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FECUNDITY OF RED SALMON AT BROOKS AND KARLUK LAKES, ALASKA

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ABSTRACT

The relation between mideye-fork length and number of eggs for red salmon at Brooks Lake (1957–58) and Karluk Lake (1958) is established. A review of available literature on fecundity at Karluk Lake indicates that there may have been a long-term decrease in the size of females and correspondingly in the average number of eggs per female.

Annual variations in age composition by life-history categories and in sex ratios affect the number of eggs available for deposition. Analyses of Karluk Lake red salmon stocks show a relation between the ocean age and size of fish and their fecundity, those fish of a greater length of ocean residence and size having the largest number of eggs. Since a distinctive seasonal pattern in the occurrence of life-history categories and related sex ratios exists, it is theorized that the commercial fishery could be so concentrated as to deplete that portion of the run of highest egg production potential.

FECUNDITY OF RED SALMON AT BROOKS AND KARLUK LAKES, ALASKA

BY WILBUR L. HARTMAN AND CHARLES Y. CONKLE, *Fishery Research Biologists*
BUREAU OF COMMERCIAL FISHERIES

Fecundity of red salmon, *Oncorhynchus nerka* (Walbaum), was studied at Brooks and Karluk Lakes, Alaska, for use in estimating the reproductive potential of spawning stocks. Reproductive potential is defined here as the total number of eggs available for seeding in a particular spawning population. Such information forms the basis for determining survival rates of red salmon during various life-history stages in fresh water.

Adult red salmon enter Brooks Lake by way of Bristol Bay and Naknek River, and enter Karluk Lake by way of Shelikof Strait and Karluk River (fig. 1). The Bureau of Commercial Fisheries maintains research stations at both lakes to investigate factors responsible for fluctuations in the abundance of salmon runs that have occurred in these areas (U.S. Fish and Wildlife Service, 1958). Certain specific problems differ between the lakes, but all research is integrated into a broad study of the physical, chemical, and biological factors affecting the fresh-water survival of red salmon.

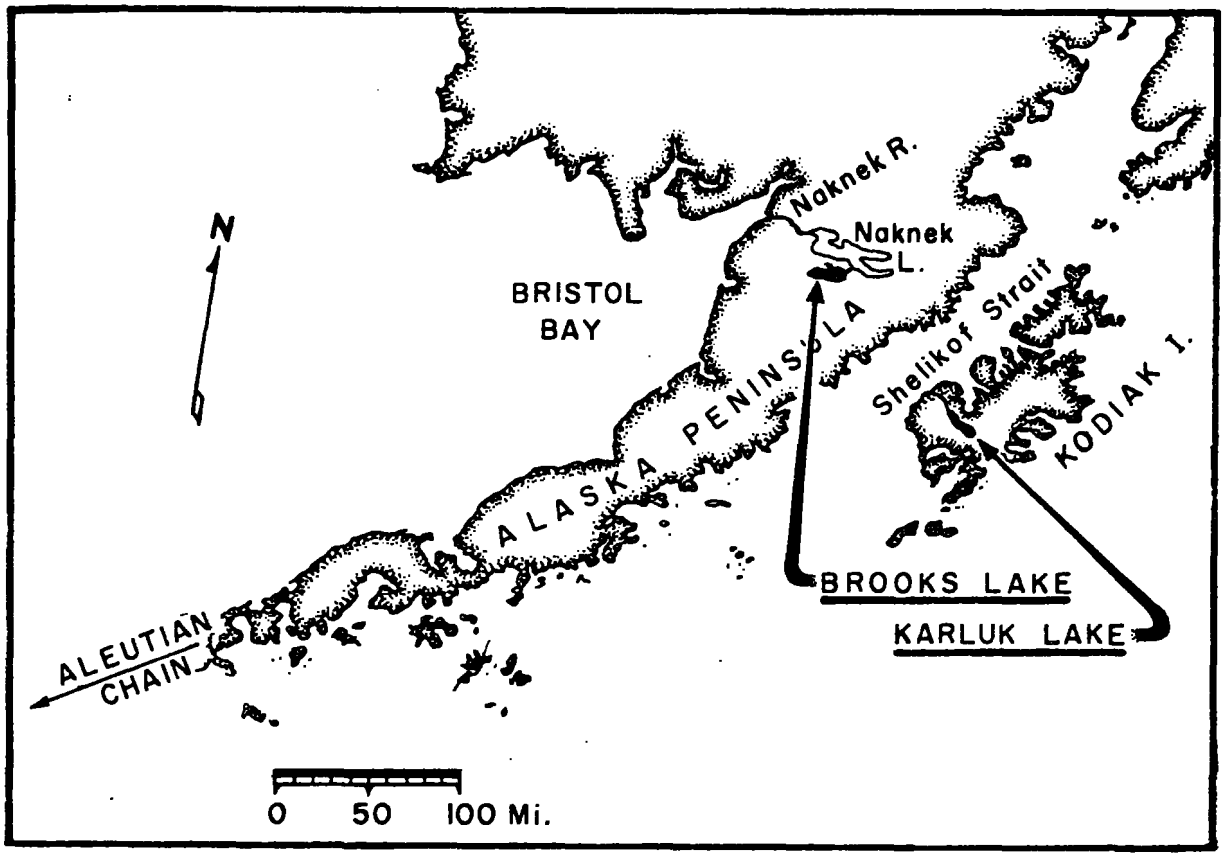

FIGURE 1.—Brooks and Karluk Lakes in western Alaska.

Red salmon were sampled from spawning migrations into Brooks Lake in 1957 and 1958, and into Karluk Lake in 1958. Earlier data are avail-

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able for Karluk Lake and are used for comparison in the discussion that follows.

We wish to express our thanks to Allen McCready, William Pogue, and Patrick Tomlinson for aid in developing and conducting field operations, and to Theodore R. Merrell and John B. Owen of the Bureau of Commercial Fisheries, for reviewing the manuscript.

COLLECTION AND TREATMENT OF MATERIALS

Ovaries used in these studies were obtained from females trapped at adult immigration sites at both lakes. They were taken throughout the season and over the size range of females in the stocks. A few females killed during beach-seining and gill-netting operations in Brooks Lake were also used. Only females not fully ripe were examined. This reduced the possibility of including partially spawned females.

Both ovaries were removed intact and placed in 20-percent formalin. An identification tag was attached to the right ovary to distinguish it from the left. After hardening for at least 48 hours, ovaries were removed from the formalin and thoroughly washed in water. The eggs were stripped from the ovarian tissue by hand and also thoroughly washed in water. Total numbers of eggs were counted in each ovary of each female sampled at both lakes. A mechanical hand tally was used.

Sampling methods involving volume or weight were experimented with at Brooks Lake in 1958. The most reliable method was to extract 3 random 100-egg samples from each gonad and estimate the total count from the average count-weight relation of the selected samples. Fecundity was usually estimated within 2 percent of the actual count. This method is sufficiently accurate and should be considered where extensive fecundity studies are scheduled.

RELATION BETWEEN SIZE OF FISH AND FECUNDITY

A relation exists between the size of fish and the number of eggs in the body cavity. Ricker (1932) shows that the relation between fish length and egg count in brook trout (*Salvelinus fontin-*

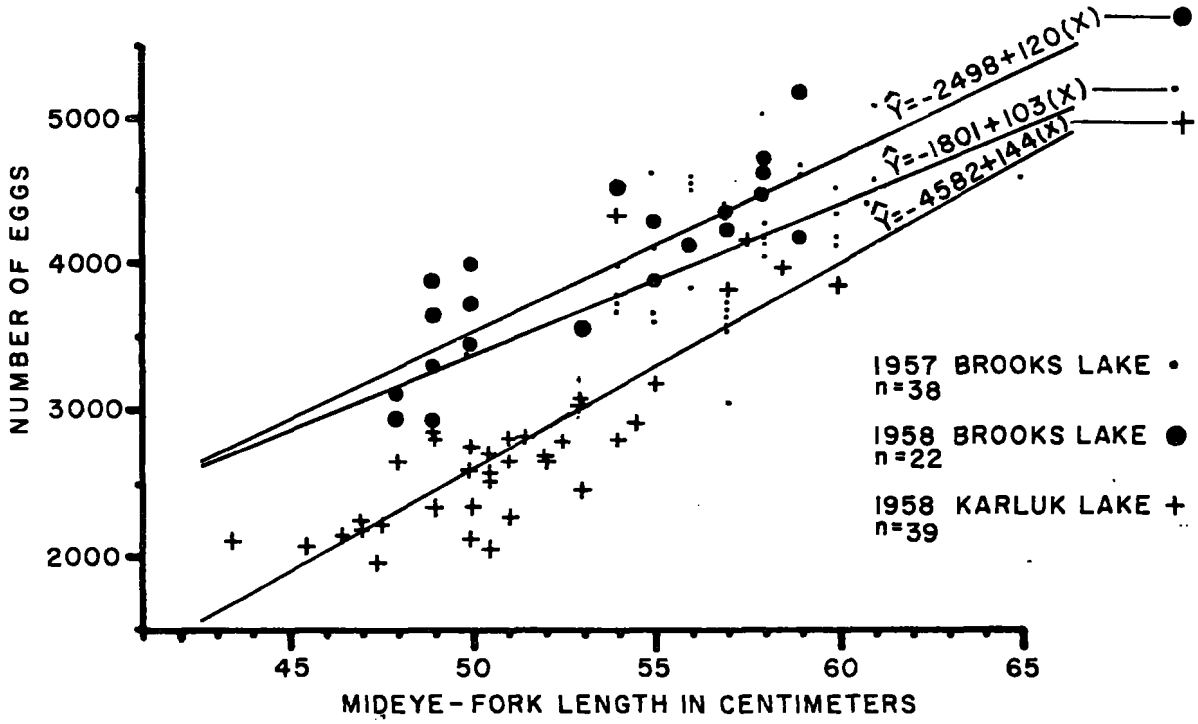

FIGURE 2.—Relation of egg counts to mideye-fork length for red salmon at Brooks Lake, 1957 and 1958, and at Karluk Lake, 1958.

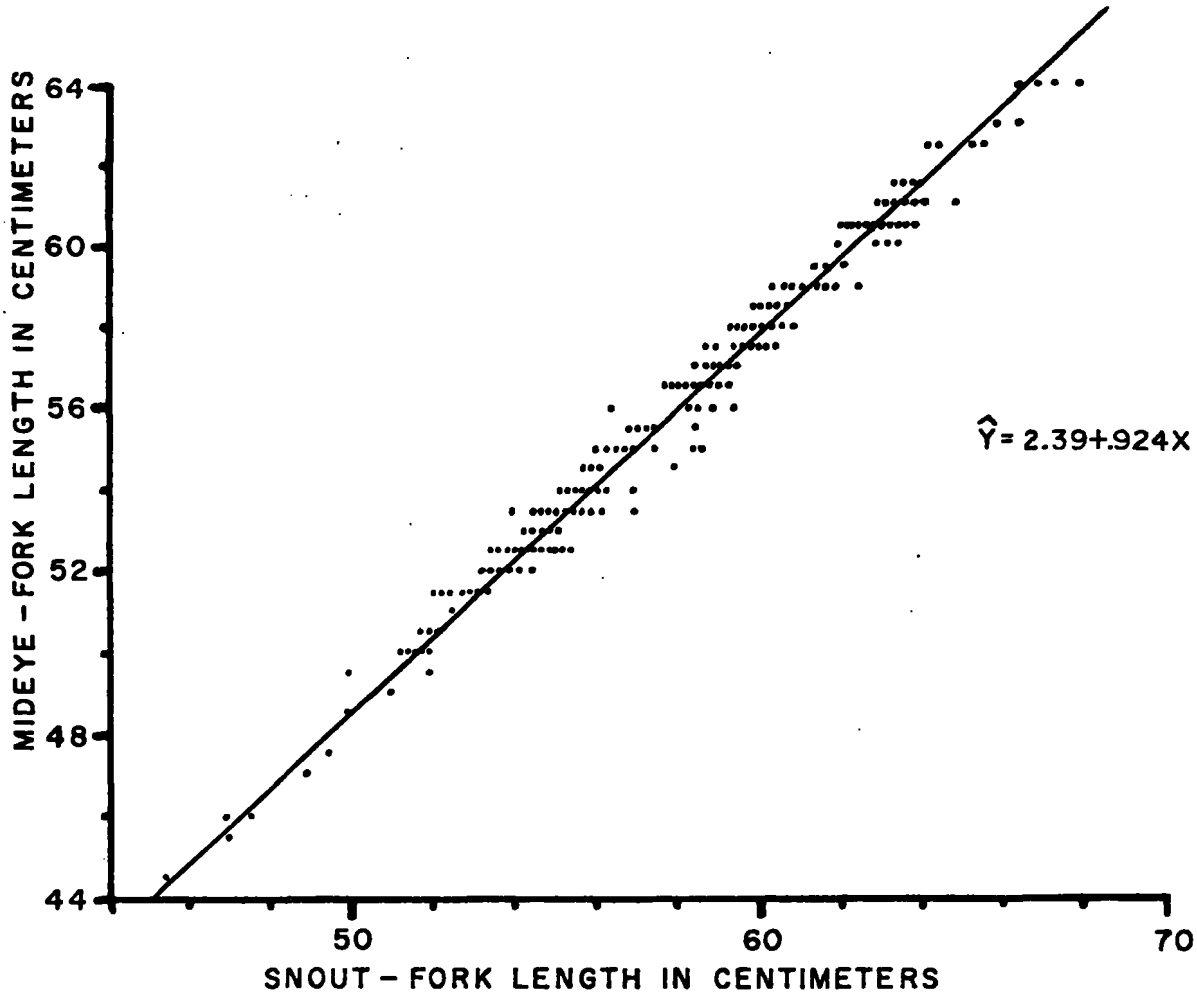

FIGURE 3.—Relation of snout-fork length to mideye-fork length for 193 female red salmon sampled in the Karluk River, 1952.

alis) is curvilinear. Rounsefell (1957) states that over the narrower ranges of length at maturity found in *Oncorhynchus* sp., the straight-line equation adequately describes the relationship. This view was held earlier for red salmon by Foerster and Pritchard (1941). They believed that the overall relation between fish length and number of eggs was probably logarithmic, but since adult spawning red salmon generally fall within a limited size range, the straight-line equation was adequate.

Total egg counts for females examined at Brooks and Karluk Lakes are plotted against mideye-fork length in figure 2. Linear regression equations were derived for these sets of data by the method of least squares.

Since fecundity studies at Karluk Lake have involved various length measurements, lengths in this paper represent transformations to mideye-fork lengths from data given in figure 3. The mideye-fork length is measured along the side of the fish from the center of the eye socket to the fork in the tail. This length was first used in Alaska by the Fisheries Research Institute of the University of Washington. It avoids the variability in total lengths associated with changes in the appearance of the skull during development of secondary sexual characteristics among most spawning salmonids.

The earliest recorded study of fecundity at Karluk Lake was conducted by Chamberlain (1907) who obtained a mean egg count of 3,500

per fish. In 1926, Smith (in: Gilbert and Rich, 1927) examined ovaries from 40 females and observed a mean fecundity of 3,728 eggs and a mean mideye-fork length of 56.4 centimeters. A mean fecundity of 3,237 eggs and a mean length of 55.4 cm. are derived from data given by Rounsefell (1957) for 411 females examined from 1938 to 1941. The average length of female red salmon in the 1958 escapement at Karluk Lake was 51 cm., and the average fecundity was 2,762 eggs.

These data suggest a long-term decrease in size and fecundity of red salmon at Karluk Lake that may be real and thus an important consideration in the declining abundance of that stock. This indication of a downward trend in size and fecundity may also be due to sampling inadequacies. The 40 fish studied by Gilbert and Rich (1927) were collected on a single day, September 15, 1926. The 411 fish included in the analysis by Rounsefell (1957) were taken chiefly from the spring portion of the run. As we shall see in a later section, age and size composition of the run changes during the season. Therefore, differences in mean size and fecundity may reflect differences within seasons as well as between seasons.

Recent data on red salmon in Alaska show that lengths and fecundity vary considerably. Mathisen (1955) [1] found for 1948 and 1950–52 that the mean mideye-fork length of females at Pick Creek (a tributary of Lake Nerka in the Bristol Bay area) was 53.0 cm., and the average fecundity was 4,011 eggs. Average lengths and fecundities at Brooks Lake for 1957 were 55.5 cm. and 3,916 eggs, and for 1958 were 53.3 cm. and 3,898 eggs. Average length was 51 cm., and average fecundity was 2,762 eggs for 1958 at Karluk Lake.

These differences are not due exclusively to variations in fish sizes between years or stocks. Real differences in fecundity for fish of the same size are shown by Rounsefell (1957) and are clearly evident between Brooks and Karluk Lakes stocks (fig. 2).

VARIATION BETWEEN PAIRED OVARIES

Although the maturation rates are the same for eggs in the left and right ovaries (Rounsefell, 1957), the number of eggs in each side is usually different. Brown and Kamp (1942) state that in brown trout (*Salmo trutta*) the posterior portion of the intestine usually bends to the right, crowding the right ovary at its posterior end and making it smaller than the left. No bend in the intestine was detected in brown trout with ovaries of the same size.

Egg counts for left ovaries were plotted against those of the corresponding right ovaries for 1957 and 1958 samples at Brooks Lake and for 1958 samples at Karluk Lake (fig. 4). Ninety percent of the left ovaries held more eggs than the right in 1957 Brooks Lake samples, 91 percent in 1958 Brooks Lake samples, and 69 percent in the 1958 Karluk Lake samples. Red salmon at Bare Lake on Kodiak Island have the opposite condition, more eggs in the right ovary than in the left (Nelson, 1959). Karluk Lake data are consistent with Rounsefell's (1957) findings in 1939, in which the number of eggs in ovaries from small fish was similar between right and left sides; but as the total number of eggs increased, the proportion in the left ovary became increasingly greater than in the right.

REPRODUCTIVE POTENTIAL OF SPAWNING POPULATIONS

The number of salmon spawning in a locality is often regarded as indicative of the reproductive potential. Escapement figures have been used since the inception of management of our salmon resources to predict the strength of future runs. However, considerable variability in the reproductive potential may actually exist independent of the actual number of spawners.

Annual differences in sex ratios alone can cause substantial differences in the number of eggs available for deposition. Average fecundity for female red salmon was relatively stable during three years at Babine Lake (Withler, 1950), but a high preponderance of males in one of these years reduced by one-half the reproductive potential of that spawning population, even though the

[1] Studies on the spawning biology of the red salmon, *Oncorhynchus nerka* (Walbaum), in Bristol Bay, Alaska, with special reference to the effect of altered sex ratios. Ole A. Mathisen, doctoral dissertation, University of Washington.

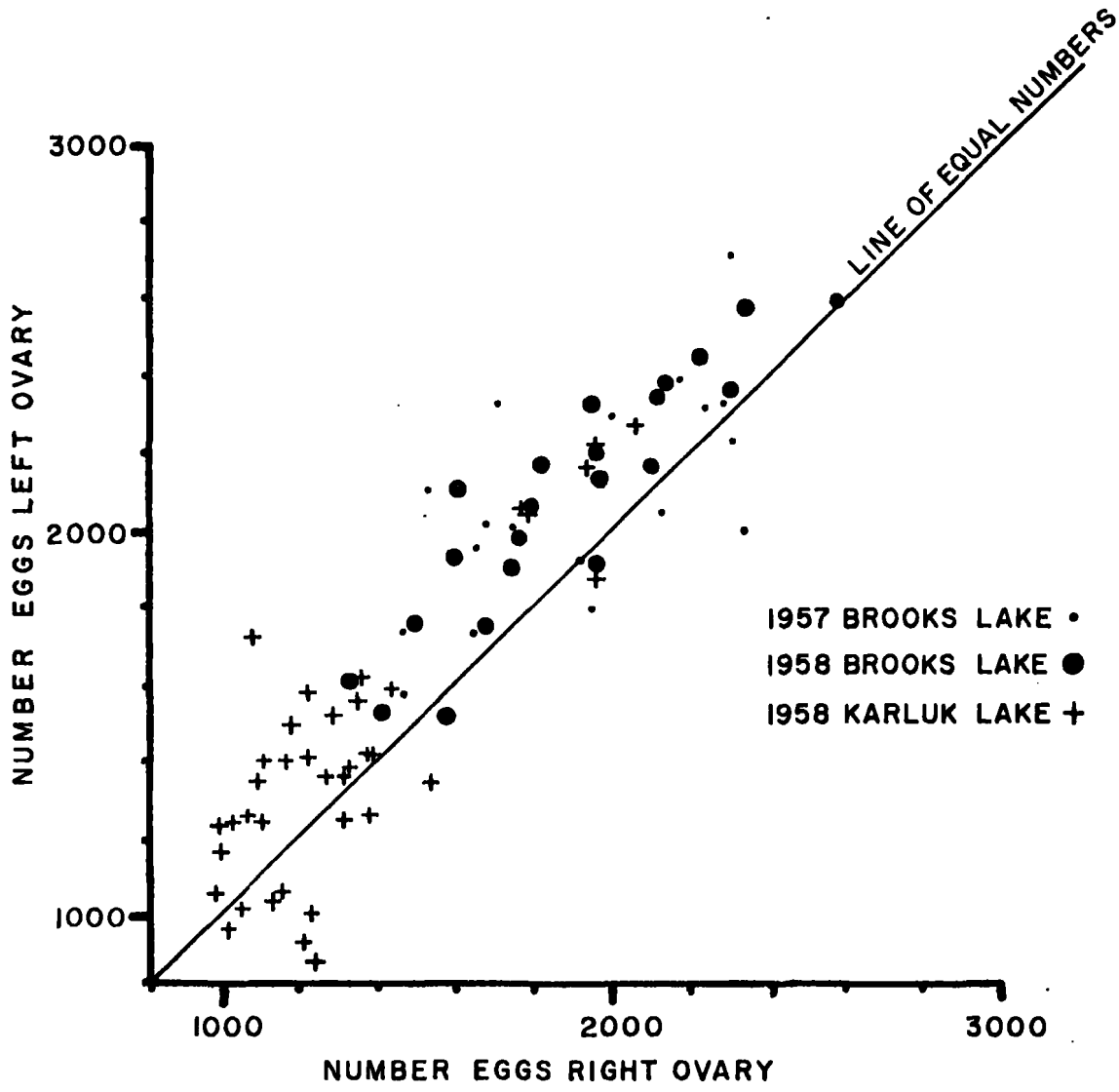

FIGURE 4.—Egg counts for right and left ovaries of female red salmon sampled at Brooks Lake, 1957 and 1958, and Karluk Lake, 1958.

number of spawners was approximately the same (table 1). Mathisen [2] in a study of egg mortality as related to sex ratio differences concludes that in red salmon, mortality of eggs was only slightly higher with a sex ratio as high as 15 females to 1 male than with a ratio of 1 to 1. Thus, even a highly unbalanced spawning stock favoring females may result in only minor decreases in ultimate egg survival from each female. Such a stock might yield a considerable increase in potential production over stocks of the same size, but with more evenly balanced sex ratios.

[2] See footnote 1.

TABLE 1.—*Reproductive potential of red salmon at Babine Lake in 1946, 1947, and 1949 (after Withler, 1950)*

Item	1946	1947	1949
Total number of red salmon	475,410	522,561	509,132
Estimated number of females	237,500	151,020	270,451
Potential egg deposition	736,000,000	461,500,000	916,600,000

Variability in life-history categories among females can be the cause of considerable change in reproductive potential from year to year, even though the number of spawners and sex ratio remain constant. Life-history categories are defined as groups of fish with different combinations of fresh-water- and ocean-years of life and are denoted by 2 figures; for instance, 5_3 denotes fish that migrated to the ocean in their third year of life and returned to spawn in their fifth year. Analysis of the Karluk Lake age data in 1958 shows that 2 major categories dominate the spawning populations, 5_3 and 6_4 (table 2). However, in some years one or more other age categories contribute considerable numbers of fish to the run. The salient feature of this population structure (table 2) is the great difference in the length and fecundity relation between life-history categories with 1, 2, and 3 years of ocean life; i.e., 4_3 and 5_4 versus 5_3 and 6_4 versus 6_3 and 7_4. Marked annual differences in the abundance of 1-ocean-year, 2-ocean-year, or 3-ocean-year fish could substantially alter the reproductive potential.

TABLE 2.—*Reproductive potential of the 1958 escapement at Karluk Lake by life-history categories*

Life history category	Number of females [1]	Mean length (cm.) [2]	Mean fecundity [3]	Potential egg deposition
4_3	814	43.5	1,674	1,363,000
5_4	2,471	43.8	1,717	4,243,000
5_3	60,872	51.4	2,810	171,050,000
6_4	53,601	51.3	2,796	149,868,000
6_3	8,695	54.3	3,227	28,059,000
7_4	2,186	53.8	3,155	6,897,000
Total [4]				361,480,000

[1] Based on a sample of 2,108 red salmon from the 1958 escapement.
[2] Mideye-fork length.
[3] Determined by substituting mean lengths into the fecundity equation (fig. 2).
[4] The very minor categories, 4_2, 6_5, and 7_5, contribute an estimated 1,000,000 eggs to the potential egg deposition.

Sex ratios for each life-history category must be considered in any study of the reproductive potential of spawning populations. Barnaby (1944) shows that the sex ratio of the Karluk Lake spawning populations varied considerably when important life-history categories varied in dominance. He found over several years that the average proportion of males in the 1-ocean-year categories (4_3 and 5_4) ranged from 100 to 75 percent, the 2-ocean-year categories (5_3 and 6_4) ranged from 62 to 32 percent, and the 3-ocean-year categories ranged from 38 to 35 percent.

The reproductive potential and the egg contribution from each of the six major life-history categories comprising the 1958 run at Karluk Lake is shown in figure 5. Examination of these data indicates that 89 percent of the eggs for potential deposition came from the two 2-ocean-year categories, 5_3 and 6_4.

Barnaby (1944) shows that a seasonal pattern of appearance of the different life-history categories exists at Karluk Lake. As the daily composition of the run changes throughout the season, obviously so does the reproductive potential. It is possible that the commercial fishery could have been concentrated during that seasonal time of migration when important groups such as the 5_3 and 6_4 categories were moving through the fishing grounds. As a result, the reproductive potential of the spawning populations could be seriously reduced because of a shift in age composition to younger ocean-age groups. These fish on a one-for-one basis are less fecund. It is interesting that the 3-ocean-year categories (6_3 and 7_4) accounted for only about 6 percent of the 1958 escapement, which is the lowest contribution by these groups ever recorded (Rounsefell, 1958: 156). At the same time the 1-ocean-year categories (4_3 and 5_4) accounted for 17 percent of the 1954 escapement, which is by several times the highest contribution from those categories ever recorded. Analysis of future Karluk escapements will determine if this substantial shift in ocean-age composition is the result of a real trend or merely variability in year-class strength.

It is concluded that a detailed study of the reproductive potential of the spawning populations is necessary to establish a basis for fresh-water survival studies of red salmon. It may also serve to help explain, at least in part, the causes for declines in red salmon runs over the past decades.

SUMMARY

The relation between egg count and mideye-fork length was derived for Brooks and Karluk Lakes red salmon. Comparing recent Karluk Lake data with past fecundity studies indicates that a long-term decrease in mean size and fecundity of females has occurred.

Red salmon at Brooks and Karluk Lakes consistently had more eggs in the left ovary than in the right.

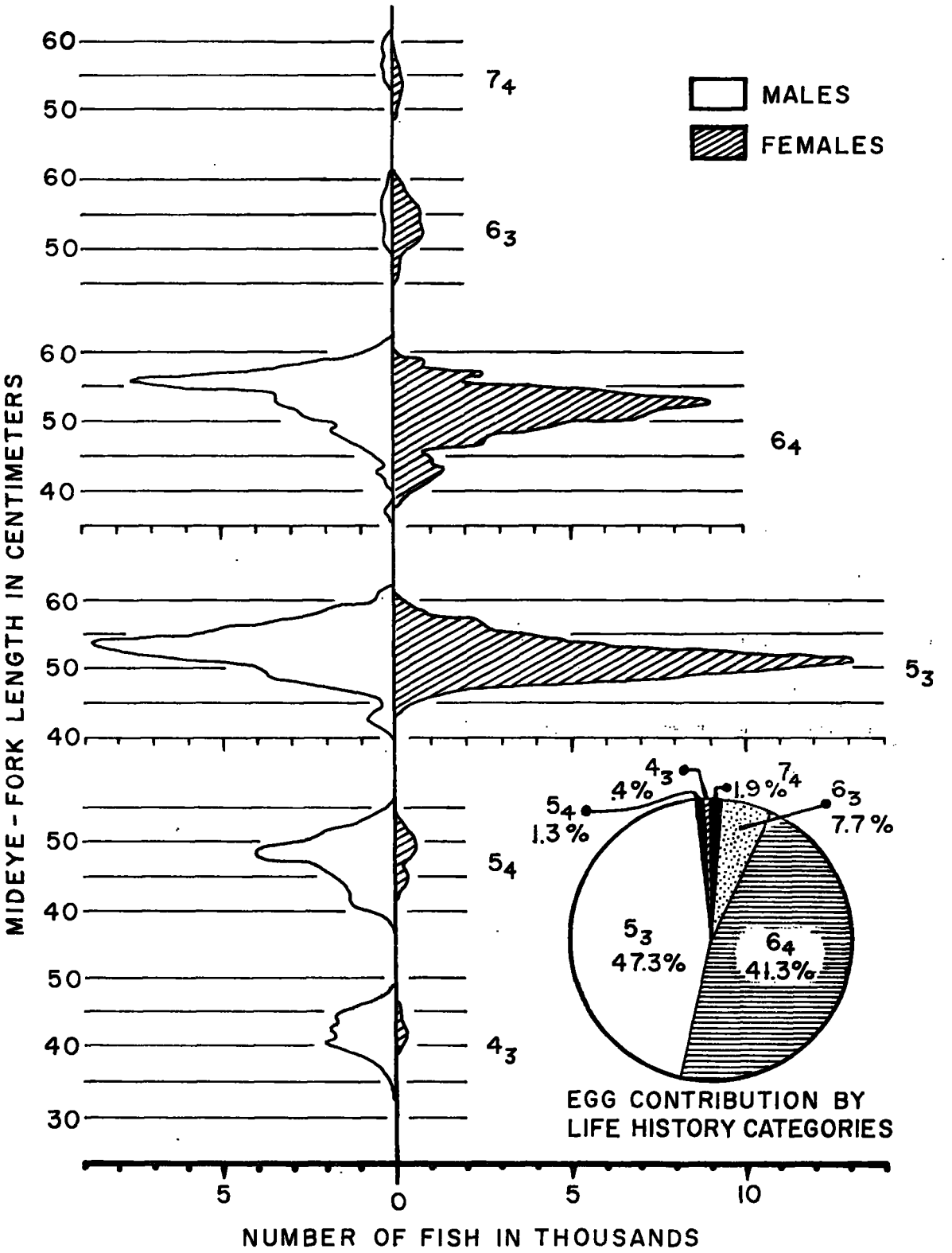

FIGURE 5.—Length-frequency distributions and reproductive potential by life-history categories of the escapement at Karluk Lake, 1958.

Variability in the reproductive potential of spawning stocks was shown to be attributable to at least 4 factors: (1) biological differences in fecundity between fish of the same size, (2) change in the life-history composition of spawning stocks, (3) differences in sex ratios between life-history categories, and (4) seasonal differences in reproductive potential evidenced from the well defined pattern of occurrence by life-history categories at Karluk Lake.

The possibility of the commercial fishery being concentrated on the most fecund life-history categories is theorized as a contributing factor to the declines in red salmon runs over the past several decades.

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