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EFFECTS OF FERTILIZING BARE LAKE, ALASKA, ON GROWTH AND PRODUCTION OF RED SALMON (*O. NERKA*)

BY PHILIP R. NELSON

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ABSTRACT

Bare Lake, a 120-acre, unstratified lake on Kodiak Island, Alaska, was fertilized each year from 1950 to 1956 with inorganic fertilizers to determine whether fertilization will increase production of red salmon (*Oncorhynchus nerka*). Various phases of the life history of the species were studied.

From 1950 through 1956 the annual spawning population of red salmon in Bare Lake ranged from 52 to 551 fish. Red salmon vary in age at maturity. The majority of Bare Lake red salmon remain in the lake slightly longer than a year, then migrate to the sea to spend 3 years before returning to the lake to spawn. Females predominated over males in the spawning escapement each year. Data are presented on fecundity, egg retention, and the annual egg deposition.

A relation was found between the growth of young red salmon and the gross rate of photosynthesis. Fertilization has brought about an increase in size of the seaward-migrating red salmon smolts. There is good evidence to show that the larger smolts survive in greater numbers at sea. For the years 1950–53, fresh-water survival has ranged from 1.0 to 5.1 percent and marine survival increased from 3.3 to 7.9 percent. Limited information is available on the effect of fertilization on other fish populations in Bare Lake.

EFFECTS OF FERTILIZING BARE LAKE, ALASKA, ON GROWTH AND PRODUCTION OF RED SALMON (*O. NERKA*)

By PHILIP R. NELSON, ***Fishery Research Biologist***
BUREAU OF COMMERCIAL FISHERIES

Bare Lake, on Kodiak Island, Alaska, was fertilized each year for 7 years, from 1950 to 1956. The limnological effects of fertilizing the lake were described by Nelson and Edmondson (1955). The present paper deals primarily with the effects of fertilization on the red salmon population and briefly with the effect on other fish populations in Bare Lake.

Fertilization experiments were initiated at Bare Lake on the basis of studies conducted earlier at Karluk Lake, which is only 15 miles from Bare Lake. The hypothesis upon which the fertilization experiments were based was discussed by Nelson and Edmondson (1955). Briefly, it was proposed by these investigators that the decline in the Karluk River salmon runs may have resulted from a decline in the productivity of the lake waters. The carcasses of spawned salmon in the earlier years, when the escapements were large, contributed a great amount of nutrients to the lake water. In recent years, with small escapements, the amount of nutrients furnished has been considerably less. It was hypothesized that by the addition of inorganic fertilizer the earlier productive capacity of Karluk Lake might be restored. Rounsefell (1958) cites other hypotheses as possible reasons for the decline in the Karluk River red salmon runs in his comprehensive report on Karluk Lake. It is recognized that many other factors, including meteorological conditions, diseases, and predator and competitor fishes influence the survival and growth of red salmon. The effects of these factors on the production of red salmon at Bare Lake were considered.

In this study, Bare Lake was fertilized to determine if this process would bring about an increase in fish food so as to augment red salmon production. Bare Lake (fig. 1) was selected for this study because it has a run of red salmon; it is located close to the major red salmon producing lakes in the area; and, because of its small size (120 acres), the costs of experimentation would not be excessive and the results of fertilization could be more accurately determined.

For fertilization to be a useful management tool, not only must production of fish be increased but the costs must be economically justifiable. At Bare Lake, nitrate and phosphate fertilizers were added each summer in amounts necessary to increase the nitrate concentration approximately 0.25 milligram per liter, and the phosphate concentration 0.05 milligram per liter. In 1950 and 1951, the lake was fertilized just prior to mid-July. During the years 1952 to 1956, fertilizer was added in two lots during the first half of the months of June and July. The concentration achieved on each addition was one-half the amount specified. Choice of the amount was based on a prognostic experiment conducted during 1949 in which jugs of water were fertilized with varying concentrations of nitrate and phosphate and the rates of photosynthesis and of phyto-

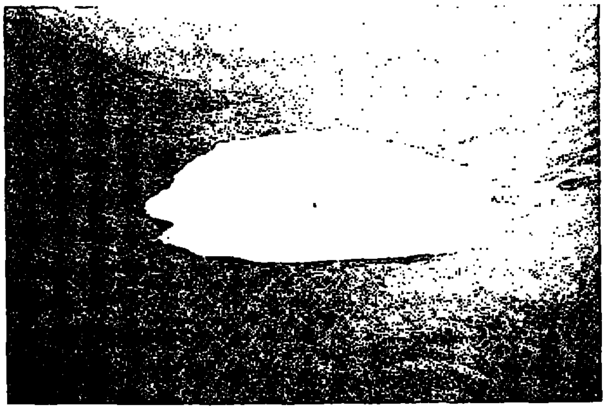

FIGURE 1.—Aerial photograph of Bare Lake.

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plankton growth measured (Nelson and Edmondson, 1955).

The fertilizers most frequently used were sodium nitrate and ammonium monohydrogen orthophosphate. The application consisted of mixing the fertilizers on a raft and subsequently using brooms to sweep the mixture into the water as the raft was towed about the lake. Usually the mixture was applied to the littoral zone, but on two occasions it was spread over the entire lake. No significant difference was found between the two methods in the concentration achieved in the lake water. The annual cost of fertilizers averaged less than $400.

Numerous lake fertilization studies have been conducted by other investigators with the objective of increasing fish growth or survival. The lakes fertilized have differed widely in their characteristics and the amount and types of nutrients introduced have varied considerably. Lakes are extremely dissimilar in productive capacity and until more is learned of the extent to which various factors govern productivity, fertilization programs will continue to be exploratory.

Good bibliographies and reviews of fertilization studies are presented by Mortimer and Hickling (1954) and Maciolek (1954). Maciolek reports that "Conclusions drawn from all lake-fertilization trials indicate that fish may have benefited from enrichment in only three experiments." Fortunately, much has been learned even from the unsuccessful attempts to aid workers in future studies.

Since these reviews, Weatherley and Nicholls (1955) reported on the results of fertilizing a small, shallow Tasmanian highland lake. The added nutrients stimulated growth of aquatic plankton and epiphytic fauna which created a marked increase in the growth of trout.

Fertilization experiments had been confined to rather small lakes until Eguchi and others (1954) reported the enrichment of Lake Skikotsu in Hokkaido. This lake has an area of 75 square kilometers and a mean depth of 265 meters. It was enriched in May 1953 with the objective of increasing the size of landlocked red salmon. Since fertilization of the lake, an increase in plankton abundance has occurred, but as yet no report has been given on the effect on fish populations.

In fertilization studies a constant danger exists of overfertilizing. In such instances vast amounts of blue-green algae usually appear and eventually upon decomposition of the algae an anaerobic condition develops in stratified lakes or, during winter, in lakes covered by ice. This happens not only in fertilization experiments (Ball 1950; Ball and Tanner, 1951), but lakes often have been rendered excessively productive by large introductions of domestic sewage. A recent example of the latter is reported by Edmondson, Anderson, and Peterson (1956) to be taking place in Lake Washington at Seattle, Washington. At present we have observed no indications of overfertilization at Bare Lake. A winter trip in February 1955 showed a plentiful supply of oxygen at all depths except immediately over the bottom, and other symptoms of overfertilization have not appeared.

Following the last fertilization of Bare Lake in 1956, limited studies were planned in subsequent years to provide a comparison of conditions in the lake and red salmon production during and after fertilization. At the time of this writing it was too early in the investigation to ascertain the full effects of fertilization on fresh-water survival of salmon; nevertheless, some interesting effects have been found in regard to the fresh-water growth and marine survival of red salmon.

The primary purpose of this study was to determine whether fertilization will substantially increase red salmon production. If the method is successful, it might prove useful for increasing red salmon production in other red salmon lakes. It also was necessary to study most phases of the life history of the Bare Lake red salmon. The first section of the paper deals with characteristics of the adult population, while the latter sections show the effect fertilization has had on the growth and survival of the species.

Many have contributed to the studies at Bare Lake. Men of the United Fishermen of Alaska helped support the work financially. Field workers who contributed materially to the collection of data were Carl E. Abegglen, Robert C. Davison, Charles J. Hunter, Clark S. Thompson, Carl R. Schroeder, Alfred J. Schroeder, Ralph L. Swan, Robert T. Heg, Charles W. Huver, Robert Raleigh, Jerry Larrance, and Paul H. Hatch. W. T. Edmondson assisted in the limnological

analysis and reviewed the manuscript. Advice on statistical analyses was given by members of the Biometrics Unit, Pacific Salmon Investigations.

ADULT RED SALMON POPULATIONS OF BARE LAKE, 1950–56

ANNUAL ESCAPEMENT AND RUN

All that is known of the history of the Bare Lake red salmon population has been obtained from scattered reports of a few men who visited the lake before 1949. About the only information available was that some red salmon spawned in the lake; no surveys or counts had been recorded of the numbers of fish present.

The present study was commenced in 1949, when observations on the spawning escapement into the lake, estimated at 300 fish, were made by airplane. Because of the many errors involved in measuring fish populations by aerial observation, the accuracy of this figure is questionable. Subsequently, a trap for salmon has been maintained each year of the study on Bare Creek, the outlet stream. The trap was located about 50 feet downstream from the outlet, where the creek is 6½ feet wide. At the lower (downstream) end of the trap a picket fence was constructed with an upstream lead in it. About 10 feet farther upstream another picket fence was placed across the stream to block the passage of adult salmon. Fish migrating upstream were led into the trap and were easily captured in the shallow water. A section of the trap bottom was deepened to provide a suitable resting place for the fish. The smolt trap was placed immediately upstream from the adult trap. This trap consisted of an 18-gauge, 6-mesh-to-the-inch screen placed across the stream to block the downstream movement of smolts. Above this was a V-shaped lead constructed of mesh of the same size. A diagram of the weir structures is shown in figure 2.

Daily, all adult salmon entering the trap were removed by dip net. The fish were measured, a scale sample was taken for age determination and the sex recorded. The fish were then released into Bare Creek above the trapping area. The annual count of salmon released into Bare Lake from 1950 to 1956 is shown in table 1; not included in these data are a few salmon taken for fecundity studies. The escapements ranged from 52 to 551 red salmon with an annual mean of 319 during the 7-year period. The bulk of the escapement appeared at the weir from mid-June

TABLE 1.—*Weekly escapement of red salmon into Bare Lake 1950 to 1956*

Week ending	1950	1951	1952	1953	1954	1955	1956
May 24					2		
31						5	2
June 7	8			16	1	7	8
14	18	4	45	5	26	20	40
21	200	20	130	97	113	137	98
28	76	21	64	103	10	85	108
July 5	90	3	28	27	49	139	57
12	150	3	110		15	9	26
19	2	1		1		12	6
26	6		2		3	2	
Aug. 2			1		13	1	
9			1			1	1
16	1						1
23							
30				1		2	
Sept. 6			1				
Total	551	52	382	250	232	420	347

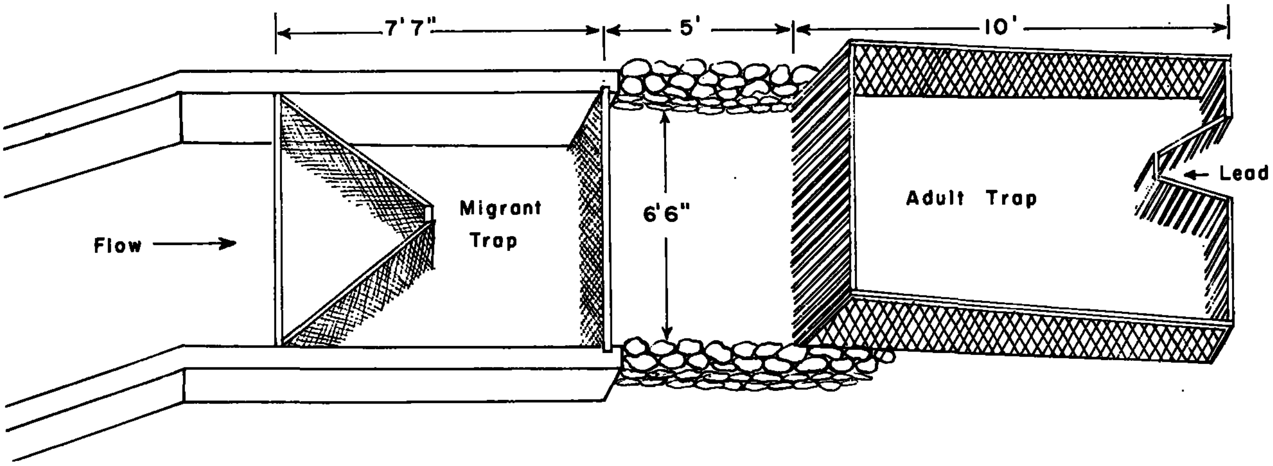

FIGURE 2.—Diagram of smolt and adult salmon traps placed across Bare Creek.

to mid-July. In 6 of the 7 years, the median of the escapement occurred during the week ending June 28.

There seems to be a tendency for the years with the largest total escapement, namely 1950, 1952, and 1955, to have two distinct peaks of abundance. For these years one peak occurred during the week ending June 21, and the other peak appeared 3 weeks later in 1950 and 1952 and 2 weeks later in 1955. The 4 years of small escapements show one prominent peak of abundance, and 1953 and 1954 each had a low subsidiary peak. Some Bare Lake fish are taken in the fishery; however, upon combining the escapement and catch, the peaks of abundance were unchanged. It is not known at present whether fish occurring during these two peak periods represent distinct populations, or if they are parts of a common population.

To determine the annual Bare Lake run (catch plus escapement), it was necessary to determine the number of Bare Lake fish taken in the commercial fishery of the Red River district. Since Bare Creek is a tributary of the much larger Red River it is believed the fishery in the district removes a proportional amount of fish from the two runs. A map of Kodiak Island (fig. 3) is presented to show the location of Red River, Bare Lake, and the fishing district which extends along the coast from the mouth of Red River

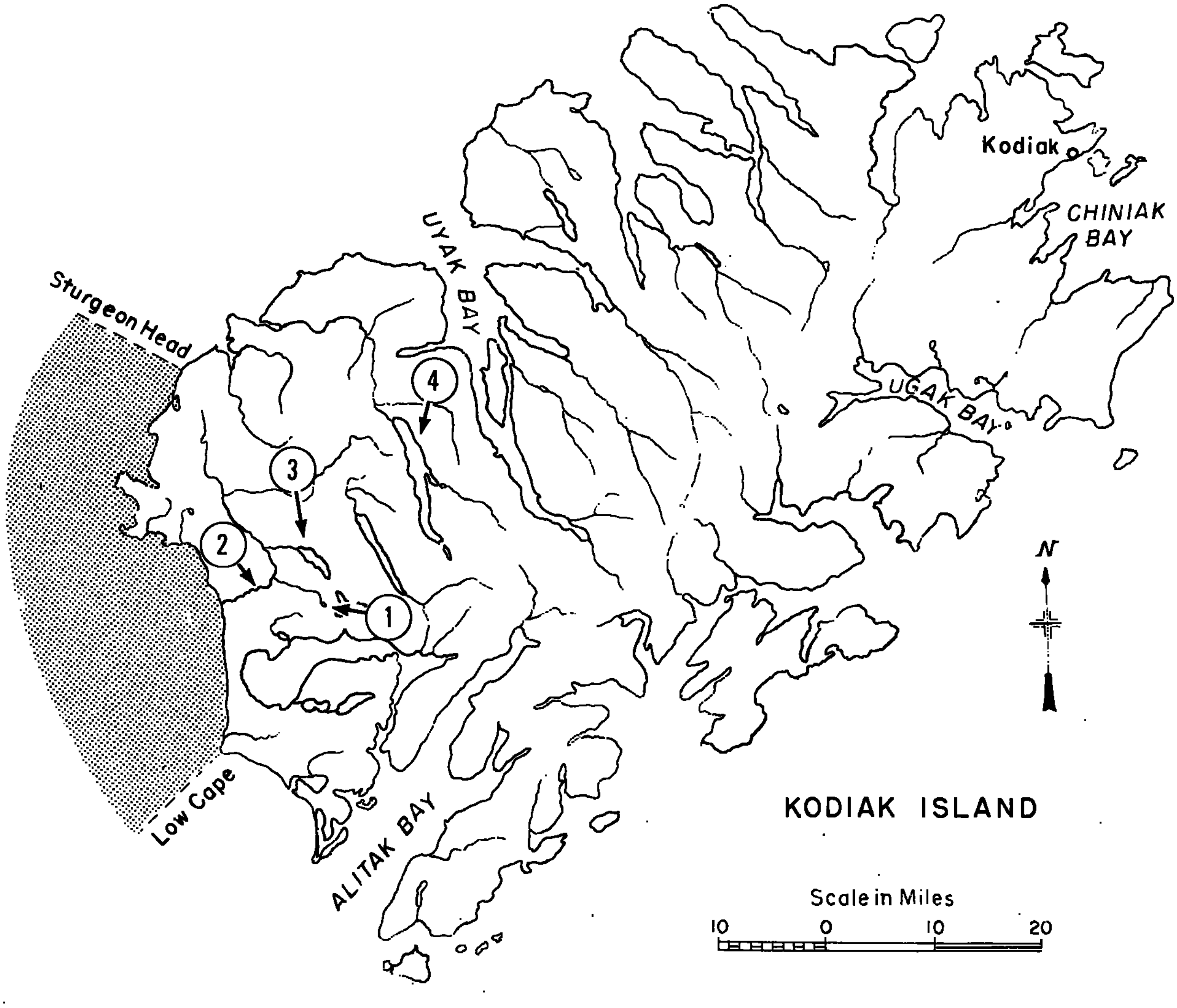

FIGURE 3.—Kodiak Island, Alaska. Shaded areas indicate Red River fishing district. (1) Bare Lake; (2) Red River; (3) Red Lake; (4) Karluk Lake.

approximately 30 miles north to Sturgeon Head and about 15 miles south to Low Cape. All fish captured in the fishing district are assigned to the Red River run of which Bare Lake is a part. Of the total run in the district, the Bare Lake run comprises less than 1 percent.

Annually a count is made of the number of red salmon entering Red Lake by means of a weir situated immediately downstream from the lake outlet. Tagging of red salmon at the mouth of Red River by fishery-management biologists indicates the fish spend approximately 1 week en route from the sea to the weir. Travel time to Bare Lake, although not determined, is estimated to be 1 week also, since the distances involved are about the same for both runs. To relate the occurrence of the escapement to the time of the catch, weekly escapement records were set back 1 week. Thus, escapement figures for Bare and Red Lakes were standardized to the time the fish appeared in the fishery. Hence, during periods of fishing it was possible to calculate for Red River what percentage the catch was of the escapement. This percentage was then applied to weekly escapement figures at Bare Lake to determine the catch of Bare Lake salmon (table 2). It is assumed in this calculation that the ratio of escapement to catch is the same for Bare Lake and Red Lake. In table 2, the weekly escapement and catch were added to show the weekly run of fish to Bare Lake. The weekly runs were then summed to provide the annual run.

Table 2.—*Calculated Bare Creek red salmon run*

[Based on catch-escapement ratios of the Red River run]

Week ending	Red River [1]			Bare Lake		
	Escapement [2]	Catch	Ratio of catch to escapement	Escapement [3]	Calculated catch	Run [4]
1950						
May 31				8		8
June 7	6,900	2,000	71 percent	18	13	31
14	1,200	11,800		204	145	349
21	29,400	14,600		76	54	130
28	53,400	16,100		90	64	154
July 5	19,400	13,900		150	106	256
12	200	26,200		2	1	3
19	57,300	25,700		6	4	10
Aug. 9	1,500	9,100		1	1	2
Total				555	388	943
1951						
June 7	[5] 5,000	2,300	214 percent	4	8	12
14	17,500	6,900		21	45	66
21	3,300	37,300		21	45	66
28	1,500	12,000		4	9	13
July 5	800	1,700		3	6	9
12				1		1
Total				54	113	167
1952						
June 7	800			45		45
14	4,800			132		132
21	9,300	3,100	33 percent	64	21	85
28	1,700			35		35
July 5	17,200			114		114
12	600			2		2
19	800			2		2
26	6,200	1,100	109 percent	1	1	2
Aug. 2	400	6,100		1	1	2
30				1		1
Total				397	23	420
1953						
May 31	500			16		16
June 7	10,100			5		5
14	8,100			101		101
21	27,900	16,000	56 percent	108	60	168
28	(6)	2,500		27	15	42
July 5	14,400	3,000				
12	13,800	9,800		1	1	2
Aug. 23				1		1
Total				259	76	335
1954						
May 17				2		2
24						
31				1		1
June 7				27		27
14	33,900			118		118
21	800	1,800	225 percent	10	22	32
28	27,100			51		51
July 5	400			15		15
12	500	300	74 percent			
19	14,300	12,800		3	2	5
26	11,400	3,500		13	10	23
Aug. 2	900	3,500		1	1	2
Total				241	35	276
1955						
May 24				5		5
31				7		7
June 7	2,900			20		20
14	10,300			142		142
21	10,800			88		88
28	23,500			144		144
July 5	9,100			12		12
12	9,200	300	22 percent	12	3	15
19	8,000	1,100		3	1	4
26	100	1,600		1		1
Aug. 2	100	900		1		1
23				2		2
Total				437	4	441
1956						
May 24				2		2
31				8		8
June 7	200			41		41
14	9,200			98		98
21	21,300			108		108
28	19,800			58		58
July 5	2,100			26		26
12	10,900	4,700	204 percent	7	14	21
19		11,600				
26	3,300	3,800				
Aug. 2	100	10,800		1	2	3
9	2,800	3,900		1	2	3
Total				350	18	368

[1] Red River escapement and catch figures rounded to nearest 100 salmon.

[2] The Red Lake escapement was set back 7 days to coincide with the time salmon were taken in the catch.

[3] The Bare Lake escapement, including salmon mortalities at the weir plus fecundity samples, was set back 7 days to coincide with the time salmon were taken in the catch.

[4] Catch plus escapement. [5] Estimated escapement. [6] Less than 50.

The calculated catch of Bare Lake red salmon exceeded the escapement approximately twofold in 1951, and amounted to about 60 percent of the escapement in 1950 and 30 percent of the escapement in 1953. For the years 1952, 1954, 1955, and 1956, the catch ranged from less than 1 percent to 15 percent of the escapement. Low percentages of Bare Lake fish taken in the fishery those years were brought about by regulations which prohibited any fishing of the early Red River run. Since Bare Lake fish appear in greatest numbers early in the season, the majority escaped the fishery.

AGE COMPOSITION

Each year of the study, with the exception of 1950, scale samples were taken from all adult fish that entered Bare Lake. In the 1950 season, scales were taken from more than half of the fish in the escapement, and the weekly age composition was based on the age composition of the samples taken. Nine age groups[1] of adult salmon have been noted at Bare Lake: 3_2, 4_1, 4_2, 5_2, 5_3, 6_3, 6_4, 7_3, and 7_4. Of these, only three age groups are of major importance to the escapement, 5_2, 6_3, and 5_3, in decreasing order of importance.

The weekly percentage occurrence of each age group in the escapement has been calculated for each year (table 3). During the years 1950 through 1953, the 5_2 age group predominated, while fish of the 6_3 age group were most abundant in subsequent years. The predominance of one age group over the other is dependent on the percentage age composition of 2- and 3-year-old smolts 3 years before the escapement. A tendency exists for fish in the 6_3 age group to return early in the season. As shown in table 3, in 5 years out of 7 high percentages of this age group occurred early in the season and declined as the season progressed. Gilbert and Rich (1927) noted a similar characteristic in red salmon of this age group at Karluk Lake.

TABLE 3.—*Weekly percentage occurrence of red salmon, by age group, in the Bare Lake escapement, 1950 to 1956*

Year	Percentage occurrence in age groups—								
	3_2	4_1	4_2	5_2	5_3	6_3	6_4	7_3	7_4
1950									
June 7	------	------	------	75	------	25	------	------	------
14	------	------	------	94	------	6	------	------	------
21	------	------	------	94	1	5	------	------	------
28	------	------	------	95	------	5	------	------	------
July 5 *b*	------	------	------	94	------	6	------	------	------
12	------	------	------	91	5	------	------	------	4
19	------	------	------	100	------	------	------	------	------
26 [1]	------	------	------	100	------	------	------	------	------
1951									
June 7	------	------	------	------	------	------	------	------	------
14	------	------	------	75	25	------	------	------	------
21	------	------	5	50	5	35	------	------	5
28	------	9	------	76	5	10	------	------	------
July 5	------	------	------	67	------	33	------	------	------
12	------	------	------	25	50	25	------	------	------
19	------	------	------	100	------	------	------	------	------
1952									
June 7	------	------	------	------	------	------	------	------	------
14	------	------	2	69	7	22	------	------	------
21	------	1	2	58	7	32	------	------	------
28	------	2	3	74	5	16	------	------	------
July 5	------	------	3	37	20	40	------	------	------
12	------	------	5	74	6	15	------	------	------
19 [1]	------	------	------	87	------	13	------	------	------
1955									
June 7	------	------	------	69	6	25	------	------	------
14	------	------	------	80	------	20	------	------	------
21	------	------	1	79	14	6	------	------	------
28	------	1	2	80	14	3	------	------	------
July 5	------	3	------	93	4	------	------	------	------
12	------	------	------	------	------	------	------	------	------
19 [1]	------	------	------	100	------	------	------	------	------
1954									
May 31	------	------	------	------	------	100	------	------	------
June 7	------	------	------	------	------	100	------	------	------
14	------	------	8	4	15	73	------	------	------
21	------	1	10	5	24	60	------	------	------
28	------	------	------	10	40	50	------	------	------
July 5	------	------	4	6	47	41	2	------	------
12	------	------	33	13	27	27	------	------	------
19	------	------	------	------	------	------	------	------	------
26	------	------	------	33	67	------	------	------	------
Aug. 2	------	------	8	------	61	31	------	------	------
1953									
May 31	------	------	------	40	20	40	------	------	------
June 7	------	------	------	43	------	57	------	------	------
14	------	------	------	20	15	60	------	------	5
21	------	------	2	40	20	38	------	------	------
28	------	------	1	33	22	43	------	------	1
July 5	------	------	4	44	20	32	------	------	------
12	------	------	8	33	42	17	------	------	------
19	------	------	------	42	8	50	------	------	------
26	33	------	33	33	------	------	------	------	------
Aug. 2 [1]	25	------	------	50	25	------	------	------	------
1956									
May 31	------	------	------	------	------	100	------	------	------
June 7	------	------	------	25	13	62	------	------	------
14	------	------	------	20	24	56	------	------	------
21	------	------	3	28	14	55	------	------	------
28	------	------	8	30	17	43	------	------	2
July 5	------	------	------	29	14	53	------	2	2
12	------	------	4	15	------	81	------	------	------
19 [1]	------	------	------	50	12	38	------	------	------

[1] Added to the escapement for this week are a few red salmon which entered the lake after this date. The number of red salmon involved are as follows: 1 in 1950, 5 in 1952, 1 in 1953, 3 in 1955, and 2 in 1956.

The annual age composition of the Bare Lake run and the number of salmon in each age group were determined by calculating the number of fish in the weekly run (table 2) that fell in the various age groups (table 3). The weekly totals for each age group were combined to give the total number of fish in each group and percentage

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[1] The method, first used by Gilbert and Rich (1927) to designate the age of red salmon, is as follows: A fish resulting from an egg laid in the spawning gravels in 1950 and that migrated to the ocean in 1952 and returned to the river in 1955 is called a five-two and designated thus, 5_2. Such a fish would have emerged from the gravels of the spawning beds in the spring of 1951 and would have spent 1 growing season or summer in fresh water. In referring to its fresh-water history it is called a two-fresh-water fish because it migrated seaward in its second year. It would have spent 3 full growing seasons, i.e., 1952, 1953, 1954, and part of a fourth year in the ocean: but in referring to its ocean history it is called a three-ocean fish, because it returned as an adult in the third year following its seaward migration. A fish that migrated to the ocean in its third year and returned in its sixth is called a six-three and is designated 6_3.

TABLE 4.—*Age composition of the red salmon run at Bare Lake, Alaska*

[Percentage in parentheses]

Year	Number in run	Number and percentage in age group—								
		3_2	4_1	4_2	5_2	5_3	6_3	6_4	7_3	7_4
1950	943				880 (93.3)	16 (1.7)	37 (3.9)			10 (1.1)
1951	167		6 (3.6)	3 (1.8)	104 (62.3)	15 (9.0)	36 (21.5)			3 (1.8)
1952	420		3 (0.7)	13 (3.1)	276 (65.7)	30 (7.2)	98 (23.3)			
1953	335		3 (0.9)	4 (1.2)	271 (80.9)	41 (12.2)	16 (4.8)			
1954	276		1 (0.4)	23 (8.3)	17 (6.2)	92 (33.3)	142 (51.4)	1 (0.4)		
1955	441	2 (0.5)		12 (2.7)	172 (39.0)	87 (19.7)	166 (37.6)			2 (0.5)
1956	368			13 (3.5)	104 (28.3)	54 (14.7)	193 (52.4)		1 (0.3)	3 (0.8)

age composition of the run each year (table 4). In this calculation it is assumed that the age composition of the escapement reflects the age composition of the run. If it were possible to distinguish Bare Lake fish in the catch, it might be found that this was not true in 1950 and 1951, the years of large catches. Since then the calculated catches have been small and probably have had little influence on the age composition of the escapement.

With knowledge of the size and age composition of the annual runs, the return of salmon from known spawning escapements or smolt migrations can be measured.

LENGTHS

In the process of taking scales of adult salmon at the weir, the sex and fork length of each fish were recorded. In figure 4, the mean fork length by sex for fish of each ocean age is presented for each year. As insufficient numbers of 2-year-old ocean-age fish were present in samples for 1950, this group has been omitted. It is quite apparent from the figure that the size of the adults is dependent on the years spent in the sea and the sex of the fish. In fact, the criteria affecting ocean growth apply to both sexes and to both ocean ages. Indications of this were recorded by Gilbert (1915) for red salmon in British Columbia and have been reported since from other areas. The good relation in size each year between 2- and 3-year-old ocean-age fish of both sexes would suggest that environmental factors in the ocean, probably during the last year, have the greatest influence in determining size at maturity.

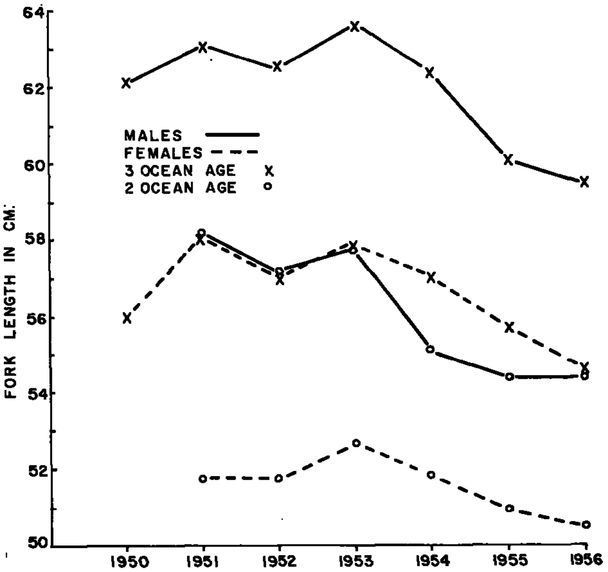

FIGURE 4.—Mean fork length of red salmon in the escapement, by sex and ocean age.

No significant difference in the size of adults of the same ocean age but of different fresh-water ages was found. Over the years, the average percentage increase in length of fish spending an additional year in the ocean was 9.2 for both sexes. At the same time, males averaged 8.2 percent longer than the females. On the basis of female red salmon taken for fecundity samples at the weir (appendix table 1), the average weight of 2-year-old ocean fish was 3.68 pounds, while 3-year-old ocean fish averaged 4.78 pounds. Although the 3-year-old ocean females averaged 9.2 percent longer than the 2-year-old ocean females, the increase in weight was 23 percent. Weights of adult males have not been taken, but it is probable that a similar weight relation exists between 2- and 3-year old ocean males.

SEX RATIOS

Sex ratios were established by examining live fish in a holding box at the weir site. Although it was possible to examine the fish rather carefully, some errors are made in sexing live fish, especially when the spawning characteristics of fish of each sex are only partially developed. For example, in 1953, spawning-ground recoveries were made of 901 live red salmon, sexed at the Karluk River lagoon (Nelson and Abegglen, 1955). The fish were placed in a holding box and sexed by superficial examination before being tagged. Later, on the spawning grounds the tagged fish were recovered dead and at that time the sex could be accurately determined by dissection. It was found that 5 percent of the live fish were sexed incorrectly; however, there was no tendency to sex incorrectly a greater proportion of fish of one sex than the other (Fish and Wildlife Service, unpublished data). Similiarly, at Bare Lake, during the 4 years that recoveries on the spawning grounds exceeded one-third of the escapement into the lake, the sex ratio was in close agreement with the ratio established at the weir.

A predominance of female salmon has occurred each year in the escapement at Bare Lake (fig. 5). This could be due to a higher percentage of females in the annual smolt migrations. The sex ratio of Bare Lake smolts has not been determined, but at Karluk Lake (Barnaby 1944) and Cultus Lake (Foerster 1954b), the sexes were found to be equally represented in the seaward migrations. Nevertheless, a predominance of female sockeye salmon also occurred in the spawning migrations to these lakes, and Foerster concludes that males may suffer a higher mortality at sea. A greater ocean mortality of the males could explain the situation at Bare Lake.

It could also be argued that the predominance of female red salmon at Bare Lake is due to the selectivity of gill nets in the Red River district fishery since gill nets account for two-thirds of the catch, with purse seines taking the balance. The selectivity of gill nets in capturing sockeye salmon of certain size ranges is a well-established fact. With the 5½-inch-stretch mesh nets used in the fishery, according to findings of the Fisheries Research Institute of Seattle, Wash. (unpublished data), the larger 3-year-old ocean-age males would be more available to the nets than the smaller females of that age. During the years 1952, 1954, 1955, and 1956, however, the catch was calculated to range from less than 1 percent to 15 percent of the escapement (table 2). Such a small catch could have had little influence on the sex ratio during those years, although it may have affected the sex ratio in the other years. Both Barnaby and Foerster considered the selectivity of gill nets, but they did not believe this factor could account for the imbalance in sex ratios that they found in the sockeye.

It is of interest at Bare Lake that the ratio of females to males was greater in the 2-year ocean-age group than in the 3-year ocean-age group (fig. 5). Thus, it would appear females have a tendency to return after less time at sea than males. As 2-year ocean-age fish usually comprise a small part of the run, they would have little influence on the sex ratio of the run. It might be concluded that the high percentage occurrence of 2-year ocean-age females is due to their small size which enables them to escape more readily the 5½-inch gill net mesh. The fact they were predominant even in years of very little fishing would tend to discount this. At Karluk Lake, Barnaby (1944) found males predominant in the

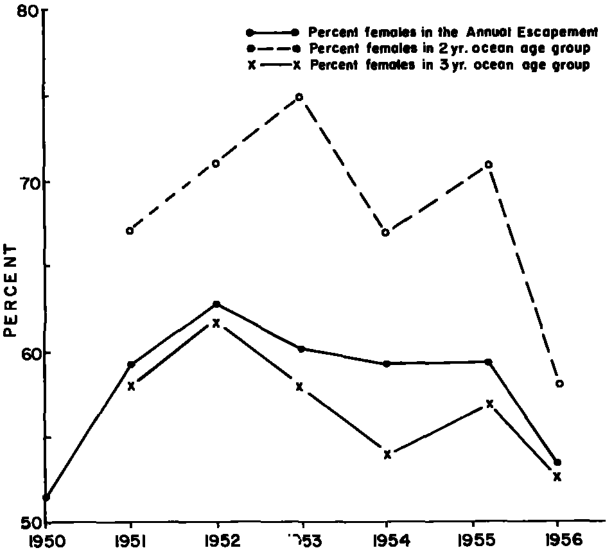

Figure 5.—Percentage of female red salmon in the annual escapement and in each ocean-age group.

2-year ocean-age group and females in the 3-year ocean-age group. He mentioned that, since males on the average spend less time in the ocean than females, the mortality of males would be less than that of the females, which should result in a preponderance of males. Actually, the reverse occurs. As he did not think it probable that a differential mortality in favor of the females occurred during the ocean life he had no explanation for this phenomenon. The fact that females predominate in the returns to the three lakes strengthens Foerster's belief that males suffer a higher mortality at sea. For this to apply at Karluk Lake, the greater survival of females would have to exceed the survival advantage male fish might have from a shorter ocean life.

SPAWNING

Once the ocean life of the Bare Lake red salmon has been completed, the fish enter Red River and travel upstream a distance of 16 miles to the outlet of Bare Lake. Upon entering the lake they linger for approximately 2 months before spawning. Duration of this ripening period varies considerably in the different river systems. The period of lake residence averages 1 month in Karluk Lake (unpublished tagging data). In Lakelse Lake, British Columbia, the period averaged 54 days (Fisheries Research Board of Canada, 1954). Howard (1948) found in Cultus Lake, B.C., that the period was approximately 1 month. In the Harrison River system of British Columbia, Schaefer (1951) noted the time was a month or less. It would appear the distance from salt water to a lake has little if any bearing on the length of the red salmon ripening period. Perhaps the length of this ripening interval is a characteristic of particular runs.

To determine the fecundity of Bare Lake salmon, egg counts were made of a few salmon captured at the weir during the years 1952 through 1955. The fork length, weight, age, and egg count by ovary, of the fish sampled is presented in appendix table 1, page 84. It was found that the right ovary of Bare Lake salmon usually contains more eggs than the left ovary. This is rather unusual as the reverse generally occurs with salmon in other areas. It was determined that the fecundity of the fish sampled increased with the age and length of the salmon, with length accounting for 44 percent of the variation in egg count. As egg counts were not taken in all years, it was necessary to calculate a regression line of egg count on fork length with the existing data. This common regression line was used to estimate the fecundity of the fish each year. It was hypothesized that the regression of egg count on fork length might be the same for all years. Covariance analysis failed to reject this hypothesis at the 5-percent level.

Spawning occurs on certain areas of the littoral zone around the lake; the one tributary stream and several small seepages are not used. During the spawning period, frequent surveys were made of the spawning areas to recover dead fish. All fish recovered were dissected and the sex and spawning condition recorded.

Except in 1950, all eggs retained in the body cavity of partially spawned female salmon were counted. As only two female salmon were recovered in 1951, the sample size was inadequate to determine the average egg retention that year. For the years 1952 through 1956, the mean annual egg retention, which in this calculation included partially spawned as well as unspawned salmon, ranged from 66 to 208 eggs per female (table 5). The mean retention for the 5-year period was 148 eggs per female while the mean retention for partially spawned fish was only 96 eggs per fish. The figure of 148 eggs was used to estimate egg retention in 1951.

Of the female salmon examined on the spawning grounds in 1950, 26.8 percent were totally unspawned. Since no count was made of the eggs retained in the ovaries of spawned fish, the mean egg retention of 96 eggs per spawned female for the years 1952 to 1956 was used. Upon calculating egg retention for all female salmon in 1950, the average retention was found to be 970 eggs per female, or a total egg retention of 28.7 percent of the eggs available for deposition. This loss may have been caused by high water temperatures during the middle of August when the fish were on the spawning grounds. That year the mean surface temperature from August 9 to August 19 averaged 16.9° C., which is higher than the average temperature recorded in the same period during the following 6 years. Foerster (1938) noted a very low egg retention in spawned female sockeye examined on the spawning grounds at Cultus Lake in 1925 and 1935.

TABLE 5.—*Annual egg deposition of red salmon in Bare Lake, Alaska*

Year	Escapement of females	Mean fork length of females (cm.)	Fecundity[1]	Potential egg deposition	Dead female spawners examined			Corrected egg deposition
					Number	Recovery (percent)	Egg retention per fish	
1950	285	57.1	3,374	961,600	71	24.9	[2] 970	685,100
1951	30	57.5	3,417	102,500	2	6.7	[3] 148	98,100
1952	235	56.6	3,319	780,000	158	67.2	114	753,200
1953	146	57.0	3,363	491,000	22	15.1	166	466,800
1954	134	54.7	3,112	417,000	64	47.8	208	389,100
1955	244	54.5	3,090	754,000	104	42.6	66	737,900
1956	185	54.4	3,079	569,600	59	31.9	184	535,600

[1] Fecundity based on regression line of fish fork length on egg count for samples taken during years 1952–55 (9 fish, 1952; 9 fish, 1953; 9 fish, 1954; 16 fish, 1955). Equation for regression line $Y=-2849.18+108.98X$.

[2] Egg retention based on the percentage of unspawned female salmon recovered and the mean egg retention of spawned fish for the years 1952–56.

[3] Sample size was inadequate, so mean egg retention for years 1952–56 was used.

However, unspawned fish were found dead on the spawning grounds in those years, and if they are included, a mean egg retention of 6.3 and of 19.8 percent occurred.

In table 5, the egg deposition is shown in two ways. The first is based on the escapement, the mean fork length of the females for the year, and the mean number of eggs for that size fish, calculated from the regression formula $Y = -2849.18 + 108.98X$. The second includes a correction applied to those figures based on the mean egg retention of the females recovered on the spawning grounds each year. The largest egg deposition occurred in 1952, yet the escapement that year was smaller than in 1950 and 1955. This indicates that the egg deposition based on the number and fecundity of female salmon in the escapement alone can often be in error. A measure of the egg deposition is important in measuring the survival to later stages in life. Later the survival from egg deposition to the smolt stage will be shown.

EFFECTS OF FERTILIZATION ON YOUNG RED SALMON

FIRST-YEAR GROWTH OF RED SALMON

As previously pointed out, the majority of the adult red salmon spawn during August. By the first part of November the lake is generally covered with ice and remains thus until the following April or May. Seine hauls indicate the young emerge from the gravels during May and June. The time of emergence is dependent upon the time of spawning and water temperatures during the incubation period.

If fertilization is augmenting the food supply of the young red salmon, one of the first indications probably would be the increased growth of the young fish. To determine if such an increase occurred, seine hauls were taken each growing season during this investigation. The fish captured were counted and a sample of juvenile[2] red salmon was anesthetized, after which lengths and weights were recorded and scale samples were taken. The salmon were held in live boxes to recover from the anesthetic and were then released into the lake. The catches included young red salmon of three age groups with the fish from the hatch of the year being the most prevalent. Although the three age groups generally can be easily separated by lengths, scales were taken from each fish sampled to validate the age determination.

The growth of red salmon during their first year of life in the lake is shown in figure 6. As noted in the figure, a rather progressive increase in growth occurred during the years 1950 through 1955. It is unfortunate that more seine hauls were not taken in 1950; however, it is believed that the length of the fish taken then is representative of the growth at that time. The rather sharp decline in growth rate during 1956 is discussed in a later section.

AGE COMPOSITION AND SIZE OF SMOLTS

At Bare Lake the majority of the red salmon smolts migrate to sea at the beginning of their second or third year of life. Occasionally, a few fish remain until their fourth year, but only rarely do the fish leave the lake in their first year or remain as long as their fifth.

The smolt migration commences the latter part of May each year, reaches a maximum during

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[2] Stages of the life history of red salmon used in the text are defined as follows: Fry—the period following the absorption of the yolk sac up to the time of active feeding: juvenile—the period commencing with feeding to the time of seaward migration; smolt—the period of migration from fresh to salt water.

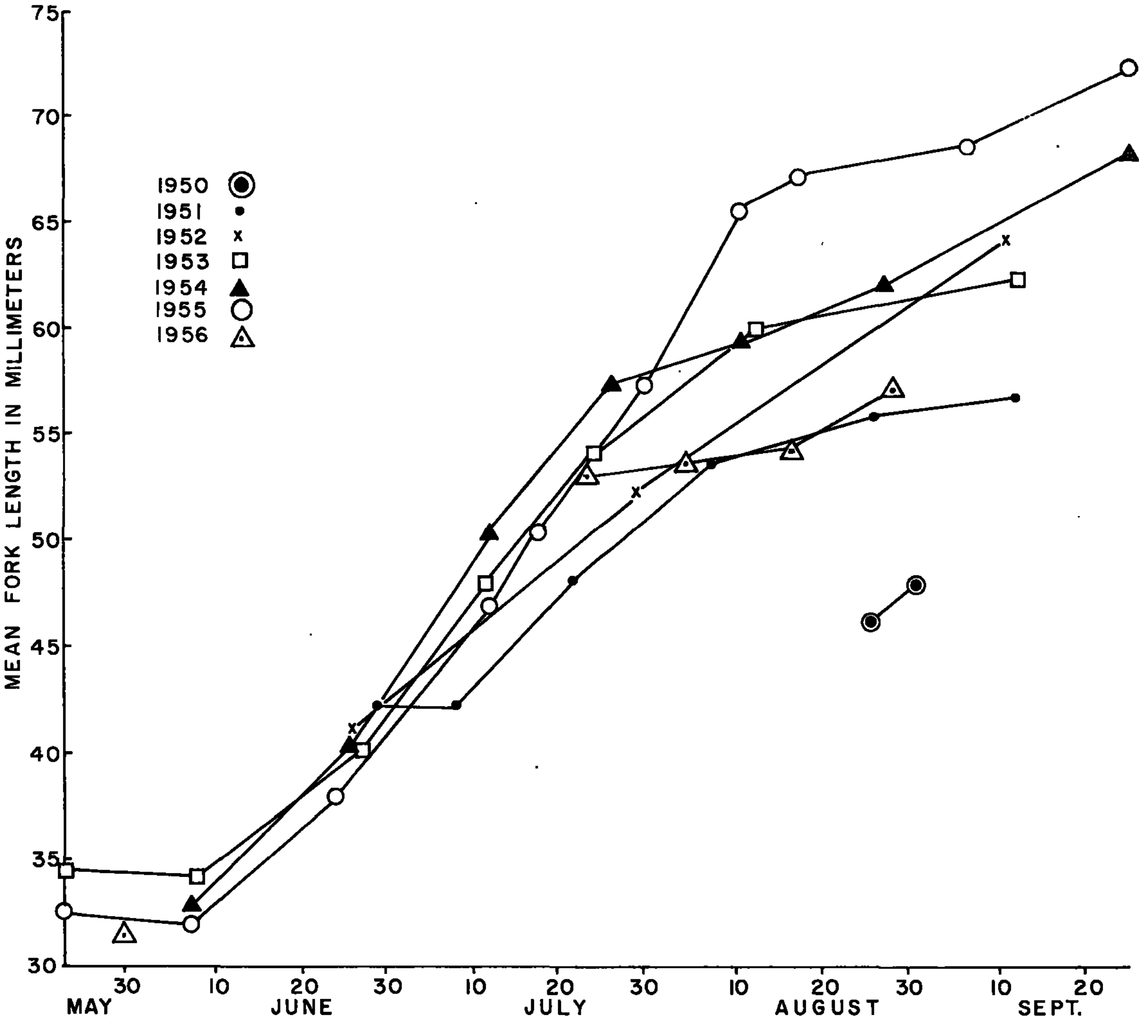

FIGURE 6.—Growth curves of red salmon during their first summer in Bare Lake.

June, and is generally over by the end of July. Unlike in most other areas, smolts in Bare Lake tend to leave the lake during the day on their seaward migration. The reason for this is not known, although large migrations have been witnessed occasionally at Karluk Lake during daylight hours and have also been reported from other areas.

Each day during the migration, the smolts were counted, and a sample was taken to determine the age composition, weight, and length of fish in the migration. The trap (fig. 2) is of simple construction. The smolts migrating downstream tail first are led into the trap. They were captured with a small seine and transferred into tubs of water; the species were sorted and counted; the red salmon smolts were placed in a live box, and other species were released below the weir. During days of large migrations the trap was seined frequently and the red salmon smolts were accumulated in the live box. At the end of the day a sample of the catch was taken for processing. The live box has two compartments of equal size separated by a removable partition. To obtain a sample of the catch, the partition was lowered to divide the catch in half. One-half was released in the stream below the weir and the remainder subdivided if necessary until a sample of 50 to 100 fish was obtained.

Once the sample of fish was separated from the daily catch, the sample was placed in a tub of fresh water. From the tub a few fish at a time were dipped into a bowl containing a 0.5-percent solution of urethane. After the fish were anesthetized, fork lengths and scale samples were taken, and each fish was weighed on a beam balance having a sensitivity of 0.01 gram. Before the first fish was weighed, the balance pan was wetted down and the weight of the wet pan set at zero grams. In standardized manner, a fish was placed on the pan, weighed, and transferred to a container of fresh water. Before the next fish was weighed the pan was given a quick shake to eliminate the bulk of the water that had drained from the fish. Periodically the zero setting was checked. By this method, the weight of the fish as recorded here actually includes a film of water that amounts to about 3 percent of the body weight. The smolts were held in the live box for several hours, or until they appeared fully recovered, and then were released to continue their seaward migration. Mortality has been very slight in this operation, and fish were held as long as 2 days without showing signs of distress from the handling and anesthetic.

In appendix table 2, data are presented showing by weekly periods the migration, age composition, mean length, and mean weight of smolts in each age group during the years, 1950–56. Also given is the number of smolts sampled each week from which the measurements were derived.

The weekly age composition of smolts during the season has followed a rather consistent pattern from year to year. In general, the older smolts migrate to sea earlier in the season. In the years of study the 2- and 3-year-old smolts have accounted for over 99 percent of the annual migrations while the 1-, 4-, and 5-year-old smolts make up the balance. Because the minor age groups make up such a small part of the migration, they are discussed only briefly.

Figure 7 shows the percentage of 2-year-old smolts in the weekly migrations during the years 1950–56. Although the 3-year-old smolts are not shown, it is easy to visualize the complement of the curves presented. Usually the bulk of the 3-year-old smolts has migrated by early June while the 2-year-old smolts migrate in their greatest numbers the latter part of June. In 1950 and 1954, some variations occurred in the normal migration. In the former year, over 60 percent of the July migration was composed of 3-year-

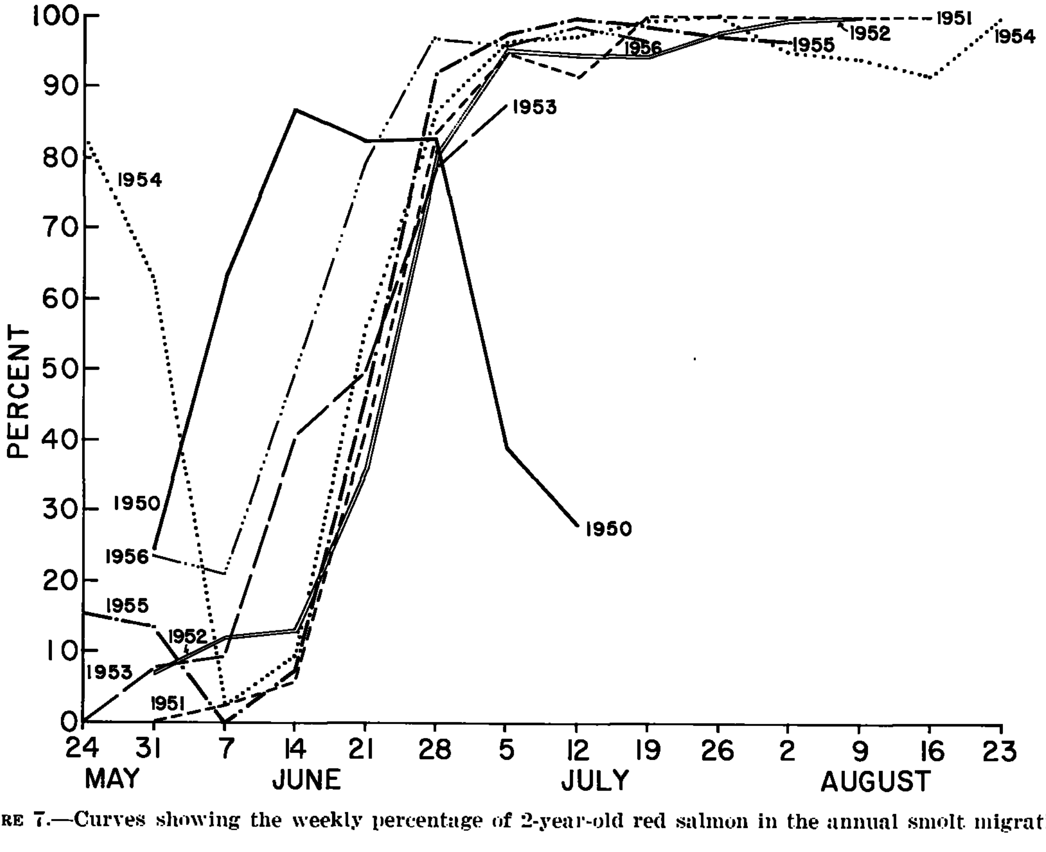

FIGURE 7.—Curves showing the weekly percentage of 2-year-old red salmon in the annual smolt migrations.

old smolts, while during May 1954, 2-year-old smolts predominated over the older fish. Very few fish migrated during these periods; but that does not account for the unusual age composition, for which there does not seem to be a satisfactory explanation.

The percentage of 2-year-old red salmon in the annual smolt migration has ranged from a high of 86 percent in 1954 to a low of 23 percent in 1951 (fig. 8, *c*). A comparison of the annual percentage composition of 2-year-old smolts with the size of the smolt migration (fig. 8, *d*), shows that in years of large smolt migrations (1950, 1954, and 1955) the younger smolts predominated. This no doubt applied also to the smolt migrations of 1947 and 1949. From each of these migrations large numbers and a high percentage of the 2-year-old smolts returned 3 years later as adults at age 5_2 (table 4). For this to occur, the smolt migrations in those years must have been large and made up mostly of 2-year-old fish.

To determine the effect that the number of smolts produced by a brood year might have on the age at which they migrate to sea, a calculation was made of the number of smolts produced by brood years 1948–53 and the percentage of smolts which migrated to sea from each brood as 2-year-old fish. It was found that approximately 60 percent of the variability in the percentage of smolts migrating to sea in their second year was associated with the number of smolts produced in a brood year. Greater percentages of smolts migrated to sea at an earlier age from brood years of high production than from years of low production. Possibly population pressure caused the bulk of fish in the big-brood years to migrate earlier. This could account for the low populations of 3-year-old smolts, because only in brood years of low smolt production could they dominate in numbers over the 2-year-old smolts. Also, limiting the abundance of the older smolts would be the additional mortality imposed on this group by the extra year in fresh water.

There is a general tendency for the slower-growing fish in the population to migrate later in the season or remain in the lake another year. This is apparent over the years and is shown in a comparison of the length curves each season of 2-year-old smolts taken in the smolt trap and 2-year-old juvenile red salmon captured in seine hauls (fig. 9). However, size alone appears to have little influence on the age composition of the smolt migration. The increase in size of smolts since 1950 has not brought about an increase in the percentage of younger smolts in the annual migrations.

A considerable increase in the size of smolts has occurred since 1950. The smolts of 1950 could receive no benefit from the first fertilization of Bare Lake, as they migrated before the application. The rather progressive increase in length and weight of smolts, which occurred, built up to a peak in 1955 and declined somewhat in 1956 (fig. 8, *a* and *b*). The smolts of 1955 in all age groups were more than 30 percent longer and more than 150 percent heavier than those of 1950. During the years 1951–55, increase in size of smolts was rather consistent among all age groups. Upon comparing figures 8, *a* and 8, *b* with figure 8, *d*, no relation is found between the size of the migration and the increase in length or weight of the smolts during the years of study. More often, as reported by others, there is a tendency for smolts to be small in years of large migrations. Evidently this did not take place at Bare Lake as the food supply of juvenile red salmon was adequate even in years when they were abundant.

Information was obtained on the size of smolts in the years 1947, 1948, and 1949 through use of a procedure involving scale radius measurements. The method involved taking scale-radius measurements from 100 smolts each of 2- and 3-year-old fish for the years 1950 through 1953. It was determined that a highly significant correlation ($r = .983$; $P < .01$) exists between scale radius and fork length of smolts when the age groups are kept separate. When the age groups were combined for each year, the correlation between mean annual length and mean scale radius weighted by the age composition of the migrations was found to be significant at the 5-percent level in which $r = 0.91$.

Since a relation existed between the scale radius and size of the smolts, it was necessary to show agreement between the fresh-water scale radii of the adults and the scale radii of the smolts that produced the adults. To do this, scale-radius measurements of the fresh-water growth were taken from almost all of the adult

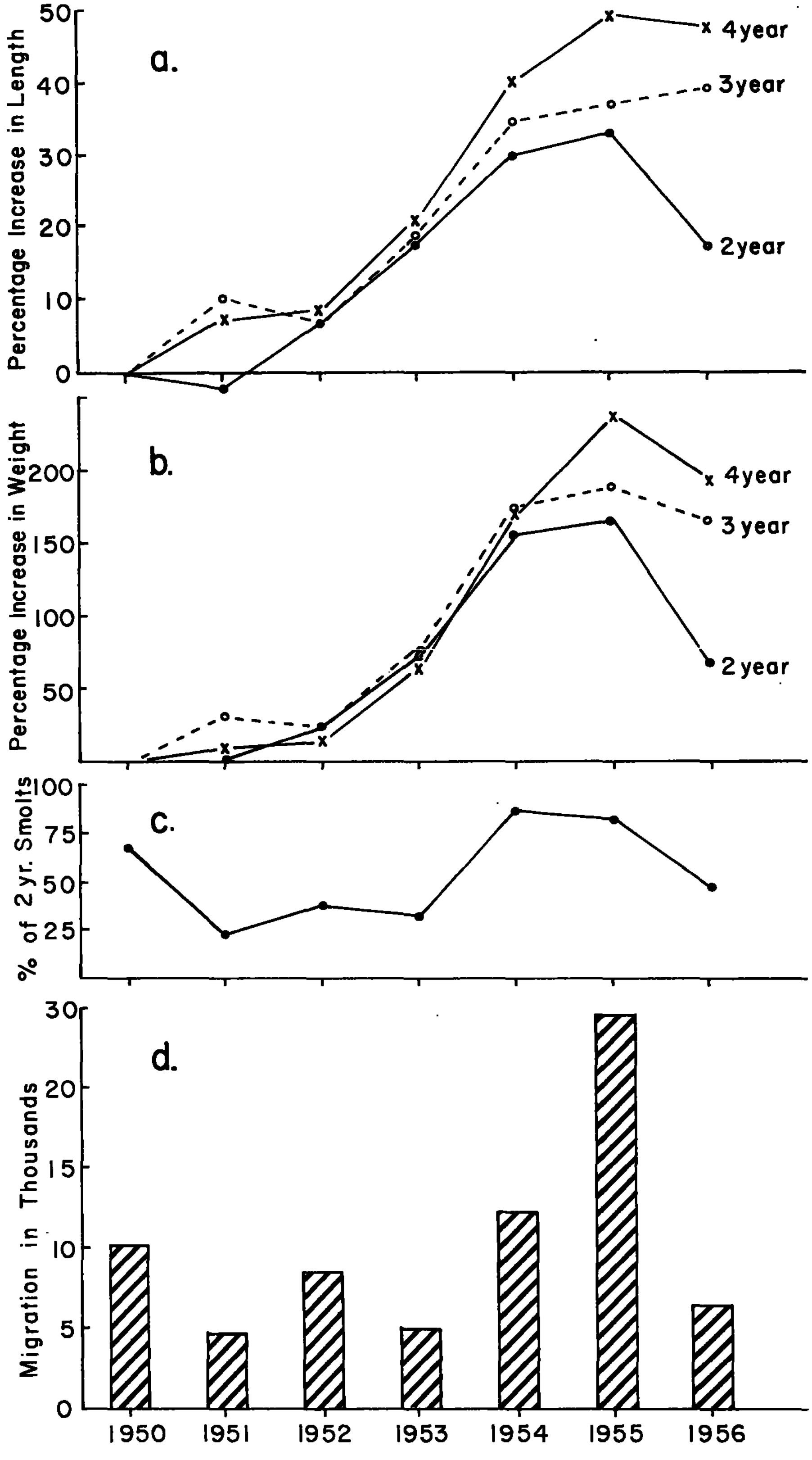

FIGURE 8.—Relation between size of the smolt migration and (1) the age composition and (2) increment in smolt length and weight. a. Percentage increase in length of smolts between 1950 and the years 1951 to 1956. b. Percentage increase in weight of smolts between 1950 and the years 1951 to 1956. c. Percent of 2-year-old smolts in the annual migration, 1950 to 1956. d. Total annual smolt migration, 1950 to 1956.

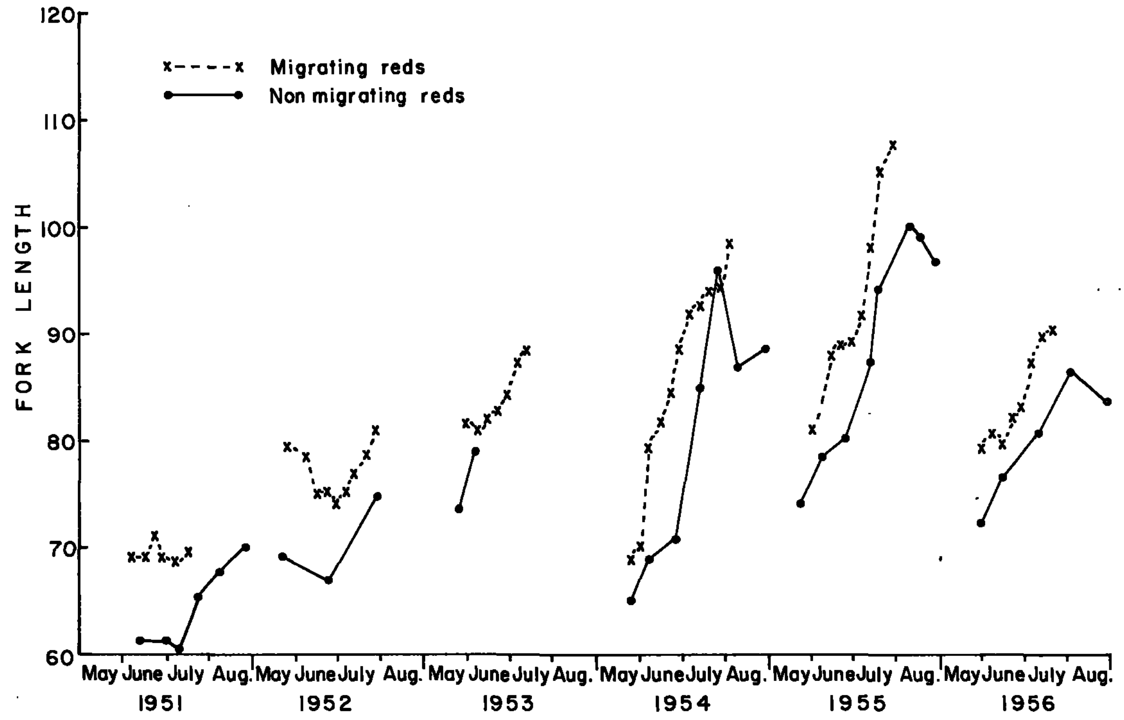

FIGURE 9.—Fork length (in millimeters) of 2-year-old migrating and of 2-year-old nonmigrating red salmon juveniles, Bare Lake, Alaska, 1951–56.

salmon in the escapement produced by the smolt migrations of 1950 through 1953. In several instances, returns of adult salmon by individual fresh-water age were quite small, so the age groups were combined. The mean scale radius and length of smolts for the years 1950 through 1953 and the mean fresh-water scale radius of adults returning from each of these migrations are shown in table 6. Comparative data for the 4 years show the fresh-water-zone scale radii of returning adults were larger than or equal to those of the smolts producing them. The increase probably is caused by a greater mortality of the smaller smolts at sea. Measurements of the fresh-water-zone scale radius were also taken from scales of adult salmon returning from the smolt migrations of 1947 through 1949, and data in table 6 indicate that these radius measurements were slightly smaller than those of the adult salmon in 1950. This is good evidence that the smolts of 1947 to 1949 were smaller than those of 1950, although it does not necessarily mean they were smaller in all age groups.

TABLE 6.—*Weighted mean length and mean scale radius of 2-year-old and 3-year-old smolts combined and mean fresh-water-zone scale radius of adults returning from the smolt migration*

Year of smolt migration	Combined 2- and 3-year-old smolts		Mean fresh-water scale radius of returning adults (mm.)[1]
	Mean length (cm.)	Mean scale radius (mm.)	
1947	----------	----------	0.29
1948	----------	----------	.28
1949	----------	----------	.30
1950	72.8	0.28	.32
1951	81.8	.34	.37
1952	79.1	.32	.32
1953	90.2	.39	.41

[1] Combined 2- and 3-year-old fresh-water age groups.

RELATION BETWEEN RED SALMON GROWTH AND RATE OF PHOTOSYNTHESIS

As pointed out previously, the size of the red salmon increased progressively between 1950 and 1955. A decline in size occurred in 1956 among the fry and 2- and 4-year-old smolts. Although the 3-year-old smolts in 1956 were slightly larger than those of the year before they weighed less (fig. 8, *b*) which indicates poor growing conditions. Curves showing the trend in size of fish in each group for years 1950–56 are presented in figure 10, *a*. Juvenile lengths are based on the length the fish attained on August 27 of each year, as shown in figure 6. That date was selected since it is the latest date in the season for which length data were available for all years. Annual mean smolt length of each age group was determined by sampling throughout the period of smolt migration.

The observed progressive increase in fish size might be expected, because the organisms the fish eat are relatively long lived, and some time would be required for the population to build up in response to an increase in food supply brought about by fertilization. The decline in 1956 was unexpected, and an effort was made to determine the cause. Possible explanations for this decline, particularly temperature and primary food production, were examined. Air temperatures taken at Kodiak, 80 miles northeast of Bare Lake, were examined for the months from September 1955 to May 1956 and for like periods in the preceding years. Temperature data were insufficient from Bare Lake; however, for the months in which temperatures were recorded, they were closely correlated with temperatures at Kodiak.

The mean temperature at Bare Lake from September 1955 to May 1956 was 33.7° F., which was 2.5° below the mean for like periods of the preceding 6 years. Furthermore, each monthly mean temperature was lower than the monthly mean temperature of the 6 previous years. The air temperature could hardly influence the water temperature once the lake was frozen, but a prolonged period of low air temperatures could increase considerably the thickness and duration of the ice cover. Also, because of the severity of the conditions at time of freezing, the lake water may have been at a somewhat lower

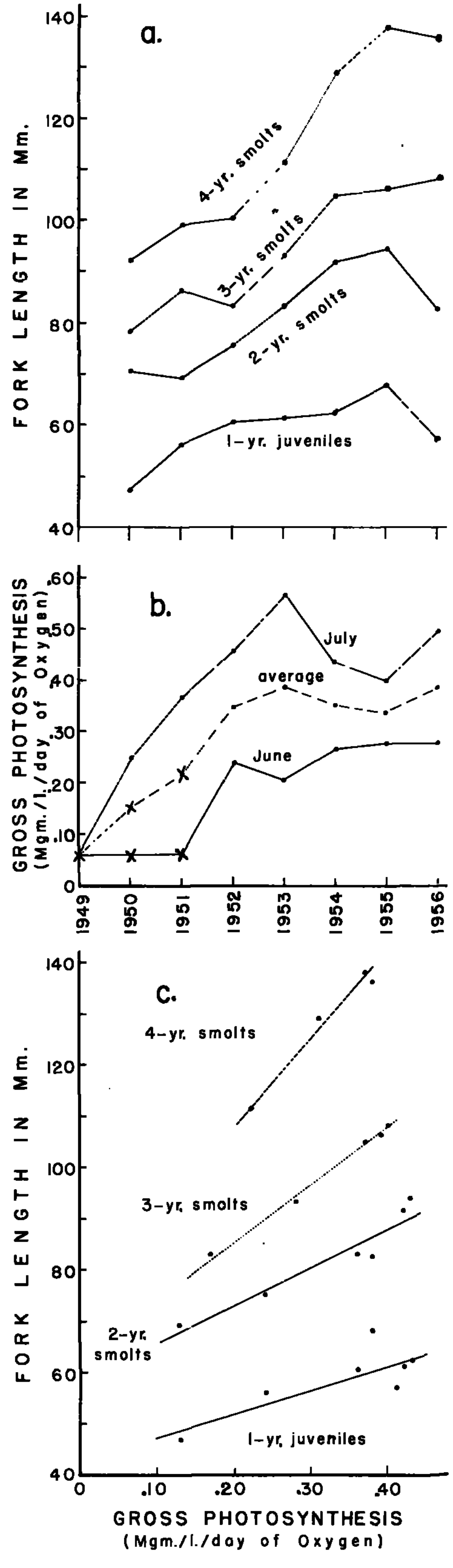

FIGURE 10.—The relation between gross rate of photosynthesis and growth of red salmon juveniles. a. Curves showing the mean length of juvenile red salmon on August 27 of their first growing season and of red salmon smolts migrating to sea in the beginning of their 2d, 3d, and 4th year of life for the years 1950–56. b. Curves showing the mean rate of gross photosynthesis during the years 1949–56 for the 40-day periods after the June application of fertilizer and for a similar period after the July application. Also presented is a curve of the average of the two periods for those years. Points on the curves marked by an x denote that the values are estimated or partly estimated. c. Scatter diagrams showing the relation between gross photosynthesis and fork length for each age group of fish. Regression lines are drawn by inspection.

temperature than at the time of freezing in other years. These conditions could have resulted in reduced growth and increased mortality of fish food organisms and may have had some effect on the fish themselves. When all years were considered, however, no relation was found between mean temperatures during this period or during the summer period and fish growth.

The data gathered each year on growth rate of young salmon and primary productivity as measured by the rate of photosynthesis of the phytoplankton were examined to determine if a relation existed between them. If a relation was found it would tend to substantiate the proposition that the salmon population is held in check by insufficient food and would provide an explanation for the decline in fish growth during 1956.

Plotted in figure 10, *b* are the mean rates of gross photosynthesis, determined by the method described by Nelson and Edmondson (1955), for the 40-day period after each June and July application of fertilizer and the average rate of the combined periods. The gross rate of photosynthesis for the period after the July fertilization increased progressively each year up to 1953, was considerably lower in 1954 and 1955, and increased again in 1956. The rates of photosynthesis after the June fertilization show a different trend during the years 1952–56. Unlike in the later period, a small decline in rate of photosynthesis from 1952 occurred in June 1953, and a progressive minor increase occurred in subsequent years. As photosynthetic activity was greatest after the July fertilization, the curve of the combined periods followed a similar pattern although the fluctuations were smaller. No actual measurements were made in 1949 when the lake was not fertilized, but on the basis of measurements made just before fertilizing the lake in July of 1950 and 1951 (Nelson and Edmondson, 1955), it is believed the mean rate of oxygen production would not have exceeded 0.12 mgm. per liter per day and may well have been about 0.06. This figure is plotted as the rate during 1949 and during the early part of the 1950 and 1951 seasons when the lake was not fertilized in June. The causes of the fluctuation in rates of photosynthesis during these years has not yet been analyzed, but the changes are of considerable magnitude, particularly in July.

A cursory comparison of the curves of seasonal rate of photosynthesis with the size of young red salmon reveals a certain correspondence between them (fig. 10, *a* and *b*). To show the relation more clearly, correlation diagrams were made (fig. 10, *c*). In the case of juvenile red salmon in their first growing season, it was thought three periods in time would be important in affecting the population size and growth of the new crop of insect larvae hatching in early summer and which would be fed upon by salmon hatching that spring. The period after the July fertilization of the previous year was considered important to the survival of the brood stock of insect larvae that was to produce the new generation utilized by the recently hatched fry. Periods after both the June and July fertilizations would influence the growth and survival of the newly hatched larvae. Thus, in figure 10, *c* for the years 1950–56, the length the juveniles attained on August 27 of their first growing season is plotted against the mean rate of photosynthesis after June and July fertilizations of that year and after July fertilization of the preceding year. All three periods were weighted equally in establishing the mean.

To show the relation between smolt size and rate of photosynthesis, the mean fork length of smolts for each age group was plotted against the mean rate of photosynthesis over those periods mostly responsible for the development of insect larvae upon which the fish fed during their lake residence. As the bulk of the smolts usually migrated prior to the third week in June during the years of study, the period after the June 10 fertilization in the year of smolt migration would be of little or no value in providing fish food organisms for the smolts before they migrated. However, conditions in the preceding years would affect the food supply of these fish, with the older smolts being subjected to the environment for the longer period of time.

The following example shows the procedure adopted in making the scatter diagrams (fig. 10, *c*) for smolts of various ages: The mean fork length of the 2-year old smolts migrating to sea in 1955 was plotted against the mean rate of photosynthesis in the fall of 1953 and during 1954; the mean fork length of the 3-year-old smolts migrating the same year was plotted against the mean rate of photosynthesis during the years 1954 and 1953 and the fall of 1952; correspondingly, the mean fork length of 4-year-old smolts in 1955 was plotted against the mean rate of photosynthesis for the years 1954, 1953, 1952, and the fall of 1951. The rate of photosynthesis over each 40-day period was given equal weight in establishing the mean rate.

A good relation between fork length and rate of photosynthesis was found in smolts (fig. 10, *c*). The relation was weaker in fry. Perhaps sampling in the lake was inadequate to establish with sufficient accuracy the size of the juveniles on August 27. Nevertheless, the decline in rate of photosynthesis during 1954 and 1955 appears to have had considerable effect on the size the fish achieved in 1956. The relation between fork length and photosynthetic rate indicates a much closer dependence of fish growth on primary photosynthetic productivity than might have been expected *a priori.*

Phytoplankton is immediately or indirectly available to zooplankton and to many of the bottom organisms which are used as food by the salmon. Since so many steps exist between the original synthesis of food materials by the phytoplankton and the growth of the salmon and since fish are affected by so many environmental factors in addition to food supply, one might not expect a relation to exist between salmon growth and photosynthetic rates of the phytoplankton. Since such a relation does exist, it might be understandable in terms of the food chain involved. A higher primary production would result in a better state of nutrition of the crustaceans, insect larvae, and other animals on which the fish feed. The food animals would grow larger and be more nutritious to the fish. Adult insects produced from well-fed larvae would presumably be able to lay more eggs, and this would increase the potential population of insect larvae in the lake.

It will be interesting to follow this relationship when fertilization of Bare Lake is discontinued. Furthermore, it will eventually be possible to make a rather complete assessment of food conditions at Bare Lake when all the time-consuming censuses of plankton and bottom fauna are finished.

EFFECTS OF FERTILIZATION ON RED SALMON SURVIVAL

FRESH-WATER SURVIVAL

It is hypothesized that fertilization of Bare Lake increases the fresh-water survival of young red salmon. To determine this requires many years of observations. For example, to measure survival from one brood year to the smolt stage requires an enumeration of the number of smolts of that brood migrating seaward 2, 3, 4, and 5 years later. Up to the present time no measurements have been made of the fry hatch from known egg depositions. In fact, very little has been done in other areas toward measuring fry production from a beach spawning area because of the many difficulties involved in conducting such work. If this could be done it would be extremely useful in evaluating the effect of meteorological conditions on the eggs over winter. To some extent, conditions that produce poor survival to the smolt stage might in part be created during the period the eggs are in the gravels rather than during the free-swimming period in the lake. In such a case any benefits fertilization might have on survival would be masked.

Survival to the fry stage has been measured in several streams in British Columbia. In Scully Creek, a small tributary of Lakelse Lake, fry production for 5 years averaged 11.8 percent (range, 9.3 to 13.7); Williams Creek, located in the same system, had a production of approximately 7.5 percent in 1954; Six Mile Creek, Babine Lake, had survivals of 19 percent in 1954 and 12 percent in 1951; Port John survivals were 13.4 percent in 1954, a mean of 9.5 percent for earlier years, with a range of approximately 1.7 to 25.5 percent (Fisheries Research Board of Canada, 1955, p. 81). The range of fry production at Scully Creek was small over the 5-year period, but at Port John the range was large.

Because of lack of information on survival to the fry stage at Bare Lake, the range in fry survival is not known. To determine if fertilization has increased survival of red salmon from the egg to the smolt stage, will require that observations be made both during the years of fertilization and those of no fertilization.

At the present time rates of fresh-water survival have been measured from the brood years of

1950 through 1953. During those years an increased survival was indicated which could have been caused by a buildup of nutritional benefits. As shown in table 7, the average annual survival rate during the period was 2.96 percent. These survivals are based on egg depositions (table 5), with the correction applied to unspawned and partially spawned fish. In many areas, this correction has not been so readily assessed; hence, survival rates have been based on the potential egg deposition, as determined from the number and fecundity of female salmon in the escapement. When no correction is made to Bare Lake data, the mean survival rates during the years average 2.76 percent (range, 0.74 to 4.86)—a survival somewhat greater than has been reported from other areas. Barnaby (1944) found the fresh-water survival of Karluk River red salmon usually to be less than 1 percent. He suggested that the survival is low because the fish have a longer residence in fresh water. Measurements of fresh-water survival at Cultus Lake, British Columbia, during 1925, 1927, and 1930 were 1.13 percent, 1.05 percent, and 3.16 percent, respectively (Foerster 1936a). The smolts ranged in length from 2 to 4 inches, which would be comparable in size to the smolts of Bare Lake. At Lakelse Lake, Brett and McConnell (1950) report survivals of 1.1 percent, 0.4 percent, and 1 to 2 percent during the years 1946 through 1948. At Babine Lake, British Columbia, survivals of 0.48 percent, 0.77 percent, 1.57 percent, and approximately 2 percent were found for the years 1949 through 1952, respectively (Fisheries Research Board of Canada, 1955). From Dombroski (1954), the average lengths of Babine Lake smolts for years 1950 through 1953 were 83.1 mm., 82.5 mm., 80.6 mm., and 86.5 mm., respectively. During this period these fish averaged slightly longer than Bare Lake smolts. The lower fresh-water survival of Babine Lake red salmon may be compensated by the larger size of smolts migrating to sea.

The fresh-water survival values of red salmon at Bare Lake were measured during the years the lake was fertilized. Although the fresh-water survival at Bare Lake averages slightly higher than reported from other areas, this could be normal. With a high average fresh-water survival, the marine survival might be expected to be lower than the normal; otherwise, production would be unusually high compared with other areas. It is possible that a compensating factor operates, so that if fresh-water survival is low marine survival is high, and vice versa.

TABLE 7.—*Fresh-water survival of young red salmon in Bare Lake, Alaska*

Brood year	Egg deposition	Downstream smolt production [1]				Survival (percent)
		2 years	3 years	4–5 years	Total	
1950	685,100	3,668	3,441	51	7,160	1.05
1951	98,100	1,644	1,692	292	3,628	3.70
1952	753,200	10,532	4,311	46	14,889	1.98
1953	466,800	20,033	3,808	[2] 50	23,841	5.11

[1] Including mortalities at the trap.
[2] Estimated.

For fertilization to increase survival, it should indirectly create more food for the young red salmon. With an increase in food, growth would be increased before survival would be improved, as is indicated in the preceding section. To determine the end product in the food chain from fertilization of the lake to food of the young red salmon, the stomach contents of 150 juvenile red salmon were examined, including 51 smolts, 10 juveniles taken during February 1955, and 89 juveniles taken in seine hauls during the following summer. The diet of the young fish, including the smolts, taken during May through September, consisted mostly of bottom fauna with chironomids comprising the major part. The fish taken during February 1955 from under the ice were found to be feeding chiefly on ostracods and copepods.

OCEAN SURVIVAL

Measurements of the fresh-water survival, as described in the preceding section, represent only a portion of the life of the red salmon. Once the smolts leave the lake for their ocean sojourn, they are subjected to a new set of environmental hazards that may be very important in determining the survival rate. For comparison with results at Bare Lake, other observations on ocean survival of red salmon will be briefly reviewed.

The most comprehensive studies of ocean survival of red salmon have been made by Foerster (1934, 1936b, 1954a) at Cultus Lake and by Barnaby (1944) at Karluk Lake. In the former investigations, all smolts were captured at the weir and the annual seaward migration was enumerated. During each of the 3 years following each smolt migration, the age composition of the escapement was determined, and from this the number of adults in the escapement returning from the smolt migration was calculated. As the Cultus run makes up a small portion of the Fraser River run, and, since the catch usually exceeds the escapement, it was difficult to assess the portion of the fish returning to Cultus Lake that were taken in the fishery. To measure the total return of smolts as adults, during 1930 and 1931 all the smolts were marked by clipping a different combination of fins each year. Thereafter, fish returning to the weir and taken in the fishery as adults were examined for marks. The percentage of marked fish returning from each year's marking indicated the ocean survival. Foerster (1936b) reported recoveries of 3.67 percent and 3.5 percent from the two markings. Previous marking experiments, however, had indicated that marked fish suffer a 62-percent differential mortality over unmarked fish. Upon correcting for this loss, he concluded that the most probable survival during those years was approximately 9.9 percent. For other years at Cultus Lake, Foerster (1954a) presents a table of the smolt migrations and the percentage survival of smolts that returned in the spawning escapement only. The survival rates ranged from 0.31 to 6.68 percent, with a mean of 2.74. From recoveries of marked fish in 1930 and 1931 the catch accounted for one-half of the recoveries in the one year and three-fourths of the recoveries in the other year. If the catch usually takes from one-half to three-quarters of the run, the percentage survival as given by Foerster should be two to four times greater than indicated, if they are to account for the total return of smolts.

During the period in which ocean survival of salmon was measured at Cultus Lake, the smolts averaged 88.2 millimeters in length (range, 66 to 107) and 7.47 grams in weight (range, 2.7 to 12.8). In regard to the relation between ocean survival and smolt size Foerster (1954a) concluded—

> Analysis of these data indicated a negative correlation between size of migration (in number of smolts) and percentage return of adults which is found (by multiple correlation treatment) to be related principally to the size (weight in grams) of the smolts.

In a somewhat different manner, Barnaby measured the ocean survival of Karluk smolts. Results of his studies showed a greater survival in the ocean among the older and larger 4-year-old smolts than among the smaller 3-year old smolts. Average survivals for 6 years for the two groups were 25.7 percent and 17.4 percent, respectively. Average survival for all age groups was 21.4 percent. Barnaby points out that these high survivals were due to the large size of the smolts. As shown in the table of smolt sizes which he presents, the fish averaged approximately 137 millimeters in length and 24 grams in weight during the years of study.

By using table 4, the number of smolts returning as adults from the Bare Lake smolt migrations of 1950 through 1953 can be determined. For example, from the 1950 smolt migration, 3 adults returned as age-group 4_1 in 1953, 13 adults as 4_2 in 1952, 271 adults as 5_2 in 1953, 30 adults as 5_3 in 1952, and 16 adults as 6_3 in 1953. Summing these returns gives a total of 333 adults returning from the 1950 smolt migration. The number of fish returning and percentage return from this migration and subsequent smolt migrations is shown in table 8. This table, patterned after Foerster's table (1954a, p. 342), shows the relation between the size and number of smolts and the return of smolts as adults. The percentage of smolts returning (ocean survival) increased during the 4 years. This corresponds with an increase in size of smolts during the period and is in agreement with the work of Barnaby and Foerster previously mentioned. The slight discrepancy in the relation between size and percentage return in 1951 and 1952 probably is not significant, since size of the smolts and percentage return are quite similar.

It is of interest that the return of adults from the smolt migration of 1953 was greater than from that of 1950 although the migration of 1953 was less than one-half as large as that of 1950. This resulted from the increased survival at sea of the large smolts migrating in 1953. Possibly these smolts, by being larger and more vigorous, were better equipped to evade predators and withstand other hazards of their early life at sea. Thus, fertilization in an indirect manner may have caused a profound effect on survival. On the basis of the large smolt migrations of 1954 and 1955 and the large size of the smolts since 1953 (table 8), we might expect good returns of adult salmon during the years 1957 and 1958.[3] Adverse ocean conditions could influence the number returning and in fact, this factor probably accounts in part for the wide range in returns found by Foerster at Cultus Lake.

Table 8.—*Annual smolt migration, mean annual lengths and weights of smolts, and number and percentage of smolts returning as adult salmon, 1950 through 1956*

[All age groups combined]

Year	Smolt migration			Returning adults	
	Number	Mean fork length (mm.)	Mean weight (gm.)	Number	Percentage of smolt migration
1950	10, 199	73. 2	3. 35	333	3. 26
1951	4, 503	82. 2	4. 83	205	4. 55
1952	8, 620	80. 5	4. 59	457	5. 30
1953	5, 058	90. 2	6. 54	399	7. 89
1954	12, 189	93. 7	8. 23	----------	----------
1955	24, 100	97. 2	8. 99	----------	----------
1956	6, 525	97. 0	8. 23	----------	----------

EFFECTS OF FERTILIZATION ON OTHER FISHES

In addition to red salmon, Bare Lake supports populations of six other fish species, coho salmon (*Oncorhynchus kisutch*), king salmon (*Oncorhynchus tshawytscha*), steelhead trout (*Salmo gairdneri*), Dolly Varden charr (*Salvelinus malma*), sculpin (*Cottus aleuticus*), and the threespine stickleback (*Gasterosteus aculeatus*). Of these species, juvenile king salmon, steelhead trout, and sculpin are present in small numbers and probably have little effect on the general ecology of the lake. The other species are important as predators or competitors of juvenile red salmon. Of interest in this study is the effect fertilization of the lake may have had on these species.

Only limited observations were made on fish populations other than red salmon in Bare Lake during the years 1950 to 1954.

Observations on the growth and population size of Dolly Varden charr were initiated in 1954 and expanded in 1955. These are to be reported by C. S. Thompson at a later date. In addition, some samples of coho smolts have been obtained since 1954 for determination of age and size composition. At the smolt trap, records have been kept of the number of coho and red salmon smolts, Dolly Varden charrs, and steelhead trout migrating to sea (table 9). Included in the coho count are a few king salmon smolts, which closely resemble coho smolts; time did not permit the necessary careful examination for separate counts.

Table 9.—*Number of coho smolts, Dolly Varden charr, and steelhead smolts in seaward migration, Bare Lake, Alaska*

Year	Coho[1]	Dolly Varden charr	Steelhead
1950	1, 134	----------	----------
1951	2, 389	2, 733	21
1952	1, 781	3, 905	48
1953	2, 014	797	13
1954	3, 341	1, 058	23
1955	3, 247	2, 360	21
1956	2, 946	2, 777	26

[1] May include some king salmon smolts.

Coho salmon.—As shown in table 9, there is some indication of an increase in the coho population over the years. As adult coho salmon do not enter Bare Lake until after the weir is removed, we have no measure of the size of the spawning population. Thus, an increase in numbers of smolts may be caused by an increase in egg depositions rather than by an increase in survival. Because we do not have adequate data on spawning populations, it is not possible to determine the fresh-water survival rates. Also, length data of coho smolts is insufficient to determine if fertilization might have brought about an increase in the growth rate during the years of study.

The coho smolts migrate to sea in their second or third year and are, in general, larger and more robust than the red salmon smolts. The stomach contents of a few cohos have been examined. During the summer, juvenile cohos feed mostly on insects or insect larvae. To some extent the larger juvenile cohos are predaceous on the juvenile red salmon but, in general, their role seems to be that of competitors for food rather than predators.

Dolly Varden charr.—A fairly large Dolly Varden charr population is present in Bare Lake. This is indicated by the numbers captured in the smolt trap (table 9). It is not known if these counts are indicative of the population which

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[3] Data that have become available since completion of this report show that in 1957 approximately 265 red salmon returned. From stream surveys of Bare Creek, it is estimated that the stream was impassable to salmon from the period July 1 to July 19. Lack of rainfall created this condition. The blocking of the migration during this period might at least in part explain the poor run. The run in 1958 was the largest on record. Although no weir was maintained in Bare Creek this year, 914 red salmon were recovered on the spawning grounds. Upon considering the number of salmon not recovered on the spawning grounds and the number taken in the fishery, it is estimated that the 1958 run was approximately 2,000 red salmon.

would have migrated to sea had the trap not been installed. Large charrs cause heavy losses of salmon smolts when the two are confined together. To reduce predation, the opening of the trap was made small enough that large fish could not enter. Occasionally large charrs enter the trap during high water, and some have been captured above the trap and released downstream. To some extent their normal migration has been impeded, so the counts in the table may not be representative of the population normally migrating at this time. To facilitate upstream movement of juvenile coho salmon and Dolly Varden charrs, seine hauls periodically are taken below the trap, and the catch is released in the lake. The marking of these fish has indicated that they are migrating to the lake, as less than 10 percent of those marked have worked back downstream to the weir.

As data are not available on the size of the spawning stock or survival to various stages in the life history of Dolly Varden, it is not possible to say whether fertilization increased survival. Also, samples were inadequate to determine rate of growth during years 1950–56.

Stomach contents of charrs examined during the summer show they feed on caddisfly larvae, winged insects, gastropods, salmonids, and sticklebacks. To a small extent competition for food exists between the small charrs and juvenile red salmon. During the smolt migration, charrs feed to some extent on the smolts; however, their predation on red salmon from May to September does not seem to be important.

Threespine stickleback.—There is a large population of sticklebacks in Bare Lake. Beach-seine catches each year at the north and south ends of the lake show this species to predominate in numbers over juvenile red salmon (appendix table 3). Sticklebacks feed on about the same items of food as the juvenile red salmon; thus, they are direct competitors of the salmon for food. Their abundance is perhaps kept in check because Dolly Varden charrs and cohos feed on them to some extent, which may result in less predation by these species on juvenile red salmon. From seine-haul catches it would seem the peak in abundance of sticklebacks occurred during 1953 and of juvenile red salmon during 1954. Although seine-haul catches probably provide only a rough index of population size, the fact that the red salmon smolt migration of 1955 was the largest observed during these studies strengthens the finding of juvenile red salmon being unusually abundant during the preceding year.

Growth studies of threespine sticklebacks have been conducted in Bare Lake since 1950. Greenbank and Nelson (1959) present growth curves of sticklebacks for year classes 1951 through 1954. An examination of these data indicate no progressive increase in growth rate occurred. Thus, unlike red salmon juveniles, sticklebacks did not respond to fertilization by increased growth.

DISCUSSION

To understand the effect on the growth of fish of fertilizing a lake with inorganic material, it is necessary to consider the food chain involved. It has been shown that fertilization increased primary productivity in Bare Lake manyfold (Nelson and Edmondson, 1955), and that a large crop of phytoplankton resulted and was maintained during the rest of the summer. This increased food supply would be expected to benefit directly many of the invertebrates. Invertebrates that would be of most direct value to the red salmon are a variety of benthic insect larvae and the planktonic copepod *Epischura nevadensis*. All of these animals have a long life cycle and even the copepod appears to produce but one generation a year. Therefore, an increased food supply would not express itself immediately in an increased number of animals, and the invertebrate populations might well take some years to build up, especially if there is much predation. In fact, during the period 1950–52 the zooplankton population showed no progressive increase. It would seem that a population of active predators with versatile hunting behavior may keep the prey population at a low level and absorb extra production, so that a distinct increase in production may not show up as an increase in the standing crop of food organisms, but rather as an increase in the mass of the predator population.

There are certain immediate effects that might result in better growth of the fish. It has been shown that increases of the food supply for a natural population of the copepod *Calanus fin-*

marchicus were followed shortly by increases in length, weight, and fat content of the mature animals (Marshall, Nicholls, and Orr, 1934). This effect is to be expected with most animals, and it may well be that the food organisms in Bare Lake have provided much more nourishment for the fish since 1950 than is suggested by their numbers alone.

In reviewing the results of fertilization of Bare Lake to date, the most important development is that smolt size has increased. This progressive increase may have brought about the observed increase in return of adult salmon, since larger smolts have been found to survive in greater numbers at sea (Barnaby 1944, Foerster 1954a). Data from 4 years' observations indicate that ocean survival has increased more than twofold. If growth and fresh-water survival rates decline when fertilization is discontinued, the theory that observed increases have resulted from fertilization will be greatly strengthened.

Other factors were examined which might have brought about the increase in length of Bare Lake smolts during 1950 to 1956. At nearby Karluk Lake, the smolt migration was sampled annually for length and age composition. No increase in size of smolts occurred in this unfertilized lake over the 7 years of our Bare Lake study. As stated earlier, no relation could be found between water temperatures and smolt growth at Bare Lake. Diseased juvenile red salmon were uncommon in Bare Lake, which indicated disease was not a factor influencing growth or survival. It might be argued that a decline in population density or intraspecific competition could have brought about the increased growth of red salmon juveniles and smolts during the years 1950 to 1956. This was examined on the basis of population biomass of all species of fish in the lake during those years. From text tables 8 and 9 and appendix table 3, estimates of the biomass of fish present in the lake were made from both seine-haul and weir-count data. No relation could be found between the biomass of all fish or the abundance of certain fish species and the size attained by the young red salmon. On the contrary, it appears a slight increase in biomass of fish occurred while at the same time the size of red salmon smolts and juveniles increased. Evidently the increment in fish food brought about by enrichment of the lake was of such magnitude that the influence of biomass or intraspecific competition on red salmon growth was of minor importance.

Although the type and concentration of fertilizers used increased organic production, no doubt more extensive experimentation would show that smaller amounts of various elements would do equally well. For example, during 1955 trace elements were added to jugs of Bare Lake water whereupon accelerated photosynthesis resulted from an extremely minute amount of material. The possibility exists that productivity might be increased in lakes by small, inexpensive additions of material.

SUMMARY

1. Spawning escapements entering Bare Lake, Alaska, have ranged from 52 to 551 salmon during the years 1950–56. During this period, the commercial catch of Bare Lake fish was small, except in 1950 and 1951.
2. Nine age groups of adult salmon have been found at Bare Lake. Of these the 5_2, 5_3, and 6_3 age groups are the most important.
3. The size at maturity of Bare Lake red salmon appears to be dependent upon sex and environmental conditions during the last year the fish spend in the ocean.
4. A predominance of female salmon occurred each year in the spawning escapement. It would seem a differential mortality in favor of the females exists during the marine period of life.
5. The fecundity of Bare Lake female red salmon is dependent mostly upon size at maturity.
6. Greater percentages of smolts migrate to sea at an earlier age from brood years of high smolt production than from brood years of low smolt production. Population pressure may cause this.
7. An increase in the size of smolts has not brought about an increase in the percentage of the younger smolts in the seaward migrations. Generally the older smolts migrate to sea earlier in the season than the younger smolts.
8. Fertilization of Bare Lake has been accompanied by increased growth of young red salmon during residence there.
9. A close relation was found between the growth of red salmon of various fresh-water ages and the gross rate of photosynthesis during peri-

ods which would be likely to influence the food supply.

10. The fresh-water survival rate of red salmon from the annual egg deposition (corrected for egg retention of spawners) to the smolt stage has averaged 2.96 percent (range 1.0 to 5.1 percent) for years 1950–53.

11. The increase in the size of smolts since fertilization has been followed by an increase in their survival at sea.

12. Limited studies were conducted on juvenile coho salmon, Dolly Varden charr, and the threespine sticklebacks. Sticklebacks and cohos compete with young red salmon for a common food supply. Dolly Varden prey on the red salmon smolts.

13. Growth studies were conducted only on the threespine stickleback. It was found that this species, unlike red salmon, did not respond to fertilization by increased growth. Data were inadequate on juvenile coho salmon, threespine stickleback, and Dolly Varden charr to determine the effect of fertilization on survival.

14. Other factors, including population biomass, incidence of diseased red salmon, and water temperatures, had no influence on the growth of red salmon juveniles and smolts for the years 1950 through 1956.

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APPENDIX

Appendix Table 1.—*Egg counts of red salmon sampled at the weir site, Bare Lake, Alaska, 1950 to 1956*

Date fish collected	Fork length (cm.)	Weight (lb.)	Age group	Egg count		
				Right ovary	Left ovary	Total
1950						
June 24	56.5	4.62	5_2	1,845	1,480	3,325
1951						
June 19	58.0	4.00	5_2	1,961	1,891	3,852
July 2	44.5	2.19	5_3	999	950	1,949
1952						
June 16	58.6	5.19	----------	1,749	1,866	3,615
18	59.1	5.84	5_2	2,131	2,326	4,457
July 2	56.0	4.62	5_2	1,696	1,217	2,913
2	60.8	5.88	5_2	1,822	1,722	3,544
3	51.2	3.25	5_3	1,370	1,183	2,553
3	55.4	4.25	5_3	1,607	1,461	3,068
3	57.3	5.31	6_3	1,737	1,580	3,317
8	56.3	4.44	5_2	1,600	2,163	3,763
12	58.7	4.88	5_2	1,980	1,868	3,848
12	55.6	4.22	5_2	1,435	1,220	2,655
12	55.9	4.62	5_2	1,736	1,802	3,538
14	57.5	4.56	5_2	1,920	2,003	3,923
15	52.6	3.53	5_2	1,506	1,122	2,628
1953						
June 18	54.2	4.12	5_3	1,521	1,536	3,057
18	53.5	4.28	5_3	1,457	1,441	2,898
18	56.3	4.72	5_2	2,051	1,593	3,644
21	60.2	----------	5_2	1,962	1,613	3,575
23	57.3	5.40	5_2	1,635	1,786	3,421
25	55.3	4.22	5_3	1,268	965	2,233
25	57.1	5.40	5_2	1,569	1,685	3,254
25	57.4	5.29	5_2	2,014	1,417	3,431
25	57.9	6.39	5_2	2,195	1,669	3,864
1954						
June 10	59.0	5.40	6_3	1,945	1,487	3,432
17	55.0	4.31	6_3	1,458	1,371	2,829
19	51.5	3.62	5_3	1,533	1,074	2,607
20	55.0	4.62	6_3	1,939	1,547	3,486
20	50.5	3.09	5_3	946	1,071	2,017
20	59.0	5.31	6_3	1,722	1,714	3,436
July 5	53.0	3.88	5_3	1,131	1,317	2,448
5	52.0	3.62	5_3	1,642	1,373	3,015
Aug. 4	59.0	5.31	----------	1,334	1,310	2,644
1955						
June 15	52.0	3.69	5_3	1,601	1,818	3,419
17	54.0	4.15	5_2	1,463	1,361	2,824
17	49.0	3.21	5_3	1,065	1,367	2,432
18	56.0	5.06	5_2	1,749	1,391	3,140
21	52.0	3.69	----------	1,363	1,530	2,893
26	55.0	4.34	6_3	1,302	1,493	2,795
26	49.5	3.31	5_3	1,262	1,150	2,412
27	55.5	3.88	6_3	1,607	1,435	3,042
July 1	51.0	3.47	5_3	1,498	1,386	2,884
1	57.0	4.94	5_2	1,828	1,562	3,390
1	51.5	3.88	5_3	1,603	1,423	3,026
1	51.0	4.78	5_3	1,843	1,586	3,429
3	55.5	4.40	5_2	1,922	1,355	3,277
6	52.0	3.72	4_2	1,631	1,413	3,044
6	51.5	3.62	5_3	1,411	1,300	2,711
11	53.0	3.81	5_2	1,394	1,122	2,516
1956						
June 11	57.0	5.25	----------	1,642	1,644	3,286
July 3	54.0	4.62	----------	1,624	1,622	3,246
14	47.0	----------	----------	1,632	1,040	2,672

APPENDIX TABLE 2.—*Migration, percentage age composition, mean fork length, mean weight, and sample size of red salmon smolts, by weeks, Bare Lake, Alaska, 1950 to 1956*

Week ending	Weekly migration[1]	2-year-old smolts			3-year-old smolts			4-year-old smolts			Sample size
		Percent	Mean length (mm.)	Mean weight (gm.)	Percent	Mean length (mm.)	Mean weight (gm.)	Percent	Mean length (mm.)	Mean weight (gm.)	
1950											
May 31	707	24.2	70.9	3.26	74.4	78.4	4.31	1.4	92.5	7.67	97
June 7	5,530	63.1	70.8	2.92	36.9	78.0	3.91	---	---	---	503
14	1,936	86.4	70.4	2.96	13.6	78.6	4.05	---	---	---	225
21	1,001	82.3	71.0	3.18	17.7	77.0	3.93	---	---	---	98
28	690	82.6	71.0	3.17	17.4	79.0	4.15	---	---	---	25
July 5	181	39.2	75.2	4.24	60.8	77.9	4.68	---	---	---	21
12	117	28.2	---	---	71.8	---	---	---	---	---	---
July 19–Aug. 9	[2] 37	---	---	---	---	---	---	---	---	---	---
1951											
May 31	439	0	---	---	100.0	87.2	5.71	---	---	---	78
June 7	1,688	2.5	69.6	3.36	96.7	86.0	5.31	.8	96.8	7.89	439
14	1,241	6.0	69.4	3.44	93.2	85.9	5.24	.8	102.0	8.87	365
21	174	42.0	71.2	3.19	57.4	87.2	5.57	.6	105.0	10.01	191
28	511	83.4	69.2	2.96	16.2	86.2	5.47	.4	104.0	10.12	303
July 5	294	94.6	68.8	2.97	5.4	84.1	5.83	---	---	---	318
12	142	91.5	69.7	3.15	8.5	80.1	4.78	---	---	---	138
July 19–Aug. 16	14	100.0	---	---	0	---	---	---	---	---	---
1952											
May 24	3	0	---	---	100.0	90.3	6.42	---	---	---	4
31	326	7.0	79.6	4.38	90.5	88.1	6.12	2.5	102.2	9.52	209
June 7	1,664	12.0	78.7	4.09	87.4	85.5	5.45	.6	96.3	7.82	488
14	2,646	13.2	75.2	3.65	83.8	82.0	4.77	3.0	100.1	8.74	485
21	1,383	36.0	75.5	3.75	62.1	82.0	4.75	1.9	101.3	9.29	421
28	1,400	80.0	74.3	3.50	19.2	79.7	4.27	---	---	---	448
July 5	636	95.1	75.4	3.79	4.9	81.0	4.72	---	---	---	361
12	396	94.9	77.1	4.16	5.1	83.1	5.07	---	---	---	274
19	107	94.4	78.7	4.57	5.6	85.8	5.93	---	---	---	94
26	50	98.0	81.1	4.99	2.0	97.0	9.15	---	---	---	36
Aug. 2	7	100.0	---	---	---	---	---	---	---	---	---
9	2	100.0	---	---	---	---	---	---	---	---	---
1953											
May 24	26	0	---	---	100.0	93.9	7.20	---	---	---	11
31	1,104	7.5	81.7	4.62	92.3	93.4	7.08	.2	109.0	11.35	435
June 7	1,377	9.3	81.4	4.76	90.7	94.0	7.27	---	---	---	409
14	911	40.8	82.3	4.96	59.2	92.4	6.99	---	---	---	404
21	900	49.8	82.9	5.03	50.2	93.1	6.99	---	---	---	370
28	612	78.9	84.4	5.56	20.4	94.6	7.81	.7	113.0	13.45	298
July 5	135	87.4	87.5	6.36	12.6	96.6	8.33	---	---	---	135
12	3	66.7	88.5	6.72	33.3	94.0	8.24	---	---	---	3
1954 [3]											
May 24	36	83.3	69.0	2.77	16.7	99.0	8.13	---	---	---	13
31	135	76.2	70.3	2.86	32.8	97.1	8.34	.7	116.0	13.17	79
June 7	202	2.5	79.4	5.08	90.1	104.5	10.65	7.4	125.9	19.85	138
14	673	9.5	81.9	5.13	87.4	102.9	9.95	3.1	131.6	21.79	309
21	908	56.2	84.5	5.82	42.7	104.0	10.67	1.1	132.5	22.28	297
28	1,225	86.9	88.5	6.92	13.1	104.2	11.12	---	---	---	304
July 5	3,697	96.5	92.1	7.82	3.5	109.4	13.15	---	---	---	489
12	3,524	97.2	92.8	7.89	2.8	115.5	15.30	---	---	---	443
19	770	99.1	94.0	8.00	.9	115.5	15.25	---	---	---	163
26	134	100.0	94.6	8.07	0	---	---	---	---	---	65
Aug. 2	837	95.0	98.6	9.25	4.5	129.0	21.22	---	---	---	149
9–23	48	93.8	100.5	9.70	6.2	119.0	16.82	---	---	---	42
1955 [3]											
May 24	13	15.4	---	---	84.6	---	---				---
31	119	13.4	81.1	4.19	84.9	103.1	9.96	1.7	124.0	17.94	106
June 7	6	0	---	---	100.0	---	---	---	---	---	---
14	307	7.2	88.0	6.16	88.3	107.5	11.94	4.5	133.8	23.40	99
21	6,169	46.8	89.2	6.65	50.4	106.8	11.68	2.0	136.6	25.18	457
28	8,121	92.0	89.3	6.44	7.0	105.4	11.13	1.0	141.9	27.53	470
July 5	3,055	97.2	91.9	7.30	2.2	111.3	13.67	---	---	---	687
12	1,498	99.1	99.2	9.54	.9	114.6	15.25	---	---	---	514
19	3,121	98.9	105.0	11.38	.9	119.2	18.00	---	---	---	348
26	1,637	97.1	107.6	11.98	2.9	122.5	18.44	---	---	---	185
Aug. 2	52	96.2	---	---	3.8	---	---	---	---	---	---
9–30	2	100.0	---	---	0	---	---	---	---	---	---
1956											
May 31	311	22.5	79.6	4.10	77.5	109.2	11.20	---	---	---	314
June 7	2,464	20.8	80.8	4.32	78.9	108.9	10.92	.3	132.5	20.22	728
14	2,440	48.6	79.9	4.20	50.1	108.0	10.55	1.3	137.0	22.93	596
21	195	79.0	82.2	4.66	19.5	109.2	11.04	1.5	141.3	25.17	197
28	349	96.8	83.1	4.99	3.2	107.1	10.32	---	---	---	350
July 5	77	96.1	87.3	6.25	3.9	111.0	12.05	---	---	---	76
12	539	98.9	89.9	6.85	1.1	110.2	12.25	---	---	---	381
19	145	98.6	90.4	6.84	1.4	110.0	12.63	---	---	---	142
26	3	100.0	---	---	---	---	---	---	---	---	---
Aug. 2–30	2	100.0	---	---	---	---	---	---	---	---	---

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[1] Smolt mortalities at the weir are not included.

[2] Fry; migrating in their first year.

[3] Not included in the table are six 5-year-old smolts (1 taken in 1954, length 144 mm., 5 taken in 1955, mean length 157.4 mm.).

APPENDIX TABLE 3.—*Beach seine catches, Bare Lake, Alaska, 1950–56*

[Area of catch: 1—South end of lake; 2—North end of lake]

Date	Area of catch	Number of hauls	Red salmon juveniles	Stickleback	Coho salmon juveniles	Dolly Varden charr
1950						
Aug. 15	2	1	130	855	1	2
25	2	1	100	585	3	9
31	2	1	130	516	1	1
1951						
June 13	2	1	60	423	2	9
29	2	1	21	638	7	8
July 8	1	1	27	1,002	1	0
22	1	2	58	348	5	4
Aug. 7	1	1	147	146	8	6
25	1	1	171	406	16	3
Sept. 12	1	1	176	156	21	6
1952						
May 19	2	1	103	1,153	25	7
June 25	1	4	56	1,008	11	7
July 8	1	1	23	86	6	4
8	1	1	103	358	11	0
29	1	2	76	62	4	2
Aug. 1	2	1	41	1,752	14	4
6	2	1	20	768	22	12
Sept. 11	1	2	88	51	25	5
1953						
May 23	1	1	123	171	35	2
June 8	1	1	171	1,688	23	1
27	1	1	21	2,082	19	0
27	1	1	60	3,863	5	0
July 11	1	2	75	1,566	16	0
24	1	1	46	1,547	10	0
Aug. 12	1	1	288	411	8	0
26	1	1	98	207	19	1
Sept. 3	1	1	94	27	9	2
3	2	1	774	1,120	25	6
4	2	1	148	595	26	20
8	2	1	176	1,249	22	2
9	2	2	324	942	30	7
9	1	1	52	54	7	0
10	2	1	127	619	26	5
Oct. 1	1	1	46	0	7	0
1954						
May 24	1	1	122	83	22	1
June 7	1	1	90	944	10	2
7	2	1	218	2,605	14	72
24	1	1	51	291	1	2
26	1	1	251	802	7	0
26	2	1	29	4,075	3	30
July 12	1	1	372	663	35	4
24	2	1	278	[1] 700	0	0
26	1	2	114	37	27	8
29	1	2	321	[1] 100	32	12
29	2	1	461	[1] 500	4	1
Aug. 7	1	1	275	[1] 50	8	0
7	2	1	109	[1] 50	17	9
9	2	1	90	[1] 1,000	7	7
10	1	1	970	707	6	2
14	2	1	229	[1] 1,500	4	17
17	1	2	34	[1] 50	1	4
27	1	1	76	276	8	2
29	2	1	364	[1] 500	1	12
30	2	2	230	167	6	28
Sept. 5	2	1	0	[1] 400	0	0
6	2	1	0	[1] 200	0	0
28	1	1	36	250	3	0
1955						
May 23	1	1	128	1,288	49	2
June 7	1	1	130	377	0	1
24	1	1	74	607	3	6
July 12	1	1	102	986	8	7
18	1	1	190	346	10	15
30	1	1	172	17	3	2
Aug. 10	1	1	132	17	26	4
17	1	1	164	85	8	5
18	2	1	72	807	1	1
19	2	1	92	2,043	9	0
20	2	1	24	674	3	1
27	1	1	94	155	27	7
Sept. 6	1	1	70	1,370	11	1
26	1	1	42	27	4	3
26	2	1	2	26	1	1
1956						
May 30	1	2	17	533	11	0
June 20	1	2	7	1,007	13	5
July 10	1	1	44	394	12	10
23	1	2	602	452	22	1
Aug. 4	1	1	185	200	21	11
16	1	1	197	99	6	2
28	1	1	60	171	7	0

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[1] Estimated catch.