher (1930, p. 163) was used.
[4] P is the probability that the value of the transformed coefficient of correlation z would have been obtained by chance, i. e., a value of P of 0.01 indicates that if the true value of z was 0.0 a value as large as the one obtained would occur only once in 100 random samples. The relationship between z and r is such that the values of P also indicate the statistical reliability of r.

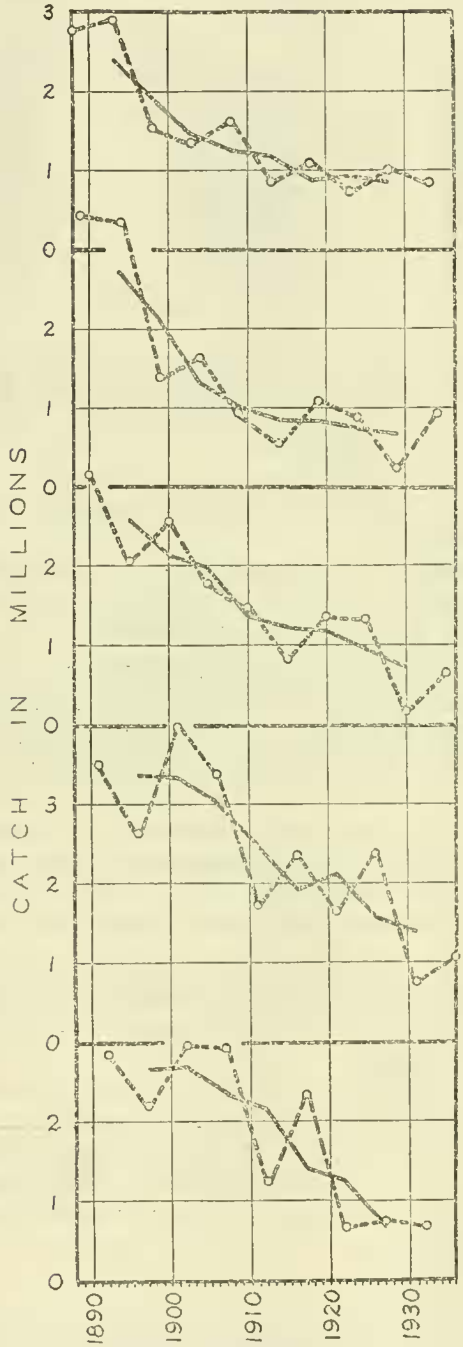

FIGURE 1.—Catch of red salmon at Karluk from 1888 to 1936, inclusive, arranged according to 5-year cycles. Solid line indicates trend.

It is evident from the statistical study of the catches of Karluk River red salmon and also from the analysis of the scale samples that the majority of the fish comprising the runs during the early years of the fishery were 5 years of age on attaining maturity. Therefore, the annual catches have been divided into five groups and the data are presented in figure 1. This method of presenting the data gives a clearer indication of the trend of catches from one cycle-year to another, as the catch of a particular year can be easily compared with the catch during a year 5 years previous to, or 5 years following that year. While these data represent the catches of red salmon, not the size of the runs for the various years, the nature of the fishing operations at Karluk from 1895 to 1921 was such that the fishing effort was fairly constant from year to year; hence the catches, in a measure, depict the relative size of the runs. The trend for each of the 5 cycles has been downward since the beginning of intensive fishing, and although such a condition might be due to a long period of unfavorable environmental conditions, it seems probably that overfishing must be largely responsible.

AGE AT MATURITY

One of the major problems involved in the study of the Karluk River red salmon is the determination of the approximate number of fish derived from each spawning population. This necessarily involves the determination of the approximate number of fish of each age group [5] found each year, but such a determination is by no means a simple matter. Karluk red salmon vary from 3 to 8 years in age, and the percentage occurrence of the various age groups changes throughout the season.

In addition to the wide spread in time of maturity of the Karluk River red salmon there is a further complication, in that fish of a given age have different combinations of fresh-water and ocean histories. Thus of the fish maturing in their fifth year, some migrate to the ocean in their second year, some in the third year, some in their fourth year, and some in their fifth year. These four groups of fish, with different fresh-water histories, may stay in the ocean 3, 2, 1, and 0 years (a few months), respectively, and all return in the fifth year as mature fish. This diversity in fresh-water and ocean history also occurs in the fish of other ages, so that 20 different age groups have been found in the samples collected for age determination, the complete list being as follows: 3_1, 3_2, 3_3, 4_1, 4_2, 4_3, 4_4, 5_2, 5_3, 5_4, 5_5, 6_2, 6_3, 6_4, 6_5, 7_3, 7_4, 7_5, 8_4, and 8_5.

The age of a fish may be determined with substantial accuracy by an examination of some of its scales under a microscope, but it is impossible to examine scales from every fish in the run. Recourse must be had to a process of sampling so that by the examination of the scales of a few thousand fish the age-group composition of the escapement and commercial catch can be calculated. Samples of scales are obtained for this purpose several times a week during each season from the fish caught in the seine fishery near the mouth of the river. It is fairly certain that the fish so caught are representative of the population of fish congregated near the mouth of the river

[5] The method, first used by Gilbert and Rich (1927), for designating the age of salmon is as follows: A fish resulting from an egg laid in the spawning gravels in 1930 and which migrated to the ocean in 1933 and returned to the river in 1935 is called a "five-three" and designated thus "5_3". Such a fish would have emerged from the gravels of the spawning beds in the spring of 1931 and would have spent two growing seasons, i. e., the summers of 1931 and 1932, in fresh water. In referring to its fresh-water history it is called a "three-fresh-water fish" because it migrated seaward in its third year. It would have spent two full growing seasons, i. e., 1933 and 1934, and part of a third year in the ocean; but in referring to its ocean history it is called a "two-ocean fish," because it returned as an adult in the second year following its seaward migration. A fish which migrated to the ocean in its fourth year and which returned in its sixth year is called a "six-four" and designated thus "6_4".

on the day of capture. Each scale sample contains scales from about 100 fish, these fish being taken at random from the day's catch. The scales are cleaned, mounted in sodium silicate between glass slides, examined under a microscope, and the age of the fish in the sample determined.

A preliminary study of the age-group composition of the various samples showed that the composition of the run changes throughout a season, and consequently it was found advisable to divide the season into a series of short successive periods of time. For the purpose of comparison these units of time should begin and end on the same dates each year, and so the scale samples, escapements, and runs have been grouped in 7-day periods which coincide from year to year.

Tables 3 to 16 give the age-group analyses of the several weekly samples taken in 1922, and in the years 1924 to 1936, inclusive. It will be seen from these tables that the age-group composition of the run changes considerably during the season, and also that the percentage occurrence of any one age group varies from year to year.

In considering the three principal age groups, 5_3, 6_3, and 6_4, it will be noted that 5_3 usually is the dominant age group present in the run. The percentage occurrence of the 6_3 age group always decreases as the season progresses, this age group never being important toward the end of the run. The percentage occurrence of the 6_4 age group generally increases as the season progresses. This age group, while seldom of importance in the early part of the season, usually is quite important in the latter part of the season.

The data included in tables 3 to 16 are of further value in that they are essential in calculating the percentage occurrence of the various age groups in the yearly escapements and in the returns from these escapements as given in tables 18 and 25, respectively. Since the salmon returning to Karluk each year from each of the previous spawning populations, or escapements, can be segregated according to age, the data in tables 3 to 16 are likewise essential in calculating the returns from known escapements. These returns are given in table 20.

TABLE 3.—*Percentage occurrence of each age group, during week, in the Karluk red-salmon run of 1922, determined by analyses of scale samples collected from a total of 2,469 fish*

Week ending—	Age groups											
	4_1	4_2	4_3	4_4	5_2	5_3	5_4	5_5	6_3	6_4	6_5	7_4
June 7	0.7				1.4	31.0			66.9			
June 14	.7	0.7			2.1	34.4			60.7	1.4		
June 21	.6	.7			.7	36.1	1.3		58.7	1.9		
June 28			2.2		1.3	32.3	.9		60.3	3.0		
July 5		.7				37.3	.7		56.0	5.3		
July 12						36.0	2.7		51.3	10.0		
July 19		.6	.6			62.0	.7		26.7	8.7		0.7
July 26		.6				76.0	.7		18.0	4.0		.7
Aug. 2						69.3			21.3	8.0	0.7	.7
Aug. 9		.7	1.3			72.0			16.6	8.7		.7
Aug. 16		.7	.7			87.2	.7		8.7	2.0		
Aug. 23		1.3				85.3	.7		6.7	6.0		
Aug. 30		1.4	.7			77.0	2.0		2.7	16.2		
Sept. 6		.7	.7	0.7		80.1	3.3		3.3	11.2		
Sept. 13		.6	2.7			91.1	2.1		1.4	2.1		
Sept. 20		2.0	2.7	1.4		87.8	2.0	0.7	1.4	2.0		

TABLE 4.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1924, determined by analyses of scale samples collected from a total of 5,132 fish*

Week ending—	Age groups										
	3_3	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_3	6_4	7_4
June 14			0.7	1.7		0.9	80.8	0.2	11.0	3.6	1.1
June 21			.6	2.2		.8	81.4	1.1	6.1	7.2	.6
June 28			.2	1.9		.2	84.3	.6	6.3	6.1	.4
July 5				5.0		.8	76.2	1.7	6.3	9.6	.4
July 12		0.2	.4	.4		1.1	75.3	.4	5.7	16.3	.2
July 19			.3			.1	73.1		5.7	19.9	.9
July 26			.9	.3			73.5	.2	4.8	19.7	.6
Aug. 2			.3	.6			77.6	.1	3.4	17.7	.3
Aug. 9				1.6		.3	71.0	.3	2.4	24.4	
Aug. 16				.9			81.0		.9	17.2	
Aug. 23			.3	4.2			75.8	4.7		15.0	
Aug. 30	0.2			2.9	0.7		77.3	2.2	1.0	15.7	
Sept. 6	.2			9.2	.4		63.3	15.1		11.8	
Sept. 13				6.9	2.8		66.1	13.2	.1	10.9	
Sept. 20				9.7	2.8		64.9	11.4	.9	10.3	

TABLE 5.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1925, determined by analyses of scale samples collected from a total of 5,518 fish*

Week ending—	Age groups										
	3_1	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_4
June 7			0.8	0.8		69.2		26.7	2.5		
June 21			.9	2.4	0.5	72.4		18.1	5.2		0.5
June 28			6.5	2.0	.2	69.1	0.2	13.9	7.7		.4
July 5		0.2	3.8	4.4		70.4	.8	10.5	9.0		.9
July 19	0.2	.2	3.3	1.2	1.0	69.6	.4	3.7	19.6		.8
July 26		1.1	1.5	.9		69.2	.2	1.5	25.2		.4
Aug. 2	2.0	.2	1.8	1.5	.1	72.7	.2	.7	20.7		.1
Aug. 9	.5		1.2	1.1	.2	75.1	.7	1.9	18.4		.9
Aug. 16	1.5	.3	1.3	3.9	.4	77.2	1.0	.6	13.0		.8
Aug. 23	.4	.3	.4	9.5	.2	70.7	1.6	.4	16.3		.2
Aug. 30			.3	10.2		69.3	2.8		17.4		
Sept. 13				10.6		52.1	7.6		29.5	0.2	

TABLE 6.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1926, determined by analyses of scale samples collected from a total of 8,172 fish*

Week ending—	Age groups													
	3_1	4_1	4_3	4_3	4_4	5_2	5_3	5_4	6_3	6_4	6_5	7_4	7_5	8_4
May 24			4.8	0.8		4.8	77.6		0.6	1.6		0.8		
May 31			4.5	.6		1.3	79.0		12.0	2.1		.5		
June 7			4.4	.8		.4	83.2		8.0	2.8		.4		
June 21			3.9	.7		2.3	77.9		13.4	1.6		.3		
June 28			5.3	1.9		2.4	75.8	0.2	10.9	3.0		.6		
July 5		0.3	7.5			3.4	71.7		9.9	6.8		.4		
July 12		.2	6.9	.4		2.4	75.4		9.1	5.2		1.2		0.2
July 19	0.4	.9	3.8			7.7	69.2		8.3	8.4		1.3		
July 26	.9	1.3	2.4			2.0	74.5		4.5	12.1		2.0	0.3	
Aug. 2	.4	.4	.6	.2		.8	81.5		4.0	11.2		.9		
Aug. 9			.6	.2		.2	82.4		3.0	12.3		1.1	.2	
Aug. 16	.3	1.0	.3	.7		.3	81.9	.5	2.4	10.2		1.9	.5	
Aug. 23	.2	1.1	.3	.2	0.2		86.1	.3	1.0	9.7	0.2	.7		
Aug. 30	.4	.7	.2	.5			84.3	.5	.7	12.3		.4		
Sept. 6	.2	.2		.2			83.6	.2	.2	15.1			.3	
Sept. 13		.2	.3	.2			79.0	.8	.3	18.9	.1	.1	.1	
Sept. 20			2.0	1.0			79.6			16.4	1.0			

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TABLE 7.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1927, determined by analyses of scale samples collected from a total of 4,963 fish.*

Week ending—	Age groups													
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_3	6_4	6_5	7_4	7_5	8_5
May 31				3.0		10.6	69.7	1.5	15.2					
June 7			0.4	.4		13.1	69.9		15.3			0.9		
June 14				.4		9.1	77.3		12.2	0.3		.7		
June 21				1.0		13.0	79.0		7.0					
June 28			.2	2.2		5.7	80.3	.4	10.8	.4				
July 5			.8	.6		9.4	73.8	.8	12.6	1.4		.6		
July 12			.8	.8		5.6	79.6	.3	11.2	1.5		.2		
July 19			1.5	1.0		4.5	76.5	1.0	9.5	6.0				
July 26				4.0		3.0	78.0	3.0		10.0		2.0		
Aug. 2				1.7		1.4	78.2	1.0	3.1	13.6		1.0		
Aug. 9				2.7		1.9	76.9	1.7	3.4	11.2		1.7	0.5	
Aug. 16		1.0	.2	4.4		1.4	69.9	3.6	4.8	12.7	0.2	1.0	.6	0.2
Aug. 23	0.2	1.0	.5	6.3		.5	66.0	2.8	2.5	20.0		.2		
Aug. 30		.2	.4	7.4		.6	58.1	8.4	.8	23.5		.6		
Sept. 13				6.7	0.4	.4	49.2	14.4	1.5	25.9	.4		1.1	

TABLE 8.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1928, determined by analyses of scale samples collected from a total of 4,247 fish.*

Week ending—	Age groups									
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_4	7_5
June 14		0.5			54.5		44.5	0.5		
June 21			1.0		60.0		36.0	3.0		
June 28		.8		0.3	44.8		51.6	2.5		
July 5		.5	.4		49.7		44.5	4.9		
July 12			.3		41.8		51.4	6.2	0.3	
July 19	0.3		.3	.7	48.3		35.0	13.0	2.4	
July 26		.5	.5	.5	66.3	0.3	18.2	12.4	1.3	
Aug. 2		1.3		.7	60.7		13.7	19.3	4.0	0.3
Aug. 9		.5			72.0		9.6	15.5	2.5	
Aug. 16			.3		76.7		6.0	16.3	.7	
Aug. 23		1.0			78.5	1.5	3.0	15.0	.5	.5
Sept. 6		.3	.5		64.5	1.2	3.5	29.8	.2	
Sept. 13		1.0	3.0		43.0	2.0	4.0	46.0	1.0	
Sept. 20			.3		42.3	2.0	2.7	51.3	.7	.7
Sept. 27			1.0		35.0	4.0	1.0	59.0		

TABLE 9.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1929, determined by analyses of scale samples collected from a total of 1,602 fish*

Week ending—	Age groups									
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_3	7_4
June 21		2.0		2.0	39.9		50.2	3.3	1.3	1.3
June 28		.8	0.8	1.9	40.2	0.4	51.7	3.1		1.1
July 5					40.4		58.9	.7		
July 12		.7			42.4		54.1	2.8		
July 19				.8	35.3		57.2	4.2		2.5
July 26				.8	54.7	.8	31.0	11.9		.8
Aug. 2			6.9		61.4		9.9	19.8		2.0
Aug. 9	0.4		1.4		47.9	.9	16.3	31.2		1.9
Aug. 16		2.3			42.4		30.3	24.2		.8
Aug. 23					50.9		14.8	32.4		1.9
Aug. 30					26.7		6.7	66.6		
Sept. 6					19.6		3.4	75.8		
Sept. 13					12.5			85.0		2.5
Sept. 20					19.4	1.2		78.2		1.2
Sept. 27					26.2	2.4		71.4		

TABLE 10.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1930, determined by analyses of scale samples collected from a total of 3,617 fish*

Week ending—	Age groups									
	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_3	7_4	7_5
May 17	-------	1.7	1.7	17.2	-------	70.8	1.7	-------	6.9	-------
June 14	-------	-------	1.3	51.9	1.3	33.9	10.3	-------	1.3	-------
June 21	-------	1.1	1.1	58.9	1.6	23.2	14.1	-------	-------	-------
June 28	0.5	1.2	3.4	51.2	4.3	29.2	9.7	-------	.5	-------
July 26	-------	.7	-------	70.7	.8	13.1	13.9	-------	.7	-------
Aug. 2	-------	.6	-------	76.4	2.3	8.2	11.7	-------	.8	-------
Aug. 9	-------	1.1	.5	79.2	1.6	10.1	5.7	-------	1.8	-------
Aug. 16	-------	1.5	-------	73.6	2.0	4.6	14.2	-------	4.1	-------
Aug. 23	-------	2.3	-------	62.0	3.3	1.9	27.9	0.3	2.3	-------
Aug. 30	.2	5.0	.2	49.5	10.0	4.1	30.0	-------	1.0	-------
Sept. 13	-------	10.6	-------	36.9	32.5	.4	18.6	-------	.7	0.3
Sept. 20	-------	12.2	-------	23.8	40.2	1.2	21.4	-------	1.2	-------

TABLE 11.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1931, determined by analyses of scale samples collected from a total of 7,258 fish*

Week ending—	Age groups												
	3_1	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_3	7_4	7_5
May 31	-------	-------	1.4	-------	0.7	48.6	-------	12.6	34.2	-------	-------	2.5	-------
June 7	-------	-------	1.6	0.9	1.2	41.8	0.5	20.4	31.5	0.2	-------	1.9	-------
June 14	-------	-------	4.4	1.3	.6	33.4	-------	22.2	36.6	-------	-------	1.2	0.3
June 21	-------	-------	2.6	.3	1.1	37.5	.3	18.9	35.2	-------	0.3	3.8	-------
June 28	0.2	-------	1.9	1.4	.4	47.1	1.4	11.5	34.2	-------	-------	1.9	-------
July 5	-------	0.5	9.9	.5	-------	50.5	.5	8.0	29.2	-------	-------	.9	-------
July 12	-------	-------	2.5	.2	1.0	51.8	1.7	9.5	31.8	-------	-------	1.3	.2
July 19	-------	-------	1.4	-------	-------	60.3	.3	8.0	28.4	-------	-------	1.4	.2
July 26	.2	-------	1.7	.5	.6	58.5	.3	7.6	29.3	-------	-------	1.1	.2
Aug. 2	-------	-------	.2	.4	.3	64.9	.2	4.9	28.6	-------	-------	.3	.2
Aug. 9	-------	-------	.3	.5	.3	68.7	.2	3.0	26.3	-------	-------	.6	.1
Aug. 16	-------	-------	.3	.6	.3	72.5	.3	1.2	23.9	-------	-------	.9	-------
Aug. 23	-------	-------	-------	-------	-------	62.9	3.9	.6	32.3	-------	-------	.3	-------
Aug. 30	-------	-------	-------	.2	-------	56.7	1.8	1.2	40.1	-------	-------	-------	-------
Sept. 6	-------	-------	.4	.6	-------	43.0	4.1	.2	51.5	-------	-------	.2	-------
Sept. 13	-------	-------	.4	-------	.9	35.7	9.0	-------	52.9	.7	-------	.4	-------
Sept. 20	-------	-------	.2	1.1	-------	26.2	13.6	-------	58.5	.4	-------	-------	-------
Sept. 27	-------	-------	.5	.5	-------	37.0	9.0	.5	51.5	.5	-------	-------	.5

TABLE 12.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1932, determined by analyses of scale samples collected from a total of 4,700 fish*

Week ending—	Age groups									
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_4	7_5
May 24	-------	-------	1.0	1.0	73.0	1.0	6.0	7.0	11.0	-------
May 31	-------	1.0	-------	-------	67.0	-------	11.0	13.0	8.0	-------
June 7	-------	-------	2.0	1.0	75.0	-------	7.0	8.0	7.0	-------
June 14	-------	1.5	-------	.5	82.0	-------	4.0	7.5	4.5	-------
June 21	-------	1.2	-------	.8	78.4	-------	3.6	11.2	4.8	-------
June 28	-------	3.3	1.0	3.3	65.8	.3	8.7	12 3	5.3	-------
July 5	-------	4.9	1.3	8.7	54.4	1.3	9.1	15.6	4.0	0.7
July 12	-------	4.0	1.1	7.4	59.5	5.1	6.3	14.3	2.3	-------
July 19	0.5	2.0	.5	3.5	67.5	1.0	5.5	17.0	2.0	.5
July 26	1.3	1.3	-------	4.7	72.7	.3	5.7	13.0	1.0	-------
Aug. 2	.2	1.8	.7	1.3	62.2	.4	9.3	21.6	1.6	.9
Aug. 9	.7	1.8	2.3	.5	43.4	1.3	9.0	38.5	1.8	.7
Aug. 16	.5	.2	.2	.5	30.3	1.8	6.0	59.0	.5	1.0
Aug. 23	-------	.5	1.0	-------	15.5	.5	3.5	77.5	.5	1.0
Aug. 30	-------	.3	.5	-------	16.6	1.4	2.6	76.9	.3	1.4
Sept. 20	-------	1.2	.8	-------	16.0	6.0	.8	73.6	-------	1.6

TABLE 13.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1933, determined by analyses of scale samples collected from a total of 3,867 fish*

Week ending—	Age groups											
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_3	7_4	7_5
June 7	-	0.5	0.3	1.3	65.3	0.2	21.3	9.8	-	0.2	1.1	-
June 14	0.2	.3	.3	2.2	54.3	.3	29.6	11.8	-	-	1.0	-
June 21	.2	1.1	.5	2.8	51.5	.6	26.3	15.7	0.2	-	.9	0.2
June 28	-	1.0	-	4.8	56.6	-	15.4	21.2	-	-	1.0	-
July 5	-	.9	2.8	11.2	44.0	.9	23.4	14.0	-	-	2.8	-
July 12	-	.5	-	4.2	51.1	-	18.6	22.8	-	-	1.9	.9
July 19	-	-	.7	1.4	55.6	.7	13.2	27.1	-	-	1.1	.2
July 26	-	.5	-	2.0	57.4	-	6.9	31.2	-	-	1.0	1.0
Aug. 30	-	-	-	.5	58.6	4.7	1.4	29.6	-	-	1.9	3.3
Sept. 6	-	.7	-	-	42.7	2.8	-	51.7	-	-	.7	1.4
Sept. 13	-	-	1.2	-	22.0	4.0	1.0	68.0	-	-	.5	3.3
Sept. 20	-	-	.5	-	23.0	1.5	1.5	65.5	-	-	2.0	6.0

TABLE 14.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1934, determined by analyses of scale samples collected from a total of 6,551 fish*

Week ending—	Age groups										
	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_4	7_5	8_5
May 24	1.3	-	-	39.5	-	47.4	11.8	-	-	-	-
May 31	-	-	2.9	47.2	2.9	38.2	5.9	-	2.9	-	-
June 7	.6	0.4	3.2	25.4	.2	53.6	11.4	-	5.2	-	-
June 14	.8	.3	2.4	27.9	.3	54.3	10.2	-	3.6	-	0.2
June 21	.5	.2	1.2	26.0	.5	62.8	6.0	-	2.6	0.2	-
June 28	.5	-	.7	31.5	.7	48.8	14.7	-	3.1	-	-
July 5	28.6	-	3.7	18.8	-	36.4	8.4	-	3.9	.2	-
July 12	23.9	-	3.3	23.5	-	29.4	15.8	-	4.1	-	-
July 19	5.5	-	.7	31.4	-	35.8	23.3	-	3.3	-	-
July 26	1.5	-	.7	30.8	-	27.5	37.2	-	2.1	.2	-
Aug. 2	1.8	-	.8	36.4	.3	22.4	35.8	-	2.3	.2	-
Aug. 9	1.2	-	-	37.3	.4	16.4	42.9	-	1.8	-	-
Aug. 16	.4	-	-	33.7	.8	8.6	54.9	-	1.6	-	-
Aug. 23	-	-	-	40.3	-	6.1	52.1	-	1.5	-	-
Sept. 13	-	0.4	-	25.2	1.4	3.2	67.6	0.4	1.4	.4	-
Sept. 20	-	-	-	30.2	2.0	3.6	63.8	-	-	.4	-

TABLE 15.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1935, determined by analyses of scale samples collected from a total of 7,152 fish*

Week ending—	Age groups															
	3_2	4_1	4_2	4_3	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
June 7	-	-	4.6	1.0	4.1	20.2	1.7	0.5	40.2	15.1	-	0.2	12.0	0.2	0.2	-
June 14	-	-	3.2	1.6	1.8	36.5	1.2	-	28.2	15.8	0.1	.5	10.7	.3	-	-
June 21	-	-	9.0	1.9	3.3	33.2	1.4	.1	24.2	16.0	-	.2	10.2	.4	-	0.1
June 28	-	-	16.0	6.6	5.8	29.7	2.7	-	19.3	13.5	-	-	6.4	.2	-	-
July 5	0.1	-	11.5	4.2	7.5	30.7	2.2	-	20.5	13.6	-	-	9.6	.1	-	-
July 12	-	1.4	3.7	5.1	6.0	35.8	3.7	-	24.7	11.6	.5	-	7.0	.5	-	-
July 19	-	2.4	8.2	.6	9.5	46.3	.6	-	12.6	15.6	.2	-	3.4	.6	-	-
July 26	-	.8	4.7	1.2	4.6	59.2	.7	-	9.0	17.7	-	-	1.6	.3	-	.1
Aug. 2	-	.5	1.5	2.1	1.1	55.4	1.5	-	8.3	25.5	.2	-	3 2	.6	-	-
Aug. 9	-	-	1.7	3.3	.8	54.1	1.7	-	4.2	31.7	-	-	2.5	-	-	-
Aug. 23	-	.4	.7	16.6	.2	21.4	3.9	-	3.0	47.3	-	-	.1	2.4	-	-
Aug. 30	-	-	-	16.7	-	19.2	6.7	-	.8	54.2	.8	-	.8	.8	-	-
Sept. 20	-	-	-	8.0	-	28.0	8.0	-	-	44.0	-	-	-	12.0	-	-
Oct. 2	-	-	-	-	-	3.0	19.0	-	3.0	69.0	3.0	-	-	3.0	-	-

TABLE 16.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1936, determined by analyses of scale samples collected from a total of 7,093 fish*

Week ending—	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
June 7			0.8	2.8		4.9	62.0	0.1		13.4	10.6		0.1	4.9	0.3	0.1	
June 14			2.5	3.8		5.0	58.8	.4	0.1	13.9	11.2		.1	3.7	.4		0.1
June 21			1.5	2.5		7.5	65.6	.4		10.9	8.5			2.7	.4		
June 28			.5	2.7		6.7	66.3	.5		11.5	8.6		.3	2.4	.5		
July 5			1.2	4.9		1.2	64.7	1.2		14.6	3.7		1.2	6.1		1.2	
July 12			4.3	3.6		27.7	49.5	.2	.5	9.7	2.8			1.5			.2
July 19		0.1	2.2	2.1		5.3	57.4	.3		16.6	11.0			4.9	.1		
July 26	0.1	.3	2.0	.7		4.4	76.1		.1	6.8	8.6			1.6	.5		
Aug. 2				.7			82.3	.3		6.8	8.0			1.3	.6		
Aug. 30				.2			75.3	5.6		1.8	14.2			1.6	1.3		
Sept. 6							72.2	7.4		1.9	15.8			1.8	.9		
Sept. 13				1.1	0.5	.3	64.3	6.4		.6	22.3			.3	4.2		
Sept. 20				.6		.6	71.2	1.3		3.2	21.2			1.3	.6		
Sept. 27				.9			61.5	5.6		1.5	22.8	0.3		1.2	6.2		
Oct. 4				1.4			60.6	2.8		1.4	29.6			1.4	2.8		

SPAWNING POPULATIONS

The determination of the size of the escapement, or spawning population, of a river or district is of vital importance in intelligently administering the fishery. In a self-perpetuating salmon population an adequate part of the yearly run must be allowed to escape the fishery and continue uninterrupted to the spawning grounds in order to insure future supplies of fish. Not only must a proper number of fish be allowed to escape in a given area or district, but each individual salmon stream, and in large watersheds, each small area in the watershed, must receive a sufficient escapement if adequate runs of fish are to be maintained. Under natural conditions, an extremely high percentage of the fish returning to spawn proceed to the same area where they emerged from the spawning gravel as fry. There is a slight degree of straying, but the fact remains that if a spawning area has not been seeded, there will not be a run of fish returning to that area in one or more subsequent years. Thus, large river systems such as the Kvichak, Copper, Fraser, Columbia, and others, must not only receive an escapement sufficient in number, but the fish must be distributed in the proper proportions to the various tributaries in the river system. If a part of the spawning area in a given watershed be depopulated for a period of time, the chief hope of restoring the productivity of that watershed to its maximum value would be to restock the depleted area by the planting of eggs or fry for a period of several consecutive years, an expensive undertaking which would have no positive assurance of success.

The determination of the magnitude of the escapement of Karluk River red salmon is important not only in regulating the commercial fishery, but is also another of the major problems involved in the biological study of this population. The calculation of the total size of populations, the returns from known spawning populations, the mortality in fresh water, and the mortality in the ocean are based upon a knowledge of the number of fish entering the river each season to spawn.

Table 17 gives the weekly escapements of red salmon to the Karluk River for the years 1921 to 1936, inclusive. The escapement records are complete except for 1921, 1922, 1924, and 1934. In 1921, the first year the weir was operated, it was removed on September 18, as the companies fishing in the Karluk area were about to discontinue canning, and the importance of keeping the weir in to the end of the season was not appreciated. The counted escapement was 1,325,654 and Gilbert and Rich (1927) estimated that the total escapement that year was approximately 1,500,000 red salmon.

TABLE 17.—*Escapements and cumulative totals of the escapements of Karluk red salmon for each week from 1921 to 1936*

Week ending—	1921		1922		1923		1924		1925	
	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands
May 24			60		141		402		19	
May 31	5,894	6	418		1,102	1	4,149	5	30,249	30
June 7	16,254	22	9,921	10	71,724	73	86,111	91	32,733	63
June 14	155,097	177	8,355	19	28,843	102	148,417	239	20,440	83
June 21	137,334	315	56,739	75	42,169	144	127,645	367	263,029	346
June 28	195,151	510	29,897	105	62,954	207	64,913	432	211,021	557
July 5	74,291	584	46,770	152	35,647	243	57,674	489	34,298	592
July 12	72,556	657	24,336	177	9,274	252	39,837	529	39,927	632
July 19	28,668	685	19,660	196	3,497	255	10,882	540	25,447	657
July 26	19,737	705	6,877	203	31,491	287	25,659	566	24,482	682
Aug. 2	70,954	776	8,035	211	24,691	312	57,894	624	64,752	746
Aug. 9	96,677	873	19,403	231	66,404	380	36,263	660	110,570	857
Aug. 16	114,102	987	7,919	238	13,036	391	61,502	721	95,852	953
Aug. 23	58,867	1,046	5,595	244	48,610	440	54,357	776	19,705	973
Aug. 30	79,316	1,125	(2)		38,467	478	(1)		33,797	1,006
Sept. 6	42,974	1,168	(2)		27,919	506			200,247	1,207
Sept. 13	143,022	1,311	24,343	285	61,389	567			74,730	1,281
Sept. 20	14,760	1,326	35,618	321	43,217	611			100,431	1,382
Sept. 27	(1)		61	321	10,570	621			51,814	1,443
Oct. 4			15,721	336	62,641	684			182,763	1,616
Oct. 11			29,116	365	9,110	693			4,619	1,621
Oct. 18			34,336	400	1,683	695				
Oct. 25			236	400						
Total	[3] 1,500,000		[3] 400,000		694,576		[3] 1,109,161		1,620,927	

Week ending—	1926		1927		1928		1929		1930	
	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands
May 24	577	1			41		22		1,008	1
May 31	80,704	81	9,539	10	13,600	14	838	1	1,128	2
June 7	479,455	661	52,532	62	152,569	166	75,305	76	42,352	44
June 14	437,051	998	209,213	271	303,976	470	85,347	162	21,808	66
June 21	127,537	1,125	188,798	460	97,503	568	116,624	278	228,405	295
June 28	45,520	1,171	85,010	545	75,234	643	50,171	328	35,018	330
July 5	41,516	1,212	51,492	597	55,817	699	12,228	341	22,427	352
July 12	43,339	1,256	13,965	611	36,723	735	10,376	351	10,064	362
July 19	34,277	1,290	7,064	618	20,048	756	9,656	361	6,901	371
July 26	30,300	1,320	2,926	621	21,781	777	1,125	362	4,706	376
Aug. 2	77,956	1,398	12,454	633	3,514	781	21,241	383	42,939	419
Aug. 9	101,703	1,500	53,219	686	22,734	804	24,725	408	82,949	542
Aug. 16	80,647	1,581	19,461	706	31,255	835	27,343	435	62,714	564
Aug. 23	104,139	1,685	7,421	713	71,015	906	69,210	504	98,491	663
Aug. 30	224,592	1,909	8,456	722	67,857	974	69,552	574	6,162	669
Sept. 6	230,498	2,140	15,392	737	19,966	994	35,960	610	118,970	788
Sept. 13	91,136	2,231	10,007	747	22,591	1,016	109,916	720	65,392	853
Sept. 20	176,939	2,408	43,245	790	14,929	1,031	93,918	814	60,590	914
Sept. 27	49,609	2,457	1,294	791	7,471	1,039	13,950	828	135,468	1,049
Oct. 4	9,448	2,467	72,559	864	167	1,039	72,667	900	1,488	1,051
Oct. 11	43,314	2,510	8,491	873	45,952	1,085	145	900	45,531	1,097
Oct. 18	23,145	2,533			9,074	1,094				
Oct. 25										
Total	2,533,402		872,538		1,093,817		900,319		1,096,511	

See footnotes at end of table.

TABLE 17.—*Escapements and cumulative totals of the escapements of Karluk red salmon for each week from 1912 to 1936*—Continued

Week ending—	1931		1932		1933		1934		1935		1936	
	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands
May 24	1,250	1	34	--------	283	--------	878	1	7	--------	32	--------
May 31	11,342	13	1,087	1	2,101	2	1,631	3	22,999	23	38,560	39
June 7	50,382	63	48,191	49	24,581	27	201,544	204	138,867	162	144,208	183
June 14	109,047	172	150,058	199	204,014	231	169,718	374	172,726	335	93,157	276
June 21	34,594	207	55,616	255	84,840	316	233,626	607	64,249	399	82,700	359
June 28	38,913	246	66,583	322	65,221	381	118,167	726	31,440	430	79,290	438
July 5	29,930	275	26,695	348	46,621	428	20,870	746	3,812	434	57,411	495
July 12	9,117	285	11,803	360	61,665	489	6,748	753	3,108	437	11,378	507
July 19	3,167	288	5,903	365	23,519	513	6,325	760	374	438	3,825	511
July 26	1,756	289	6,305	372	6,923	519	5,431	765	3,723	441	11,042	522
Aug. 2	6,191	296	10,878	383	16,454	535	3,196	768	2,836	444	2,201	524
Aug. 9	12,541	308	14,963	398	40,509	576	23,341	791	32,513	477	1,087	525
Aug. 16	54,209	362	23,403	422	6,126	581	3,943	795	30,983	508	34,950	560
Aug. 23	75,989	438	8,877	430	49,972	631	[4] 5,847	--------	52,513	560	44,451	604
Aug. 30	106,362	545	12,541	443	100,890	732	(2)	--------	19,571	580	130,582	735
Sept. 6	89,360	634	28,062	471	14,218	746	(2)	--------	12,631	592	311,917	1,047
Sept. 13	121,464	756	1,778	473	145,679	802	(2)	--------	151,051	743	204,980	1,252
Sept. 20	115	756	87,785	561	31,468	923	[4] 1,319	1,103	353	744	27,749	1,280
Sept. 27	64,601	820	120,082	681	1,885	925	43,072	1,146	115,249	859	81,156	1,361
Oct. 4	41,671	862	47,078	728	4,056	929	626	1,146	17,319	876	14,622	1,375
Oct. 11	11,427	873	10,050	738	67,540	987	17	1,146	11	876	361	1,376
Oct. 18	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Oct. 25	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Total	873,428	--------	737,772	--------	986,765	--------	[3] 1,146,299	--------	876,335	--------	1,375,659	--------

[1] Escapement to end of season estimated; see text.
[2] Escapement for these periods estimated; see text.
[3] Estimated; see text.
[4] Escapement for only a part of these weeks; see text.

In 1922, there was a large escapement of pink salmon in the Karluk River, and toward the end of their spawning season the carcasses of the fish that had finished spawning and died began drifting down stream against the weir. Although a crew was engaged in removing the dead fish from the face of the weir, it finally became impossible to remove them as fast as they accumulated. As the fish piled up against the weir, they obstructed the passage of water until there was danger of the weir collapsing from the weight of the impounded water, and consequently, a number of pickets were removed from the weir so as to allow the pink salmon carcasses to pass downstream. The weir was not in use from August 21 to September 4, inclusive. It was replaced on September 5, and the counting of fish was continued until the end of the season. The counted escapement was 383,446, and it is estimated that the total escapement that year was approximately 400,000 red salmon.

In 1924, there was a tremendous run of pink salmon to the Karluk River and, as in 1922, it was impossible to keep the weir in operation due to the dead pink salmon drifting down against it. The weir was not replaced that season, so that it is necessary to estimate the escapement from August 21 to the end of the season. The counted and partially estimated escapement was 775,705. Gilbert and Rich (1927) estimated that the total run that year was approximately 2,000,000 fish. Subtracting the catch from this figure leaves about 1,100,000 as the number of red salmon in the escapement.

In 1934, it was again impossible to keep the weir in continuous operation due to spawned-out pink salmon damming the weir and to extremely high water in the river caused by the run-off of heavy fall rains. The weir was out from August 22 to September 17, inclusive, a period of 27 days. It was replaced on September 18, and counting was continued until the end of the season. Unfortunately, fishing for that season stopped on August 18, and catch data are not available from which to judge the relative abundance of fish in the run. Data on the trend of abundance of the various age groups in the run up to August 18 have been examined and compared with data for previous years, and from this analysis it is estimated that the escapement during the period was approximately 300,000 red salmon. The counted escapement during the period the weir was in operation was 846,299.

The weir is located approximately 4 miles from the mouth of the river and in this 4-mile stretch the river widens out to form a lagoon, the lower end of which is usually slightly brackish. The fish, after entering the mouth of the river, stay in this lagoon for a varying period of time, averaging about 1 week, before they proceed up the river through the weir. Consequently, in calculating the age-group composition of the escapement, the percentages of the various age groups in one 7-day period, as determined by an analysis of the scale samples, (tables 3 to 16) were applied to the escapement of the following 7-day period.

The percentage occurrences of the various age groups in the spring, fall, and total escapements for the years 1922 and 1924 to 1936, inclusive, are presented in table 18. There was a considerable fluctuation in the percentage occurrence of the principal age groups in the escapement from year to year. The percentage of the three principal age groups in the total escapements ranged from 24.1 to 81.1 for the 5_3 group; 4.0 to 38.6 for the 6_4 group; and from 4.5 to 32.8 for the 6_3 group.

This variation in the age composition of the escapements was due mainly to the fact that each year's escapement is composed of returns from several brood years. For example, a single escapement may be composed of 5-year fish from a brood year producing a small run, together with 6-year fish from a brood year producing a large run. In this instance the percentage of 5-year fish would be below average, and the percentage of 6-year fish would be above average. However, if the 5-year fish were from a very productive brood year and the 6-year fish were from a less productive brood year, the results would be just the reverse.

TABLE 18.—*Percentage occurrence of the various age groups in the spring, fall, and total escapements of 1922, and of 1924 to 1936, inclusive*

Year of escapement	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	5_5	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_5
1922:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Spring	-----	0.4	0.4	0.5	-----	1.2	34.3	0.8	-----	-----	59.3	3.1	-----	-----	-----	-----	-----
Fall	-----	-----	1.2	1.7	0.6	-----	83.2	1.7	0.3	-----	6.1	5.0	0.1	-----	0.1	-----	-----
Escapement for year	-----	.2	.8	1.1	.3	.6	59.3	1.3	.1	-----	32.2	4.0	-----	-----	.1	-----	-----
1924:																	
Spring	-----	-----	.6	2.0	-----	.8	80.8	.5	-----	-----	9.4	5.0	-----	-----	.9	-----	-----
Fall	-----	-----	.2	4.3	.8	-----	71.7	5.7	-----	-----	1.5	15.7	-----	-----	.1	-----	-----
Escapement for year	-----	-----	.4	3.2	.4	.4	76.0	3.2	-----	-----	5.4	10.5	-----	-----	.5	-----	-----
1925:																	
Spring	-----	-----	1.4	2.0	-----	.3	71.0	.1	-----	-----	19.8	5.0	-----	-----	.4	-----	-----
Fall	0.3	.1	.6	7.4	-----	.1	63.8	3.8	-----	-----	.5	23.1	.1	-----	.2	-----	-----
Escapement for year	.2	-----	.9	5.2	-----	.2	66.8	2.3	-----	-----	8.3	15.8	-----	-----	.3	-----	-----
1926:																	
Spring	-----	-----	4.6	.7	-----	1.4	80.0	-----	-----	-----	10.2	2.6	-----	-----	.5	-----	-----
Fall	.2	.6	.6	.3	-----	.4	81.8	.4	-----	-----	1.6	13.2	.1	-----	.7	0.1	-----
Escapement for year	.1	.3	2.6	.5	-----	.9	81.1	.2	-----	-----	6.0	7.6	-----	-----	.6	.1	-----
1927:																	
Spring	-----	-----	.2	.9	-----	10.8	74.5	.2	-----	-----	12.7	.2	-----	-----	.5	-----	-----
Fall	-----	.1	.1	5.1	.2	.9	61.0	8.8	-----	-----	2.1	20.4	.2	-----	.5	.6	-----
Escapement for year	-----	-----	.1	2.1	-----	7.9	70.8	2.7	-----	-----	9.6	6.1	-----	-----	.5	.2	-----

TABLE 18.—*Percentage occurrence of the various age groups in the spring, fall, and total escapements of 1922, and of 1924 to 1936, inclusive*—Continued

Year of escapement	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	5_5	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_5
1928:	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Spring	-----	-----	.5	.1	-----	-----	53.7	-----	-----	-----	44.4	1.3	-----	-----	-----	-----	-----
Fall	-----	-----	.4	.4	-----	.1	63.5	1.3	-----	-----	6.9	26.2	-----	-----	1.0	.2	-----
Escapement for year	-----	-----	.4	.2	-----	-----	56.9	.4	-----	-----	32.8	9.0	-----	-----	.3	-----	-----
1929:																	
Spring	-----	-----	1.9	-----	-----	1.9	40.0	-----	-----	-----	50.6	3.2	-----	1.2	1.2	-----	-----
Fall	-----	-----	.4	.3	-----	-----	31.5	.4	-----	-----	9.5	56.6	-----	-----	1.3	-----	-----
Escapement for year	-----	-----	1.0	.2	-----	.8	34.8	.3	-----	-----	26.0	35.1	-----	.5	-----	1.3	-----
1930:																	
Spring	-----	-----	-----	.4	-----	1.4	51.1	1.6	-----	-----	33.9	10.2	-----	-----	1.4	-----	-----
Fell	-----	-----	-----	5.9	-----	.1	51.7	17.2	-----	-----	4.6	18.9	-----	-----	1.5	.1	-----
Escapement for year	-----	-----	-----	4.0	-----	.6	51.5	11.9	-----	-----	14.5	16.0	-----	-----	1.5	-----	-----
1931:																	
Spring	-----	-----	2.3	.7	-----	.9	42.7	.4	-----	-----	17.3	33.4	.1	-----	2.2	-----	-----
Fall	-----	-----	.2	.5	-----	.1	53.2	4.2	-----	-----	1.0	40.3	.1	-----	.3	.1	-----
Escapement for year	-----	-----	.9	.5	-----	.3	49.8	3.0	-----	-----	6.4	38.1	.1	-----	.9	-----	-----
1932:																	
Spring	-----	-----	1.1	1.0	-----	1.3	74.0	.1	-----	-----	6.6	9.8	-----	-----	6.1	-----	-----
Fall	-----	.1	1.1	.8	-----	.3	22.6	4.0	-----	-----	2.4	67.0	-----	-----	.3	1.4	-----
Escapement for year	-----	-----	1.0	.9	-----	.8	48.2	2.1	-----	-----	4.5	38.6	-----	-----	3.2	.7	-----
1933:																	
Spring	-----	.1	.6	.6	-----	3.3	57.7	.3	-----	-----	22.9	13.0	-----	.1	1.3	.1	-----
Fall	-----	-----	.3	.2	-----	.6	46.2	2.5	-----	-----	2.4	44.1	-----	-----	1.2	2.5	-----
Escapement for year	-----	-----	.5	.4	-----	2.0	52.3	1.3	-----	-----	13.1	27.9	-----	-----	1.3	1.2	-----
1934:																	
Spring	-----	-----	.9	.2	-----	2.5	32.2	1.0	-----	-----	50.6	8.8	-----	-----	3.6	.1	0.1
Fall	-----	-----	.2	.2	-----	.1	31.7	.9	-----	-----	6.2	58.9	.2	-----	1.4	.2	.2
Escapement for year	-----	-----	.7	.2	-----	1.7	32.0	1.0	-----	-----	35.7	25.7	-----	-----	2.9	.1	-----
1935:																	
Spring	-----	-----	4.8	1.2	-----	3.7	23.7	1.6	-----	0.4	36.9	15.3	-----	.3	11.6	.3	-----
Fall	-----	.1	.5	7.3	-----	.4	24.5	9.1	-----	-----	2.6	50.1	.9	-----	.9	3.6	-----
Escapement for year	-----	.1	2.7	4.2	-----	2.0	24.1	5.4	-----	.2	19.7	32.8	.5	.1	6.2	1.9	.1
1936:																	
Spring	-----	-----	1.2	3.0	-----	5.6	62.5	.3	-----	-----	12.9	9.9	-----	.2	4.0	.3	.1
Fall	-----	-----	-----	.3	-----	.1	71.3	5.0	-----	-----	2.3	15.0	-----	-----	1.6	1.4	-----
Escapement for year	-----	-----	.5	1.3	-----	2.2	69.9	3.2	-----	-----	6.2	13.1	-----	.1	2.5	1.0	-----

The time of the season during which commercial fishing takes its toll also has an effect on the age composition of the escapement due to the fact that the age composition of the fish in a season's run is not constant but varies from week to week. If the commercial catch does not take a constant proportion of each week's run of fish, the age composition of the escapement is very apt to be different from that of the run of fish from which it resulted. Except in instances where an abnormal condition indicates the advisability of giving special protection to a certain part of a run, it is considered preferable to have the commercial catch so regulated that it constitutes the same percentage of the run from week to week throughout the season. When the catch is regulated in such a manner, the age composition of the escapement for a season will closely approximate the age composition of the run from which it is derived.

The escapement data presented in table 17 are used during each season in the regulation of the fishery, and in addition are also used in the study of the number of fish returning from known escapements, a subject discussed in a later section of this publication.

The data presented in table 18 are used together with data presented in table 25 in the study of the change in the age composition of the runs. This subject also is discussed later.

TOTAL POPULATIONS

As the commercial catch of Karluk River red salmon can be ascertained from the records maintained by canneries operating in the Karluk area, and as the escapement can be determined by counting the fish passing upstream through the weir, it is possible to determine the number of fish in the total population or run. In determining the run of a 7-day period the catch of that period has been added to the escapement of the following 7-day period because of the aforementioned lag between the time the fish enter the river and the time they go through the weir. The weekly cumulative totals of the runs for the years 1921 to 1936, inclusive, are presented in table 19.

TABLE 19.—*Cumulative totals of the runs of Karluk red salmon for each week from 1921 to 1936, and percentage of the total run that had cumulated to the end of each week*

[Run based on catch plus escapement of following week, as explained in the text]

Week ending—	1921		1922		1923		1924		1925		1926	
	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run
May 24	6	0.2			1	0.1	5	0.2	30	1.0	81	1.6
May 31	22	.7	10	0.9	73	5.1	91	4.6	63	2.1	561	11.4
June 7	177	5.6	23	2.2	102	7.2	257	12.8	83	2.8	998	20.1
June 14	315	10.0	96	9.1	212	14.9	427	21.4	346	11.8	1,125	22.9
June 21	545	17.3	145	13.7	348	24.4	548	27.4	599	20.3	1,406	28.6
June 28	770	24.5	228	21.6	423	29.7	637	31.8	713	24.2	1,561	31.7
July 5	881	28.0	264	25.0	448	31.4	703	35.2	789	26.8	1,619	32.9
July 12	976	31.1	303	28.7	490	34.4	772	38.6	824	28.0	1,715	34.9
July 19	1,134	36.1	345	32.6	554	38.9	862	43.1	875	29.7	1,872	38.0
July 26	1,395	44.4	394	37.3	662	46.5	955	47.8	1,006	34.2	2,100	42.7
Aug. 2	1,636	52.1	452	42.7	791	55.5	1,027	51.4	1,391	47.2	2,415	49.1
Aug. 9	1,871	59.5	502	47.5	854	59.9	1,123	56.2	1,661	56.4	2,753	56.0
Aug. 16	2,066	65.7	561	53.1	961	67.4	1,211	60.6	1,829	62.1	3,010	61.2
Aug. 23	2,342	74.5	637	60.2	1,022	71.7	1,375	68.8	2,011	68.3	3,530	71.7
Aug. 30	2,530	80.5	704	66.6	1,105	77.5	(1)		2,291	77.8	3,894	81.2
Sept. 6	2,809	89.4	833	78.8	1,260	88.4			2,367	80.4	4,348	88.4
Sept. 13	2,913	92.7	956	90.4	1,331	93.4			2,705	91.9	4,783	97.2
Sept. 20	(1)		978	92.5	1,351	94.8			2,757	93.6	4,844	98.5
Sept. 27			994	94.0	1,414	99.2			2,940	99.9	4,853	98.6
Oct. 4			1,024	96.8	1,423	99.9	2,000	100.0	2,944	100.0	4,897	99.5
Oct. 11			1,058	100.0	1,425	100.0					4,920	100.0
Oct. 18	3,143	100.0	1,058	100.0								

Week ending—	1927		1928		1929		1930		1931	
	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run
May 24	10	0.6	14	0.7	1	0.1	2	0.2	13	0.8
May 31	62	3.9	166	7.9	76	6.7	44	3.5	63	3.9
June 7	271	17.1	470	22.4	162	14.4	66	5.3	177	10.9
June 14	460	29.0	653	31.2	282	25.0	295	23.5	274	16.9
June 21	579	36.5	753	35.9	386	34.2	331	26.4	352	21.7
June 28	680	42.8	869	41.5	415	36.8	412	32.9	421	25.9
July 5	757	47.7	934	44.6	445	39.5	432	34.4	444	27.3
July 12	798	50.3	1,000	47.7	476	42.2	450	35.9	488	30.0
July 19	835	52.6	1,088	51.9	503	44.6	480	38.3	542	33.4
July 26	891	56.1	1,215	58.0	548	48.6	549	43.8	629	38.7
Aug. 2	1,023	64.5	1,350	64.4	603	53.5	655	52.2	727	44.7
Aug. 9	1,157	72.9	1,517	72.4	657	58.2	718	57.3	787	48.4
Aug. 16	1,237	78.0	1,686	80.5	732	64.9	817	65.2	880	54.2
Aug. 23	1,304	82.2	1,770	84.5	801	71.0	823	65.6	1,003	61.7
Aug. 30	1,377	86.8	1,877	89.6	837	74.2	942	75.1	1,105	68.0
Sept. 6	1,431	90.2	1,968	93.9	947	84.0	1,008	80.4	1,374	84.6
Sept. 13	1,505	94.9	2,006	95.8	1,041	92.3	1,070	85.3	1,441	88.7
Sept. 20	1,506	94.9	2,039	97.3	1,055	93.5	1,207	96.3	1,547	95.2
Sept. 27	1,579	99.5	2,040	97.4	1,128	100.0	1,208	96.3	1,612	99.2
Oct. 4	1,587	100.0	2,086	99.6	1,128	100.0	1,251	100.0	1,625	100.0
Oct. 11			2,095	100.0						
Oct. 18										

See footnote at end of table.

TABLE 19.—*Cumulative totals of the runs of Karluk red salmon for each week from 1921 to 1936, and percentage of the total run that had cumulated to the end of each week*—Continued

Week ending—	1932		1933		1934		1935		1936		Average percentage 1921–36
	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	
May 24	1	0.1	2	0.1	3	0.1	23	1.5	39	1.6	0.6
May 31	49	3.5	27	1.5	204	9.9	162	10.6	183	7.5	5.2
June 7	223	15.8	381	21.0	503	24.4	424	27.7	375	15.3	14.1
June 14	369	26.1	575	31.7	897	43.4	625	40.8	585	23.8	23.8
June 21	481	34.1	784	43.2	1,097	53.1	710	46.4	786	32.0	31.0
June 28	541	38.3	895	49.4	1,164	56.4	749	48.9	906	36.9	35.8
July 5	597	42.3	980	54.1	1,244	60.2	809	52.8	917	37.4	38.7
July 12	634	44.9	1,029	56.8	1,309	63.4	836	54.6	979	39.9	41.3
July 19	688	48.7	1,080	59.6	1,385	67.1	878	57.3	1,069	43.6	44.7
July 26	740	52.4	1,163	64.1	1,499	72.6	984	61.9	1,198	48.8	49.9
Aug. 2	829	58.7	1,255	60.2	1,581	76.6	1,038	67.8	1,425	58.1	56.7
Aug. 9	906	64.2	1,307	72.1	1,651	80.0	1,100	71.8	1,573	64.1	62.3
Aug. 16	961	68.1	1,385	76.4	1,700	82.3	1,172	76.5	1,682	68.6	67.8
Aug. 23	1,081	76.6	1,506	83.1	([1])		1,228	80.2	1,813	73.9	72.9
Aug. 30	1,145	81.1	1,520	83.8			1,247	81.4	2,125	86.6	79.3
Sept. 6	1,147	81.2	1,666	91.9			1,398	91.3	2,330	95.0	87.0
Sept. 13	1,235	87.5	1,742	96.1			1,399	91.4	2,357	96.1	92.4
Sept. 20	1,355	96.0	1,752	96.6	2,065	100.0	1,514	98.9	2,439	99.4	96.2
Sept. 27	1,402	99.3	1,756	96.9	2,065	100.0	1,531	100.0	2,453	100.0	98.6
Oct. 4	1,412	100.0	1,813	100.0			1,531	100.0	2,453	100.0	99.7
Oct. 11											100.0
Oct. 18											

[1] The number of fish in the run from here to the end of the season was calculated as explained in the text.

In discussing the time of appearance of the runs, Gilbert and Rich (1927, p. 63) pointed out the apparent "uniformity in the development of the runs" from year to year and stated that if supported by future data the size of the total run could be predicted with some degree of accuracy at least by the end of June. Unfortunately, additional data have shown that there is considerable variation in the cumulative percentage occurrence of the runs from year to year. Up to the week ending July 5 the data indicate that from 25 to 60 percent of the run may have come in. Therefore it is impossible to estimate, with any degree of accuracy, the size of the total run early in the season. The main reason for the variation in the development of the runs from year to year is that the run of any single year is composed of fish of several age groups, and the various age groups do not appear uniformly during the season nor is there a correlation as previously explained between the abundance or scarcity of one age group appearing during one year with the abundance or scarcity of the other age groups appearing during that same year.

Figure 2 shows the average percentage of the run appearing during each 7-day period of the season. There is a definite mode in June, a minimum during the week ending July 12, followed by a second mode. The second mode itself is slightly bimodal; however, the data for any single year clearly show that the minumum occurs during the period of the week ending July 5 to the week ending July 19 and only one mode is present during the fall run. It appears that there are two distinct red salmon runs to the Karluk River each year, the spring run which reaches a maximum during June and the fall run which reaches a maximum between the last week of July and the first week of September.

Overlapping of these two runs cannot be denied, but the bimodality of the runs is evidenced not only in the appearance of the fish at the mouth of the river but also in their appearance on the spawning grounds. The spring run first appears on the spawning grounds during the last of June and the peak of the spawning occurs during the third week of July. These fish populate all the spawning streams entering the lake and, to a slight extent, certain parts of the lake shores where seepage through the gravel promotes conditions suitable for spawning. By the end of July or the first week of August the fish have completed spawning, and there is a definite scarcity of live fish on the spawning grounds. During late August, fish again appear in numbers on

FIGURE 2.—Percentage of total run appearing each week during season.

the spawning grounds. An appreciable percentage of the fall run spawns along the beaches, and some of the fish spawn in the Karluk River for a distance of a mile or two below the lake, an area never populated by fish of the spring run. The majority of the fish in the fall run do spawn, however, in the tributary streams of the lake.

Although the two runs of fish spawn, to a great extent, on the same spawning grounds, the time interval precludes a thorough interbreeding of the two populations. The only interbreeding possible is between the late spawners of the spring run and the early spawners of the fall run. Whether or not the separation between the two groups has been sufficient to produce any anatomical differences that might be detected biometrically has not been determined conclusively. Even though the differences could not be detected biometrically, such an absence of differences would not repudiate the theory of two populations of red salmon inhabiting one watershed and spawning in the same gravel. Environmental conditions undoubtedly do account, in a large measure, for the minor fluctuations in the time of appearance of the runs from year to year and may be the cause of bimodality in the runs. Regardless of the primary cause of this phenomenon, it would seem that there are two self-perpetuating components of the red-salmon population in the watershed, and that each should be given adequate protection.

During the 16 years under consideration the spring runs have ranged from 303,000 fish in 1922 to 1,715,000 fish in 1926, the average being 817,000 fish. The fall runs have ranged from 652,000 fish in 1929 to 3,205,000 fish in 1926, the average being 1,211,000 fish. The total run has ranged from 1,058,000 fish in 1922 to 4,920,000 fish in 1926, the average being 2,028,000 fish. Thus, there has been a rather wide range in the number of fish in the runs from year to year, and the average run has been far below that of the early days of the fishery when for a period of 7 years the catch alone exceeded the run (catch plus escapement) during this period by more than 1,000,000 fish per year.

RETURNS FROM KNOWN SPAWNING POPULATIONS

In order to maintain the salmon runs at a high level, an adequate escapement must be obtained for each and every suitable spawning area. The question at once arises as to what constitutes an adequate escapement. This question has confronted the salmon conservationist since the first attempt was made to regulate a fishery, and it is a question that still needs considerable study. Each small section of a spawning area must have its proper escapement, and in the final analysis, it is necessary to determine, for each small area, the size of an adequate spawning population. The problem is further complicated because an adequate spawning population for a given spawning area is not necessarily constant. Variations in meteorological conditions result in changes in environmental conditions on the spawning grounds during the spawning and incubation periods from year to year, consequently, a spawning escapement which may be adequate in one year may be inadequate, or may be more than adequate, in some other year. As there is no means of predicting what meteorological conditions will prevail during the spawning season and the subsequent incubation period, we can at best determine an average figure for the optimum size of the spawning population for each spawning area.

Most of the progeny from a year's spawning population of Karluk red salmon return as adults in their fourth to seventh year.[6] In order to determine the return from the spawning of 1930, for example, it is necessary to determine the number of 4-year fish in the run of 1934, the number of 5-year fish in the run of 1935, the number of 6-year fish in the run of 1936, and the number of 7-year fish in the run of 1937. The numbers of these several groups are then added together to determine the total return from the spawning of 1930. The returns from the escapements of the spring run, from the fall run, and from the total run of each year are given in table 20.

The escapement of 1921 (1,500,000 fish) produced a very good return both in the ratio of return to escapement and also in the total number of fish produced. While the return from the spring escapement was good, the return from the fall escapement was much better and was largely responsible for the exceptionally good total return.

[6] There are a few 3-year and 8-year fish in the Karluk runs which are included in the tabulations, but their presence is quite unimportant.

TABLE 20.—*Returns from escapements of Karluk River red salmon*

Year and season	Escapement	Return	Ratio of return to escapement	Return minus escapement
1921				
Spring	685, 245	1, 522, 032	2. 2: 1	836, 787
Fall	814, 755	2, 970, 272	3. 6: 1	2, 155, 517
Total	1, 500, 000	4, 492, 304	3. 0: 1	2, 992, 304
1922				
Spring	196, 186	1, 252, 839	6. 4: 1	1, 056, 653
Fall	203, 814	1, 001, 461	4. 9: 1	797, 647
Total	400, 000	2, 254, 300	5. 6: 1	1, 854, 300
1923				
Spring	255, 351	801, 653	3. 1: 1	546, 302
Fall	439, 228	1, 186, 950	2. 7: 1	747, 722
Total	694, 579	1, 988, 603	2. 9: 1	1, 294, 024
1924				
Spring	540, 030	409, 352	.8: 1	−130, 678
Fall	569, 131	435, 118	.8: 1	−134, 013
Total	1, 109, 161	844, 470	.8: 1	−264, 691
1925				
Spring	657, 154	538, 113	.8: 1	−119, 041
Fall	963, 773	1, 062, 953	1. 1: 1	99, 180
Total	1, 620, 927	1, 601, 066	1. 0: 1	−19, 861
1926				
Spring	1, 289, 976	336, 507	.3: 1	−953, 469
Fall	1, 243, 426	1, 177, 101	.9: 1	−66, 325
Total	2, 533, 402	1, 513, 608	.6: 1	−1, 019, 794
1927				
Spring	617, 613	926, 611	1. 5: 1	308, 998
Fall	254, 925	651, 563	2. 6: 1	396, 638
Total	872, 538	1, 578, 174	1. 8: 1	705, 636
1928				
Spring	755, 511	1, 519, 176	2. 0: 1	763, 665
Fall	338, 306	925, 453	2. 7: 1	587, 147
Total	1, 093, 817	2, 444, 629	2. 2: 1	1, 350, 812
1929				
Spring	360, 567	883, 509	2. 5: 1	522, 942
Fall	539, 752	623, 056	1. 2: 1	83, 304
Total	900, 319	1, 506, 565	1. 7: 1	606, 246

The escapement of 1922 (400,000 fish) was very poor. However, this escapement produced a fair-size run because the ratio of return to escapement was exceptionally high both in the spring and fall.

The escapement of 1923 (694,579 fish), although it produced a good ratio of return to escapement, produced only a moderate run because the size of the escapement itself was below average.

The escapement of 1924 (1,109,161), while considered satisfactory in size, produced a very poor return. In fact there were fewer fish in the return than in the escapement. This was due probably to the tremendous escapement of pink salmon in the Karluk River in 1924. Normally, the pink salmon spawn in the lower half of the river, but in that year, because of population pressure, large numbers of this species continued up the river and occupied the red salmon spawning grounds. Quoting from a report made by Fred R. Lucas in 1924 (Gilbert and Rich 1927):

. . . On August 21st hundreds of thousands of fish died in the twenty miles of river between the weir and the still water at the Larson Bay portage. The mortality included adult red salmon, humpbacks, and trout, as well as young fish. The cause is unknown unless it was due to overcrowding of humpbacks, with a possible fall of the water level in the river . . . it is estimated that over four million humpbacks passed through the weir this season.

Quoting from Lucas' notes taken while visiting the red-salmon spawning grounds at Karluk Lake, September 16 to 24:

> . . . Behind every rock and in every eddy piles of humpback eggs lay. Within twenty-two steps the writer counted twelve piles that would average five gallons to a pile; and behind a small island about six feet in diameter there were more than a fifty-gallon barrel full of humpback eggs. These eggs were all dead; . . . a small percentage of red eggs was among them. In fact, more or less red eggs were noticed adrift in every stream where humpbacks had spawned . . . The dead, red eggs . . . were more numerous than the live ones. All of these live eggs will probably be picked up by the birds and trout before they hatch. . . .

It was apparent that there was too large a pink-salmon escapement, and this was borne out by the failure of the pink-salmon run of 1926, the total return from the escapement of over 4,000,000 being less than 100,000 fish. The overcrowded conditions on the spawning grounds in 1924 not only resulted in a very poor return of pink salmon in 1926 but undoubtedly were largely responsible for the poor return from the red-salmon escapement.

The escapement of 1925 (1,620,927), while good, also produced a relatively poor return, and the total return was slightly less than the number of fish in the escapement. Karluk Lake was not visited during the summer of 1925, and consequently no information as to conditions on the spawning grounds during that year is available. The moderately large escapement should not have caused an undue mortality due to overcrowding under normal conditions, and there is no reason to believe environmental conditions were abnormal during the spawning period. It is known that the winter of 1925–26 was exceptionally mild. A mild winter should cause the eggs to hatch earlier than usual, but just what effect this would have on the fry is impossible to state.

The excellent escapement of 1926 (2,533,402) suffered from unfavorable conditions caused by an exceptionally warm, dry summer, and the return was 1,000,000 fish less than the number of spawners in the escapement. The lack of rainfall coupled with a large escapement of red salmon produced conditions somewhat similar to those encountered in 1924. Quoting from notes made by Willis H. Rich in 1926:

> On July 18, in Spring Creek . . . it was very noticeable that many of the females were not completely spawned out; six of twelve examined had eggs apparently still in good condition. Most of these were apparently not spawned at all, although ripe . . . Upper Thumb River . . . we saw many dead females, ripe but unspawned, and many others that were not completely spawned out. Causes of death quite unknown, as most of them appeared to be in fine condition.

Observers at Karluk Lake in 1926 considered that "about 25 percent of the females that reached the lake died only partially spawned out." Not only did many fish die before spawning, but large numbers of eggs deposited in the gravels died because the spawning grounds dried up. Again quoting from Rich's notes:

> August 9 . . . In Thumb River, where the spawning had been heaviest, many of the nests were exposed by the lowering of the water. We dug in some of them and found mainly dead eggs, although a very few live ones were found.

In many of the other streams similar conditions were noted. Thus, the poor return from the spawning of 1926 might have been due largely to the conditions on the spawning grounds during that year. The spawn of the spring escapement, in the opinion of observers, suffered the greatest loss, and it is significant that the return per fish from the spring escapement was only one-third as great as the return per fish from the fall escapement.

The escapement of 1927 (872,538 fish) produced a moderate-size run and probably would have produced a better run had not the spring run suffered to some extent from unfavorable conditions. Precipitation during the summer of 1927 was in marked contrast to that of 1926. In 1927 the spring spawning population suffered because the streams were at flood stage for a period of time, whereas in 1926 the fish suffered from a lack of sufficient water.

The escapement of 1928 (1,093,817 fish) produced a fairly good run, and the ratio of return to escapement in both the spring and fall was equal to, or greater than, the ratio of return of 2:1 on which the Alaska fishery regulations are based.

The escapement of 1929 (900,319 fish) produced a relatively small run. The spring escapement produced a good ratio of return to escapement, but the fall escapement produced only a few more fish than were in the escapement for that period.

Although fluctuations in the ratio of return to escapement were anticipated, it was expected that some correlation would be found between these two factors. The big escapements to the Fraser River (Rounsefell and Kelez, 1938) every fourth year prior to the rock slide in the river in 1913, always resulted in a large run 4 years later. Observations made on the escapement and returns of pink salmon in Puget Sound and Alaska indicate that usually big runs are produced from good escapements and poor or only fair runs produced by poor escapements. The cyclic nature of the catches at Karluk during most of the history of the fishery also indicates that some correlation exists between escapement and return. These and many other instances which might be cited give reason to believe that, normally, a positive correlation exists between escapement and return.

Figure 3 shows the correlation between the total yearly escapement and the total returns. The most striking point about these data is the utter lack of correlation between the escapements and the returns from the escapements. That such a condition could not have existed during the early days of the fishery is apparent when one considers that for 3 of the 9 years under consideration the ratio of return to escapement did not exceed 1.0 to 1.0. Obviously, unless this ratio is greater than 1.0 to 1.0 a fishery cannot be sustained. For only one of the years under consideration, 1921, did the return exceed the escapement from which it resulted by an amount approximately equal to the catches made during the early days of the fishery.

In the consideration of returns from escapements the most important point is the surplus, or return minus escapement, produced by a given escapement. The aim of every regulatory body governing a self-perpetuating biological resource should be to allow the greatest possible catch without endangering future supplies. The size of the population inhabiting a watershed is, in itself, of little concern. For example, if an escapement of 1,000,000 fish always produced a run of 3,000,000 fish, and an escapement of 4,000,000 fish always produced a run of 5,000,000 fish it would be wasteful to require an escapement of 4,000,000 fish solely on the basis that such an escapement produced the largest run. In this hypothetical example the escapement of 1,000,000 fish would produce a surplus of 2,000,000, and the escapement of 4,000,000 would produce a surplus of only 1,000,000. It is then of considerable importance to determine, for each given area, the size of the escapement which will consistently produce the greatest surplus.

In figure 4 the return minus escapement, or surplus, has been plotted against the escapement. A negative correlation between escapement and surplus is indicated, and it appears that, overlooking the return from the fall escapement of 1921, the

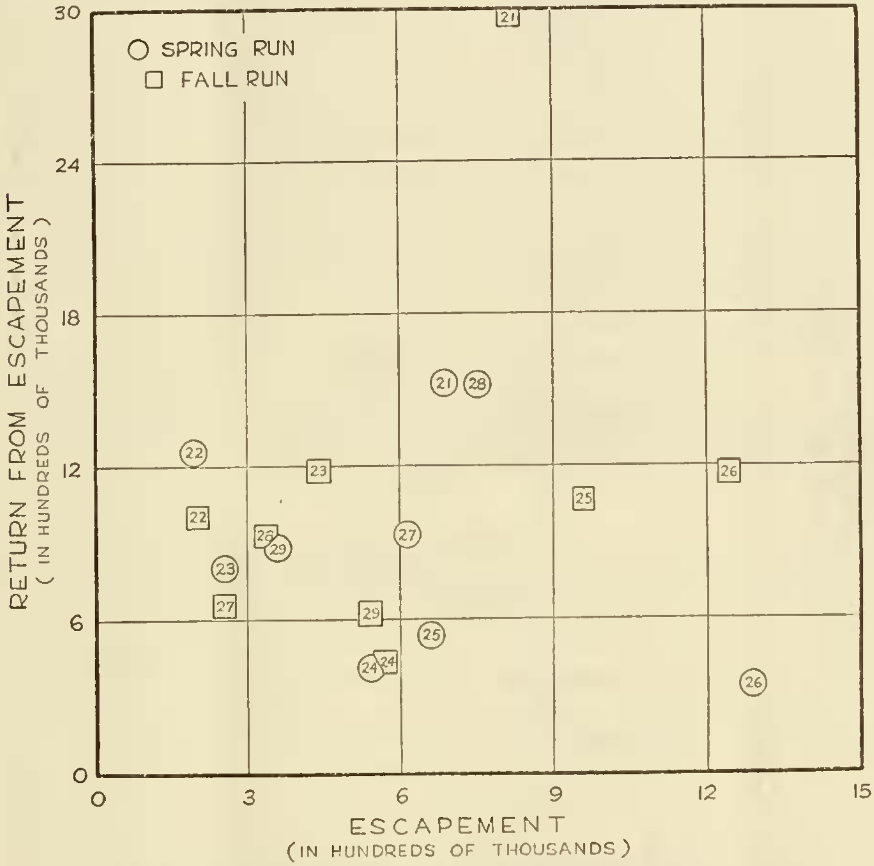

FIGURE 3.—Returns from the spring and fall escapements for the years 1921 to 1929, inclusive.

optimum escapement for the spring and fall runs was approximately 200,000 fish for each period or a total yearly escapement of 400,000 fish. There are several facts, however, that should be considered before drawing conclusions from the data. The escapement of 1921, and especially the fall escapement, produced a very good surplus. The Karluk pink salmon spawning population of 1922 produced an exceptionally large surplus, as did the red salmon spawning population of that year, indicating unusually favorable environmental conditions. Conditions on the spawning grounds were judged to be very unfavorable during 1924 and 1926, and hence the returns from those escapements were likely much lower than if the environment had been normal. Furthermore, only the escapement of 1921 (1,500,000 fish) produced a surplus comparable to the average catch made during the 20-year period from 1888 to 1907. While it is obvious that the catches made during the early days of the fishery were such as to cause serious depletion of the population, it would seem likely that the fishery could have been stabilized with a yearly catch of 1,500,000 to 2,000,000 fish.

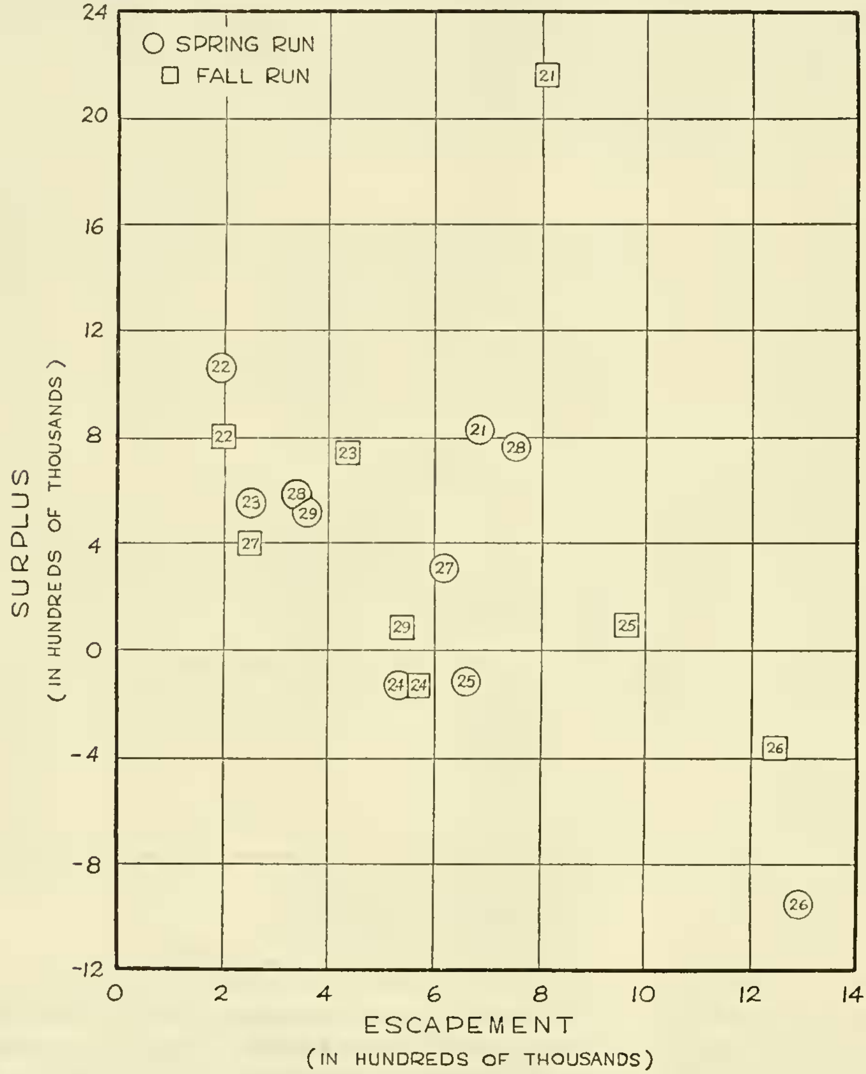

FIGURE 4.—Surplus (return minus escapement) produced by spring and fall escapements for the years 1921 to 1929, inclusive.

CHEMICAL ANALYSES OF LAKE AND STREAM WATERS

A factor to be considered in relation to the optimum magnitude of the escapements of red salmon is the addition to the lake water of phosphorus and other inorganic salts from the bodies of the fish which migrate into the watershed to spawn. Prior to the inception of the commercial fishery, Karluk Lake received a large supply of chemical compounds each year because practically all of each season's run of fish proceeded to the lake and its tributaries to spawn and die. As soon as the commercial fishery began, the spawning escapements became less, and not only were there fewer spawners available to deposit eggs in the gravel, but the yearly increment of chemical compounds to the water was considerably decreased.

That the productivity of bodies of fresh and salt water is controlled in part by the abundance of certain inorganic salts such as phosphorus has long been known and the relationship between the chemical content of the water of ponds, lakes, and the ocean and their productivity has been studied by a large number of investigators. Soluble phosphorus has been considered by most workers to be the chief limiting factor in the productivity of aquatic organisms during the summer months, although nitrogen and carbon dioxide have also been shown to be limiting factors at times.

During the 2 or 3 years that the red-salmon fingerlings spend in fresh water, prior to their sojourn in the ocean, they feed upon certain minute forms of animal life existing in the lake. These animal forms, or zooplankton, are dependent upon the plant forms, or phytoplankton, and they in turn are dependent upon the sunlight and the inorganic salts in the lake water. Hence, fluctuations in the supply of salts in the lake water can indirectly affect the growth and survival of the fish.

In tables 21 and 22 are presented the results of temperature and chemical observations made on the waters of Karluk and Thumb Lakes in 1935 and 1936. Similar data collected in 1927 were presented and discussed by Juday, Rich, Kemmerer, and Mann (1932).

The temperature of both Karluk and Thumb Lakes was higher in 1935 than in 1927 and still higher in 1936. At Station 1, in Karluk Lake (fig. 5), for example, the surface temperature on August 13, 1927, was 11.1° C.; on the same date in 1935 it was 12.2° C.; and in 1936 it was 15.5° C. There was evidently a marked difference in the amount of sunshine during these 3 years, and such a conclusion is confirmed by the precipitation data. The June-July-August precipitation at Kodiak, the nearest recording station, was 22.33 inches in 1927; 13.85 in 1935; and 6.56 inches in 1936. During the 47 years that June-July-August precipitation data has been tabulated at Kodiak, the average precipitation was 13.32 inches.

Soluble phosphorus was found in the water of Karluk and Thumb Lakes in 1927 on the dates samples were taken, and whereas the surface waters of these lakes lacked a measurable amount of phosphorus during the summers of 1935 and 1936, it was not until September, at the end of the salmon growing season, that measurable amounts of phosphorus were found.

Silica was almost entirely absent from the surface waters of Karluk Lake during 1935 and 1936, whereas a small amount was present in 1927.[7] A greater amount of silica occurred in the water of Thumb Lake in 1935 and 1936 than in 1927.

[7] The 1927 silica values should be multiplied by 1.44 to correct a change in the value used in the calculation. The method used for the determination of silica is that described by Dienert and Wandenbulcke (1923), and Juday, Rich, Kemmerer, and Mann (1932) used Dienert and Wandenbulckes value of 36.9 mgs. of picric acid as being equivalent to 50 mgs. of silica. King and Lucas (1928) showed this value to be in error and indicated that 25.6 mgs. of picric acid were equivalent to 50 mgs. of silica. This latter value was confirmed by Robinson and Kemmerer (1930a) and was used in the present analysis.

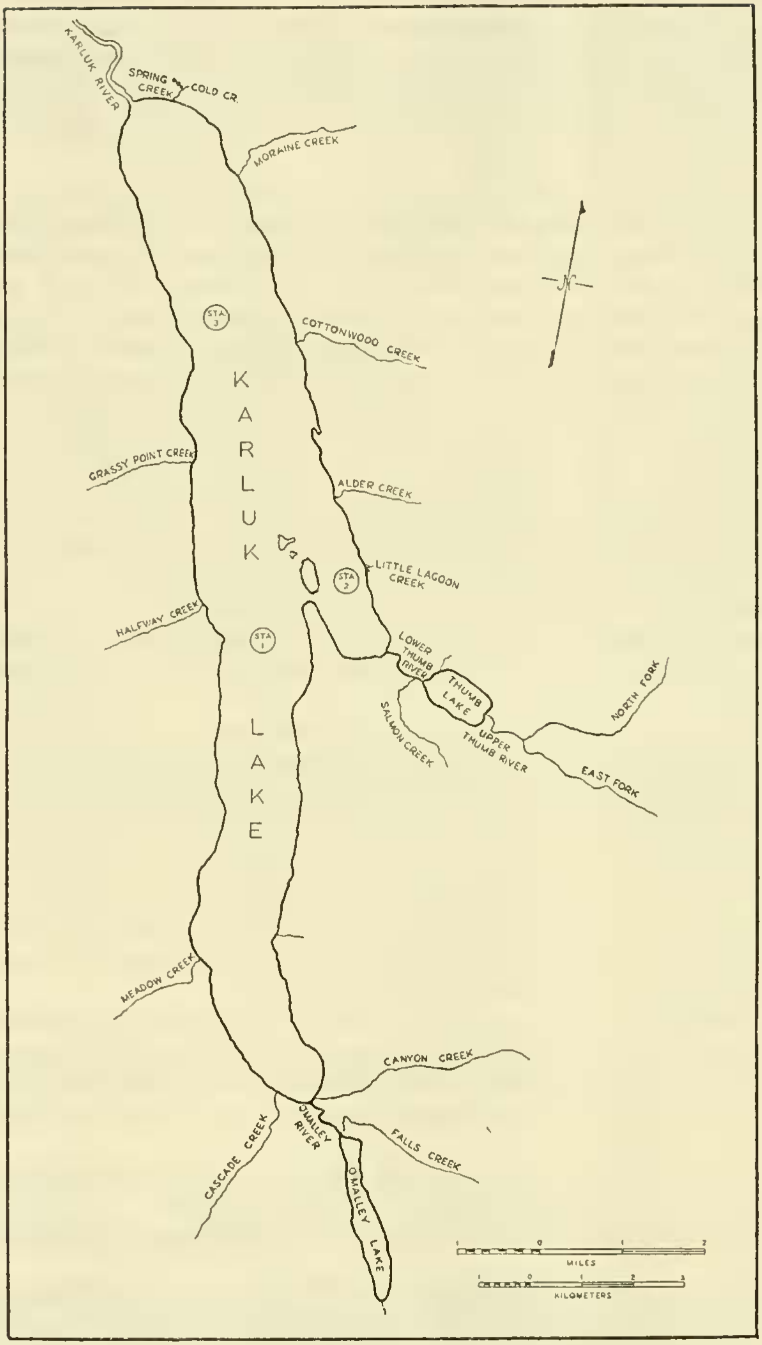

FIGURE 5.—Map of Karluk Lake region.

TABLE 21.—*Results of chemical analyses of the waters of Karluk Lake and Thumb Lake in 1935*

[The results are stated in milligrams per liter of water. Tr.=Trace]

Date	Time[1]	Depth in meters	Temperature, °C.	pH	Carbon dioxide free	Soluble phosphorus	Silica	Nitrite nitrogen
KARLUK LAKE, STATION 1								
May 26	11:15	0	5.0	7.7				
June 28	10:27	0	11.0	8.2		0.000	1.5	0.002
June 28		20	9.8	7.6		.000	1.5	.002
June 28		30	6.0	7.8		.000	0	.002
June 28		100	4.5	7.4		.002	0	.001
July 11	8:30	0	11.6	8.0	0.8	.000	Tr.	.002
July 11		20	8.7	7.7	1.2	.000	0	.001
July 11		30	6.9	7.6	1.8	.000	0	.001
July 11		100	4.8	7.3	1.8	.002	0	.001
July 30	8:21	0	11.9	7.7	.8	.000	0	.002
July 30		100	5.0	7.2	2.0	.002	0	.001
July 30		124	4.9	7.1	2.4	.002	0	.001
Aug. 13	9:45	0	12.2	7.8	.8	.000	Tr.	.001
Aug. 13		20	8.1	7.2	1.2	Tr.	0	.001
Aug. 13		100	5.1	7.0	2.0	.002	Tr.	.001
Aug. 13		122	4.9	7.0	2.5	.002	Tr.	.001
Sept. 6	11:25	0	12.7	7.9		.006	.5	
Sept. 6		20	10.3	7.3		.004	0	
Sept. 6		100	5.3	7.0		.004	0	
Sept. 6		120	5.1	7.0		.010	.5	
Sept. 6		124	5.1	7.0		.008	.5	
KARLUK LAKE, STATION 2 (THE THUMB)								
May 26	10:50	0	5.6	7.6				
July 13	8:30	0	12.8	8.2	0.6	0.000	Tr.	0.003
July 13		10	10.5	8.0	.6	.000	Tr.	.002
July 13		20	6.4	7.5	1.4	.000	0	.001
July 13		35	5.5	7.3	1.6	.000	0	.001
Aug. 13	8:20	0	12.8	8.1	.6	.000	Tr.	.001
Aug. 13		40		7.1	2.2	.008	.5	.002
Sept. 5	[2] 12:50	0	12.9	7.6		.002		
Sept. 5		20	10.4	7.0		.002		
Sept. 5		35	6.9	7.0		.002		
Sept. 5		41	6.4	6.9		.010		
KARLUK LAKE, STATION 3								
July 12	8:30	0	11.8	7.9	0.6	0.000	Tr.	0.003
July 12		20	6.5	7.7	1.0	.000	0	.001
July 12		30	6.0	7.4	1.6	.000	0	.001
July 12		50	4.8	7.2	2.4	.000	Tr.	.001
Sept. 6	9:18	0	12.6	7.4		.002	Tr.	
Sept. 6		20	8.5	7.0		.002	0	
Sept. 6		50		6.9		.010	.5	
Sept. 6		54	5.3	6.9		.008	.5	
THUMB LAKE								
May 26	10:10	0	9.2	8.2				
June 25	[2] 12.01	0	10.6	7.7		0.000	7.0	Tr.
June 25		8	9.8	7.2		.002	5.5	Tr.
July 9	11:20	0	12.2	7.3	1.6	.000		Tr.
July 21	8:23	0	11.6	7.1	2.2	.002		
July 21		9	11.1	7.1	2.8	.002		
Aug. 14	8:25	0	13.0	9.1	1.6			

[1] Time a. m. except as noted.
[2] Time p. m.

In tables 23 and 24 are presented the results of temperature and chemical analyses made on 15 affluents of Karluk Lake during the summers of 1935 and 1936. These data, with the exception of the silica values, agree with the results presented for 1927 by Juday, Rich, Kemmerer, and Mann (1932). Variations in temperature, pH, carbon dioxide, soluble phosphorus, and nitrite nitrogen depend, in a large degree, on the time of day observations are made, the number of fish in the streams, and the depth of water in the streams.

TABLE 22.—*Results of chemical analyses of the waters of Karluk Lake and Thumb Lake in 1936*

[The results are stated in milligrams per liter of water. Tr=Trace]

Date	Time [1]	Depth in meters	Temperature, ° C	pH	Soluble phosphorus	Silica	Nitrite nitrogen
KARLUK LAKE, STATION 1							
June 28	10:30	0	13.6	7.6	0.000	0	0.002
28		20	6.1	7.5	.000	0	Tr.
28		30		7.5	.000	0	Tr.
28		100	4.3	7.3	Tr.	0	Tr.
July 11	11:15	0	12.2	7.6	.000	0	.001
11		20	7.1	7.5	.000	0	Tr.
11		30	5.8	7.5	.000	0	Tr.
11		100	4.5	7.3	.000	0	Tr.
18	8:15	0	13.5	7.8	.000	0	
18		30	6.3	7.5	.000	0	
Aug. 7	9:41	0	17.1	8.4	.000	Tr.	.001
7		20	6.5	7.3	.000	0	.001
13	9:26	0	15.5	8.4	.000	0	.001
13		20	7.0	8.0	.002	0	Tr.
13		100	4.6	7.1	.003	0	.002
13		124	4.5	6.7	.018	1.0	.002
27	8:18	0	15.0	7.9	.000	Tr.	.001
27		20	8.1	7.3	.000	0	.001
27		30	6.1	7.2	.000	0	Tr.
27		100	4.8	7.1	.005	.5	Tr.
Sept. 9	9:09	0	12.7	7.6	.000	Tr.	.001
9		20	8.3	7.2	.000	0	.000
9		30	6.8	7.1	.000	0	.000
9		100	4.8	7.1	.004	Tr.	Tr.
KARLUK LAKE, STATION 2							
July 7	10:20	0	13.6	8.0	0.000	0	0.002
13	11:21	0	13.5	7.7	.000	0	.001
13		20	6.6	7.7	.000	0	Tr.
13		30	5.6	7.5	.000	0	Tr.
13		40	4.9	7.3	.000	0	Tr.
18	8:37	0	13.8	8.0	.000	0	
18		30	5.6	7.4	.000	0	
Aug. 7	8:15	0	16.5	8.5	.000	.5	.002
7		20	6.8	7.4	.000	0	.001
7		40	5.3	6.8	.036	1.0	
13	[2] 2:44	0	15.6	8.3	.000	.7	.002
13		20	6.6	7.2	.000	0	.001
13		40		7.2	.006	.5	.001
13		41	5.8	6.9	.008	.7	.001
25	8:45	0	15.2	8.1	.000	.5	.001
25		20	6.7	7.2	.000	0	.001
25		30	5.8	7.0	.004	Tr.	.001
25		40	5.5	6.9	.023	1.0	.001
Sept. 6	7:18	0	13.4	7.6	.000	.7	.001
6		20	9.8	7.1	.000	0	Tr.
6		30	6.3	7.0	.001	0	Tr.
6		40	5.8	6.9	.023	.5	.001
THUMB LAKE							
June 30	10:30	0	11.7	7.4	0.000	5.5	Tr.
30	10:25	8	9.9	7.2	.000	5.5	Tr.
July 9	11:50	0	12.5	7.3	.000	5.5	0.001
17	[2] 12:07	0	11.5	8.2	.000	3.5	
Aug. 10	11:45	0	15.6	8.5	.000	5.0	.001
10	11:50	9	11.9	6.5	.005	3.0	.000

[1] Time a. m. except as noted.
[2] Time p. m.

Applying the correction factor of 1.44 to the 1927 silica values, it is found that the silica content of the various streams ranged from 1.4 to 5.0 milligrams per liter. In 1935, the silica values ranged from 5.0 to 13.0, and in 1936 they ranged from 4.0 to 15.0 milligrams per liter. In both 1935 and 1936, it was noted that the silica content of the water of any one stream varied with the stream flow. In the summer months of 1927 there was 1.6 times as much precipitation as during the same period in 1935, and 3.4 times as much as in 1936; hence, the stream flow in 1927 must have been con-

TABLE 23.—*Results of chemical analyses of stream waters in 1935*

[Results are stated in milligrams per liter of water. Tr.=Trace]

Stream	Date	Time [1]	Temperature °C.	pH	Carbon dioxide		Soluble phosphorus	Silica	Nitrite nitrogen
					Free	Fixed			
Cold Creek [2]	July 1	9:10	3.9	6.3	12.2	10.0	0.012	13.0	
Spring Creek	do	9:15	5.8	6.8	7.8	6.8	.002	11.0	0.001
	July 15	9:00	6.1	6.7					
	Aug. 15	10:00	6.8	6.7	6.7	10.8	.022	9.0	Tr.
	Aug. 29	10:10	6.1	6.7	5.9	11.0	.006	9.0	Tr.
Moraine Creek	July 1	9:25	7.2	7.1	3.2	11.0	.018	7.0	.003
	July 15	9:30	8.3	7.2			.060	9.5	
	Aug. 15	11:15	10.4	7.8	.8	11.0	.022	8.0	.001
	Aug. 29	10:25	9.4	8.4	.0	10.2	.014	11.0	.001
Cottonwood Creek	July 1	10:05	7.2	7.2	2.8	7.8	.016	8.0	.003
	July 15	10:45	9.4	7.3			.080	9.5	
	July 27	9:30	7.8	7.3	1.4	13.4	.030	9.0	.003
	Aug. 15	[3] 12:01	9.2	7.7	1.0	13.6	.020	8.5	.002
	Sept. 7	8:45	6.6	7.8			.008		
Alder Creek [1]	July 7	9:15	6.7	7.3	2.4	14.8	.002	8.5	Tr.
Alder Creek	do	9:40	7.2	7.2	3.2	15.2	.016	9.0	.002
	July 15	11:55	8.3	7.2					
	July 27	9:05	6.7	7.3	1.6	13.8	.025	9.0	Tr.
	Aug. 15	7:40	5.5	7.7	1.6	15.0	.016	8.0	.001
	Sept. 7	9:05	6.1	7.6			.010		
Little Lagoon Creek [2]	May 26	10:42	3.5	7.9					.000
	July 7	10:10	3.6	7.7	1.4	25.0	.004	9.0	.000
Little Lagoon Creek	do	10:00	4.7	7.4	2.4	24.6	.010	9.5	.001
	July 13	10:00					.016		
Little Lagoon Creek [2]	Aug. 15	7:50	3.3	7.8	1.4	23.0	.006	8.5	.000
Little Lagoon Creek	do	8:00	3.9	7.7	2.2	23.8	.010	9.0	.000
Lower Thumb River	May 26	10:20	8.3	8.1					
	June 26	[3] 1:20	10.3	7.5					
	July 9	[3] 12:05	12.2	7.3					
	Aug. 14	9:00	12.2	9.1					
Salmon Creek	May 26	10:12	5.8	7.3					
	June 25	[3] 1:00	7.2	7.3					
	July 9	11:40	8.0	7.2	2.4	12.6	.016	8.0	.004
	July 21	9:45	7.2	7.3	2.0	11.4	.015	7.0	.002
	Aug. 14	8:40	6.1	7.5	.8	13.2	.025	7.5	.002
Upper Thumb River	June 25	11:45	7.2	7.1					
	July 9	11:10	8.3	6.9	3.8	10.0	.022	7.5	.005
	July 21	9:20	8.3	7.0	2.0	10.8	.025	7.0	.004
	Aug. 14	8:20	7.2	6.9	3.4	12.0	.035	8.0	.004
Halfway Creek [2]	July 6	9:00	7.2	7.3	1.6	9.0	.002	9.5	Tr.
Halfway Creek	do	9:15	7.8	7.1	2.4	9.0	.004	10.0	.001
	July 27	10:25	7.8	7.2	1.2	8.8	.025	9.0	Tr
	Aug. 16	10:00	6.6	7.3	1.2	9.2	.014	10.0	.001
	Sept. 7	8:00	6.1	7.4			.010		
Grassy Point Creek	July 6	9:40	8.9	7.0	3.6	10.8	.036	9.0	.005
	July 27	10:00	7.2	7.2	1.6	10.8	.045	9.0	.005
	Aug. 16	10:25	7.2	7.5	1.0	10.4	.016	8.5	.002
	Sept. 7	8:20	6.1	7.5			.014		
Meadow Creek	July 17	9:55	8.3	7.0					
	Aug. 16	9:10	7.2	7.5	1.0	9.6	.018	7.5	.004
Cascade Creek	July 3	10:35	8.9	7.3	1.6	14.5	.006	6.5	Tr.
	July 17	9:25	8.3	7.1	2.0	15.4	.024	8.0	.005
	Aug. 16	8:50	7.2	7.6	1.2	14.2	.020	7.5	.002
Canyon Creek	July 3	10:15	8.9	6.8	5.1	10.2	.032	5.5	.005
Falls Creek	do	9:30	8.3	7.3	3.8	7.8	.000	5.0	.000
O'Malley River [4]	do	10:00	9.4	7.3	1.6	9.4	.002	5.0	Tr.
	July 17	8:35	8.9	7.3	2.8	10.8	.006	5.5	.002
	July 23	10:50	8.9	7.1	2.6	10.4	.004	6.0	.002
	Aug. 16	8:35	9.2	7.0	2.2	11.0	.012	6.0	002

[1] Time a. m. except as noted.
[2] Above salmon.
[3] Time p. m.
[4] Above Falls Creek.

siderably greater than in 1935 or 1936. The streams were lower for a part of the summer of 1936 than in 1935, and this is reflected in slightly higher silica values in that year.

Karluk Lake receives silica, in part from the action of the water on the silica bearing rocks on the bottom and on the beaches, and in part from its tributary streams which leach the silica from their respective watersheds. Consequently, the yearly increment of silica, although undoubtedly affected by temperature and precipitation, is probably

TABLE 24. *Results of chemical analyses of stream waters in 1936*

[Results are stated in milligrams per liter of water, Tr.=Trace]

Stream	Date	Time [1]	Temperature ° C.	pH	Soluble phosphorus	Silica	Nitrite nitrogen
Cold Creek [2]	July 1	10:18	3.9	6.2	0.015	15.0	0.000
Spring Creek	do	10:35	7.2	6.7	.006	13.5	.000
	July 15	9:20	6.9	6.7	.005	13.5	Tr.
	Aug. 8	9:15	6.1	6.6	.005	13.0	.000
	Sept. 11	10:10	4.6	6.6	.014	11.5	.001
Moraine Creek	July 1	11:05	8.3	7.5	.032	9.5	.002
	July 15	9:55	10.3	7.3	.130	9.5	.024
	Aug. 8	9:30	11.1	6.6	.135	10.0	.018
	Sept. 11	10:35	5.6	7.8	.030	9.0	.002
Cottonwood Creek	July 1	11:40	9.5	7.1	.015	9.5	.002
	July 15	10:35	9.2	7.2	.045	9.5	.004
	Aug. 8	10:00	10.7	7.1	.180	10.0	.018
	Sept. 11	11:25	5.1	7.6	.014	9.5	.001
Alder Creek	July 7	9:40	6.7	7.5	.009	9.5	
	July 15	11:05	7.5	7.3	.020	9.5	.001
	Aug. 8	11:00	10.0	7.3	.050	10.0	.008
	Sept. 11	[3] 12:20	5.1	7.6	.012	8.0	.001
Little Lagoon Creek	June 25	[3] 2:30	8.3		.004	11.0	
Little Lagoon Creek [2]	July 7	10:00	3.6	7.8	.004	10.5	.000
Little Lagoon Creek	do	10:05	4.4	7.6	.008	10.5	.000
Lower Thumb River	June 30	11:35	12.2	7.4	.000	5.5	.000
	July 9	[3] 12:15	12.8	7.4	.000	5.5	.002
	July 17	[3] 1:35	16.7	7.5	.002	4.0	
	Aug. 29	[3] 3:35	17.1	8.9			
	Sept. 6	[3] 12:30	12.3	7.3			
Salmon Creek	June 30	11:20	8.3	7.2	.004	7.5	.000
	July 9	12:00	7.8	7.3	.018	7.5	.002
	July 17	[3] 1:10	12.2	6.9	.060	7.5	
	Aug. 10	[3] 12:40	8.9	7.0	.050	9.0	.007
	Aug. 29	[3] 3:15	11.1	7.1	.018	8.5	.001
	Sept. 6	[3] 12:05	7.8	7.3	.010	8.0	.004
Upper Thumb River	June 30	9:45	8.3	7.2	.007	6.5	.000
	July 9	11:30	8.3	7.0	.020	7.0	.002
	July 17	11:30	11.7	6.7	.045	7.5	
	Aug. 10	11:30	10.0	6.9	.070	8.5	.007
	Aug. 29	[3] 3:05	11.4	7.0	.024	8.0	.001
	Sept. 6	10:03	9.7	6.9	.026	8.0	.008
Halfway Creek [2]	July 6	9:40	7.2	7.4	.004	10.0	.000
Halfway Creek	do	10:00	7.2	7.2	.010	10.0	.000
Halfway Creek [2]	Aug. 11	11:45	8.3	7.6	.004	11.0	.000
Halfway Creek	do	[3] 12:15	8.9	7.3	.040	12.0	.002
	Sept. 11	8:40	4.0	7.3	.012	9.5	.001
Grassy Point Creek	July 6	10:25	7.8	7.2	.056	10.0	.004
	Aug. 11	[3] 12:45	9.2	7.3	.100	11.5	.006
	Sept. 11	9:05	4.4	7.4	.019	8.5	.002
Meadow Creek	July 3	11:00	9.2	7.0	.012	6.5	.001
	July 16	11:05	8.3		.025	7.5	.003
	Aug. 14	[3] 12:35	9.7	7.4	.060	9.5	.007
	Sept. 10	[3] 1:15	6.7	7.3	.008	9.0	.001
Cascade Creek	July 3	10:15	8.3	7.6	.003	6.5	.000
	July 16	10:20	9.2		.006	8.0	.001
	Aug. 14	[3] 12:04	9.9	7.5	.025	9.0	.006
	Sept. 10	[3] 12:40	7.2	7.5	.003	9.0	.001
Canyon Creek	July 3	9:55	7.8	7.4	.004	5.0	.000
	July 16	10:00	8.3		.016	6.5	.003
	Aug. 14	11:34	10.6	7.4	.030	8.5	.006
	Sept. 10	[3] 12:10	8.9	7.0	.014	8.0	.003
Falls Creek	July 3	9:35	8.3	7.4	.000	5.0	.000
	July 16	9:35	9.2		.006	6.0	.000
	Aug. 14	10:07	10.8	7.2		7.5	
	Sept. 10	12:00	8.9	7.2	.006	7.0	.001

[1] Time a. m. except as noted.
[2] Above salmon.
[3] Time p. m.

rather constant from year to year. A shortage of silica in the lake water would act as a limiting factor in the production of diatoms but would not inhibit the production of other forms of phytoplankton.

The yearly increment of soluble phosphorus is dependent, very largely, upon the number of spawning fish which enter the lake each year. There was from 1½ to 10 times the concentration of phosphorus in the water at the mouths of the streams as in the water of the same streams, on the same dates, above the area where spawning and spawned-out salmon were found. Furthermore, a part of the salmon spawn along the beaches of the lake and eventually die, and the carcasses, together with the carcasses which drift downstream into the lake from the tributaries, decompose and the phosphorus contained therein becomes available to the phytoplankton. A shortage of phosphorus in the lake water would inhibit the growth of all forms of phytoplankton.

It is apparent from a study of the chemical analyses of the lake water and of the stream waters that both phosphorus and silica are being absorbed, during the summer months, by the phytoplankton as fast as they become available, for otherwise the concentration of these chemicals in the lake water would approach that found in the streams. Since the concentration of these chemicals in the lake water during most of the summer was less than a measurable amount, it is evident that they must be limiting factors in the production of the phytoplankton and may possibly be affecting indirectly the growth and survival of the red salmon fingerlings of Karluk Lake.

CHANGE IN AGE COMPOSITION OF THE POPULATION

The percentage occurrence of the various age groups in the population, as determined from a study of the scale samples (tables 3 to 16), appears to be changing from year to year. However, a direct comparison of one year's data with another cannot truly represent the change, if any, since a given year's run is composed of the progeny from the escapements of several years.

To determine whether or not a change has been taking place in the age composition of the population, it is necessary to compare the age composition of the escapements with the age composition of the fish returning from the respective escapements. The age compositions of the escapements for a series of years are presented in table 18, and the age compositions of the returns from the escapements appear in table 25.

The percentage of 5_3 fish in the escapements for the years 1922 and 1924 to 1929, inclusive, was 59.3, 76.0, 66.8, 81.1, 70.8, 56.9, and 34.8 while the percentage of 5_3 fish in the returns from these escapements was 50.0, 49.3, 41.2, 52.5, 45.2, 39.5 and 42.0, respectively. There was a lower percentage of 5_3 fish in the return than there was in the escapement for every year with the exception of 1929. A similar condition is found to exist if the returns from the spring and fall escapements are considered separately.

The pairs of percentages for the 6_4 age group for the years 1922 and 1924 to 1929, inclusive, are as follows (the first figure being the percentage of the 6_4 group in the escapement for a given year and the second figure being the percentage of the 6_4 group in the return from the escapement): 4.0:11.3; 10.5:22.8; 15.8:39.3; 7.6:33.2; 6.1:29.4; 9.0:20.3; 35.1:27.7. In all years except 1929 there was a greater percentage of the 6_4 group present in the return from the escapements than there was in the escapements.

In considering these two major age groups there appears to be a decrease in the relative abundance of one, and an increase in the relative abundance of the other. It thus becomes of interest to determine if a change is taking place in the length of ocean residence and in the length of fresh-water residence of these fish.

TABLE 25.—*Percentage occurrence of various age groups in returns from escapements of the spring, fall, and total run for the years 1920 to 1929, inclusive*

Year of escapement	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
1920:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Spring	-----	-----	0.5	1.8	-----	0.3	69.7	0.1	-----	21.9	5.3	-----	-----	0.4	-----	-----	-----
Fall	-----	-----	.1	2.8	0.5	.1	69.4	3.1	-----	3.1	20.3	0.1	-----	.3	0.2	-----	-----
Returns for year	-----	-----	.2	2.5	.4	.2	69.5	2.2	-----	8.6	15.9	.1	-----	.3	.1	-----	-----
1921:																	
Spring	-----	-----	1.1	1.2	-----	1.8	89.3	-----	-----	6.4	.2	-----	-----	-----	-----	-----	-----
Fall	-----	0.1	.6	4.5	-----	.7	87.9	.3	-----	.7	4.6	-----	-----	.6	-----	-----	-----
Returns for year	-----	.1	.8	3.3	-----	1.1	88.4	.2	-----	2.6	3.1	-----	-----	.4	-----	-----	-----
1922:																	
Spring	-----	-----	6.3	1.1	-----	6.5	47.9	.2	-----	35.9	1.3	-----	0.4	.4	-----	-----	-----
Fall	1.2	1.8	2.1	.9	.1	1.0	52.6	4.5	-----	11.1	23.8	-----	-----	.9	-----	-----	-----
Returns for year	.6	.8	4.5	1.0	-----	4.1	50.0	2.1	-----	24.8	11.3	-----	.2	.6	-----	-----	-----
1923:																	
Spring	-----	-----	.2	1.0	-----	-----	65.9	-----	-----	30.4	1.8	-----	-----	.7	-----	-----	-----
Fall	.8	.1	.1	3.0	.1	.2	59.7	.7	-----	6.9	27.4	-----	-----	1.0	-----	-----	-----
Returns for year	.4	.1	.2	2.2	-----	.1	62.2	.4	-----	16.4	17.1	-----	-----	.9	-----	-----	-----
1924:																	
Spring	-----	-----	1.1	.4	-----	2.0	46.7	-----	-----	36.0	11.2	-----	.1	2.4	.1	-----	-----
Fall	-----	.1	1.3	.9	-----	.1	51.8	.6	-----	10.2	33.8	-----	-----	1.0	.2	-----	-----
Returns for year	-----	-----	1.2	.6	-----	1.1	49.3	.4	-----	22.7	22.8	-----	-----	1.7	.2	-----	-----
1925:																	
Spring	-----	-----	1.5	-----	-----	1.4	43.1	1.7	-----	15.1	30.7	-----	-----	6.4	.1	-----	-----
Fall	-----	-----	.2	.4	-----	.1	40.2	12.0	-----	2.0	43.7	.1	-----	.5	.8	-----	-----
Returns for year	-----	-----	.6	.3	-----	.6	41.2	8.5	-----	6.4	39.3	.1	-----	2.5	.5	-----	-----
1926:																	
Spring	-----	-----	.1	.7	-----	1.2	61.5	.8	-----	11.9	19.4	-----	.2	3.7	.3	-----	0.2
Fall	-----	-----	-----	3.7	-----	.2	49.9	3.9	-----	2.8	37.2	-----	-----	.8	1.5	-----	-----
Returns for year	-----	-----	.1	3.1	-----	.4	52.5	3.2	-----	4.8	33.2	-----	-----	1.5	1.2	-----	-----
1927:																	
Spring	-----	-----	1.5	.4	-----	1.4	50.0	.3	-----	25.9	15.1	-----	-----	5.2	.1	0.1	-----
Fall	-----	-----	.7	.8	-----	.9	38.7	2.8	-----	4.4	49.4	-----	-----	2.1	.2	-----	-----
Returns for year	-----	-----	1.2	.6	-----	1.2	45.2	1.3	-----	17.1	29.4	-----	-----	3.9	.1	-----	-----
1928:																	
Spring	-----	-----	.7	.3	-----	2.1	38.7	.2	-----	43.4	8.3	-----	.1	6.0	.1	.1	-----
Fall	-----	.2	.9	.7	-----	.7	40.9	1.9	-----	11.8	39.9	.1	-----	1.0	1.9	-----	-----
Returns for year	-----	.1	.8	.5	-----	1.6	39.5	.8	-----	31.4	20.3	-----	.1	4.1	.8	-----	-----
1929:																	
Spring	-----	.1	.8	.6	-----	3.7	43.6	1.1	0.2	31.0	14.3	-----	.1	4.1	.4	-----	-----
Fall	-----	-----	.4	.3	-----	.3	39.7	.7	-----	4.8	46.7	.7	-----	3.9	2.5	-----	-----
Returns for year	-----	.1	.6	.4	-----	2.3	42.0	.9	.1	20.2	27.7	.3	.1	4.0	1.3	-----	-----

In figures 6 and 7 is presented the relationship between the percentage of fish of a particular ocean history in the escapement and the percentage of fish of the same ocean history in the return. In these and the following figures in this section, lines purportedly fitting the data have been omitted intentionally. The two important questions on which information is desired are (1) whether or not there is a correlation between the percentage occurrence of a particular age group in the escapement and the percentage occurrence of that same age group in the return, and (2) whether or not the values fluctuate around a ratio of 1 to 1. To facilitate observation of the second point, a line representing a ratio of 1 to 1 has been included in each figure.

The relationship between the percentage of fish of a certain ocean history in the escapement and the percentage of fish of the same ocean history in the return, may be considered linear and is such that there will be approximately the same percentage of fish of a single ocean history in the return as there was in the escapement. There appears to be a slight indication that the two-ocean fish are making up a lesser percentage of the returns than they did of the escapements and, conversely, that the three-ocean fish are making up a greater percentage of the returns than they did of the escapements, but the tendency is not marked and probably is not significant.

In figures 8 and 9 is presented the relationship between the percentage of fish of a particular fresh-water history in the escapement and the percentage of fish of the same fresh-water history in the return. There is a positive correlation between the the two variables, although the relationship is very peculiar. For each 1 percent of three-fresh-water fish in the escapement there is approximately 0.75 percent of three-fresh-water fish in the return, and for each 1 percent of four-fresh-water fish in the escapement there is more than 2 percent of four-fresh-water fish in the return. Such a condition could not have prevailed for any great length of time. Obviously, if such a relationship had existed for several complete cycles, the three-fresh-water fish would disappear from the population and only those that migrate to the ocean in their fourth year would remain.

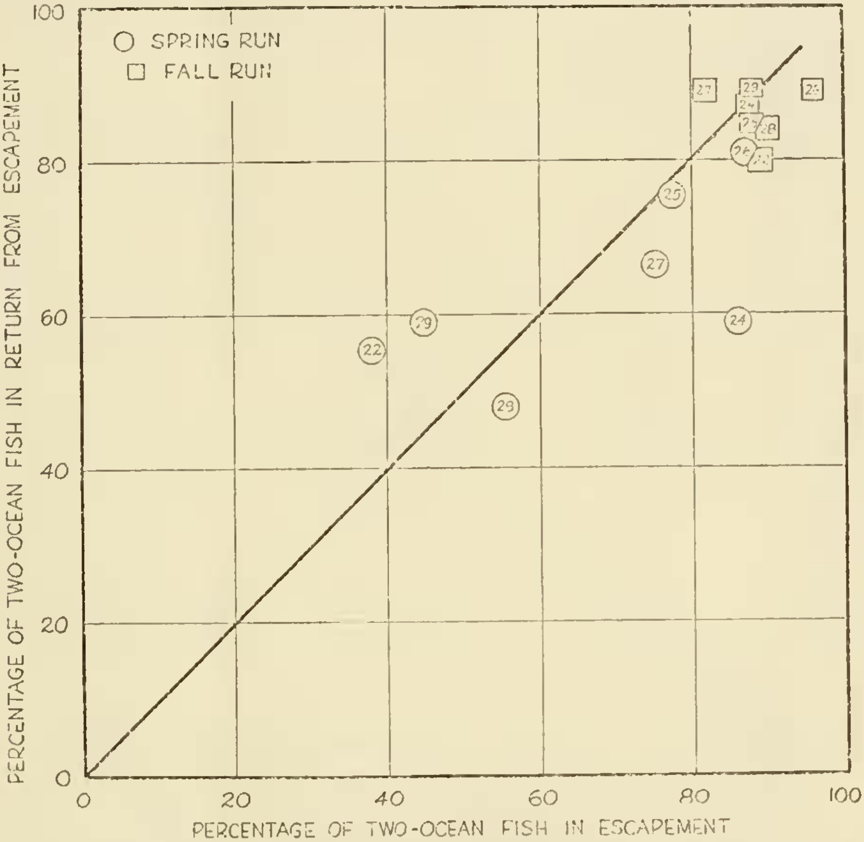

FIGURE 6.—Percentage of two-ocean fish in return plotted against percentage of two-ocean fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

The age analysis based on scale samples collected during 1916, 1917, 1919, and 1921 (Gilbert and Rich, 1927), demonstrated 88.5, 88.1, 91.3, and 93.4 percent, respectively, of three-fresh-water fish in the samples. While the percentages of three-fresh-water fish in the small samples taken from the runs of those years are not exactly comparable to the data under consideration, it is evident that the three-fresh-water age group was dominant.

The change in age composition might be due to any one, or a combination, of the following causes: (1) An increase in the ocean mortality of the 3-year seaward

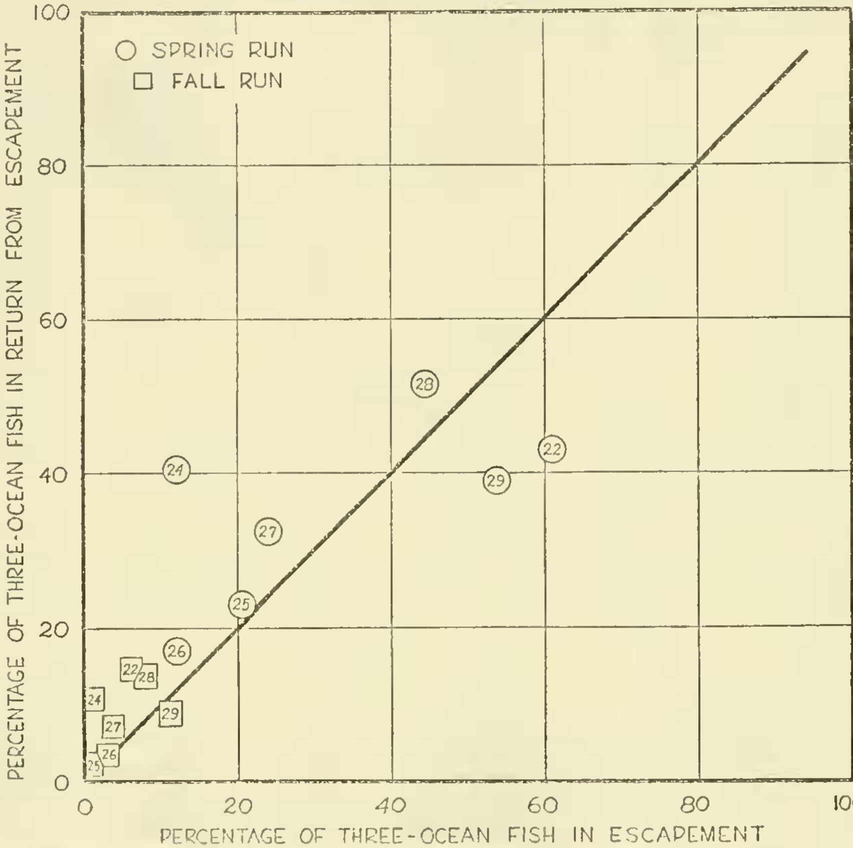

FIGURE 7.—Percentage of three-ocean fish in the return plotted against percentage of three-ocean fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

migrants or a decrease in the ocean mortality of the 4-year seaward migrants; (2) an increase in the fresh-water mortality of the 3-year seaward migrants or a decrease in the fresh-water mortality of the 4-year seaward migrants; (3) an increase in the length of fresh-water residence.

The ocean mortality of the 4-year seaward migrants, as determined by the marking experiments reported in a later section, is less than that of the 3-year seaward migrants. This might be expected as they are larger at the time of migration than the 3-year migrants. There is no evidence that a marked change has taken place in the ocean mortality of either the 3-year or the 4-year seaward migrants.

A change in environment that would increase or decrease the mortality of the fingerlings in the lake should affect each age group of seaward migrants in a similar manner. No data are at hand to indicate that environmental conditions have

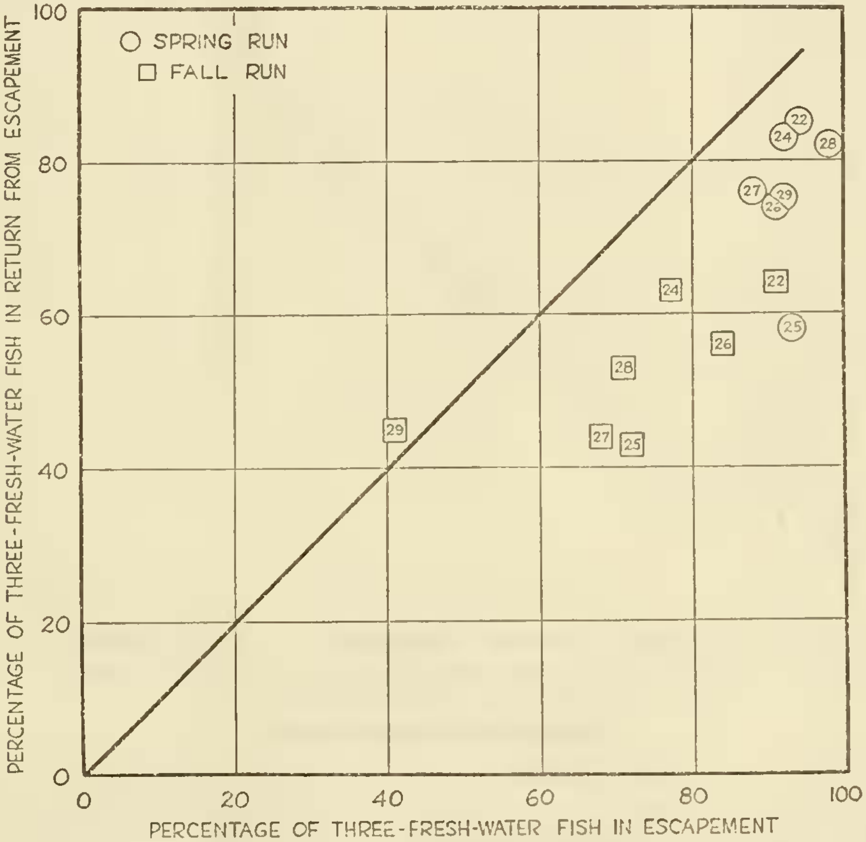

FIGURE 8.—Percentage of three-fresh-water fish in the return plotted against percentage of three-fresh-water fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

altered in such a manner as to affect the mortality of one age group without affecting the mortality of the other age group.

It is probable that the shortage of phosphorus and silica in Karluk Lake during the summer months, which acts as a limiting factor in the production of phytoplankton, also indirectly affects the growth of the red salmon fingerlings. A decrease in the growth rate of the fingerlings may well result in an increase in the length of time spent in fresh water. Data presented in a later section indicate that the fastest growing fingerlings migrate seaward sooner than do the slower growing ones. Consequently, anything affecting the growth rate of the fish would probably cause a change in the time of seaward migration.

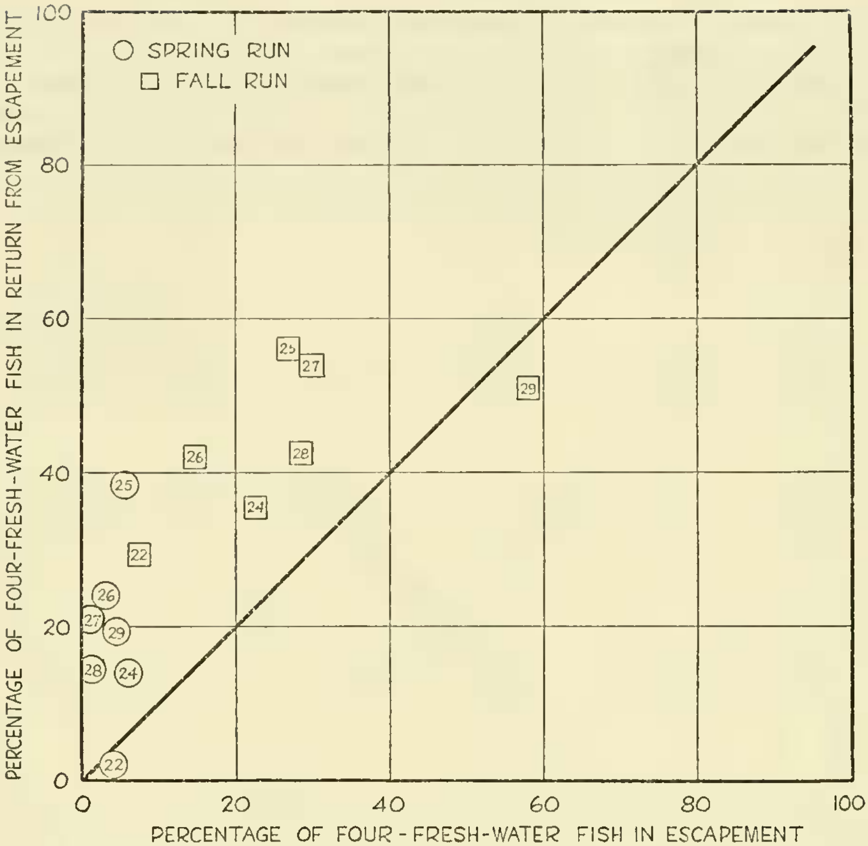

FIGURE 9.—Percentage of four-fresh-water fish in return plotted against percentage of four-fresh-water fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

SEAWARD MIGRATIONS

The seaward migration of Karluk River red salmon takes place during the last week of May and the first 2 weeks of June each year. A few fish migrate sometimes a day or two earlier or later than this period but the major part of the migration, and frequently the entire migration, takes place during these 3 weeks. During the migration period the seaward migrants can be observed in front of the counting weir where they congregate in schools of a few hundred to tens of thousands. Only occasionally can they be seen going through the weir during the daytime, but just at dusk the schools above the weir drop downstream and begin to pass through the spaces between the pickets. Where there is any appreciable current, the fish always head upstream even when migrating downstream. Seaward migrants are present in the river above the weir for only 10 to 16 days each year, although the migration period may extend over a period of 3 weeks. They may be quite abundant one day, entirely absent the next, and present again the following day.

The percentage occurrence of the various age groups in the random samples of seaward migrants collected at the weir site is presented in table 26. Samples were not collected every day that migrants were present in the river, but since 1930 samples have been taken every day that fish were abundant.

TABLE 26.—*Percentage occurrence of various age groups in the random samples of seaward migrant red salmon for the years 1925 to 1936, inclusive*

Week ending—	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936
2-YEAR SEAWARD MIGRANTS												
May 31						1.0						
June 7	0.4					1.0	0.3	0.2		0.5	0.1	4.0
June 14		0.9	0.8			1.9	1.0	.2			.7	7.7
June 21			1.7	0.8		1.2	1.0	2.0		1.0		
June 28									3.5			
3-YEAR SEAWARD MIGRANTS												
May 31		67.3			21.0	56.8	73.5	38.8	32.5	83.2	81.0	58.8
June 7	90.0	79.9	46.7	45.0	30.3	52.1	86.2	53.0	45.2	93.3	82.3	79.0
June 14	84.0	73.5	52.1	72.9	70.6	69.8	92.5	75.9	68.7		88.5	80.3
June 21			78.2	86.7		74.1	96.1	81.0		96.0		
June 28								88.0	75.5			
4-YEAR SEAWARD MIGRANTS												
May 31		32.7			77.0	40.2	25.6	60.5	65.0	15.8	19.0	40.2
June 7	9.6	19.7	53.3	54.2	69.3	45.2	13.0	46.2	52.8	6.0	17.6	17.0
June 14	16.0	25.1	47.1	26.7	29.4	27.9	6.5	23.1	30.0		10.7	11.3
June 21			20.1	12.5		24.5	2.9	15.0	21.0	3.0		
June 28								12.0				
5-YEAR SEAWARD MIGRANTS												
May 31					2.0	2.0	0.9	0.7	2.5	1.0		1.0
June 7		0.4		0.8	.4	1.7	.5	.6	2.0	.3		
June 14		.5		.4		.4		.8	1.3		0.1	.7
June 21						.2		2.0				
Number of fish in sample	644	602	358	720	1,025	1,811	2,050	2,007	1,197	900	1,800	1,000

In considering the two major age groups, 3 and 4, it will be noted that the percentage of the 4-year group decreases as the migration proceeds while the percentage of the 3-year group increases. This phenomenon, while not so obvious because of the small numbers in the samples, also appears to exist in the two minor age groups for the percentage of the 5-year group decreases and the percentage of the 2-year group increases as the migration proceeds. There is a tendency for the older age groups to migrate earlier than the younger age groups.

The average sizes of the seaward migrants in the samples collected in the years 1925 to 1936, inclusive, are presented in table 27. There is a marked decrease, especially among the 4-year migrants, in the average size during successive periods of sampling. The decrease in size of the 3-year migrants would probably be more apparent were it not for the fact that the fish are just commencing to grow at the beginning of the migration period, and those fish which migrate late in the season have grown a certain amount as indicated by two or three wide-spaced rings beyond the winter check on their scales. Fish of the 4-year and 5-year groups seldom show any new growth of the year until late in the migration period.

From a study of the rate of growth of the fingerlings, as determined by their scales, and from the above-mentioned data relating to the change in age composition and size of the migrants during each year's seaward migration, the following trend of events is indicated. Of the progeny of a given brood year, the fastest growing individuals (hence the largest) migrate to the ocean in the spring of their second year. In the spring of the third year the largest individuals of the population left in the lake

TABLE 27.—*Average length in millimeters of 2-, 3-, 4-, and 5-year seaward migrants in weekly samples for the years 1925 to 1936, inclusive*

2-YEAR SEAWARD MIGRANTS

Year	Item	Week ending— May 31	June 7	June 14	June 21	June 28	Year	Item	Week ending— May 31	June 7	June 14	June 21	June 28
1925	Number		2				1932	Number		3	1	1	
	Mean		112.50					Mean		110.17	96.50	107.5	
	σ		7.07					σ		12.34			
1926	Number			2			1933	Number					7
	Mean			100.00				Mean					113.79
	σ			10.06				σ					4.68
1927	Number			1	2		1934	Number		2		1	
	Mean			127.50	103.00			Mean		119.5		125.5	
	σ				3.53			σ		2.83			
1928	Number				2		1935	Number		1	6		
	Mean				110.50			Mean		107.5	117.5		
	σ				2.83			σ			9.36		
1930	Number	3	6	4	6	17	1936	Number		11	21		
	Mean	118.17	101.17	105.50	109.33	113.85		Mean		109.95	111.07		
	σ	2.58	7.15	4.16	4.26	6.87		σ		3.59	3.43		
1931	Number		2	6	1								
	Mean		99.50	113.17	119.50								
	σ		25.45	21.61									

3-YEAR SEAWARD MIGRANTS

Year	Item	May 31	June 7	June 14	June 21	June 28	Year	Item	May 31	June 7	June 14	June 21	June 28
1925	Number		90	131			1931	Number	399	632	527	196	
	Mean		135.56	135.09				Mean	128.87	129.96	130.55	128.06	
	σ		8.27	6.92				σ	8.22	7.93	7.06	7.73	
1926	Number	101	183	164			1932	Number	265	286	444	81	88
	Mean	136.47	135.82	134.91				Mean	131.44	131.81	131.73	132.01	135.97
	σ	5.60	6.87	7.56				σ	5.60	5.31	6.34	6.84	5.86
1927	Number		56	62	93		1933	Number	65	226	204		151
	Mean		132.59	135.40	134.11			Mean	136.90	137.68	135.95		131.15
	σ		6.71	6.69	6.04			σ	6.57	6.82	7.10		7.98
1928	Number		108	175	208		1934	Number	333	373		96	
	Mean		129.83	128.34	125.85			Mean	141.83	138.92		140.32	
	σ		5.63	6.21	8.46			σ	7.09	8.17		8.04	
1929	Number	21	23	274			1935	Number	81	660	797		
	Mean	133.21	130.07	127.69				Mean	141.56	141.96	140.86		
	σ	6.32	7.32	7.89				σ	5.01	6.16	8.16		
1930	Number	174	340	185	436	173	1936	Number	235	237	241		
	Mean	124.71	126.66	131.30	128.16	124.63		Mean	136.19	132.70	129.59		
	σ	6.52	6.81	5.71	7.31	7.61		σ	6.60	8.37	9.04		

4-YEAR SEAWARD MIGRANTS

Year	Item	May 31	June 7	June 14	June 21	June 28	Year	Item	May 31	June 7	June 14	June 21	June 28
1925	Number		47	25			1931	Number	139	95	37	6	
	Mean		147.48	141.70				Mean	143.31	139.68	135.20	132.33	
	σ		6.55	8.05				σ	7.92	8.61	7.14	6.24	
1926	Number	49	45	56			1932	Number	413	249	135	15	12
	Mean	147.13	145.90	139.98				Mean	145.11	142.94	137.83	131.30	138.00
	σ	6.92	7.00	6.22				σ	7.11	7.39	8.43	5.32	5.21
1927	Number		64	56	24		1933	Number	130	264	89		42
	Mean		145.86	146.79	144.17			Mean	149.27	147.24	142.23		138.36
	σ		7.24	4.90	5.45			σ	8.01	7.81	10.12		9.40
1928	Number		130	64	30		1934	Number	63	24		3	
	Mean		143.42	142.20	137.83			Mean	155.34	147.79		142.17	
	σ		6.74	6.02	7.87			σ	10.23	12.02		12.34	
1929	Number	77	96	114			1935	Number	19	139	96		
	Mean	146.47	145.74	137.34				Mean	153.45	153.76	148.95		
	σ	6.49	5.40	11.12				σ	6.88	6.62	11.40		
1930	Number	123	295	74	144	38	1936	Number	161	51	34		
	Mean	140.65	140.13	142.31	136.26	126.68		Mean	149.41	142.62	137.12		
	σ	8.10	7.80	7.30	9.48	9.16		σ	8.19	9.26	7.26		

5-YEAR SEAWARD MIGRANTS

Year	Item	May 31	June 7	June 14	June 21	June 28	Year	Item	May 31	June 7	June 14	June 21	June 28
1926	Number		1	1			1932	Number	5	3	5	2	
	Mean		150.50	175.50				Mean	152.90	153.50	144.50	132.50	
	σ							σ	4.98	2.00	10.75	2.83	
1928	Number		2	1			1933	Number	5	10	4		
	Mean		150.50	149.50				Mean	145.90	150.90	144.75		
	σ		0.00					σ	2.07	5.72	6.99		
1929	Number	2	1				1934	Number	4	1			
	Mean	149.00	160.50					Mean	161.75	158.50			
	σ	16.26						σ	4.79				
1930	Number	6	11	1	1		1935	Number			1		
	Mean	143.33	138.05	152.50	137.50			Mean			145.50		
	σ	6.14	6.35					σ					
1931	Number	5	4				1936	Number	4		2		
	Mean	146.50	141.75					Mean	149.75		152.00		
	σ	8.34	3.77					σ	3.10		13.44		

migrate seaward. At the end of the migration period a part of this population is present in the lake. These fish remain for another year and obtain more growth. In the fourth year, the largest individuals remaining in the lake proceed seaward, the time of appearance in the migration being correlated with their size. The slowest growing individuals of the entire progeny which have not migrated remain in the lake for another year and then migrate seaward in their fifth year.

The older fish are of a larger average size than those of lesser age and their larger size is due to the longer growing period that precedes migration. Fish in the older age groups are usually the slower growing fish of the progeny from a particular spawning. Thus, the urge to migrate seaward is related to the size and growth rate of fingerlings, and it appears that environmental conditions that affect the growth of the fish during the time spent in the lake also affect the time at which the fingerlings migrate to the ocean.

The data on the percentage of males in the samples of migrants which were examined to determine sex are presented in table 28. The males and females were equally represented. Grouping the 3- and 4-year fish, it was found that the total of 11,080 fish examined consisted of 5,557 males and 5,523 females. The slight variations in the sex ratios from year to year are probably due to chance because there is no significant statistical difference in the ratios.

TABLE 28.—*Number of 3-year and 4-year migrants examined and percentage of males in the samples*

Year	Number of 3-year fish examined	Number of males	Percentage of males	Number of 4-year fish examined	Number of males	Percentage of males
1925	570	296	51.9	72	40	55.6
1926	448	232	51.8	150	71	47.3
1927	211	115	54.5	144	75	52.1
1928	491	262	53.4	224	127	56.7
1929	318	168	52.8	287	161	56.1
1930	1,308	659	50.4	674	335	51.3
1931	1,754	831	47.4	277	132	47.6
1932	1,256	632	50.3	833	401	48.1
1933	646	320	49.5	525	252	48.0
1934	802	401	50.0	90	47	52.2
Total	7,804	3,916	50.18	3,276	1,641	50.09

SEX RATIOS OF ADULT FISH

The sex ratio of the adult fish is in marked contrast to that of the seaward migrants. Data on the percentage occurrence of males in the samples for the years 1922 and 1924 to 1936 are presented in table 29, arranged according to the length of time spent in the ocean. The percentage occurrence of the males decreases with increased ocean residence. All of the zero-ocean fish [8] are males. The average percentages of males in the one-ocean fish, of varying periods of fresh-water residence, range from 100 percent to 75 percent. The average percentages of males in the two-ocean fish range from 62 percent to 32 percent, while the average percentages of males in the three-ocean fish of varying fresh-water residence range from 38 percent to 35 percent.

[8] Fish which spend only a few months in the ocean and return as mature fish in the fall of the same year in which they migrated seaward.

TABLE 29.—*Number of fish of each age group examined, and the percentage of males in samples for the years 1922, 1924, to 1928, and 1930 to 1936, inclusive*

Age group	1922		1924		1925		1926		1927	
	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males
3_3			1	100.0						
4_4	3	100.0	18	100.0			1	100.0	1	100.0
5_5	1	100.0								
3_2										
4_3	19	89.5	16[1]	95.0	228	94.7	35	100.0	151	95.4
5_4	27	85.2	176	69.3	71	84.5	15	100.0	136	87.5
6_5	1	100.0			1	100.0	3	100.0	2	50.0
3_1					30	66.7	19	57.9	1	0
4_2	16	18.8	17	23.5	100	45.5	207	46.4	17	29.4
5_3	1,511	48.4	3,845	46.6	3,877	43.6	6,426	43.2	3,476	43.1
6_4	138	57.2	660	46.8	920	43.2	743	46.4	477	46.1
7_5							9	22.2	9	55.6
4_1	3	100.0	1	100.0	12	41.7	35	20.0	10	40.0
5_2	9	44.4	18	38.9	14	35.7	141	34.8	201	27.9
6_3	737	41.9	217	44.2	227	41.4	470	34.0	315	35.6
7_4	4	25.0	18	50.0	23	34.8	67	31.3	32	43.8
8_5									1	100.0
7_3										
8_4							1	100.0		
Total	2,469		5,132		5,513		8,172		4,829	

Age group	1928		1930		1931		1932		1933	
	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males
3_3										
4_4										
5_5										
3_2										
4_3	16	93.8	19	100.0	14	100.0	40	97.5	2	100.0
5_4	22	90.9	34	100.0	108	71.3	59	91.5	4	75.0
6_5					6	66.7			1	100.0
3_1										
4_2	18	44.4	2	50.0	51	52.9	71	36.6	2	50.0
5_3	2,391	42.2	601	42.3	1,821	42.8	1,821	40.5	85	52.9
6_4	688	41.9	141	44.7	1,453	39.2	1,314	40.4	91	48.4
7_5	4	50.0			3	33.3	25	28.0	7	28.6
4_1	1	100.0					8	25.0		
5_2	7	42.9	19	42.1	16	37.5	85	42.4	4	50.0
6_3	1,052	38.4	223	41.2	266	36.1	233	32.6	21	25.0
7_4	37	51.4	13	30.8	44	34.1	80	37.5	1	100.0
8_5										
7_3			1	100.0						
8_4										
Total	4,236		1,053		3,782		3,736		221	

Age group	1934		1935		1936		1922–36		
	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Total number examined	Number males found	Percentage males
3_3							1	1	100.0
4_4							23	23	100.0
5_5							1	1	100.0
3_2			1	100.0			1	1	100.0
4_3			210	96.2	114	100.0	1,009	970	96.1
5_4	4	75.0	64	79.7	13	92.3	733	593	80.9
6_5			2	100.0			16	12	75.0
3_1							50	31	62.0
4_2	70	38.6	148	49.3	78	48.7	807	359	44.5
5_3	311	51.8	1,312	42.5	3,510	42.2	30,987	13,517	43.6
6_4	273	39.2	898	39.9	492	43.3	8,288	3,523	42.5
7_5	1	100.0	30	23.3	22	45.5	110	36	32.7
4_1			29	41.4			99	35	35.4
5_2	22	59.1	107	30.8	241	39.4	884	317	35.9
6_3	327	43.4	284	35.9	567	35.6	4,942	1,891	38.3
7_4	34	32.4	91	33.0	154	40.9	598	227	38.0
8_5							1	1	100.0
7_3							1	1	100.0
8_4							1	1	100.0
Total	1,042		3,176		5,191		48,552	21,540	

Thus there is a decrease in the percentage of males, and conversely an increase in the percentage of females, with increased length of time spent in the ocean. The males tend to mature after a shorter period of ocean residence than the females, and this precocious development of the males also is apparent from a consideration of the total age of the mature fish. In a group of the same ocean history, with the exception of the three-ocean fish, the younger fish are more predominately male than the older members of that group.

The percentages of males and females returning from the seaward migrations of 1923 to 1933, inclusive, are presented in table 30. These percentages were determined by calculating the number of males and females of various ocean histories returning from a single seaward migration and then adding the several groups together to obtain the total number of males and females returning from that migration. The percentage of males varied from 40.1 to 48.8 percent and the percentage of females from 51.2 to 59.9 percent, and the average for all years was 43.9 percent males and 56.1 percent females.

Table 30.—*Percentage of males and females in the returns from the seaward migrations of 1923 to 1933*

Year of seaward migration	Percentage of males in return	Percentage of females in return	Year of seaward migration	Percentage of males in return	Percentage of females in return
1923	44.3	55.7	1930	40.1	59.9
1924	45.3	54.7	1931	48.8	51.2
1925	43.0	57.0	1932	43.5	56.5
1926	45.0	55.0	1933	40.7	59.3
1927	43.3	56.7			
1928	42.0	58.0	Average	43.9	56.1
1929	47.0	53.0			

The sex ratio of these fish changes from approximately 50 percent males and 50 percent females at the time of seaward migration to approximately 44 percent males and 56 percent females on their return from the ocean. Since the males, on the average, spend less time in the ocean than the females, the mortality of the males should be less than that of the females, which should result in a preponderance of males. A part of the Karluk run is intercepted by a gill-net fishery to the north and east of the Karluk River, and because of the size of the gill-net mesh employed, a great percentage of the larger fish in the run is captured. As the average size of the males is slightly greater than the average size of the females, more males than females are captured and thus the percentage of males in the fish arriving at the Karluk River, where the data for table 30 were obtained, is reduced. It is not considered that the selective action by the gill nets accounts entirely for the discrepancy in the sex ratio because the gill-net catches are fairly small in relation to the size of the run as a whole. A differential mortality in favor of the females during the time spent in the ocean does not appear probable. A satisfactory explanation of this phenomenon is lacking at the present time.

MARKING EXPERIMENTS

A series of marking experiments was begun at Karluk River, Alaska, in 1926.[9] In these experiments, red salmon migrating seaward were marked by the removal of

[9] These marking experiments were initiated by the late Dr. C. H. Gilbert, and Dr. W. H. Rich, both of the former United States Bureau of Fisheries.

two or three fins, so that their presence in the future runs of fish could be noted. The experiments were initiated to determine the rate of survival of the fish during their stay in the ocean.

Rich and Holmes (1929), in reviewing the results of previous marking experiments, pointed out that fish occasionally have one fin, or two fins in close proximity to each other (both ventrals), accidentally missing. In the marking experiments carried on at Karluk the adipose and one or two other fins were amputated, as it was considered that the finding of a fish with two widely separated fins missing as a result of an accident would be an extremely rare occurrence.

During the marking of seaward migrants at Karluk and the subsequent examination of the run of adult fish, salmon have been found with the following fins missing: adipose, right ventral, left ventral, both ventrals, right pectoral, and left pectoral. Fish with the dorsal, anal, and caudal, or one of the above mentioned fins badly deformed, have also been observed. More than 400,000 seaward migrant red salmon have been examined at Karluk, and in no case has a fish been found which had both the adipose and some other fin missing or badly deformed.

The results of other marking experiments, in which data on the percentage return of marked fish from the experiments were obtained, are reviewed for the sake of comparison with the results obtained at Karluk. It should be noted that in several instances species other than red salmon were marked, and in no instance were the fish marked as large as the seaward migrants marked in the Karluk experiments.

Rich and Holmes (1928) in their experiemnts in marking chinook salmon on the Columbia River, from 1916 to 1927, had returns ranging from 0.002 to 0.45 percent of the number of fish liberated from a single marking experiment. They pointed out that—

> These figures have very little significance, however, because they represent not the total returns but an unknown and varying proportion of the total.

In four of their experiments the records are believed to be fairly complete, and in their opinion

> . . . the returns that have not come to our attention certainly would not add enough to make the totals more than 1 or 2 percent of the liberation.

Snyder (1921, 1922, 1923, 1924) marked chinook salmon on the Klamath and Sacramento rivers in California, and the proportion of marked fish recovered was approximately the same as in the experiments of Rich and Holmes.

In 1930, Davidson (1934) marked 36,000 seaward migrant pink salmon at Duckabush River, Hoods Canal, Wash., by amputating the adipose and dorsal fins. In 1931, 50,000 seaward migrant pink salmon were similarly marked at Snake Creek, Olive Cove, Alaska. These fish were approximately 40 mm. long at the time of marking. From the first experiment 10 marked fish were recovered, or 0.028 percent of the number marked. From the second experiment 23 marked fish were recovered, and it was calculated that the total number of marked fish in the escapement was 54, or 0.108 percent of the number marked. These data represent only the return of marked fish in the escapement. However, the total return from either experiment could hardly have equaled 1 percent of the number of fish marked.

Pritchard (1934a) marked 8,741 pink-salmon fingerlings at Cultus Lake, British Columbia, in 1932, by the amputation of both ventral fins. These fish were released into the Vedder River below the mouth of Sweltzer Creek which is the outlet stream of Cultus Lake.

One hundred and twenty-four thousand pink-salmon fingerlings of Tlell River (east coast of Graham Island) were marked by the amputation of the adipose and left ventral fins. These fish together with 750,000 unmarked individuals, from the same source, were liberated in McClinton Creek, Massett Inlet.

In 1933, fish with the following fins missing were recovered at various localities in Puget Sound, British Columbia, and Chignik, Alaska: adipose 576, adipose and left ventral 40, both ventrals 64, right ventral 54, adipose and right ventral 20, left ventral 56. No marked fish were recovered in Sweltzer Creek, Tlell River, or McClinton Creek though counting weirs were maintained in these streams.

During 1933, Pritchard (1934b) marked 108,000 pink-salmon fry at McClinton Creek, Massett Inlet, by amputating both ventral fins. The following numbers of fish with fins missing were recovered at various localities in British Columbia during 1934: both ventrals 3,285, left ventral 195, right ventral 139, adipose 100, and left pectoral 15.[10] Of these totals, 2,950 with both ventrals, 66 with left ventrals, 95 with right ventrals, and 2 with adipose fins absent were recovered at McClinton Creek. Thus, of the number of fish marked by removal of both ventrals 2.73 percent returned to McClinton Creek. The total return was possibly higher than 3,285 (3.04 percent of the number marked) because all of the fish bound for McClinton Creek were not sampled.

In 1934, Kelez (1937) initiated two marking experiments on hatchery-raised coho salmon at Friday Creek, a tributary of the Samish River. In the first experiment 26,150 fingerlings were marked by the amputation of the adipose and dorsal fins. The fish were liberated during May when they averaged 47.4 mm. in length. Seven marked fish were recovered as adults, or 0.027 percent of the number marked.

In the second experiment 26,150 fingerlings of the same brood were marked by the amputation of the dorsal and left ventral fins and liberated during November when they averaged 101.6 mm. in length. From this experiment 469 marked fish were recovered, or 1.79 percent of the number marked.

Assuming that there was not a differential mortality caused by the marking in the two groups of fish in the experiments, these data indicate a striking increase in the survival rate of the fingerlings retained in the hatchery ponds for a longer period of time. The returns from these experiments comprise only those fish which escaped the sport and commercial fisheries.

A series of marking experiments has been conducted on the red salmon of Cultus Lake, British Columbia. In 1927 (Foerster, 1934), 91,600 seaward migrants were marked by the amputation of the adipose and both ventral fins. From this marking, 804 fish, or 0.88 percent, were recovered during 1929 and 1930 at the counting weir below Cultus Lake, these being the total number of marked fish returning to Cultus Lake from this experiment. Of the 158,100 unmarked fish, 3,930, or 2.49 percent, returned to Cultus Lake.

During 1928 (Foerster, 1936a), 99,700 seaward migrants were marked by the

[10] The finding of fish with adipose fins missing, and left pectoral fins missing only confirms the long established fact that fish occur in nature with fins missing. The finding of fish with right or left ventral fins missing is due in part to natural deformities, and may be due to regeneration of one or the other of the fins of the fish marked both ventrals. A part of the fish with both ventral fins missing may not be returns from the experiment but may be fish with natural deformities.

amputation of both ventral fins and the posterior half of the dorsal. From this marking, 1,340 fish, or 1.34 percent of the number marked, were recovered at the counting weir below Cultus Lake; and these were the total number of marked fish that returned to Cultus Lake from this experiment. Of the unmarked seaward migrants, 3.2 percent returned to Cultus Lake.

In 1930 (Foerster, 1936b), 104,061 seaward migrants were marked by the amputation of both ventral fins. A total of 3,821 fish, or 3.67 percent of the number marked, was recovered from the commercial fishery and at the counting weir below Cultus Lake. It was considered that the recovery was at least 90 percent of the total number of marked fish returning from the experiment, so that the actual return ". . . probably lay somewhere between 3.67 and 4.1 per cent."

During 1931 (Foerster, 1936b), 365,265 seaward migrants were marked by the amputation of the adipose and both ventral fins. A total of 12,803 fish, or 3.51 percent of the number marked, was recovered from the commercial fishery and at the counting weir below Cultus Lake. The recovery was at least 95 percent of the total number of marked fish returning from the experiment so that the actual return ". . . lies between 3.5 and 3.7 percent."

In Foerster's experiments of 1927 and 1928 a greater survival was found among the unmarked fish than among the marked fish. Three factors were considered in an endeavor to account for the disparity.

> . . . infiltration of unmarked adults from other areas, the straying of marked individuals to other spawning regions or a definite differential mortality among marked groups.

Evidence was produced to show cause for ruling out the first two factors, and it was concluded that—

> There remains, therefore, only the factor of differential mortality among the marked individuals, and on the data available this is held to be the one largely responsible for the lower return of marked adults when compared with that for the unmarked.

The differential mortality was calculated to be 65 percent for the 1927 experiment and 58 percent for the 1928 experiment, and the probable value was considered to be the mean of the two values or 62 percent. Thus there was a 186 percent greater survival among the unmarked fish than among the marked fish of the first experiment, and a 138 percent greater survival among the unmarked fish than among the marked fish of the second experiment, and the probable value was considered to be approximately 163 percent.

Based on the information on differential mortality between marked and unmarked fish derived from the 1927 and 1928 marking experiments and on the data collected from the marking experiments of 1930 and 1931, Foerster considered that the survival of Cultus Lake red salmon during the time spent in the ocean ranged between 3.5 percent (his lowest percentage return uncorrected for differential mortality) and 11.7 percent (his highest percentage return, 4.1 percent, multiplied by 2.86 to correct for differential mortality). The most probable value was considered to be 9.9 percent (the mean probable value of the recoveries, 3.75 percent, multiplied by a mean value, 2.63, to correct for differential mortality).

MARKING OF KARLUK RIVER RED SALMON

The Karluk River is relatively shallow, and as the seaward migrant fingerlings tend to congregate above the counting weir, they can easily be captured. A pen about 5 feet square of ½-inch bar wire netting, having a gate for the fish to enter, was constructed in the river. A seine was passed around a school of fish, and an end of the seine brought to each side of the gate. By gradually drawing in the ends of the seine, the fish were induced to enter the pen, and the gate was closed. Several thousand migrants can be held in the pen at one time without injury. Two or three hundred migrants were caught and transferred to a wash tub partially filled with water. The tub of fish was then carried from the pen to the marking shed below the weir. The fish were removed from the tub one at a time, the adipose and one or two other fins removed by means of a nail clipper, and the fish dropped into the river free to proceed downstream. During the entire operation the fish are out of water for less than 10 seconds. Samples of marked fish have been held in tanks for several days after marking, and the fish have shown no ill effects from the operation, though some of the fish marked by the removal of either of the pectoral fins appeared to have a slight list.

The age group composition of the marked migrants was determined by multiplying the number of migrants marked each day by the percentage of the various age groups in the migration for that day as determined by the analysis of data obtained from scale samples of the fish.

RECOVERY OF MARKED FISH

Owing to the magnitude of the run of Karluk red salmon, it was impossible to examine every fish to search for marked individuals. The method employed to determine the total number of marked fish was as follows:

As large a portion as possible of each day's catch of red salmon, taken by means of beach seines near the mouth of the Karluk River, was examined for the presence of marked fish by an employee of the Fish and Wildlife Service who, during the examination, was stationed in the cannery. Each red salmon was examined and counted as it passed along the chute. All fish with missing or mutilated fins were put aside and re-examined later to determine whether they were marked fish. Scale samples were taken from all marked fish found, and scale samples were taken at random from the catch to determine the age composition. The number of marked fish of each age found and the number of fish of that same age examined were determined at weekly intervals throughout the season. The total number of marked fish of each age found was divided by the total number of fish of the same age group examined to determine the percentage occurrence of marked fish in that age group. Data were collected on the number of Karluk red salmon in the commercial catch and also the number in the escapement, hence, the total number of fish of each age group in the run can be determined for the season. Multiplying the number of fish of a given age in the run by the percentage occurrence of marked fish in that age group gave the calculated number of marked fish of that age group returning.

Since it is considered that there are two runs of red salmon to the Karluk River, it would be preferable to divide each marking experiment into two parts, i. e., spring run and fall run. Unfortunately, there is no way of determining which are spring run or which are fall run seaward migrants. The percentage occurrence of marked fish of each age group is fairly constant throughout the season, indicating that proportionate numbers of the two runs are marked.

EXPERIMENTS IN 1926

A total of 47,691 seaward migrant red salmon were marked by the amputation of two fins. Two combinations were used, the adipose and right ventral, and the adipose and left ventral. Since approximately the same number of fish were marked each day by each mark, the data can be grouped together and considered as one experiment or divided according to the marks used and considered as duplicate experiments. Although the experiments were carried on simultaneously, the one in which the fish were marked by the amputation of the adipose and right ventral fins will be referred to as the first experiment, and the one in which the fish were marked by the amputation of the adipose and left ventral fins will be referred to as the second experiment.

Commercial fishing was limited in 1929 and the run of that year could not be adequately sampled to detect the presence of marked fish. Consequently, no accurate means of determining the number of three-ocean fish returning from these experiments is available. The number of marked fish returning and the percentage return, as presented, are lower than they would have been had information on the three-ocean fish been available.

In the first experiment (table 31), 25,000 seaward migrants were marked, 740 marked fish were recovered and a calculated total of 5,151 marked fish returned from this experiment, not counting the marked fish returning during 1929. The return from this experiment was at least 20.6 percent.

TABLE 31.—*Data for the first 1926 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1926 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	92	4_2	1,509	1	0.066	9,934	7	7.6	[1] 7.6
		5_2				8,836			
3	19,196	4_3	2,690	5	.186	43,551	81	.4	[1] 19.5
		5_3	168,042	498	.296	1,236,953	3,661	19.1	
		6_3				325,643			
		7_3				20			
4	5,641	4_4				1,040			[1] 24.3
		5_4	4,527	11	.243	47,298	115	2.0	
		6_4	44,264	219	.495	254,138	1,258	22.3	
		7_4				14,294			
5	71	6_5				895			40.8
		7_5	279	6	2.151	1,325	29	40.8	
Total	25,000		221,311	740		1,943,927	[1] 5,151		

[1] Based on incomplete data, see text.

The incomplete returns from the marked 2-, 3-, 4-, and 5-year seaward migrants were 7.6, 19.5, 24.3, and 40.8 percent, respectively. Very few 2- and 5-year seaward migrants were marked, and the returns from those age groups are based on the recovery of only one and six fish, respectively; hence, the percentage returns are unreliable. As the size of the migrants increases with age, the data indicate that the larger migrants have the highest survival value.

In the second experiment (table 32) 21,791 migrants were marked, 659 were recovered, and a calculated total of at least 4,582 marked fish returned from this experiment (at least 21.0 percent). The incomplete returns from the marked 2-, 3-, 4-, and 5-year seaward migrants were 0.0, 20.5, 23.0 and 28.6 percent, respectively.

The returns from the two experiments agree closely except for the 2- and 5-year fish of which few were marked. If the data are combined as one experiment, 46,791 seaward migrants were marked, 1,399 were recovered, and a calculated total of at least 9,733 fish returned (a minimum of 20.8 percent).

TABLE 32.—*Data for the second 1926 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1926 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	52	4_2	1,509			9,934			[1] 0.0
		5_2				8,836			
3	16,730	4_3	2,690	3	0.112	43,551	49	0.3	[1] 20.5
		5_3	168,042	458	.273	1,236,953	3,377	20.2	
		6_3				325,643			
		7_3				20			
4	4,925	4_4				1,040			[1] 23.0
		5_4	4,527	5	.110	47,298	52	1.1	
		6_4	44,264	188	.425	254,138	1,080	21.9	
		7_4				14,294			
5	84	6_5				895			28.6
		7_5	279	5	.792	1,325	24	28.6	
Total	21,791		221,311	659		1,943,927	[1] 4,582		

[1] Based on incomplete data, see text.

EXPERIMENTS IN 1927 AND 1928

Fifty thousand seaward migrants were marked in both 1927 and 1928. However, the curtailment of commercial fishing in 1929 and 1930 made it impossible to adequately sample the runs of those years for the presence of marked fish, and the data are consequently not included here.

EXPERIMENTS IN 1929

In 1929 (table 33), 50,061 seaward migrants were marked by the amputation of the adipose and both ventral fins, 1,315 fish were recovered, and a calculated total of 11,157 marked fish returned from this experiment (22.3 percent). The return from the 3-, 4-, and 5-year marked seaward migrants was 18.3, 24.4, and 13.5 percent, respectively. As very few 5-year seaward migrants were marked and only 3 recovered, the latter figure cannot be considered reliable; however, considering the returns of the 3- and 4-year seaward migrants, it is again apparent that the older and larger migrants had the highest survival value.

TABLE 33.—*Data for the 1929 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1929 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1	----------	3_1	57	----------	----------	311	----------	----------	----------
		4_1	204	----------	----------	1,938	----------	----------	----------
2	----------	4_2	2,734	----------	----------	18,573	----------	----------	----------
		5_2	1,990	----------	----------	19,133	----------	----------	----------
		4_3	212	3	1.415	46,344	656	3.0	
3	21,858	5_3	100,844	366	.363	793,931	2,882	12.2	18.3
		6_3	8,308	51	.614	73,293	450	2.1	
		7_3	92	----------	----------	752	----------	----------	
		5_4	679	5	.736	136,159	1,002	3.5	
4	28,041	6_4	96,863	826	.853	628,663	5,362	19.1	25.4
		7_4	3,110	61	1.961	39,920	783	2.8	
5	162	7_5	176	3	1.705	1,308	22	13.5	13.5
Total	50,061	----------	215,269	1,315	----------	1,760,325	11,157	----------	----------

EXPERIMENTS IN 1930

Three marking experiments were carried on simultaneously (tables 34–36). Although the experiments were simultaneous they have been designated first, second, and third for reference purposes and to provide for facility in discussion.

In the first experiment (table 34), 25,000 seaward migrants were marked by amputation of the adipose and right ventral fins, 631 of these were recovered, and a calculated total of 5,177 fish returned (20.7 percent).

In the second experiment (table 35), 25,000 seaward migrants were marked by amputation of the adipose and left ventral fins, 666 of these were recovered, and a calculated total of 5,350 marked fish returned (21.4 percent). Two marked fish of the 7_3 age group were recovered, but according to the data, no fish of that age group were examined or were present in the return from the migration. The 7_3 age group, undoubtedly, was present among the fish examined, but its numbers were so few that representation was not afforded in the samples from which scales were secured for age determination.

TABLE 34.—*Data for the first 1930 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1930 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1	----------	4_1	130	----------	----------	804	----------	----------	----------
2	252	4_2	2,078	----------	----------	18,664	----------	----------	4.8
		5_2	3,212	1	0.031	38,624	12	4.8	
		4_3	1,252	4	.319	8,764	28	.2	
3	14,676	5_3	67,451	163	.242	714,745	1,730	11.8	16.9
		6_3	32,251	87	.270	268,334	725	4.9	
		5_4	8,669	26	.300	48,829	146	1.5	
4	9,773	6_4	72,392	322	.445	502,844	2,238	22.9	26.8
		7_4	1,769	19	1.058	21,838	231	2.4	
5	299	6_5	325	1	.308	1,507	5	1.7	22.4
		7_5	1,146	8	.698	8,835	62	20.7	
Total	25,000	----------	190,675	631	----------	1,633,788	5,177	----------	----------

TABLE 35.—*Data for the second 1930 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1930 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	130			804			
2	237	4_2	2,078			18,664			0.0
		5_2	3,212			38,624			
3	14,923	4_3	1,252	6	0.479	8,764	42	0.3	16.3
		5_3	67,451	150	.222	714,745	1,587	10.6	
		6_3	32,251	97	.301	268,334	808	5.4	
		7_3		[1] 2					
4	9,554	5_4	8,669	37	.427	48,829	230	2.4	29.2
		6_4	72,392	345	.477	502,844	2,399	25.1	
		7_4	1,769	13	.735	21,838	161	1.7	
5	286	6_5	325		1.396	1,507			41.6
		7_5	1,146	16		8,835	123	41.6	
Total	25,000		190,675	666		1,633 788	5,350		

[1] See p. 284.

TABLE 36.—*Data for the third 1930 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1930 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	130			804			
2	46	4_2	2,078			18,664			0.0
		5_2	3,212			38,624			
3	2,956	4_3	1,252	1	0.080	8,764	7	0.2	15.2
		5_3	67,451	31	.046	714,745	329	11.1	
		6_3	32,251	14	.043	268,334	115	3.9	
4	1,939	5_4	8,669	8	.092	48,829	45	2.3	20.8
		6_4	72,392	50	.069	502,844	347	17.9	
		7_4	1,769	1	.057	21,838	12	.6	
5	59	6_5	325			1,507			25.4
		7_5	1,146	2	.175	8,835	15	25.4	
Total	5,000		190,675	107		1,633,788	870		

In the third experiment, 5,000 seaward migrants were marked by amputating the adipose and right pectoral fins, 107 of these were recovered, and a calculated total of 870 marked fish returned (17.4 percent).

The data for the first and second experiments are considered more reliable than those of the third, because more fish were marked and more fish recovered, and because there is the possibility that an unusual mortality occurred among the fish of the third experiment. Some of the seaward migrants, marked by removal of the adipose and right pectoral fins appeared to have a slight "list" and appeared to be maintaining balance with difficulty.

Grouping the data for the first and second experiments, 50,000 were marked, 1,297 were recovered, and a calculated total of 10,495 marked fish returned (21.0 percent). The return from the marked 2-, 3-, 4-, and 5-year seaward migrants was 2.4, 16.6, 28.0, and 32.0 percent, respectively.

EXPERIMENTS IN 1931

Two marking experiments were conducted in 1931 (tables 37 and 38). For easy reference they have been designated first and second although they were simultaneous.

In the first experiment, 50,000 seaward migrants were marked by amputating the adipose and both ventral fins, 1,549 of these fish were recovered, and a calculated total of 11,790 fish returned (23.6 percent of the number marked). The return from the 2-, 3-, 4-, and 5-year marked fish was 54.8, 21.2, 34.5, and 40.8 percent, respectively.

In the second experiment, 5,000 seaward migrants were marked by amputating the adipose and dorsal fin, 124 were recovered, and a calculated total of 1,016 fish returned (20.3 percent). The return from this experiment, although slightly lower, agrees closely with results of the first experiment. Amputation of the entire dorsal fin close to the base results in a large wound that may have a deleterious effect on the fish. The results of the first experiment are believed to be more reliable than those of the second.

TABLE 37.—*Data for the first 1931 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1931 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	84	4_2	786	2	0.254	9,191	23	27.4	54.8
		5_2	5,947	4	.067	34,756	23	27.4	
		6_2	49	----	----	2,143	----	----	
3	41,403	4_3	1,166	4	.343	11,516	39	.1	21.2
		5_3	86,623	345	.398	966,015	3,845	9.3	
		6_3	136,439	863	.633	767,240	4,857	11.7	
		7_3	249	5	2.008	2,276	46	.1	
4	8,145	5_4	1,434	8	.558	21,291	119	1.5	34.5
		6_4	48,318	246	.509	461,549	2,349	28.8	
		7_4	10,669	58	.544	62,249	339	4.2	
		8_4	17	----	----	1,016	----	----	
5	368	7_5	1,721	14	.813	18,407	150	40.8	40.8
		8_5	----	----	----	671	----	----	
Total	50,000	----	293,418	1,549	----	2,358,320	11,790	----	----

TABLE 38.—*Data for the second 1931 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1931 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	9	4_2	786	----	----	9,191	----	----	0.0
		5_2	5,947	----	----	34,756	----	----	
		6_2	49	----	----	2,143	----	----	
3	4,131	4_3	1,166	1	0.086	11,516	10	0.2	18.0
		5_3	86,623	37	.043	966,015	415	10.0	
		6_3	136,439	57	.042	767,240	322	7.8	
		7_3	249	----	----	2,276	----	----	
4	824	5_4	1,434	----	----	21,291	----	----	30.1
		6_4	48,318	24	.050	461,549	231	28.0	
		7_4	10,669	3	.028	62,240	17	2.1	
		8_4	17	----	----	1,016	----	----	
5	36	7_5	1,721	2	.116	18,407	21	58.3	58.3
		8_5	----	----	----	671	----	----	
Total	5,000	----	293,418	124	----	2,358,320	1,016	----	----

EXPERIMENTS IN 1932

Four marking experiments were conducted (tables 39–42). The fish marked in the first experiment were captured on May 27 and 28; those in the second experiment on May 30, 31, June 3, and 4; the fish for the third experiment on June 6, 7, 8, and 9; and the fish in the fourth experiment on June 11, 12, and 22. The experiments were planned, in part, to determine whether or not a differential mortality in the ocean existed between fish marked by the amputation of the adipose and one ventral fin and fish marked by the amputation of the adipose and one pectoral fin, and to determine if a correlation existed between the time of occurrence of fish in the migration period and the time of their occurrence in the runs on their return as adults.

In the first experiment (table 39), 15,000 seaward migrants were marked by amputation of the adipose and right ventral fins, 341 fish were recovered, and a calculated total of 2,957 marked fish returned (19.7 percent). The return from the 3-, 4-, and 5-year marked seaward migrants was 19.1, 20.5, and 3.0 percent, respectively.

TABLE 39.—*Data for the first 1932 marking experiment*

Age of seaward migranta marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each aga group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
		4_2	12,225			53,258			
2		5_2	5,525			41,299			
		6_2	148			790			
		4_3	1,041	2	0.192	6,771	13	0.2	
3	6,275	5_3	88,164	116	.132	632,884	835	13.3	19.1
		6_3	26,912	30	.111	304,079	338	5.4	
		7_3	113	1	.885	1,281	11	.2	
		5_4	2,077	11	.530	20,626	100	1.3	
4	8,593	6_4	56,660	139	.245	494,716	1,212	14.1	20.5
		7_4	9,551	39	.408	100,909	412	4.8	
		8_4	57	2	3.509	664	23	.3	
		6_5	60			418			
5	132	7_5	171			1,778			3.0
		8_5	46	1	2.174	207	4	3.0	
Total	15,000		203,593	341		1,662,491	2,957		

TABLE 40.—*Data for the second 1932 marking experiment*

Age of seaward migrants marked	Calculated uumber of each age marked	Age of fish returning from 1932 migration	Calculated number of each aga group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
		4_2	12,225			53,258			
2		5_2	5,525			41,299			
		6_2	148			790			
		4_3	1,041			6,771			
3	6,020	5_3	88,164	97	0.110	632,884	696	11.5	20.7
		6_3	26,912	49	.182	304,079	553	9.2	
		7_3	113			1,281			
		5_4	2,077	1	.048	20,626	10	.1	
4	8,824	6_4	56,666	91	.161	494,716	796	9.0	14.6
		7_4	9,551	46	.482	100,909	486	5.5	
		8_4	57			664			
		6_5	60			418			
5	147	7_5	171	1	.585	1,778	10	6.8	9.8
		8_5	46	1	2.174	207	4	3.0	
Total	15,000		203,593	286		1,662,491	2,555		

TABLE 41.—*Data for the third 1932 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
2		4_2	12,225			53,258			
		5_2	5,525			41,299			
		6_2	148			790			
3	9,381	4_3	1,041			6,771			23.7
		5_3	88,164	175	0.198	632,884	1,253	13.4	
		6_3	26,912	82	.304	304,079	924	9.8	
		7_3	113	4	3.540	1,281	45	.5	
4	5,580	5_4	2,077	5	.241	20,626	50	.9	17.3
		6_4	56,666	68	.120	494,716	594	10.7	
		7_4	9,551	29	.304	100,909	307	5.5	
		8_4	57	1	1.754	664	12	.2	
5	39	6_5	60			418			0.0
		7_5	171			1,778			
		8_5	46			207			
Total	15,000		203,593	364		1,662,491	3,185		

TABLE 42.—*Data for the fourth 1932 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
2		4_2	12,225	2	0.016	53,258	9	[1]	[1]
		5_2	5,525			41,299			
		6_2	148			790			
3	11,420	4_3	1,041			6,771			16.2
		5_3	88,164	99	.112	632,884	709	6.2	
		6_3	26,912	101	.375	304,079	1,140	10.0	
		7_3	113			1,281			
4	2,416	5_4	2,077			20,626			12.0
		6_4	56,666	20	.035	494,716	173	7.2	
		7_4	9,551	11	.115	100,909	116	4.8	
		8_4	57			664			
5	164	6_5	60			418			6.1
		7_5	171	1	.585	1,778	10	6.1	
		8_5	46			207			
Total	14,000		203,593	234		1,662,491	2,157		

[1] See text.

In the second experiment (table 40), 15,000 seaward migrants were marked by amputation of the adipose and right pectoral fins, 286 fish were recovered, and a calculated total of 2,555 fish returned (17.0 percent). The return from the 3-, 4-, and 5-year marked fish was 20.7, 14.6, and 9.8 percent, respectively.

In the third experiment (table 41), 15,000 seaward migrants were marked by amputation of the adipose and left ventral fins, 364 fish were recovered, and a calculated total of 3,185 marked fish returned (21.2 percent). The return from the 3-, 4-, and 5-year marked fish was 23.7, 17.3, and 0.0 percent, respectively.

In the fourth experiment (table 42), 14,000 seaward migrants were marked by the amputation of the adipose and left pectoral fins, 234 fish were recovered, and a calculated total of 2,157 fish returned (15.4 percent). The return from the 3-, 4-, and 5-year marked fish was 16.2, 12.0, and 6.1 percent, respectively.

Two marked fish of the 4_2 age group were recovered (table 42). However, according to the data presented, no 2-year seaward migrants were marked. Some 2-year seaward migrants, undoubtedly, were marked but their numbers probably were so few that they were not represented in the samples of fish from which scales were taken for age determination.

From the results of these experiments it appears that there was a differential mortality between the fish marked by excising the adipose and one ventral fin, and those marked by excising the adipose and one pectoral fin. The average survival from the first and second experiments was 18.4 percent, and the average survival from the last two experiments was also 18.4 percent. However, the average survival from the first and third experiments was 20.5, while the average survival from the second and fourth experiments was only 16.2 percent. Hence, there was only 79.2 percent as good a return from the fish marked by removing the adipose and one pectoral fin as there was from the fish marked by removing the adipose and one ventral fin. These results agree closely with those obtained in the 1930 experiment in which the total return from the the fish marked by amputing the adipose and one ventral fin was 21.0 percent, and the total return from the fish marked by amputating the adipose and one pectoral fin was 17.4 percent. In the 1930 experiments, there was only 89.2 percent as good a survival of fish marked by excising the adipose and one pectoral fin as there was of fish marked by removing the adipose and one ventral fin.

The percentage occurrence of marked fish of a single age and one type of mark remained fairly constant throughout the seasons in which they were sampled. However, from the marking of 3-year seaward migrants, the ratio between the return of two-ocean fish and the return of three-ocean fish was 2.38 to 1, 1.25 to 1, 1.37 to 1, and 0.62 to 1 for the first, second, third, and fourth experiments, respectively. Thus, of the 3-year seaward migrants the early migrating fish spent, on the average, a shorter time in the ocean than the late migrating fish. From the marking of 4-year seaward migrants, the ratio between the return of two-ocean fish and the return of three-ocean fish was 2.94 to 1, 1.64 to 1, 1.95 to 1, and 1.5 to 1 for the first, second, third, and fourth experiments, respectively. The returns from the marking of 4-year seaward migrants and the returns from the marking of 3-year seaward migrants both demonstrated a positive correlation between the time of occurrence during the migration period, and the length of time spent in the ocean.

As there appears to be a differential mortality between fish marked by removal of the adipose and one ventral fin, and fish marked by removal of the adipose and one pectoral fin, in comparing the results of the 1932 experiments with experiments of other years, it seems advisable to consider only the two experiments in which the fish were marked by the amputation of the adipose and one ventral fin. Grouping the data of the first and third experiments, 30,000 migrants were marked, 705 fish were recovered, and 6,142 marked fish returned (20.5 percent). The returns from the marked 3-, 4-, and 5-year seaward migrants were 21.9, 19.1, and 2.3 percent, respectively, giving evidence for the first time contrary to the hypothesis that there is no positive correlation between age at time of migration, and survival.

EXPERIMENTS IN 1933

In 1933 (table 43) 40,000 seward migrants were marked by the amputation of the adipose and both ventral fins, 959 fish were recovered, and a calculated total of 8,212 marked fish returned (20.5 percent of the number marked). The return from the 2-, 3-, 4-, and 5-year marked seaward migrants was 18.8, 18.3, 24.9, and 15.6 percent, respectively.

TABLE 43.—*Data for the 1933 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1933 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1	----------	4_1	166	----------	----------	474	----------	----------	----------
2	250	4_2	7,614	2	0.026	58,018	15	6.0	18.8
		5_2	9,942	4	.040	80,153	32	12.8	
		4_3	548	1	.171	3,654	6	0.0	
3	25,394	5_3	64,728	453	.700	458,344	3,208	12.6	18.3
		6_3	24,536	189	.770	187,190	1,441	5.7	
		7_3	----------	----------	----------	----------	----------	----------	
		5_4	901	3	.333	13,655	45	0.3	
4	13,692	6_4	34,756	202	.581	417,073	2,423	17.7	24.9
		7_4	6,244	98	1.570	59,934	941	6.9	
		6_5	----------	----------	----------	638	77	11.6	
5	664	7_5	1,037	4	.386	20,043	26	4.0	15.6
		8_5	51	3	5.882	409	----------	----------	
Total	40,000	----------	150,523	959	----------	1,299,675	8,212	----------	----------

DISCUSSION OF MARKING EXPERIMENTS

In comparing results of the several years marking experiments, it seems advisable to consider the returns from only those experiments in which the fish were marked by the amputation of the adipose and one, or both, ventral fins. It also seems advisable to combine the results in those years when duplicate experiments were run.

In those experiments in which the adipose and one, or both, of the ventral fins were amputated, the returns from the experiments of the years 1926, and 1929 to 1933, inclusive, are 20.8 (incomplete), 22.3, 21.0, 23.6, 20.5 and 20.5 percent, respectively. These results are remarkably uniform and indicate that the survival rate of the fish, during their stay in the ocean, has been quite constant.

Grouping the data of all experiments wherein the fish were marked by the amputation of the adipose and left, right, or both ventral fins gives a total of 169,836 three-fresh-water fish marked and a calculated return of 29,560 marked fish, or a 17.4 [11] percent return. For the four-fresh-water fish it is found that 93,944 were marked, and 24,142 marked fish returned, or a 25.7 percent return.

While combining the data in this manner may be subject to some criticism, it is quite evident that a differential mortality exists between the three-fresh-water fish and the older and larger four-fresh-water fish. The greater survival of the four-fresh-water fish during their stay in the ocean would seem to indicate that a longer lake residence was advantageous. However, this greater ocean survival may be drastically over-balanced by the mortality during the extra year spent in fresh water.

The percentage occurrence of marked fish in the different age groups examined varied considerably, and while a certain amount of the variation is due to random errors in sampling, it cannot all be ascribed to that factor. The age-group composition of the seaward migration changes considerably during the migration period, and as there is no means of determining, actually or relatively, how many migrants pass downstream each day, it is impossible to mark a constant proportion of the migration.

[11] Does not include the three-ocean fish from the experiments of 1926. However, this omission would not materially affect the results.

Since a constant proportion of the migrating population cannot be marked day by day during the migration period, and as the 1932 experiments indicated that early migrating fish tended to return after a shorter period of ocean life, it is apparent that critical comparisons of the returns of any two or more years cannot be made. The longer the period of time spent in the ocean the greater the mortality will be, consequently, for exact comparisons between marking experiments of 2 or more years, it is necessary that the fish of one experiment have remained in the ocean the same length of time as the fish of the other experiments.

In view of the possible errors in the calculated percentage return from the marking of any one age of seaward migrants, especially in the returns of the 2- and 5-year age groups, it is believed that the best average value for the ocean survival is the mean of the several yearly values, i. e., 21.45 percent.

Unfortunately, there is no way of knowing whether or not a differential mortality exists between marked and unmarked fish, although a differential mortality was found to exist between fish marked by the amputation of the adipose and one pectoral fin, and the fish marked by the amputation of the adipose and one of the ventral fins. This might be caused by any one, or a combination, of the following:

1. Regeneration of the pectoral fins. The pectoral fins were amputated as close to the body of the fish as possible, and it does not seem probable that any of the amputated fins could have regenerated to such an extent as to be unrecognizable. None of the marked fish recovered showed the slightest sign of regeneration of this fin.

2. Mortality of the fish as a direct result of the operation. Some of the fish were held in a pen for several days after being marked and then carefully examined. The wounds had begun to heal and the fish showed no ill effects other than that a few specimens appeared to have a slight "list." Consequently, the marking probably did not have a direct influence on the mortality.

3. Mortality caused by the inability of the fish to elude their enemies to as great an extent as could the fish marked by the amputation of the adipose and one ventral fin. The pectoral fins are used, almost entirely, for maintaining equilibrium, and it is possible that fish marked by the amputation of the adipose and one pectoral fin were handicapped. Such a handicap should not hinder fish feeding on plankton. However, it might be a serious disadvantage when being pursued by predators. This is considered the most likely of the several possible explanations for the differential mortality found between the two groups.

There may have been a differential mortality between the unmarked fish and those marked by the amputation of the adipose and one, or both, of the ventral fins. It is not believed that the differential mortality could have been very great in view of the relatively good returns from all the experiments. If the factor used by Foerster at Cultus Lake, to correct for differential mortality, were applied to the Karluk data, the survival of unmarked Karluk fish would be in excess of 56 percent.

MORTALITY IN FRESH WATER

Having ascertained the probable average ocean mortality of Karluk red salmon to be 78.55 percent, as determined by the marking experiments, it is of interest to calculate the mortality of this species between the egg stage and the seaward migrant stage. The average number of eggs per female, as reported by Gilbert and Rich (1927), is approximately 3,700. If the spawning fish are 56 percent females (table 30), then there would be an average of 2,072 eggs per fish in the escapement. With a ratio of return to escapement of 2 to 1 the mortality between eggs and seaward migrants would be 99.55 percent, while with a ratio of return to escapement as high as 4 to 1 the mortality between eggs and seaward migrants would still be over 99 percent. Thus the mortality rate of these salmon, during the fresh-water stage of their life history, is extremely high.

There are a number of factors which contribute to this terrific loss in fresh water. Many eggs are destroyed by the spawning fish which, during their spawning activities, dig out eggs laid by earlier spawners. While the eggs are being deposited and during the incubation period, there is a loss caused by predators such as trout and birds. Meteorological conditions during the incubation period affect the success or failure of a brood year. Floods, dry spells, or freezing weather may affect the eggs adversely. After hatching, the fry work their way out of the gravels of the spawning beds and, if in the tributaries, migrate downstream to the lake. Until the young fish distribute themselves along the lake shores and seek shelter among the rocks and boulders on the bottom, they are preyed upon by trout. During the next 2 or 3 years they are subject to diseases and parasites, and many are devoured by fish-eating birds such as mergansers and terns. Thus, there is a constant decimation of the population, until less than 1 percent of the possible number of progeny have survived to migrate to the ocean.

Of the fraction of 1 percent of possible progeny which have survived to the seaward migrant stage, 79 percent perish while in the ocean due to disease and natural enemies, leaving only 21 percent of the seaward migrants (between 0.1 and 0.2 percent of the possible number of progeny) to return as mature fish.

SUMMARY AND CONCLUSIONS

1. There has been a marked reduction in the abundance of Karluk River red salmon since the inception of intensive commercial fishing in 1888. The average yearly catch for the period 1888 to 1894, inclusive, was more than 1,000,000 fish greater than the average yearly total run (catch plus escapement) for the period 1921 to 1936.

2. Karluk red salmon migrate to the ocean in their first to fifth year counting from the time the eggs are deposited in the gravel of the spawning beds, the majority migrating in their third or fourth year.

3. From a few months to 4 years are spent in the ocean, after which the fish return as adults to spawn.

4. While the fish range from 3 to 8 years of age at maturity, the 5-year age group is usually dominant, followed in importance by the 6-year age group.

5. The number of fish in the spawning escapements during the period 1921 to 1936 has ranged from 400,000 to 2,533,402 and averaged 1,113,594.

6. The runs of red salmon at Karluk are bimodal, and it is considered that there are actually two distinct runs, spring and fall.

7. The fluctuations in the ratio of return to escapement have been considerable, and no correlation has been found between escapement and return. This is due in part to unfavorable environmental conditions on the spawning grounds in certain years.

8. A negative correlation exists between escapement and surplus which might indicate that most of the escapements have been too large. This suggestion is believed to be untrue. The negative correlation is related to adverse factors influencing the survival value.

9. While the affluents of Karluk Lake contained appreciable amounts of phosphorus and silica, during the summer months, less than a measurable quantity of these inorganic salts were present in the lake water, indicating that they are limiting factors in the production of phytoplankton and indirectly of the zooplankton of Karluk Lake. As the lack of these inorganic salts indirectly affects the production of zooplankton it is probable that it also indirectly affects the growth and survival of young red salmon which depend, to a large extent, on the zooplankton as a source of food.

10. Little change, if any, is taking place in the relationship between the percentage of fish of a certain ocean history in the escapement and the percentage of fish of the same ocean history in the return. However, a marked change is occurring in the percentage of fish of a particular fresh-water history in the escapement in relation to the percentage of fish of the same fresh-water history in the return. This relationship is quite unusual, and though evidently existent during most of the period of time under consideration could not possibly have existed for any great length of time in the past. Unless the relationship changes, the majority of the fish in the Karluk runs will be four-fresh-water fish, whereas formerly the three-fresh-water age group was domiuant.

11. The change in the period of time spent in fresh water is considered to be due to unfavorable environmental conditions, which may also adversely affect the survival value of the population.

12. The seaward migration of Karluk red salmon takes place during the last week of May and the first 2 weeks of June.

13. The percentage of 4-year fingerlings decreases, and the percentage of 3-year fingerlings increases, during the period of the migration.

14. The time of seaward migration depends on the growth rate of the fingerlings, the fastest growing individuals migrating first.

15. Among the seaward migrants the males and females are equally represented.

16. Among the adult fish there is a greater proportion of females than males.

17. There is a decrease in the percentage of males among the adult fish, with increased ocean residence.

18. Among the fish of a single ocean history, there is usually a decrease in the percentage of males with increased total age.

19. The returns from the marking experiments at Karluk have been consistently greater than returns from similar experiments in other areas. This is probably true because the Karluk seaward migrants were larger at the time of marking and migration than the fish in similar experiments in other areas.

20. A greater return, or survival, was found among the older and larger 4-year migrants than among the 3-year migrants.

21. Although the ocean survival is greatest for fish that have had the longest lake residence, these fish suffer a greater mortality in fresh water due to the longer residence in the lake.

22. Removal of the adipose and right, left, or both ventral fins is considered preferable in marking fish rather than the removal of adipose and dorsal, or adipose and one pectoral fin.

23. The adipose and dorsal mark compared equally well with the adipose and right ventral mark in the returns. However, the removal of the dorsal fin left a large wound on the back of the young fish which may cause a high rate of mortality.

24. The right and left pectoral marks are definitely inferior to the others, due probably to the need of these fins by the fish for maintaining their equilibrium when eluding their enemies.

25. The total calculated returns from those experiments wherein either the adipose and left ventral, adipose and right ventral, or adipose and both ventral fins were amputated were 20.8 (incomplete), 22.3, 21.0, 23.6, 20.5, and 20.5 percent for the experiments of 1926, 1929, 1930, 1931, 1932, and 1933, respectively.

26. The average return from the marking of 3-year seaward migrants was 17.4 percent and for the 4-year seaward migrants 25.7 percent.

27. While a slight differential mortality probably exists between the marked and the unmarked fish, it is not considered to be great in the case of the fish marked by the amputation of either the left, right, or both ventral fins, as the survival of the marked fish during their stay in the ocean is relatively high, averaging 21.45 percent.

28. The mortality of Karluk River red salmon during the fresh-water stage of their life history is usually over 99 percent.

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