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THE SOCKEYE SALMON FISHERIES IN
THE FRASER RIVER SYSTEM

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RACIAL IDENTIFICATION OF FRASER RIVER SOCKEYE SALMON BY MEANS OF SCALES AND ITS APPLICATIONS TO SALMON MANAGEMENT

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ABSTRACT

A method of racial identification of Fraser River sockeye salmon is developed in this study based principally on the number of freshwater scale circuli. The utility of the scale identification method in estimating daily racial catches and hatchery production is discussed. Applications of the racial scale analysis method to many salmon management problems demonstrates its value in the management of the Fraser River sockeye salmon fishery and illustrates the principles upon which the management of the Fraser River sockeye salmon fishery is based as well as some of the practical problems that must be solved in a successful salmon management program. The numerous management problems discussed include the determination of route of saltwater migration, time of saltwater migration, speed of migration, delay, escapement, marine survival, production relationships and fishing mortalities.

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INTRODUCTION

The maintenance and development of our salmon resources presents one of the most important fisheries problems on the Pacific Coast. Historically, a salmon run of any species to a particular river system has been considered as a biological unit, and the basic practice has been to allow a certain number of fish of the total run, defined as adequate escapement, to reach the spawning grounds and to allow the remainder of the total run to be caught. Throughout the history of this practice it did not matter whether the escapement came from the early part of the run, the middle part of the run, or the latter part of the run because it was not recognized that the early, middle, or late parts of the total run might actually consist of several different populations, or races, each destined for distinctly different spawning areas. Consequently, the escapement obtained was not necessarily the most productive on the basis of the individual requirements for each particular spawning area.

In recent years there has been a significant change in this historic management practice through recognition of the fact that, in general, a salmon run to a particular river system consists of a group of units or races each having its own requirements for maximum production.

The presence of separate races of Fraser River sockeye salmon (FIGURE 1) was first recognized by C. H. Gilbert as early as 1913 (Gilbert, 1914-1925). Dr. W. F. Thompson also recognized the racial problem as evidenced by his statement (1945, page 20): "As basic as age in the problem of rehabilitation are the races of which the Fraser sockeye is composed."

Royal (1953) proposed the concept that each race or spawning population is a separate management problem and stated (page 5) that: "The character of the migration is related to the character of the environmental cycle in the reproductive area, the timing being controlled indirectly by the solar cycle, hence the maintenance of maximum productivity in a fishery depends upon the maintenance of normalcy in the character of the escapement." He also proposed that for any given race the early arrivals on the spawning ground and those fish that arrive late do not usually reproduce as effectively as the central portion of the run because they are not timed properly with the environmental cycle. Nevertheless, the early and late fish are vital to perpetuation of the run in certain years when conditions affecting the timing of the spawning migration are unusual. A similar concept is discussed by Thompson (1959). However, the individual sockeye races to the Fraser River overlap in their times of migration to such a degree that it is not possible to isolate and obtain the escapement from the peak of each race. In view of this, the present management practice for Fraser River sockeye consists of regulating the commercial fishery so that, in general, the escapement of each race to the spawning grounds is proportional to the daily abundance of fish present in the fishery.

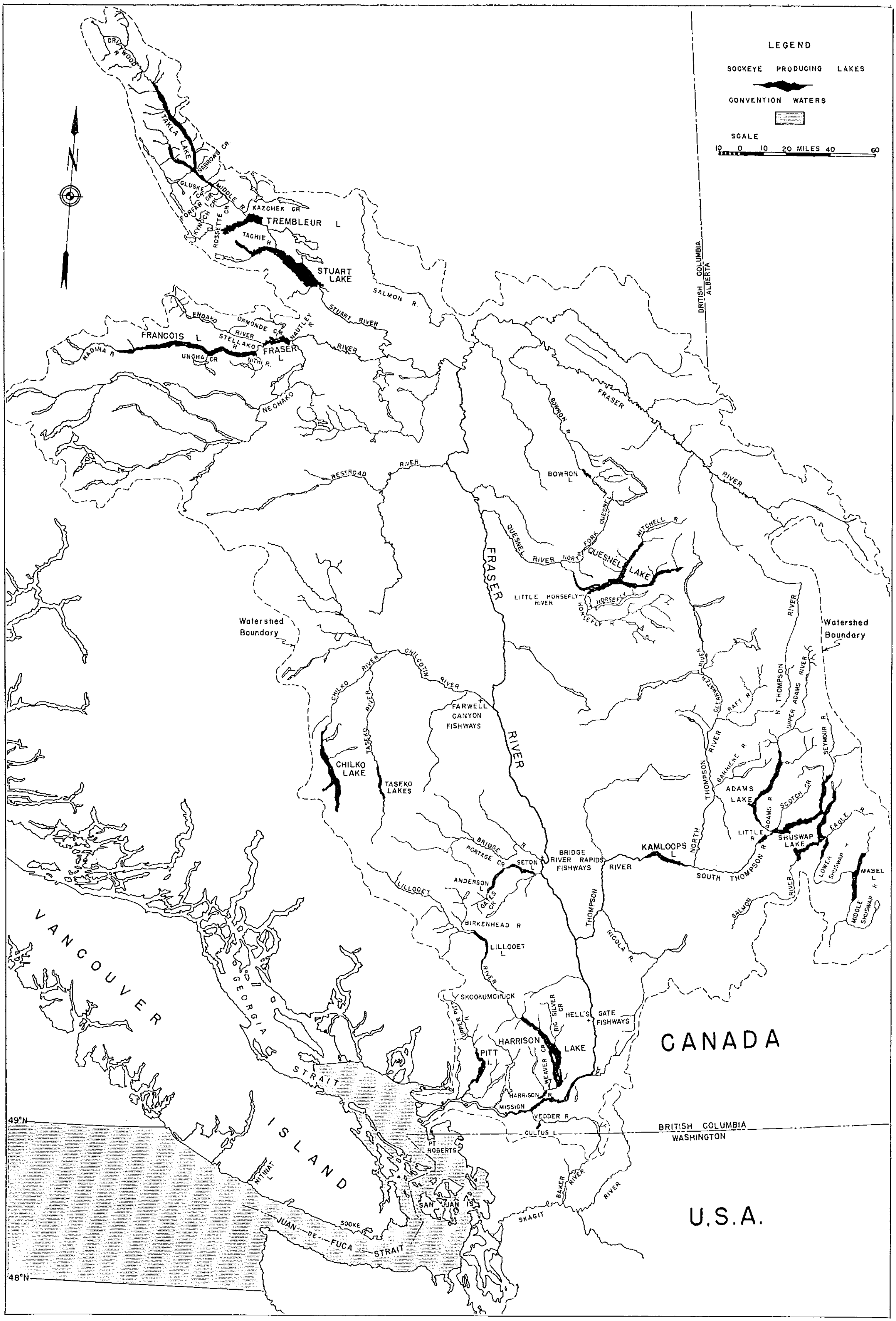

FIGURE 1—Fraser River Watershed showing areas utilized by major sockeye salmon spawning populations.

If, as proposed by Royal (1953), each race is a separate management problem and the escapement of each race should originate either from the central portion of each race or at least in proportion to the daily abundance of fish, then it becomes necessary that there be some method of identifying the various races in the fishery. Other information required for the proper administration of the fishery such as racial fishing mortality, racial timing and marine survival rates are also all dependent on racial identification in the fishery.

Royce (1960) in discussing the required fishery regulations for the Alaska salmon fishery lists the following information needed to acquire maximum sustained yield:

1. A definition of each major race of salmon
2. Statistics of catch and escapement of each major race
3. A forecast of the return of each major race
4. Optimum escapement of each major race
5. Efficiency of the fishery gear.

This information is certainly fundamental to sound salmon management. The data presented in this study will demonstrate that it is also basic in the regulatory policies of the International Pacific Salmon Fisheries Commission, and that racial scale analysis provides much of the required information.

METHODS OF RACIAL IDENTIFICATION

Once having decided on the principle of racial salmon management it then becomes necessary to devise a usable method of racial identification. There are several characteristics which are currently being used to identify the racial origins of salmon. At present the most commonly used methods for racial identification include the use of blood, parasites, meristic and morphometric characteristics, chemical differences by means of paper chromatography, otoliths and scales.

Blood

Since blood groups in man have received so much publicity in recent years in relation to parental identification it is not surprising that considerable effort has been expended in the study of possible differences in salmon blood as a means of racial identification. Considerable progress in this respect has been made by Ridgeway, *et al.* (1958, 1959, 1960) working under the direction of the International North Pacific Fisheries Commission. They report in their 1959 publication (page 20): "The best antisera produced in the present study, for the detection of differences between American and Asian red salmon were obtained by injecting sera of red salmon from areas in the southern part of this species' range in America (Cultus Lake and Adams River). These antisera would react with the antigen I and/or II components of northern American areas but not with any corresponding components in Asian samples." However, as with most of the research done under the guidance of the North Pacific Commission, the emphasis has been mainly on separating Asian and American stocks rather than the identification of individual races within one river system. Furthermore, it is evident that for even such a gross separation as that of Asian from American stocks this method is tedious and time consuming and, at the present time, it is doubtful if it could be applied on a practical basis to several hundred fish daily as is required in the day to day regulation of the fishery.

Parasites

Parasites as a method of salmon racial identification are also being used by the scientists working under the direction of the North Pacific Commission. Here again the main emphasis has been on the separation of Asian from American stocks, but even with such a gross separation this method has been found to have important limitations (Margolis, 1959 and 1960). These limitations, coupled again with the doubtful probability of being able to apply this method in a practical manner to several hundred fish daily, as is required in the proper regulation of the salmon fishery, makes this method also of doubtful utility.

Meristic and Morphometric Characteristics

These characteristics are probably the most popular and widely used means of identifying the racial origin of fish, although their use in connection with salmon is relatively recent. Almost every conceivable anatomical feature in fish has been used, either singly or in combination, for racial separations. Inasmuch as most of the techniques using meristic and morphometric characteristics are not applicable to the requirement of salmon management, it would not be practical to list here all known publications relating to this subject. A few typical examples of this type of analysis are Schmidt (1921 on *Zoarces,* McHugh (1951) on the anchovy (*Engraulis*), Godsil and Holmberg (1950) on the tunas, *Thunnus,* and Roedel (1952) on the mackeral, *Pneumatophorous.* Ahlstrom (1957) summarizes most of the studies utilizing these characteristics.

A number of special statistical treatments have been devised for use in this type of racial study and most of them have been used at one time or another, either as originally proposed or with slight modifications. Ginsburg (1938) formulated an arithmetical definition for races based on frequency curves. Pearson (1926) proposed a Coefficient of Racial Likeness and this, with some modification, was used by Royce (1952) in his studies on yellowfin tuna. Some workers use an analysis of variance for comparison of mean values (Buchanan-Wollaston, 1933). Harding (1949) and Cassie (1950) use probability paper or polymodal frequency distribution analysis, and this method most nearly fits the conditions for adequate identification of Fraser River sockeye salmon. However, this method requires considerable personal interpretation, particularly with numerous similar curves, and would not warrant the computations and time involved.

Probably the most popular method in use today is a comparison of multiple features by means of the discriminant function, first introduced by R. A. Fisher. Rao (1952) discusses the use of this function. The discriminant function has also been used extensively by the scientists working under the direction of the North Pacific Commission for Separation of Asiatic and North American salmon; Fukuhara *et al.* (1960) for the red salmon; Amos *et al.* (1960) and Pearson (1960) for the pink salmon, and LaLanne (1960) for the chum salmon. As many as seven characters are used in the red salmon investigations (Fukuhara, 1960). Like most statistical treatments, this function does not lend itself to the rapid sampling, analysis and interpretation of results that are required in the proper regulation of the salmon fishery where the racial identification of a single day's catch is required the following day.

McGregor (1924) used counts of gill rakers, vertebrae, ova and pyloric caeca to separate Sacramento and Klamath River king salmon (*O. tschawytscha*). Aro and Broadhead (1950) concluded that there was a significant difference in egg count for Babine and Lakelse sockeye salmon, and Enyutina (1954) examined morpho-biological and morphometric characteristics of pink salmon of the Amgun' and Isba Rivers.

It is interesting to note in the case of several species that where groups of fish were judged to be different on the basis of morphometric studies they were found to have considerable intermixing based on the results of tagging (Tester, 1949 and Roedel, 1952).

Paper Chromatography

Distinguishing chemical differences in fish by means of paper chromatography is sometimes used in racial investigations, although it is too slow a procedure to be suited to the type of racial analysis required for current salmon management. Matsumoto (1960) used it to identify tuna larvae. Dannevig (1955) has shown that some 23 species of marine fish have different ninhydrin-positive compound patterns, and Buzzati-Traverso and Rechnitzer (1953) have shown that various species of fish can be separated on the basis of their chromatographic patterns.

Otoliths

Otoliths have been used in racial investigations of herring (Einarsson, 1952). Although the Salmon Commission uses sockeye otoliths in the spawning ground age determinations and McMurrich (1912) also discusses the use of otoliths in aging salmon, no work is known where salmon otoliths have been used for racial identification. In view of the generally greater difficulty in interpreting salmon otoliths as compared with scales, it is doubtful if otoliths would be a practical method for salmon racial identification.

Scales

Gilbert (1913) first discussed the use of scales for racial identification of sockeye salmon and Lea (1929) discussed the use of scales for racial identification of herring. Hamilton (1947) and Clutter and Whitesel (1956) examined the use of scales for the racial identification of Fraser River sockeye. Krogius (1958) used ocean growth as well as other scale characteristics in distinguishing scale patterns for different local populations of Kamchatka sockeye.

Scientists working under the direction of the North Pacific Commission have also begun using scales in recent years in their salmon investigations. Mosher (1959), Mosher *et al.* (1960) and Kubo (1959) discuss the use of scales for separating Asian and North American red salmon while Tanaka *et al.* (1960) discuss their use with chum salmon. The method used is essentially to compute a number of scale measurements for each unknown fish, such as radius to each annulus and number of circuli in each growth zone, and then compare these measurements by a series of bivariate charts against known fish from each of the two localities. Unfortunately, here again their procedure is generally too time-consuming to be practical for current salmon management.

Although scale characteristics are currently used by other agencies for racial identification, the uniqueness of the Salmon Commission's detailed applications of the scale method to current salmon management problems is believed to be unparalleled in present day salmon management programs.

DESCRIPTION OF THE RACIAL SCALE ANALYSIS METHOD

The method of racial identification used today for Fraser River sockeye salmon management is based essentially on the method originally proposed by Gilbert (1913-1925) for separating the races by the number of circuli in the freshwater growth zone of the scales. Dr. Gilbert in his studies noted a difference in the area of freshwater growth for the various major Fraser River sockeye races. He concluded that the appearance in the fishery of fish having different types of freshwater growth recorded on their scales could be used to note changes in the racial composition of the catch. Although this information was known since 1913, it has only been within the past decade that a scale identification technique has been developed and applied on a major basis to daily management problems of Fraser River sockeye salmon.

In FIGURE 2 is shown a typical Fraser River sockeye scale. The anterior portion of the scale is marked by the formation of more or less concentric series of ridges called circuli. The circuli are subdivided into an inner nuclear zone formed in fresh water and an outer zone formed in the sea. Ridges formed in fresh water are finer in structure, of lesser height, and closer together than seawater ridges.

Basic Characteristic

The number of freshwater circuli in the nuclear zone is the basic characteristic used in this racial scale identification method. The various races of Fraser River sockeye spend the first year, or possibly two, in separate lakes under differing environmental conditions. These different environmental conditions result in different growth patterns in the young sockeye during their lacustrine existence, and since fish growth and scale growth are closely correlated (Clutter and Whitesel, 1956), these differences are recorded on the freshwater growth area of the scales and are permanently retained so that they are still available on the scales of the returning mature fish.

Hamilton (1947) attempted to establish a basis for using the number of freshwater circuli as a method of identifying the racial origin of Fraser River sockeye. He concluded (page 26): "However the variations from year to year are sufficiently extensive to make it impossible to separate the races one from the other in a homogeneous mass, as would be encountered in a commercial fishery, and to predict with any degree of accuracy the ring counts of a future year would be out of the question." Hamilton's work was done under the auspices of the Salmon Commission and eventually stimulated further work by Clutter and Whitesel (1956) who established: ". . . the methodological basis for the use of scales in the development and implementation of fundamental concepts in the scientific manage-

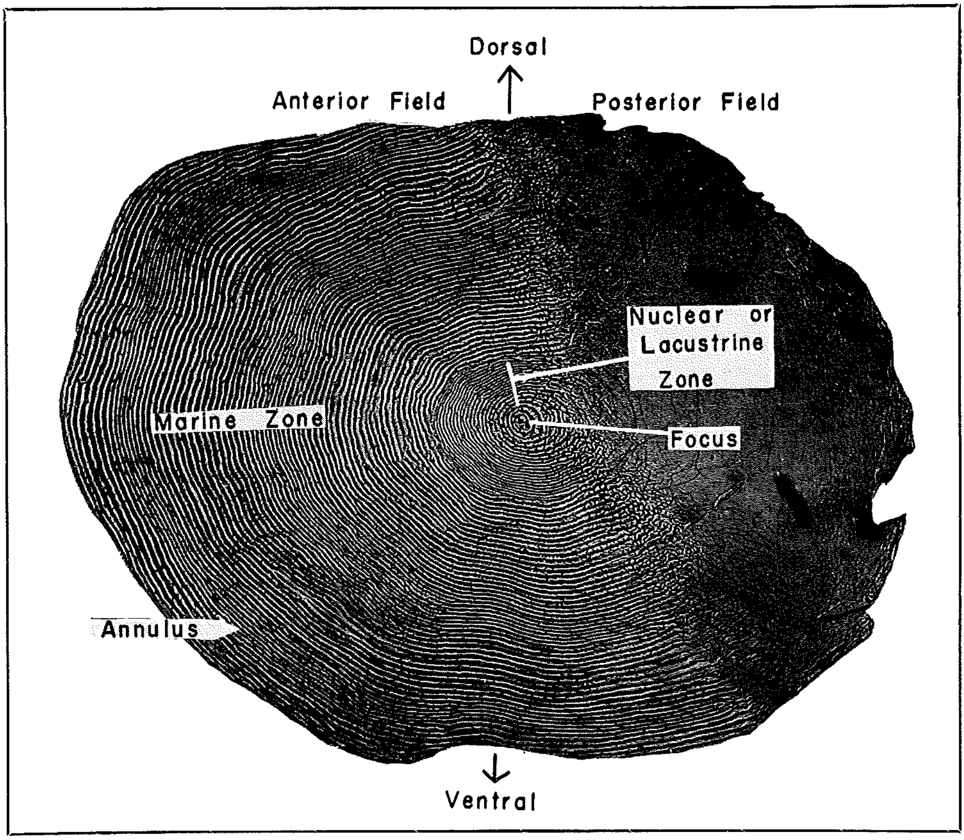

FIGURE 2—Fraser River 4_2 sockeye scale with descriptive notations.

ment of Fraser River sockeye salmon." This publication discusses the sampling problems and requirements upon which the present racial analysis method is based, such as sample size and selection of the proper scale for analysis. However, the basic formula (9) on Page 80, which was developed by Dr. D. G. Chapman, of the University of Washington department of Mathematics, to determine the necessary sample size for this analysis, was printed with an error in that publication. The correct formula should be as follows:

Let:

n = number of fish in commercial sample

0_i = observed proportion of fish in commercial sample having ring count i

ρ = relative error of 0_i

α = confidence coefficient

Z = $1 - \alpha$ critical level of Normal distribution

The 0_i are approximately normally distributed with variance approximately equal to:

$$\frac{0_i\ (1 - 0_i)}{n}$$

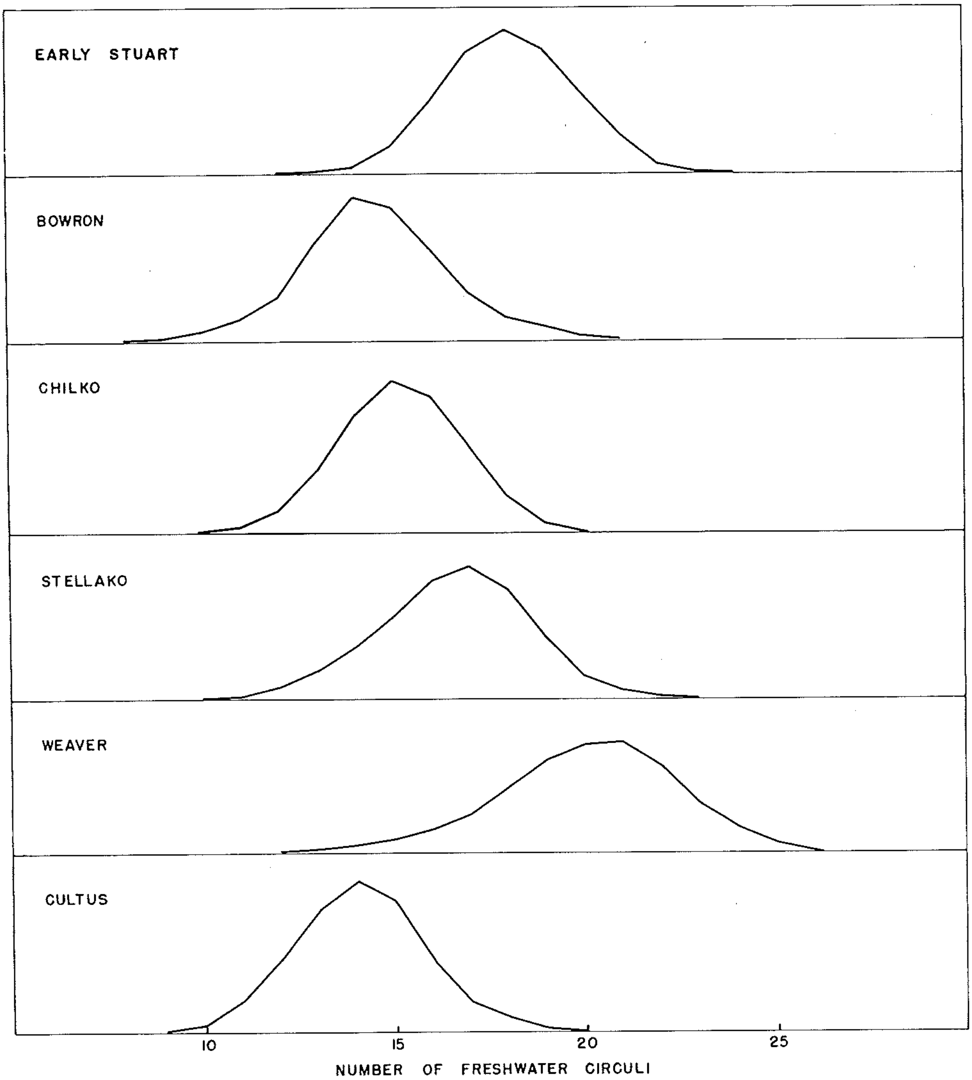

FIGURE 3—Smoothed freshwater scale circuli frequencies for certain Fraser River sockeye races in 1956 (4_2 only).

In order to restrict the relative error of the 0_i to the desired degree at the desired confidence level (α) it is necessary to choose a sample of size n

Where:

$$Z \sqrt{\frac{0_i \ (1 - 0_i)}{n}} \leq \rho 0_i$$

Or, at the critical level:

$$n = \frac{Z^2 \ (1 - 0_i)}{\rho^2 0_i} \qquad (1)$$

Of course, with any given sample size and an observed proportion of fish in the sample with ring count i, confidence limits, or the relative error, can also be determined.

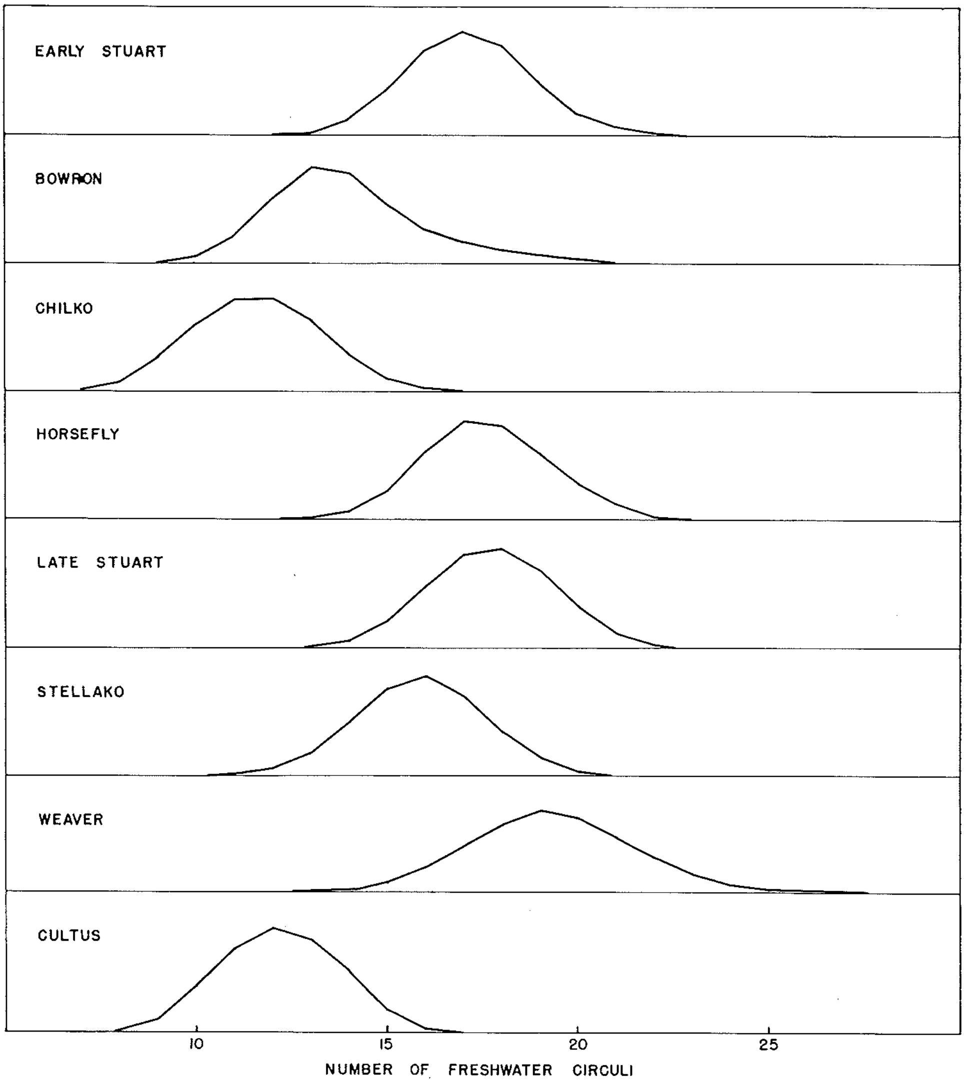

FIGURE 4—Smoothed freshwater scale circuli frequencies for certain Fraser River sockeye races in 1957 (4_2 only).

Structure of Method

Freshwater circuli frequencies generally form a normal-shaped curve. FIGURES 3 - 6 show the smoothed ring count frequencies, as a per cent, for certain races of adult Fraser River sockeye from 1956 through 1959, and TABLE 1 lists the means, standard deviations and ranges. Ring count frequencies used in this study are smoothed by three's using the relationship

$$\frac{a + 2b + c}{2}$$

where a, b and c represent the three ring counts being smoothed.

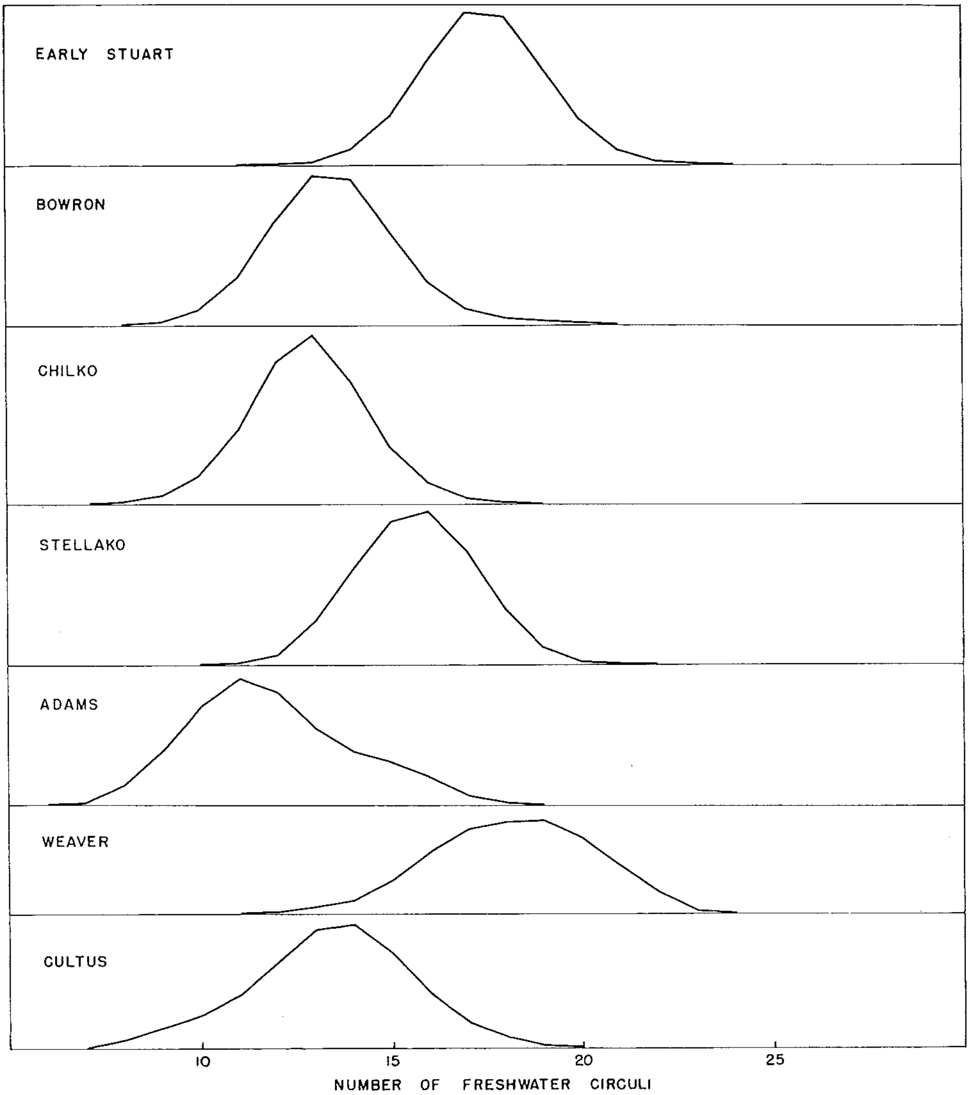

FIGURE 5—Smoothed freshwater scale circuli frequencies for certain Fraser River sockeye races in 1958 (4_2 only).

Since the method of sampling, mounting and reading the scale samples is thoroughly discussed by Clutter and Whitesel (1956), only the actual design of the scale method and its applications to management will be stressed in this report. No attempt normally is made to identify individual fish as to racial origin since only the percentage racial composition of the catch is required. However, individual fish can be separated by race in certain instances, particularly for the two-year-in-freshwater type of scale.

The age terminology used by the Salmon Commission is that proposed by Gilbert and Rich (1927). Counting from the time the eggs were deposited, the

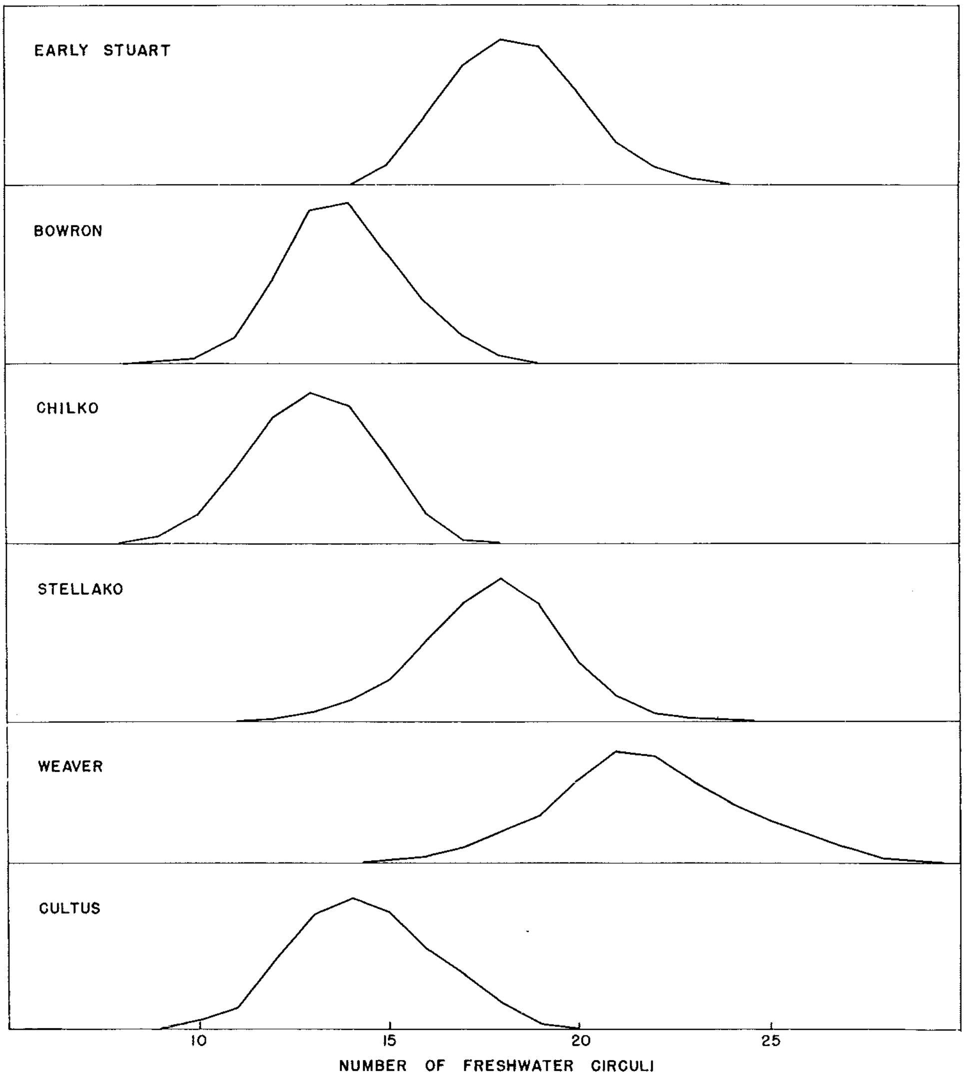

FIGURE 6—Smoothed freshwater scale circuli frequencies for certain Fraser River sockeye races in 1959 (4_2 only).

first number indicates the year of life of the fish at maturity or capture and the second number indicates the year of life at seaward migration. A fish that is four years old at capture and has spent one complete year of lacustrine life would be designated 4_2.

In order to use the scale analysis method for racial identification of the commercial catch, an estimate of the freshwater ring count to be expected is needed for the various races as they enter the fishery. Normally over 80 per cent of the Fraser River sockeye mature at four years of age, as 4_2 fish. Thus, whenever possible, spawning ground scale samples from 3_2 fish are obtained the previous year for each of the different races. The smoothed freshwater circuli frequencies

TABLE 1—Freshwater circuli frequency data for 4_2 sockeye of certain Fraser River races, 1956 - 1959.

YEAR	RACE								
	Early Stuart	Bowron	Chilko	Horsefly	Late Stuart	Stellako	Adams	Weaver	Cultus
1956									
Sample Size	584	195	165	—	—	195	—	185	192
Mean Number Circuli	18.30	13.88	13.25	—	—	17.58	—	21.96	14.58
Standard Deviation	1.55	1.42	1.33	—	—	1.64	—	2.43	1.73
Range	14-22	10-18	10-17	—	—	12-21	—	16-28	11-19
1957									
Sample Size	1502	181	478	199	371	181	—	188	32
Mean Number Circuli	18.79	14.13	11.59	17.79	17.73	15.68	—	19.25	15.00
Standard Deviation	1.49	1.56	1.55	1.65	1.42	1.46	—	1.96	1.27
Range	14-22	11-20	8-17	9-22	14-22	12-19	—	15-26	13-18
1958									
Sample Size	356	184	370	—	—	159	176	168	200
Mean Number Circuli	17.30	13.64	12.85	—	—	15.81	11.94	18.90	13.22
Standard Deviation	1.56	1.63	1.51	—	—	1.59	2.10	2.42	2.11
Range	11-22	9-19	9-21	—	—	12-21	8-21	10-25	8-21
1959									
Sample Size	123	171	427	—	—	191	—	167	187
Mean Number Circuli	18.05	14.70	15.36	—	—	16.53	—	19.89	14.17
Standard Deviation	1.59	1.70	1.47	—	—	1.77	—	2.21	1.60
Range	14-23	9-19	9-19	—	—	12-21	—	13-24	11-20

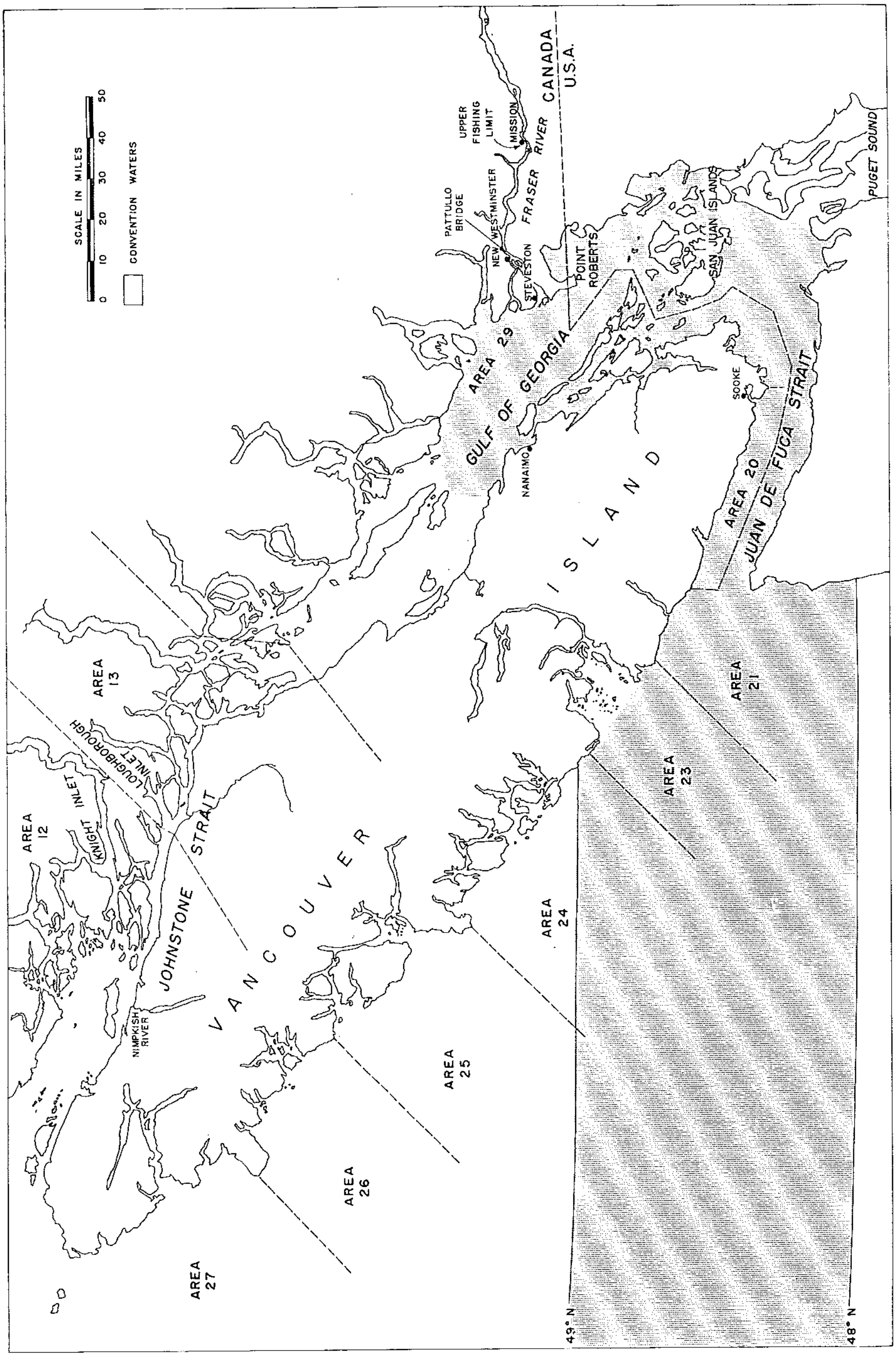

FIGURE 7—Coastal area adjacent to Fraser River mouth, including Vancouver Island, showing various statistical fishing areas.

from these 3_2 fish are then used as the expected ring count frequencies for the 4_2 fish of the same brood returning the following year. As pointed out by Hamilton (1947), the relationship between 3_2 freshwater ring count and 4_2 freshwater ring count from the same brood is not constant and generally the 3_2 ring count is higher. Therefore, an adjustment in the 3_2 ring count usually is made to compensate for this expected difference.

Scale samples from downstream migrants are obtained for some races and these also can be used to estimate the expected freshwater ring count of the returning adults. These migrant scales are not as desirable as those from the 3_2 fish because there appears to be an even greater discrepancy between smolt and 4_2 ring counts of the same brood than there is between 3_2 and 4_2 ring counts. In contrast to the 3_2 ring count, however, the smolt ring count is usually less than that for the 4_2 fish of the same brood, which probably reflects a greater marine mortality of the smaller fish.

Scale samples are subsequently obtained from each racial spawning ground and the daily catch samples re-analyzed using the exact freshwater circuli counts for each age group.

The general procedure used during the fishing season is to obtain daily scale samples from each fishing area. The daily samples are immediately forwarded to the central laboratory where they are mounted on gummed paper and pressed onto plastic. Scale samples from a key sampling area, usually the San Juan Islands (FIGURE 7), are analyzed for racial composition by noon of the following day. The daily samples from the other fishing areas are analyzed as a specific need arises.

After each scale is aged the freshwater circuli are counted. The daily freshwater circuli frequencies obtained for each age group are then smoothed and separated into their racial components. For the 4_2 fish this is done by applying a series of racial quasi-normal curves based on the racial circuli frequencies obtained from 3_2 fish the previous year. A similar procedure is used for the 5_2 fish and the two age groups are analyzed separately.

The data in TABLE 2 and FIGURE 8 show a hypothetical example illustrating the basic method of superimposing the quasi-normal racial curves on a sample frequency curve. There are three races present in the hypothetical sample as illustrated. The smoothed sample frequency curve in FIGURE 8 is obtained from the last column of TABLE 2. The mean ring count for race A is 15 and the shape of the circuli frequency curve for race A is such that the 15 ring count is approximately three times that of the 11 ring count, or five times that of the 10 ring count. A curve fulfilling these requirements is superimposed on the sample frequency curve. A similar procedure is then followed for race C and finally race B. The height of the individual racial curve is controlled by the requirement that the combined areas A B C must fully occupy the area under the sample frequency curve. The percentages under each of the racial curves are then counted and the total for all the races present must equal 100 per cent. Since the three racial curves are superimposed on the sample curve in an empirical manner, it might be thought that three different racial curves, which would give a different racial composition

TABLE 2—Hypothetical example demonstrating use of the scale method in the racial analysis of freshwater scale circuli frequencies.

NUMBER OF CIRCULI	EXPECTED RING COUNT ON BASIS OF 3_2 SCALES						SAMPLE OF 4_2 FISH				
	Race A		Race B		Race C						
	Number Scales	Smoothed Per Cent	Number Scales	Smoothed Per Cent	Number Scales	Smoothed Per Cent	Race A	Race B	Race C	Total	Smoothed Per Cent
		0.29									0.13
9	1	1.44					5			5	0.64
10	3	3.45					15			15	1.54
11	5	5.75		0.51			25			25	2.73
12	7	8.05	2	2.04			35	6		41	4.22
13	9	10.34	4	4.08		0.21	45	12		57	5.92
14	11	13.22	6	6.12	1	1.24	55	18	2	75	8.08
15	15	14.94	8	8.16	4	3.31	75	24	8	107	9.99
16	11	13.22	10	10.20	7	5.79	55	30	14	99	10.45
17	9	10.34	12	12.24	10	8.26	45	36	20	101	10.40
18	7	8.05	14	13.27	13	10.74	35	42	26	103	10.30
19	5	5.75	12	12.24	16	13.22	25	36	32	93	9.58
20	3	3.45	10	10.20	19	14.46	15	30	38	83	8.24
21	1	1.44	8	8.16	16	13.32	5	24	32	61	6.41
22		0.29	6	6.12	13	10.74		18	26	44	4.66
23			4	4.08	10	8.26		12	20	32	3.30
24			2	2.04	7	5.79		6	14	20	2.06
25				0.51	4	3.31			8	8	0.98
26					1	1.24			2	2	0.31
27						0.21					0.05
Total	87		98		121		435	294	242	971	
Mean	15.00		18.00		20.00		45%	30%	25%		

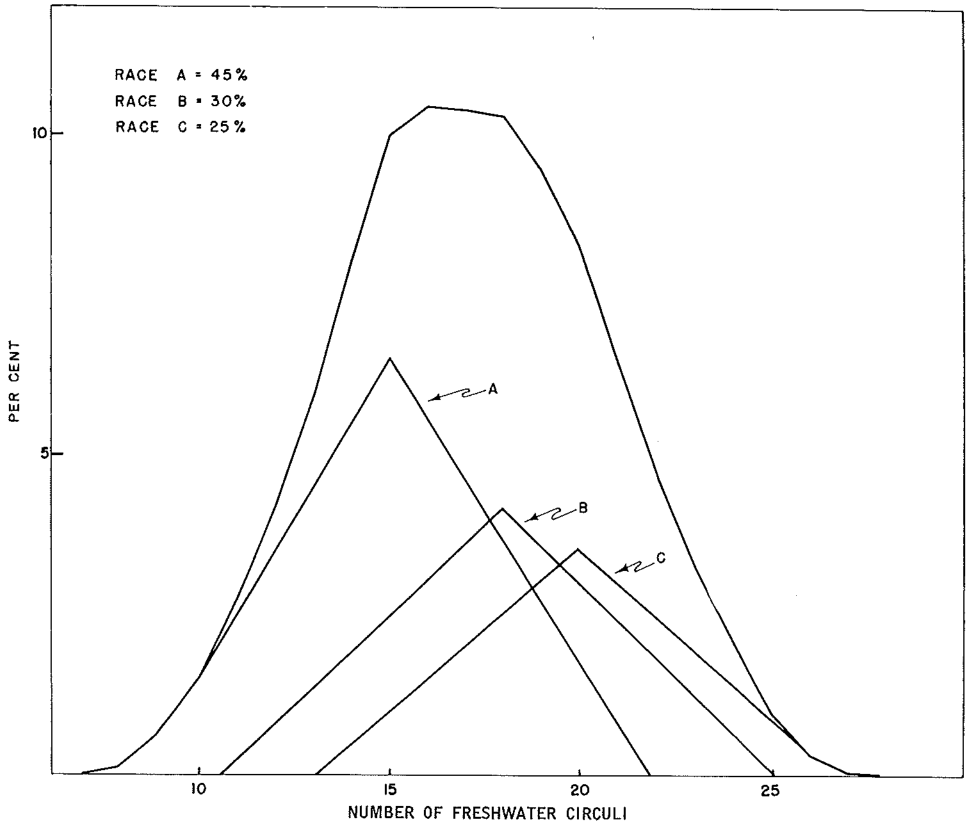

FIGURE 8—Hypothetical example demonstrating use of the scale method in the racial analysis of freshwater scale circuli frequencies.

estimate, might also be superimposed in place of the racial curves shown. However, it is quite easy to verify that if any of the racial curves in FIGURE 8 is made larger or smaller than shown, it would not be possible to have the three racial curves fully occupy the area under the sample frequency curve and still maintain the proper shape of each racial curve.

It is apparent that the shape of the racial circuli frequency curve, as well as the mean circuli count, is very important in this method. As is discussed in later sections, it is frequently necessary to depart from the stylized triangle-shaped racial frequency curve to achieve a complete apportioning of the sample curve into its racial components.

It is also obvious that experience and extensive auxiliary information are necessary for developing the scale identification method. Some knowledge of the races to be expected in the daily sample is a first prerequisite. Fortunately, there is an extensive background of information on the usual times of migration of various races. Moreover, tagging information, fishery statistics, and spawning ground observations can all be used to supplement any assumptions on times of migration.

While a precise and seemingly unbiased mathematical separation of the sample frequency curves would appear to be more sophisticated, the judicious empirical approach would seem to be much more flexible considering the complexity and variability inherent in the stocks of fish involved and the fishery to which they are subjected. In all of the discussion which follows, the inherent weakness of any inflexible mathematical procedure should be apparent.

Refinement of the Method

Although the number of freshwater circuli is the basic characteristic used in the scale method, other information such as racial timing, age of the fish, and the presence of "spring growth" on the scales are also used in refining this method.

RACIAL TIMING

Some knowledge of racial timing, particularly for the major races, is the most important additional information that is required. Certain races have freshwater ring count frequency curves which are very similar or overlap one another enough so that without some knowledge of the racial timing it would be almost impossible to separate these particular races on the basis of scale analysis alone. Therefore, information on past racial timing, gathered from tagging studies, marking experiments, spawning ground arrival curves, daily Indian catches, weir counts and scale analysis are all used to establish a general time of migration for most races in the fishery. Having established a general chronology for racial timing the daily scale samples during the season can then be separated into their racial components by scale analysis on the basis of the possible races present each day.

In many instances, the timing of certain races can be determined directly from the scale analysis during the season. The race can either be large enough in comparison with the other races present to create a very dominant and characteristic mode in the scale count frequencies, or the mean ring count can be considerably smaller or larger than the mean ring counts for the other races present so that it also creates a distinctive mode. Generally, however, after the fishing season, the exact racial timing for several major races is definitely determined from weir counts, Indian catches or spawning ground arrival curves using the method established by Killick (1955), and any refinements in the preliminary racial estimates made during the season, due to differences between the estimated and actual racial timing, then can be made.

It is not always possible, or even necessary, to determine from scale analysis the exact contribution of the smaller races to the daily catch. Scale analysis is not sensitive enough even after the season is over to distinguish the fish of small races which may have circuli counts overlapping those of larger races migrating at the same time. However, with a knowledge of racial timing the contribution of these minor races can be estimated on the basis of calculated racial catches for a major race migrating at approximately the same time. Thus, during the fishing season, if the catch of two or more races migrating at the same time have had to be combined because of similar freshwater circuli curves, the contribution of each race can be estimated on the basis of the comparative size of the parent escapements in the brood year. After the fishing season is over, a more exact estimate of the contribution of each race can be made on the basis of the actual escapements enumerated on each racial spawning ground and also on the basis that all races appearing in the fishery at the same time are subjected to similar racial fishing mortalities.

AGE

Age is also important in the refinement of the racial scale identification method. Gilbert and Rich (1925) noted a difference in age composition between Nushagak and Karluk red salmon in Alaska. Koo and Smith (1960, page 9) noted that red salmon from various spawning localities in the Iliamna-Clark system at the headwaters of the Kvichak River, Alaska, showed different age composition and stated that this was clear evidence of the segregation of subpopulations.

Fraser River sockeye are predominately of one age group. TABLE 3 lists the number of each age group present for Fraser River sockeye as determined for the eight years from 1952 to 1959. These figures include the commercial catch in Convention waters (FIGURE 7) plus the escapement. The 4_2 age group during this period has ranged from 80.4 per cent in 1957 to 98.9 per cent in 1958. These percentages are typical of the dominance of this age group in past years (Killick and Clemens, MS.). The 5_2 age group is next in importance with the 5_3 age group usually being somewhat less abundant than the 5_2. The 3_2 age group is only abundant in years preceding the return of the dominant Adams race, e.g., in 1953 and 1957. There are so relatively few 4_3 and 6_3 fish that these age groups are of no numerical importance.

4_2 sockeye are present in all Fraser River races and 5_2 and 3_2 fish are present in most races. Two-year-in-the-lake type fish are consistently of importance in only three races, Chilko, Taseko and Birkenhead, although they appear occasionally in other races. Taseko is a very minor race, numerically, in comparison with Chilko and Birkenhead.

The daily catches in the fishery are separated into the different age groups on the basis of the age determinations from the daily scale sample. The scales from fish of the 5_2 and 3_2 age groups are analyzed for racial composition on the basis of freshwater circuli frequencies in the same manner as for the 4_2 fish. Each individual two-year-in-the-lake type scale in the daily samples is usually analyzed separately for racial origin. In TABLE 4 are listed the 5_3 freshwater circuli counts as obtained from spawning ground samples in 1956 for the three races which had significant numbers of 5_3 fish. Over 99 per cent of the total number of Fraser River 5_3 fish present in 1956 belonged to these three races. The low second year ring count for Chilko and Taseko fish as compared with the high second year ring count for the Birkenhead fish are consistent racial features year after year and this makes it relatively simple to separate most 5_3 scales into the two major groups, Chilko-Taseko and Birkenhead. Both during and after the fishing season, the portion of the combined Chilko-Taseko catch attributable to Taseko can be estimated based on the comparative sizes of the Chilko and Taseko escapements.

SPRING GROWTH

Another criterion which is a useful aid to the racial scale method is the presence of what is known as "spring growth" or "plus growth." This is an area of

TABLE 3—Age composition of the catch plus escapement of Fraser River sockeye salmon for Convention waters, 1952 - 1959.

YEAR	AGE						
	3_2	4_3	4_2	5_3	5_2	6_3	Total
1952	77,451	12,213	2,715,084	102,927	287,196	3,926	3,198,797
1953	579,565	10,495	4,363,164	255,829	188,673	6,220	5,403,946
1954	45,262	5,227	11,842,822	87,785	119,759	2,800	12,103,655
1955	40,367	6,121	2,269,596	58,207	180,373	3,203	2,557,867
1956	19,411	3,160	2,307,237	81,902	328,957	1,532	2,742,199
1957	715,654	5,031	3,859,003	47,695	167,572	4,905	4,799,860
1958	67,801	9,208	14,267,854	190,656	79,983	1,312	14,441,814
1959	38,456	4,924	4,030,016	134,948	194,292	1,600	4,404,236

freshwater circuli that is indicative of growth after the last freshwater annulus has been formed. FIGURE 9 shows Fraser River sockeye scales with typical spring growth. This is a very variable phenomenon, both within a given race and between races. However, in certain instances the presence of spring growth on the scales of fish from a particular race has aided in separating these fish from those of a different race with a similar freshwater ring count and migrating at the same time, but lacking spring growth.

TABLE 4—Number of freshwater circuli, by race, for 5_3 Fraser River sockeye salmon in 1956.

Number of Freshwater Circuli	RACE		
	Taseko	Chilko	Birkenhead
	6+10		
	7+8		
	7+9		
	7+10 (3)		
	7+11		
	7+12		
	8+9	8+9	
	8+10 (6)	8+10	
	8+11 (4)		
	8+12		
	8+13		
	9+9 (2)	9+9	9+17
	9+10 (2)		9+19
	9+11 (2)		9+20
	10+9	10+10	10+13
			10+18
			10+20
	11+7		
			12+12
			12+18
			12+24
			12+25
		13+11	13+21
			13+22
			13+27
		14+8	14+21

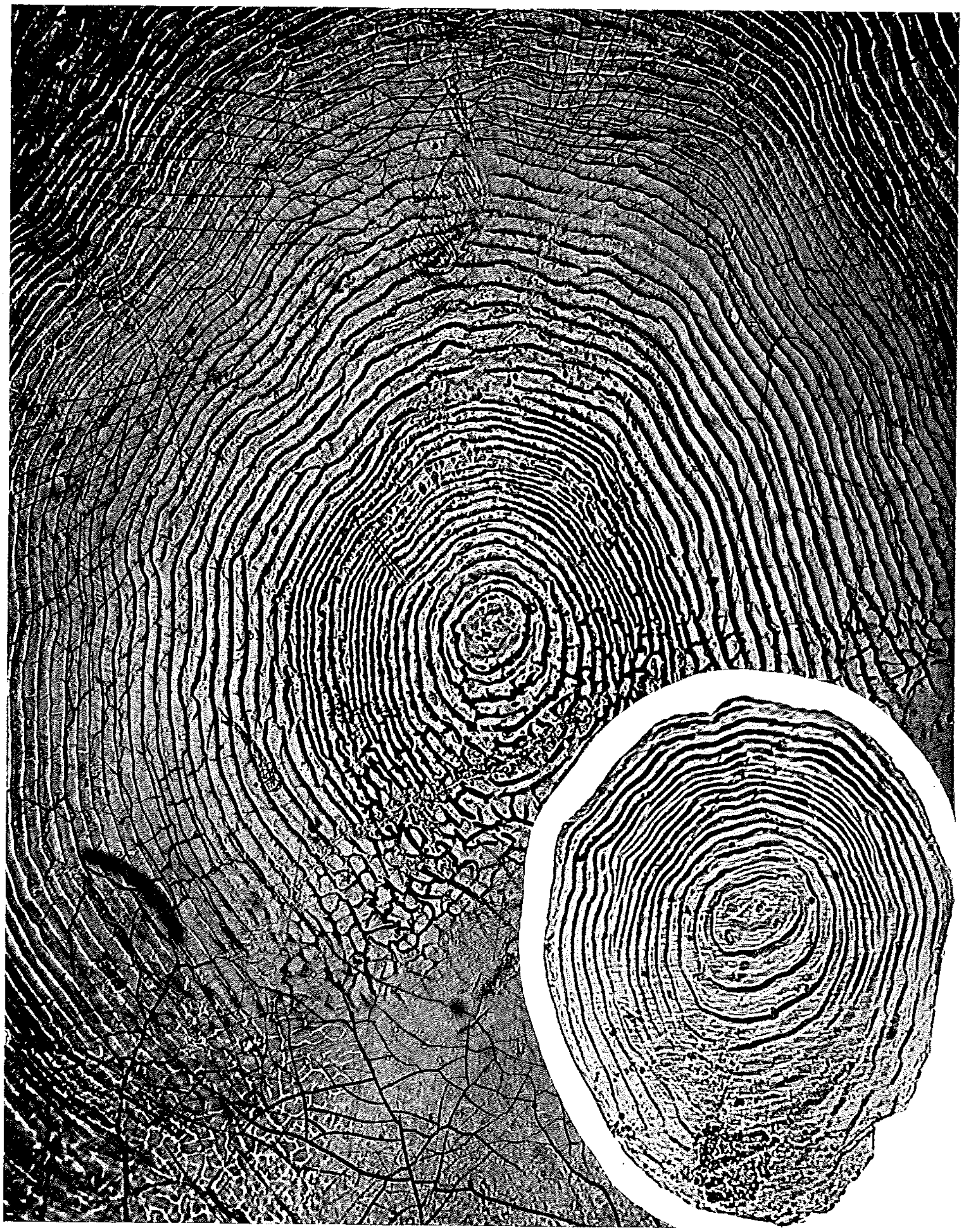

FIGURE 9—The nuclear area of a 1955 Adams River 4_2 sockeye scale and a similar scale from a 1953 yearling smolt both showing "spring growth."

RELIABILITY OF THE RACIAL SCALE ANALYSIS METHOD

Accuracy of Racial Composition Estimates

THEORETICAL

Table 5 lists the theoretical relative sampling error, at the 95 per cent level of confidence, for different percentages of racial composition based on formula (1), page 8, and sample sizes of 50, 350, and 900. The relative error curves for these different percentages are shown in Figure 10 so that the relative error for any intermediate size sample can be determined directly from this graph. The theoretical relative sampling error increases quite rapidly with smaller sample sizes.

Table 5—Theoretical per cent relative error of racial percentages using different sample sizes and 95 per cent confidence limits.

Sample Size	Per Cent Racial Composition							
	1	2	5	10	20	30	50	80
50	276	194	121	83	55	42	28	14
350	104	73	46	31	21	16	10	5
900	65	46	28	20	13	10	6	3

It is impractical to obtain a large enough sample so that any race represented by a relative small percentage would have a small theoretical relative sampling error. With a sample of 900, a race representing five per cent of the daily catch would still have a theoretical relative sampling error of 28 per cent, while one representing only one per cent would have a 65 per cent relative error. Even with a sample of 10,000, the relative error for a race comprising one per cent of the catch would be 20 per cent.

These estimates of the relative error apply to a particular race on a particular day. Although sampling theory permits an estimate of the relative error that applies equally to plus or minus deviations, the total racial estimates on a given day must equal 100 per cent so that these estimates are not independent. Any race that has a plus deviation in the daily sample must be compensated for by another race, or races, having a minus deviation, and it is reasonable to assume that these deviations are random.

EMPIRICAL

The theoretical relative error discussed above is based on the true racial composition of the daily catches. However, in applying the scale method, the racial composition is estimated from the daily samples so that in addition to the theoretical sampling error there is the added factor of a possible error in the daily racial estimates. This error in the daily racial estimates could either be additive or compensatory to the theoretical sampling error. The most logical method of examining the accuracy of these daily racial estimates is to examine the results based on actual applications of the scale method.

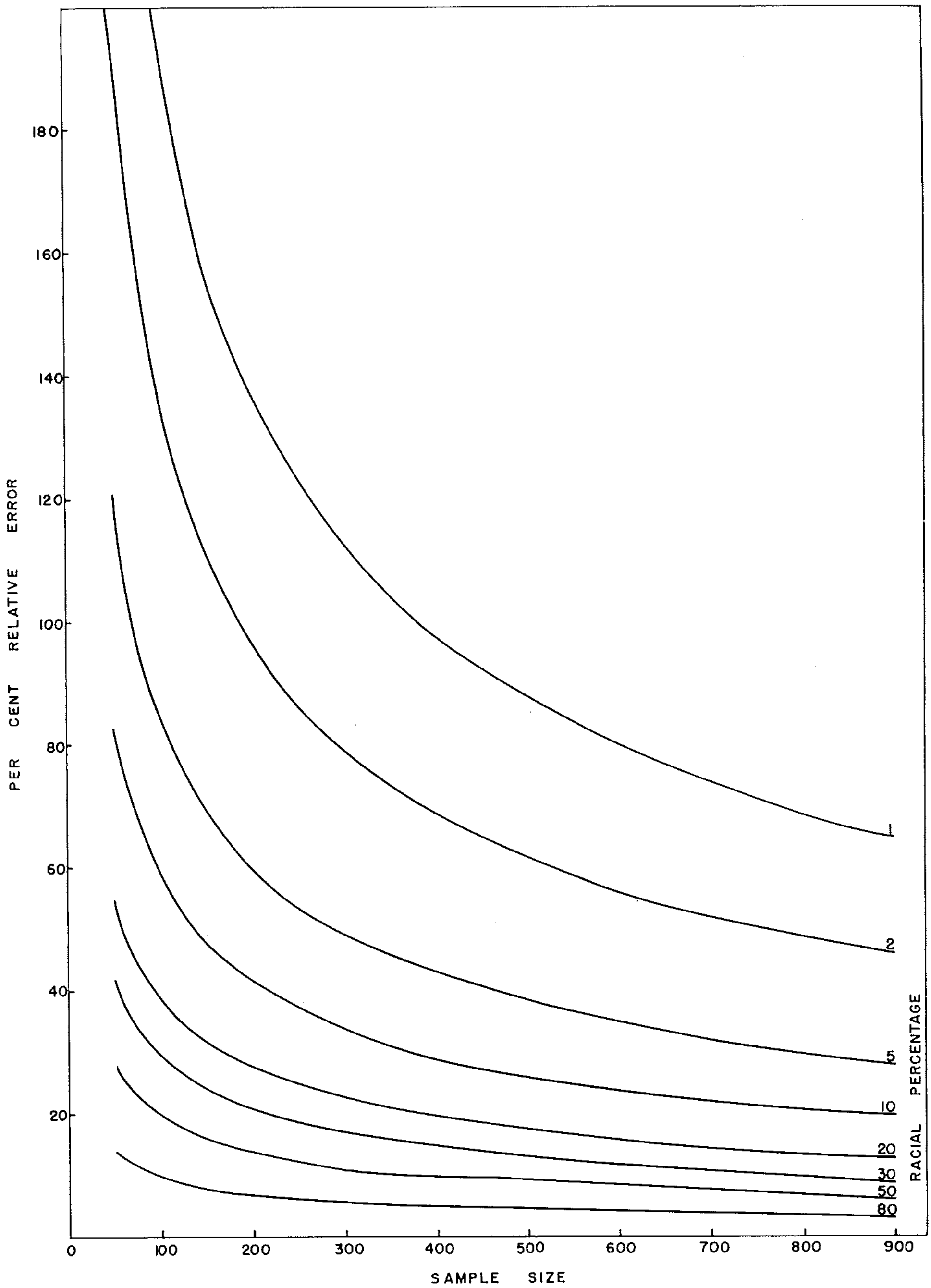

FIGURE 10—Theoretical relative error for various racial percentages and different sized samples.

Paired Analyses

In 1960, scale samples from certain daily catches were independently analyzed by the writer and another individual referred to as Reader B. Reader B had little previous training in these analyses other than being informed of the details of the general method. Paired analyses were begun on July 20 and were continued through early August by which time approximately 20 comparisons had been made. TABLE 6 lists three of these comparisons spaced periodically throughout this period. These three comparisons are all from the same fishing area. Even on the first day of comparisons, July 20, the analyses were remarkably similar. As might be expected, the last comparison made on August 2, after Reader B had had considerably more experience, was very similar.

TABLE 6—Comparisons of two independent estimates of racial composition of randomly selected scale samples based on the number of freshwater circuli, 1960.

DATE	RACE	RACIAL PERCENTAGES	
		Author	Reader B
July 20	Chilko	75	67
	Nadina, Gates	5	10.5
	Birkenhead	16	16
	Bowron	0.5	—
	Pitt	3	2
	Misc.	0.5	0.5
July 25	Chilko	89	85
	Birkenhead	2.5	8
	Stellako	3	4
	Weaver, Silver	2	2
	Misc.	3.5	1
Aug. 2	Chilko	80	82
	Stellako	6	2.5
	Birkenhead	11	11
	Misc.	3	4.5

While these paired analyses do not necessarily validate the accuracy of the estimates, they do demonstrate consistency, which is also an important quality for a racial identification method. Furthermore, these paired analyses indicate that the results are dependent upon the method rather than upon the investigator.

Test Fishing

If the fishery is to be regulated so that each race is a separate problem in management, it is necessary that the racial escapement be of the proper amount at the proper time. Since some method of measuring the current escapement is mandatory, a method of daily test fishing has been devised, based to some extent on the work of Petersen (1954).

Very little escapement occurs while the Fraser River gill net fishery is in operation (Royal, 1953), so test fishing is only conducted during the periods when the river fishery is not operating. Furthermore, experience has shown that as a result of the very intense river fishery, there is no significant escapement out of the fishing area during the first day after the river is closed to fishing.

On the basis of a number of years experience, certain fishing drifts near the upper end of the commercial fishing area have been selected where catches provide reliable estimates of the daily migration passing that point. Different drifts are used for different water levels of the river. Usually there are two test drifts made daily during the period that the river is closed to commercial fishing commencing approximately 36 hours after commercial fishing ceases. Each of these drifts is about one-half hour in duration and a standard gill net of approximately 150 fathoms in length is used.

Four different times are recorded: (1) time started setting net, (2) time net full out, (3) time started bring net into boat, and (4) time net full in. The difference between the average of times (1) and (2) and the average of times (3) and (4) gives the number of minutes that the net was fished. This number of minutes is then multiplied by the length of the net, in fathoms, to give the number of fathom-minutes fished. The number of fathom-minutes is then divided by 1,000 to reduce the number to a more convenient magnitude. The catch, divided by the number of 1,000-fathom-minutes, is then expressed as the catch-per-1,000-fathom-minutes. This procedure standardizes all catches for any differences in length of the net or in length of time fished.

After the fishing season is over, all the individual racial escapements are enumerated on the spawning grounds and the Indian catches are also recorded so that the total gross escapement for each year is known. There are then two possibilities for establishing a relationship between the test fishing catches and the probable daily escapement: (1) when test fishing is conducted throughout the entire season, and (2) when test fishing is conducted during only a portion of the season.

If test fishing has been conducted throughout the season so that the entire escapement has been measured on a daily basis, and this is certainly the most desirable situation, then a daily catch-per-1,000-fathom-minutes from test fishing can be assigned to represent a portion of the total escapement in such a manner that the total daily catches estimated from test fishing will equal the total escapement.

If test fishing is conducted during only a part of the season, and this was the case in 1958, 1959, and 1960, it becomes necessary to estimate the portion of the known total escapement or known racial escapement which occurred during the periods when there was no test fishing, and the portion which occurred during the periods when there was test fishing. This is done by establishing racial time-abundance curves after the fishing season is over for the known racial escapements based on Indian catches, weir counts, spawning ground arrival curves and scale analyses. These racial arrival curves, or time-abundance curves, are projected from the spawning grounds back to the test fishing site using the method established by Killick (1955). On the basis of these racial time-abundance curves, it is then possible to estimate the portion of the known total escapement or the known racial escapement which occurred during periods when there was no test fishing, and the portion which occurred during periods when there was test fishing. The portion of the known total escapement estimated to have occurred during the test fishing period is then used to establish the relationship between test fishing catches

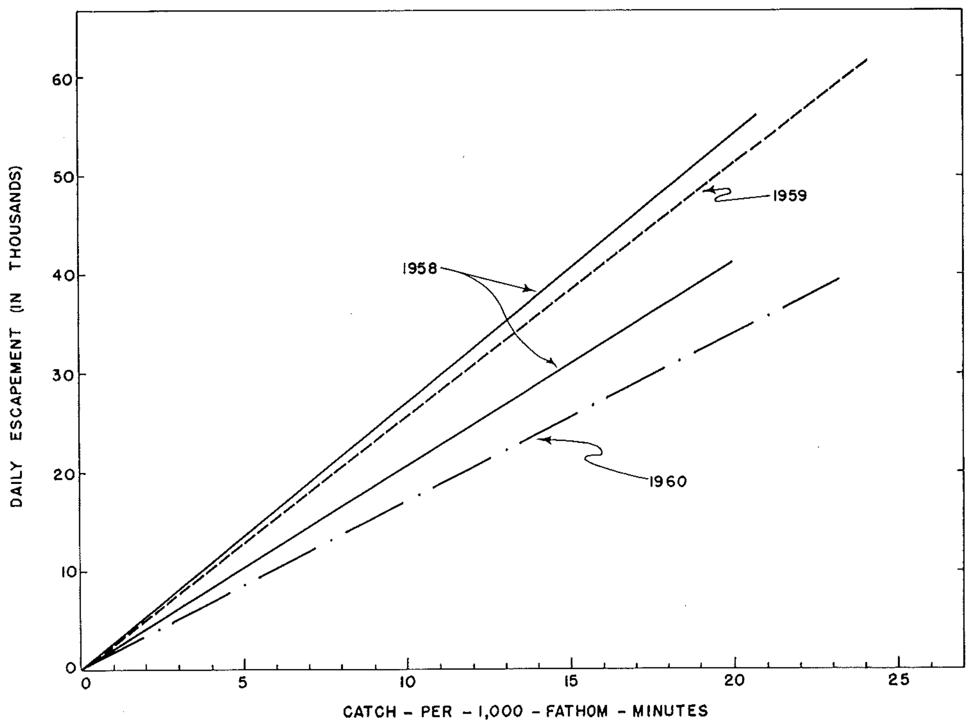

FIGURE 11—Relationship between test fishing catches and known adult sockeye escapements.

and known escapements in the same manner as described above, when test fishing was conducted throughout the entire season. The only difference is that in this case an estimated portion of the known escapement is used for the comparison whereas the total known escapement was used before.

It is obvious that test fishing throughout the entire season is the most desirable situation for establishing the relationship between test fishing catches and the actual escapement, because this eliminates the possible additional error in this relationship that might result from incorrectly estimating the portion of the total known escapement that occurred only during the period when there was test fishing.

On the basis of this relationship between test fishing catches and actual escapements, established in previous years, any daily catch-per-1,000-fathom-minutes from test fishing for the current year can then be converted directly into an estimated daily escapement. FIGURE 11 shows this relationship for the years 1958, 1959 and 1960.

It has been found that the results of this method are subject to some variability between years. In 1958 the relationship between test fishing catches and escapements is described by two separate curves. The upper curve represents the results for the majority of the season while the lower curve represents a short period at the end of the test fishing period of that year. The 1959 test fishing relationship closely paralleled the upper curve for 1958. Therefore, in 1960 a composite of the

TABLE 7—Estimated total daily escapement and certain racial daily escapements on the basis of test fishing and scale analysis, compared with actual escapements during the same period, comprising Indian catches and spawning ground enumeration by tagging.

DATE	SAMPLE SIZE	1959 CALCULATED ESCAPEMENT		
		Total	Chilko	Stellako & Late Stuart
July 27	3	17,500	7,808	200
28	24	16,500	7,852	700
29	10	18,500	8,846	1,320
30	49	27,000	12,045	2,220
31	29	18,500	9,504	4,320
Aug. 1	46	27,000	15,058	2,035
2	143	48,000	22,636	2,430
3	45	49,000	33,484	4,800
4	53	55,000	30,058	3,430
5	15	54,000	25,184	9,900
6	101	42,000	26,142	11,340
7	72	40,500	26,190	8,400
8	103	65,000	44,808	4,050
9	139	75,000	49,397	7,150
15	63	21,000	10,370	2,733
16	95	27,000	15,861	1,620
21	29	10,500	7,943	6,300
22	102	49,000	33,776	3,920
23	68	40,000	22,991	4,000
28	18	8,625	4,313	1,725
29	23	11,000	3,850	2,420
30	32	15,000	6,450	4,200
Calculated Total		735,625	424,566	98,773
Actual Total		726,999	489,723	92,432

DATE	SAMPLE SIZE	1960 CALCULATED ESCAPEMENT	
		Total	Chilko
July 29	36	30,000	26,100
30	40	22,000	19,000
31	48	26,000	20,000
Aug. 1	106	51,000	42,300
2	103	60,000	40,800
4	1	1,000	800
5	126	52,000	43,400
6	94	42,000	26,200
7	71	37,000	26,000
8	135	57,000	46,200
13	49	22,000	18,000
14	111	50,000	36,000
15	100	43,000	28,000
20	155	47,000	45,000
21	83	29,000	17,000
28	25	12,000	2,880
30	20	10,000	2,000
31	6	3,000	450
Sept. 1	10	5,000	500
2	11	5,000	500
3	11	4,000	400
Calculated Total		608,000	441,530
Actual Total		555,742	391,594

upper 1958 and 1959 curves was used to make the estimates of the daily escapement. For some as yet unknown reason, however, the actual 1960 curve, which was compiled after the actual total escapement had been enumerated on the spawning grounds, was below the upper 1958 and 1959 curves. This meant that for a given catch from test fishing in 1960 the actual escapement was somewhat less than was indicated by the 1958 and 1959 composite curve and, consequently, the total escapement was overestimated.

More years of data are needed to determine whether the 1960 curve is an exception or whether it merely represents the normal variation that can be expected in the relationship between test fishing and the actual number of fish escaping. Normally, the racial escapement is not known for one or two months after it has left the fishery, so even with the differences found in these three years, the ability to approximate the escapement as soon as it leaves the fishery is extremely valuable to any agency managing a salmon fishery on a racial basis.

In addition to obtaining an estimate of the total daily escapement, scale samples are collected from every fish caught during test fishing and the daily racial escapements are also estimated, particularly for the dominant races, using the same method illustrated in TABLE 2 and FIGURE 8.

The total daily escapement and the daily escapement of certain races for the defined periods in 1959 and 1960 are summarized in TABLE 7. In discussing these test fishing results, the total escapement means the total gross escapement and includes all the Indian catch and the total escapement enumerated on all the racial spawning grounds. Likewise, the racial escapements include the total racial Indian catch and the total racial escapement enumerated on the spawning ground.

For the period shown in 1959, the total calculated escapement based on test fishing differed only slightly over one per cent from the portion of the known total escapement for the same period calculated on the basis of the time-abundance curves. The dominant races in the escapement for the period under consideration were Chilko and Stellako plus Late Stuart. These latter two races had similar freshwater ring count curves and could not reasonably be separated in the catches by ring count alone. The escapement to Chilko represented about 50 per cent of the total adult escapement for the year and Stellako-Late Stuart about 9 per cent (Internat. Pacific Salmon Fish. Comm., 1960).

The difference between the calculated Chilko escapement in 1959, determined from test fishing and the portion of the actual Chilko escapement representing the same period, as determined from the racial time-abundance curve, was 13 per cent, or about 65,000 fish out of a total of 489,000. The difference for Stellako-Late Stuart was 7 per cent, or about 6,000 fish out of a total of 92,000.

In 1960 the escapement to Chilko represented about 69 per cent of the total adult escapement (Internat. Pacific Salmon Fish. Comm., 1961) so this race was the most important from a management standpoint. Although in 1960 there was a greater error in the total escapement estimate based on test fishing for the period shown, the racial escapement to Chilko was actually estimated more accurately than it was in 1959. For example, the total estimated escapement in 1960 was approximately nine per cent, or 53,000 fish, greater than actually was calculated during the period of test fishing on the basis of the time-abundance curves. Therefore, the estimated Chilko escapement would have been approximately nine per cent too high in 1960 even if the correct racial composition had been estimated each day. Actually, the Chilko estimate was 11 per cent too high, including a two per cent error attributable to incorrect racial identification.

It has already been pointed out that the reason the 1960 escapement was overestimated was because the actual 1960 curve shown in FIGURE 11, which was compiled after the season was over, was below a composite of the upper 1958 and 1959 curves which was used to estimate the 1960 escapements. This meant that for a given catch from test fishing in 1960 the actual escapement was somewhat less than was estimated. There are many possible reasons for the variability in this relationship between test catches and actual escapements, but these reasons are not of particular importance in view of the close agreement between the estimated escapements and the actual escapements in spite of these variations.

Accuracy of Age Composition Estimates

There are many problems relating to salmon management which make it necessary that both the commercial catch and the escapement be separated into the different age groups. These problems include the need to measure racial marine survival from a known number of smolts, to calculate racial fishing mortality, and to measure total survival from a given escapement. The accuracy of the age composition estimates will have a related effect on the accuracy of the estimated racial composition.

Although the method of age determination proposed by Koo (1955) is very reliable, it is rather tedious in the case of large samples requiring rapid analysis. Furthermore, Fraser River sockeye are predominately of one age group, with over 80 per cent normally returning as 4_2 fish, so the difficulties in correct age determination created by salmon runs consisting of a large number of different age groups do not exist.

Clutter and Whitesel (1956) discuss the basic methodology and problems of age determination for Fraser River sockeye in both the commercial fishery and on the spawning grounds, including proper sample size, so all that will be discussed in this report is two problems basic to accurate age composition determinations: (1) possible selectivity for 5_2 fish, and (2) accuracy of 3_2 or jack, composition estimates.

5_2 COMPOSITION

The possibility of selectivity by different types of fishing gear is a very important problem in connection with sampling for age composition determinations. Selectivity by fishing gear would be most apt to occur between the 4_2 and 5_2 adult fish where there is considerable difference in size of the fish. Clutter and Whitesel examined the possibility of a difference in selectivity for 5_2 fish between purse seine and nylon gill net gear and state (page 117): "Thus it may be concluded that the examples of Table 47 show no significant or consistent difference in 5_2 age composition between purse seines and nylon gill nets." However, this conclusion was based upon one year's data only. Since this is of such importance in

TABLE 8—Comparison of relative numbers of 5_2 sockeye between concurrent purse seine and nylon gill net catches, 1957-1959.

FISHING AREA	DATE	PURSE SEINES Number Adults	PURSE SEINES Number 5_2	PURSE SEINES Per Cent 5_2	GILL NETS Number Adults	GILL NETS Number 5_2	GILL NETS Per Cent 5_2
1957							
San Juan Is.	July 24	400	12	3.0	409	36	8.8
	Aug. 6	394	32	8.1	407	11	2.7
	Aug. 27	403	16	4.0	228	12	5.3
Total		1197	60	5.0	1044	59	5.7
1958							
San Juan Is.	July 21	47	6	12.8	88	8	9.1
	Aug. 11	398	5	1.3	350	8	2.5
	Aug. 25	410	1	0.2	378	9	2.4
	Sept. 1	418	—	—	393	—	—
	Sept. 8	409	—	—	404	—	—
	Sept. 15	184	—	—	361	1	0.3
Pt. Roberts	Aug. 6	65	2	3.1	62	1	1.6
Total		1931	14	0.7	2036	27	1.3
1959							
San Juan Is.	July 22	123	11	8.9	185	19	10.3
	Aug. 4	412	19	4.6	208	9	4.3
	Aug. 12	412	18	4.4	168	7	4.2
	Aug. 13	425	17	4.0	164	10	6.1
	Aug. 17	411	13	3.2	410	25	6.1
	Aug. 24	400	24	6.0	223	15	6.7
	Aug. 31	393	31	7.9	134	5	3.7
Total		2576	133	5.2	1492	90	6.0
GRAND TOTAL		5704	207	3.6	4572	176	3.8

the accurate segregation of age classes in the catches, additional data for the years 1957, 1958 and 1959 have been collected and are presented in TABLE 8. For all the samples the combined weighted mean percentage of 5_2 fish is 3.6 per cent for purse seines and 3.8 per cent for nylon gill nets. For the combined samples the unweighted mean percentage of 5_2 fish is 4.2 per cent for purse seines and 4.4 per cent for nylon gill nets. There is a tendency on the average for a slightly higher percentage of 5_2 fish to be taken by gill nets, but certainly in view of the apparent random variations between samples these differences do not appear to be significant. This conclusion is substantiated by the data in TABLE 9, where the differences in the total catches of 5_2 fish shown in TABLE 8 for the two types of fishing gear for these three years have been examined by means of chi-square. The three chi-square values: 0.452 for 1957, 3.505 for 1958 and 1.377 for 1959, all with one degree of freedom, indicate that there is no significant difference in the yearly percentages of 5_2 sockeye caught by each of these two types of fishing gear. The pooled data for the three years was also not significant ($X^2 = 0.344$).

3_2, OR JACK COMPOSITION

A fairly accurate estimate of the number of jacks in the daily samples can be determined on the basis of size alone. However, there is an occasional overlap in sizes between jacks and adult sockeye so scale samples are also taken each day to correct for any possible error in distinguishing jacks from adults on the basis

TABLE 9—Chi-square tests for differences in 5_2 catch by purse seine and nylon gill net fishing gear, 1957-1959. Expected values in parentheses.

YEAR		PURSE SEINE	GILL NET	TOTALS
1957	5_2	60 (63.56)	59 (55.44)	119
	Other	1137 (1133.44)	985 (988.56)	2122
Totals		1197	1044	2241
		$X^2 = 0.452$		
1958	5_2	14 (19.96)	27 (21.04)	41
	Other	1917 (1911.04)	2009 (2014.96)	3926
Totals		1931	2036	3967
		$X^2 = 3.505$		
1959	5_2	133 (141.21)	90 (81.79)	223
	Other	2443 (2434.79)	1402 (1410.21)	3845
Totals		2576	1492	4068
		$X^2 = 1.377$		

$$X^2_{.95\ (1\ \text{d.f.})} = 3.841$$ [1]

[1] Snedecor, 1948, Table 92.

of size. The numbers of jacks in the daily samples are grouped by three-day periods to eliminate much of the day to day sampling variation. Jacks are caught mainly by purse seines and reef nets and the catch of jacks by the gill net fishery, other than in the Fraser River, is relatively unimportant. In the Fraser River gill net fishery, scale samples alone are used to determine the number of jacks in the daily catch.

Samples from the purse seine catch at San Juan Islands for the years 1956 through 1959 have been examined to obtain the best possible measure of any error in the estimated number of jacks caught. Using the data for 1959, as listed in TABLE 10, lower and upper 95 per cent confidence limits (Ricker, 1937) on the number of jacks in the daily sample are listed as L_1 and L_2, respectively. The smoothed daily percentage of jacks, as well as the daily lower and upper confidence limits was then used to calculate the daily number of jacks in the total purse seine catch. These three daily estimated catches are listed in the last three columns of TABLE 10. The total estimated jack catch from the smoothed percentages is 4,348, which is within the totals of 2,263 and 7,084 estimated from the daily lower and upper 95 per cent confidence limits, respectively. With random sampling it is unlikely that either the daily estimate based on the lower confidence limit or the daily estimate based on the upper confidence limit would occur every day. A more reasonable situation would be an average of these two extremes, or a total of 4,874 jacks. The estimate of 4,348 jacks based on the smoothed percentage differs from the total estimate of 4,874 based on the average of the lower and upper confidence limit totals by 526 fish, or 10.8 per cent.

Similar analyses have been conducted for 1956, 1957 and 1958 and the results for these three years as well as for 1959 are summarized in TABLE 11. For the year in which the most jacks occurred, 1957, the total estimated number of jacks based on the smoothed percentages differed from the mean of the totals based on the daily confidence limits by only 1,995 fish, or —2.8 per cent. For 1956 and 1958, when there were not as many jacks, the total smoothed estimate differed from the mean of the confidence limit totals by 258 fish, or —18.4 per cent, in 1956 and 1,374 fish, or —20.2 per cent, in 1958. In all four years the smoothed estimate total is within the 95 per cent confidence limit totals.

Also listed in TABLE 11 are the yearly total calculated jack catches from Convention waters (FIGURE 7) based on smoothed sample percentages. Assuming that the percentage differences listed in TABLE 11 for the San Juan Islands purse seine samples applies equally to the total commercial catch for all Convention waters, a corrected figure for the estimated total jack catch has been calculated. The difference between the total calculated jack catch based on the smoothed percentages and the corrected total jack catch amounts to 1,367 fish in 1956, 11,143 fish in 1957, 6,205 fish in 1958, and 1,122 fish in 1959.

The greatest numerical difference of 11,143 fish occurred in 1957. Therefore, the 1957 tagging information used in estimating the size of the Lower Adams River jack spawning population, which composed about 79 per cent of the jacks in the total escapement, has been examined. The size of the 1957 Adams River jack spawning ground population was estimated on the basis of 4,550 tags, 552

TABLE 10—Possible error in the estimated total number of jack sockeye in the San Juan Islands purse seine catch, based on 1959 sampling.

Date	Total Sample	Number Jacks	Per Cent Jacks	Smoothed Per Cent Jacks	95 Per Cent Confidence Limits on Number Jacks		Total Purse Seine Catch	Calculated Jack Catch		
					L_1	L_2		Smoothed Per Cent	L_1	L_2
July 20	471	5	1.06	1.77	1.6	11.7	2267	40	8	56
21	1728	34	1.97	1.95	23.5	47.5	1678	33	23	46
22	52	5	9.62	2.19	1.6	11.7	1833	40	56	412
27	297	11	3.70	2.11	5.4	19.7	2310	49	42	153
28	2266	43	1.90	1.80	31.1	57.9	10617	191	146	271
29	1500	19	1.27	1.28	11.5	29.6	14720	188	113	290
30	2000	12	0.60	0.89	6.2	21.0	30536	272	95	321
Aug. 3	800	5	0.63	0.63	1.6	11.7	18131	114	36	765
5	1172	16	1.37	0.76	9.2	26.0	31609	240	248	701
6	7692	51	0.66	0.66	38.8	67.1	61728	407	311	538
7	7222	39	0.54	0.66	27.7	53.3	71446	472	274	527
8	10126	76	0.75	0.66	60.7	95.1	47689	315	286	448
10	1239	9	0.73	0.55	4.0	17.1	28107	155	91	388
11	6279	32	0.51	0.44	21.8	45.1	32613	143	113	234
12	4060	10	0.25	0.38	4.7	18.4	30799	117	36	140
13	9974	36	0.36	0.33	25.1	49.8	43820	145	110	219
17	14236	77	0.54	0.54	61.6	96.2	54144	319	256	400
24	1000	1	0.10	0.60	0.1	5.6	64120	385	6	359
25	3000	23	0.77	0.60	14.6	34.4	29922	180	146	343
27	440	11	2.50	2.50	5.4	19.7	21735	543	267	973
							604824	4348	2663	7084
									Mean = 4874	

TABLE 11—Possible error in the estimated total numbers of jack sockeye in the San Juan Islands catch and the total catch, 1956-1959.

YEAR	SAN JUAN ISLANDS CATCH						TOTAL CALCULATED JACK CATCH	CORRECTED TOTAL	DIFFERENCE
	L_1	L_2	Limit Mean	Smoothed Per Cent	Difference	Per Cent Difference			
1956	863	1943	1403	1145	258	—18.4	7427	6060	1367
1957	64422	78774	71599	69604	1995	— 2.8	317950	386807	11143
1958	2599	10973	6786	5412	1374	—20.2	30717	24512	6205
1959	2663	7084	4874	4348	526	—10.8	11003	9881	1122

tag recoveries, and a total sample of 29,961 jacks. Analyzing these tagging data by means of formula 55, the normal approximation to the hypergeometric distribution (Chapman, 1948), the 95 per cent confidence limits on the 1957 Adams River jack spawning grounds population estimate show a range of 40,985 fish. In view of this possible variation in the spawning ground estimate for this large population of 3_2 jacks, the possible variation noted in the commercial catch of only 11,143 jacks is not considered to be significant.

On the basis of these data, it can be concluded that the present method of determining the jack composition of the commercial catch involving smoothing samples over a three-day period, gives estimates within the 95 per cent confidence limit totals for the daily samples and unquestionably eliminates the effects of the wide daily variations that occur. However, there is also an indication that this method tends to minimize the jack estimates in that the estimates based on the smoothed percentages were always less than the mean of the confidence limit totals. In view of the possible variation in the spawning ground enumeration estimates, however, this tendency to minimize the jack estimates is not considered serious.

APPLICATIONS OF RACIAL SCALE ANALYSIS TO SALMON MANAGEMENT PROBLEMS

The racial scale analysis method has some very valuable applications to salmon management including the determination of routes of racial migration, racial times of migration, racial escapements, and racial fishing mortality. All the applications of the scale method to management problems are dependent upon the ability to distinguish the racial composition of the daily catches on the basis of racial freshwater scale circuli frequencies. A hypothetical example of the basic method of superimposing racial curves in the determination of the racial composition of a daily sample by the scale method was previously illustrated in TABLE 2 and FIGURE 8. However, before examining the specific applications of the racial scale analysis method to management, some actual daily samples from the 1957 fishing season will be examined to further illustrate the method of daily racial identification on the basis of freshwater scale circuli. All the applications of racial scale analysis to salmon management problems, which subsequently will be discussed, are based on the initial determination of the daily racial catch in the same manner as demonstrated for these 1957 data.

FIGURE 12 graphically illustrates smoothed freshwater scale circuli frequencies for certain samples of 4_2 sockeye taken from the daily sockeye catches at the San Juan Islands in 1957. The contribution of major races to each of these samples, based on the scale analysis method, is also shown. Certain relatively minor races may be present in the samples shown, but temporarily they are considered as part of the major races. The contribution of minor races to the daily catches can be determined either during the fishing season on the basis of the comparative size of parent escapements of different races migrating at the same time, or after the fishing season is over on the basis of the comparative sizes of the current escapements, assuming that races migrating at the same time are subjected to similar racial fishing mortalities.

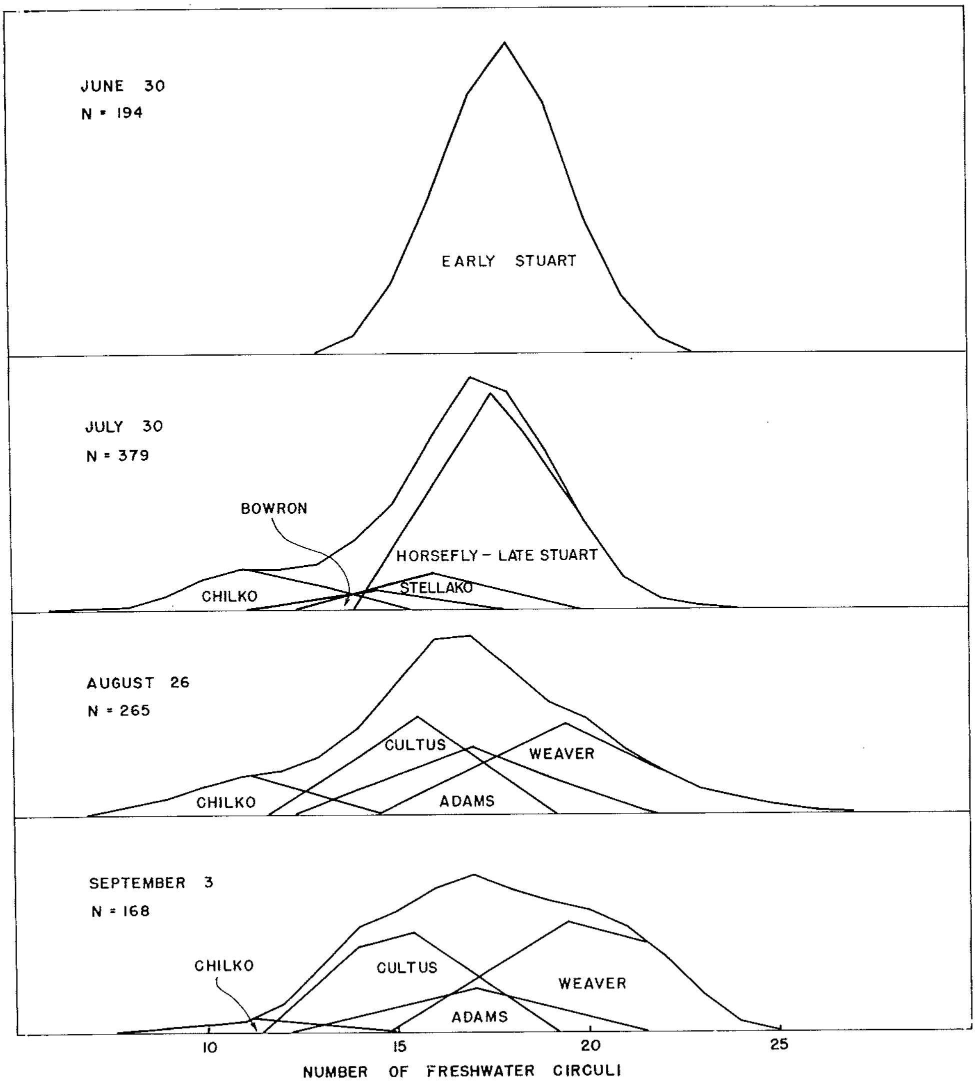

FIGURE 12—Smoothed freshwater scale circuli frequencies for samples of 4_2 sockeye from the San Juan Islands catches in 1957 showing estimated racial composition.

As explained previously, the approximate contribution of each race to the daily catch is obtained during the fishing season on the basis of the expected mean freshwater scale circuli count and the expected shape of the freshwater scale circuli frequency curve for each race, as determined either from jack scales the previous year or from smolt scales taken at the time of seaward migration. After the fishing season is over, the daily freshwater scale circuli frequency curves are re-analyzed and a more exact estimate of the daily racial composition is obtained using the freshwater ring counts from scales taken on each racial spawning ground.

The first curve in FIGURE 12 shows the freshwater scale circuli frequency for the sample at San Juan Islands on June 30, 1957. It is known from previous information, such as tagging and spawning ground arrival curves, that only the Early Stuart race is likely to be present at this time. The symmetrical distribution of the ring count frequencies in this sample, which is very similar to the freshwater circuli curve expected for Early Stuart fish on the basis of the 3_2 scales the previous year, indicates that only the Early Stuart race is present on this date.

The second curve in FIGURE 12 shows the smoothed freshwater circuli frequency curve for the sample taken from the San Juan Islands catch on July 30 of the same year. The skewness of this curve indicates that the catch is now obviously composed of sockeye of more than one race. Also, the mode of the circuli count has shifted to the left indicating a greater abundance of smaller circuli count fish. It is known from data previously referenced that the Early Stuart race has passed through the fishery by July 30, and the races which would most likely be present on this date are Chilko, Bowron, Stellako, Horsefly and Late Stuart, with the latter two races being by far the most abundant on the basis of comparative parent spawning escapements. Scale samples from the 1956 jacks indicated that the expected mean freshwater circuli count in 1957 would be about 11 for Chilko, about 14 for Bowron, about 16 for Stellako and close to 18 for Horsefly and Late Stuart. Horsefly and Late Stuart had very similar ring count curves on the basis of the 1956 jack samples. The mean freshwater scale circuli count for Horsefly jacks in 1956 was 17.98 and for Late Stuart jacks was 17.66. Furthermore, since there is considerable overlap in the time of migration of these two races, data for both Horsefly and Late Stuart have been combined in this analysis.

In estimating the racial composition of a daily sample curve such as the one for July 30, which is obviously composed of more than one race, the usual procedure is first to estimate the abundance of the races with both the highest and the lowest mean circuli counts, and then to estimate the abundance of the races comprising the remaining area under the central portion of the sample curve. In most instances, a triangle-shaped curve will sufficiently approximate the shape of the expected racial circuli curve. However, in addition to changes in the shape of the daily sample curves resulting from varying racial composition, sampling variation also has some effect on the shape of the curve. Thus, in some instances, the shape of the sample frequency curve can be such that the area under the curve cannot be completely assigned to the races known to be present, by using only triangle-shaped racial circuli frequency curves. In these instances, the shape of certain estimated racial curves has to be slightly adjusted so that all the area under the sample curve will be assigned to racial curves. Examples of such adjustments in the racial curves will be pointed out in the subsequent discussion of the 1957 data.

In analyzing the July 30 sample, the first step was to superimpose a quasi-normal curve which approximated the combined 1956 Horsefly and Late Stuart jack freshwater circuli curve, since these combined races had the highest mean ring count. Chilko, which had the lowest mean ring count of about 11, was estimated next. Since Chilko was the only race present with any significant number of ring counts below 11, the actual sample frequency curve up to eleven ring counts was used for the Chilko curve instead of a triangle-shaped curve. This is an example of how an expected racial curve can be adjusted so that all the area under the sample curve will be identified as to racial origin. After estimating the abundance of the Horsefly-Late Stuart and Chilko races, there was a small area from about 11 to 18 ring counts which was still unassigned as to racial composition. Two additional quasi-normal curves, one with a mean about 14 and a shape approximating the 1956 Bowron jack freshwater circuli curve, and the other with a mean about 16 and a shape approximating the 1956 Stellako jack freshwater circuli curve, were then superimposed on the sample frequency curve so that the total area under these four racial curves equalled the total area under the sample curve. The height of the superimposed Bowron and Stellako racial curves was of course restricted by the amount of unassigned area under the sample curve for each mean racial ring count. Thus, the area remaining unassigned for the Bowron mean ring count of 14 was slightly less than the area remaining unassigned for the Stellako mean ring count of 16, so it would be expected that the height of the Bowron curve would be somewhat less than the height of the Stellako curve. Certain other unknown races may also be present in these samples, but they are so unimportant in comparison with the races shown that, for the present, they are merely included in the estimated composition of the major races. After the fishing season is over the racial timing of these minor races can be determined from weir counts, Indian catches, or spawning ground arrival curves. Then, on the basis of the comparative sizes of the actual escapements enumerated on each racial spawning ground, and on the basis that all races appearing in the fishery at the same time are subjected to similar racial fishing mortalities, an estimate of the contribution of these minor races to the daily catch can be made. Naturally, any portion of the daily estimated racial composition credited to the minor races in this manner must be subtracted from the estimated racial composition of the appropriate major race or races.

The third curve in FIGURE 12 shows the smoothed freshwater circuli frequency curve for the sample taken from the San Juan Islands catch on August 26, 1957, and it is obvious that there has been considerable change in the shape of the curve since the July 30 sample. The dominant ring count mode has again shifted further towards the smaller ring counts indicating increased abundance of smaller ring count fish. On the basis of previous information regarding racial times of migration, Weaver, Cultus, Adams and Chilko would be the major races to expect in the catches on this date. Therefore, racial freshwater scale circuli frequency curves approximating the curves obtained from the 3_2 scales for these four races the previous year, were superimposed on the August 26 sample frequency curve in the same manner as described for the July 30 sample. A curve for Weaver with a mean ring count of slightly under 20 was first superimposed; then one for Chilko with a mean ring count of about 11, and again the Chilko curve was adjusted to account for all the area under the sample curve up to the ring count of eleven. Finally, a curve for Adams, with a mean ring count of about 17, and a curve for Cultus, with a mean ring count of about 15, were superimposed on sample curve. If the area under any ring count is known for a given race, then the area under the entire racial curve would be known, since the shape of each racial frequency curve is theoretically constant and there is a definite relationship between the area under the different ring counts in each racial curve. Therefore, the area under the 19 and

20 ring counts of the sample curve not assigned to Weaver, could be assigned to Adams. The area under these two ring counts determines the total area as well as the height of the Adams curve. The height and the area under the Cultus curve was restricted by the area remaining under the sample curve which had not been assigned to the other three races.

The presence of the Weaver fish in the August 26 sample is very clearly indicated by the increased number of fish in the 19 and 20 ring count group. Although Chilko represented about the same percentage of the August 26 sample as it did for the July 30 sample, there were actually considerably less Chilko fish caught on August 26 since the total catch on this date was much smaller than the catch on July 30. This can be seen from FIGURE 13 where the daily catches for the San Juan Islands fishery in 1957 are shown graphically.

The fourth curve in FIGURE 12 shows the smoothed freshwater circuli frequency curve for the sample taken from the San Juan Islands catch on September 3, 1957. In this fourth sample the decreased number of fish with a low freshwater scale circuli count indicates the declining contribution of Chilko fish to the catch. The increased percentage of Weaver fish, with a mean ring count around 20, is very obvious. For this September 3 sample, as with the previous samples, quasi-normal racial curves, based on the 3_2 scales from the previous year, were superimposed on the sample frequency curve to estimate the racial composition of the sample. Again the low ring count frequencies were assigned to Chilko. A curve for Weaver was also superimposed on this sample curve. However, in this sample a triangle-shaped curve for Weaver would have left a small area for the 21 and 22 ring counts which could not have been otherwise assigned, since there was no other known race appearing on this date with any significant number of 21 and 22 ring counts. Therefore, the shape of the Weaver curve had to be slightly adjusted to include this additional area. Likewise, a triangle-shaped curve for Cultus would have left a small unassigned area under the sample frequency curve for the 14 ring count. Therefore, the Cultus curve was also slightly adjusted to include this additional area. In this sample, as with the August 26 sample, the area under the 19 and 20 ring counts which was not assigned to Weaver, and could be assigned to Adams, immediately determined the total area as well as the height of the Adams curve. It might be thought that the alteration of the Cultus curve, to allow for the bulge at 14 ring count, could just as well have been made in the Adams curve. However, when there are two possible racial curves that could be altered to assimilate such additional areas, the alteration is always made in the curve for the most abundant race so that the effect of such a change on the estimated daily racial composition will be minimized.

To summarize the daily racial analysis procedure, it can be stated that the racial composition of the daily samples is estimated by systematically superimposing a series of expected racial curves on the daily sample frequency beginning with the races having the highest and the lowest mean ring counts. The expected racial curves can generally be approximated by a triangle-shaped curve. However, all the area under the sample curve must be assigned to the races known to be present, and in certain instances the triangle-shape of a racial curve is slightly altered so that no area remains unassigned. Such differences between an expected racial curve

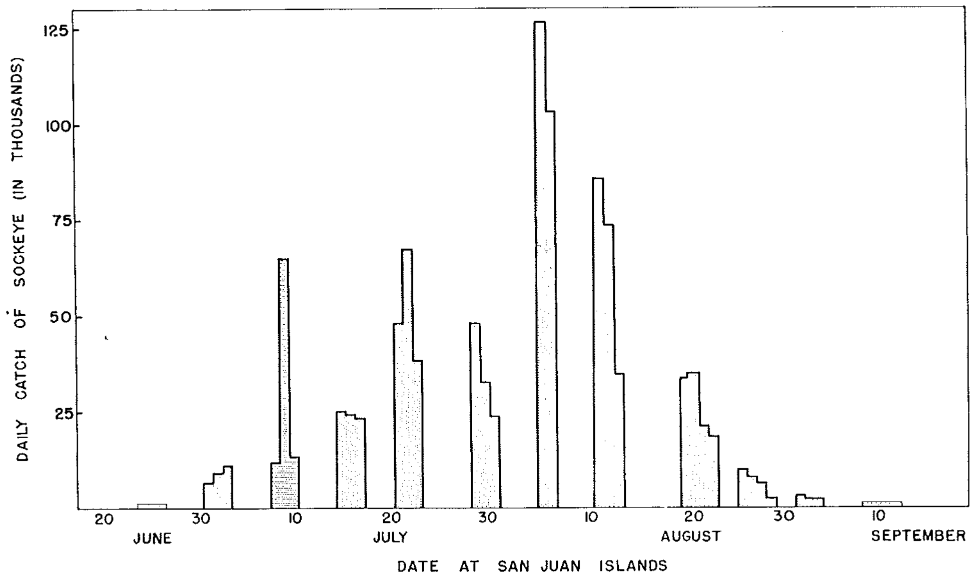

FIGURE 13—Daily commercial catch of sockeye in the San Juan Islands fishery, 1957.

and an adjusted racial curve should be expected in view of the possible sampling variation. Certain relatively unimportant races that may be present in the daily samples are initially included in the estimated composition of the major races. After the fishing season, racial time-abundance curves determined from spawning ground data, as well as the comparative size of the escapements of various races migrating at the same time, are used to estimate the contribution of these minor races to the daily catches. Any portion of the sample frequency credited to these minor races in this manner must be subtracted from the estimated catch of the appropriate major race or races.

In addition to estimating the racial composition of the daily catches, the scale identification method often can be used to estimate the contribution of hatchery reared sockeye compared with natural reared sockeye even though both groups may be from the same race.

Normally the production, or return, from a planting of hatchery raised salmon has been evaluated by means of marking experiments, whereby certain combinations of the fins are removed from the small fish prior to their release so that they can be recognized when they return as mature salmon. This is an expensive procedure and it also introduces into the results the not inconsequential physical effects of marking.

Although the Salmon Commission has had limited occasion to use hatchery fish in its rehabilitation program, the few experiments using hatchery fish have demonstrated that the racial scale method can be extremely useful in the evaluation of hatchery production.

In 1949, eggs taken from sockeye spawning in the Horsefly River were reared in the Commission's hatchery on Horsefly Lake. The fry from the natural spawning fish in the Horsefly River migrate downstream and are reared in Quesnel Lake. The fish reared in the hatchery were all marked by the removal of either the left or right ventral fins prior to their release directly into Quesnel Lake in November, 1950. The four-year-old sockeye from this experiment returned to the spawning grounds in 1953 (Internat. Pacific Salmon Fish. Comm., 1954). The freshwater scale circuli frequencies from a sample of the marked fish that returned to the hatchery, compared with a sample of naturally propagated, unmarked fish recovered on the Horsefly River spawning ground, are illustrated in FIGURE 14. The difference between the two curves is obvious. The hatchery reared fish had a mean ring count of 14.75 circuli, compared with a mean of 18.07 freshwater circuli for the naturally reared fish. The difference in the freshwater environment effecting each group of fish was reflected on their scales. Therefore, even if the one group of fish had not been marked, a composite frequency curve including freshwater scale circuli frequencies from both groups of fish could have been separated into the two racial components, even though they originated from the same population. This could be accomplished by superimposing two racial scale circuli frequency curves, one approximating the hatchery reared circuli frequency curve and one approximating the naturally reared circuli frequency curve, onto the composite curve in the manner previously explained in describing the racial scale identification method.

Route of Saltwater Migration

Usually, most of the returning Fraser River sockeye enter through Juan de Fuca Strait at the southern end of Vancouver Island (FIGURE 7), where they are subjected to a major Canadian fishery (Verhoeven and Davidoff, MS.). They then proceed through northern Puget Sound, the principal United States fishery, and enter the Fraser River Area, being subjected here to an extensive gill net fishery. Fishing regulations, based on past relationships between these three fishing areas, are designed for this normal migration path. Each year a relatively small portion of the run migrates past the northern end of Vancouver Island and approaches the Fraser River through Johnstone Strait. Usually, this does not represent much more than about 10 per cent of the total run and allowance is made for this in formulating the fishing regulations. On occasion, however, an unusually large percentage of the Fraser River sockeye run returns through Johnstone Strait and upsets the normal fishery relationships upon which the regulations are based. Gilhousen (1960) discusses this phenomenon and indicates some of the years in which unusually large portions of the sockeye run returned to the Fraser River via Johnstone Strait. Fortunately, racial scale analysis has proved to be an effective and extremely valuable management tool by which the occurrence of an unusually large portion of the run returning through Johnstone Strait can be detected early in the fishing season.

The initial identification of Fraser River sockeye in the Johnstone Strait catches is somewhat easier than the detailed division of the catch into individual Fraser River races, because in this instance there are only two groups to consider, Fraser and non-Fraser fish. The major non-Fraser sockeye race migrating through Johnstone Strait is believed to be the run to the Nimpkish River (FIGURE 7) on Vancouver Island. In 1957, the escapement to the Nimpkish area was reported to

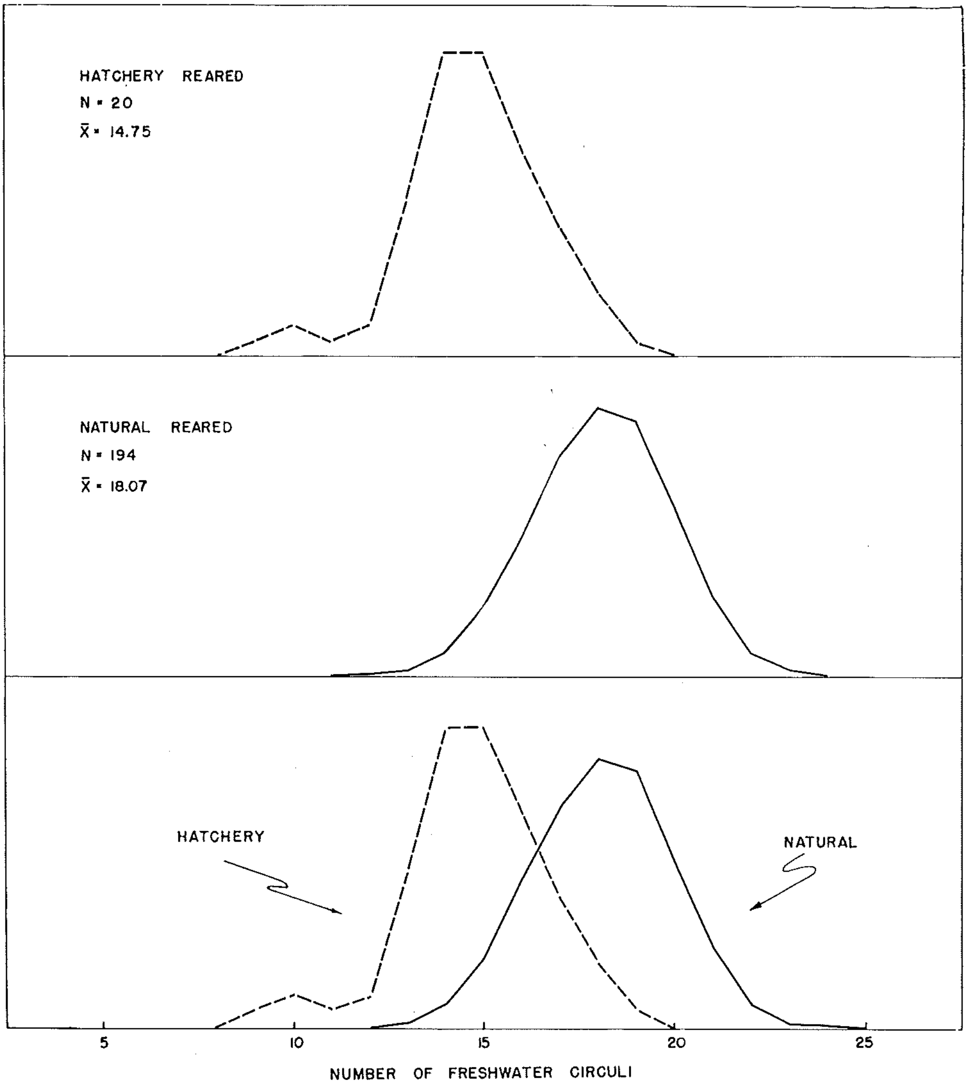

FIGURE 14—Smoothed freshwater scale circuli frequencies for samples of hatchery reared and naturally reared 1953 Horsefly River 4_2 sockeye.

be heavy, about 150,000 fish, and greater than the brood year (Can. Dept. Fish., 1957). In 1958, the Nimpkish escapement was estimated to be about 70,000 fish (*ibid,* 1958). These Nimpkish fish normally do not enter the lower Johnstone Strait, Area 13, fishery (Statistical Area for Canada Department of Fisheries). Rivers Inlet fish may contribute to the catch in the northern part of Area 12. However, as can be seen from the data in TABLE 12 both Nimpkish and Rivers Inlet fish are predominately 5_2, compared with 4_2 for the Fraser River. Furthermore, the mean freshwater ring count for these two races is consistently so low that they can be distinguished quite easily from Fraser River sockeye.

TABLE 12—Scale characteristics of Nimpkish River and Rivers Inlet sockeye salmon.

YEAR	SAMPLE SIZE	PER CENT					MEAN FRESHWATER CIRCULI COUNT	
		4_2	5_2	6_2	5_3	6_3	4_2	5_2
	Nimpkish River							
1939	27	48	52				7.92	9.64
1945	225	64	36				9.80	11.30
1950	175	40	60				7.71	8.32
1951	111	7	93				10.50	10.10
	Rivers Inlet							
1951	305	37	58	1	3	1	8.91	8.57
1952	402	52	45		1	2	9.00	7.36
1953	89	47	50		1	2	8.57	8.32

There are a number of other small sockeye races migrating through Johnstone Strait and spawning in streams along the British Columbia Coast north of the Fraser River, including runs to Hayden Bay, Phillips River, Sakinaw Lake, Klina-Klini River and Tzoonie River. Very little information is available on the characteristics of these runs although it is believed that they are generally of small magnitude, numbering a few thousand fish at most. A scale sample of 121 sockeye from Loughborough Inlet in 1951 was 96 per cent 5_3 fish. Four 4_2 and one 5_2 sockeye were recovered at the head of Knight Inlet in 1940 and 1941, presumably heading for the Klina-Klini River. The 4_2 sockeye had a mean freshwater ring count of 11 while the 5_2 fish had a freshwater ring count of 6. Low ring count fish are most abundant in the Area 12 samples and comprise only a small portion of the Area 13 samples. In the discussion that follows, the non-Fraser portion of the daily samples is assumed to include any Nimpkish or Rivers Inlet fish as well as fish from all the small sockeye runs spawning between the Fraser River and Rivers Inlet.

In FIGURE 15 are depicted a few representative freshwater circuli frequencies from samples of the Johnstone Strait catches in 1959 which will indicate the relative ease with which Fraser River sockeye can be identified in this area. In the top curve for Area 12, the presence of the two groups of 4_2 fish, low ring count non-Fraser and higher ring count Fraser, is very evident. The second curve is for the 5_2 fish of the same date, and as would be expected in view of the predominance of 5_2 fish in the non-Fraser runs, this sample appears to be composed primarily of low ring count, non-Fraser fish. The third curve in FIGURE 15 is for the sample of 4_2 sockeye from the catch in Area 13 at about the same date as the first sample for Area 12. The differences between the first and third curves indicates clearly that most of the non-Fraser, low ring count sockeye do not enter the Area 13 fishery and this sample is composed almost entirely of Fraser River fish. The fourth curve is for a sample of 4_2 fish taken from the Area 12 catch later in the fishing season. This curve shows the disappearance of the non-Fraser mode at about 11 to 12 ring count and the predominance of Chilko fish having a mean ring count of about 15.

In 1958, an unusually large portion of the Fraser River sockeye run returned through Johnstone Strait. This was initially detected through racial scale analysis of the Johnstone Strait catches. In TABLE 13 are listed the weekly calculated catches of Fraser River sockeye in Johnstone Strait in 1954 and 1958. As the season progressed in 1958, it became obvious that there was a large number of Fraser River sockeye returning by this northern route. However, it was not possible on the basis of these data alone to tell whether this actually represented a larger percentage of the run or merely a large run. Therefore, the weekly Johnstone Strait catches of Fraser River sockeye in 1958 were compared with the weekly Puget Sound catches one week later to allow for migration (TABLE 14). Also listed in TABLE 14 are similar comparisons for the weekly catches in the brood year, 1954, and in 1957, when a relatively large portion of the Fraser River sockeye run returned through Johnstone Strait. The unusual character of the approach path of Fraser River sockeye in 1958 made it necessary, in that one year only, to compare the weekly Johnstone Strait catch with the Puget Sound catch one week

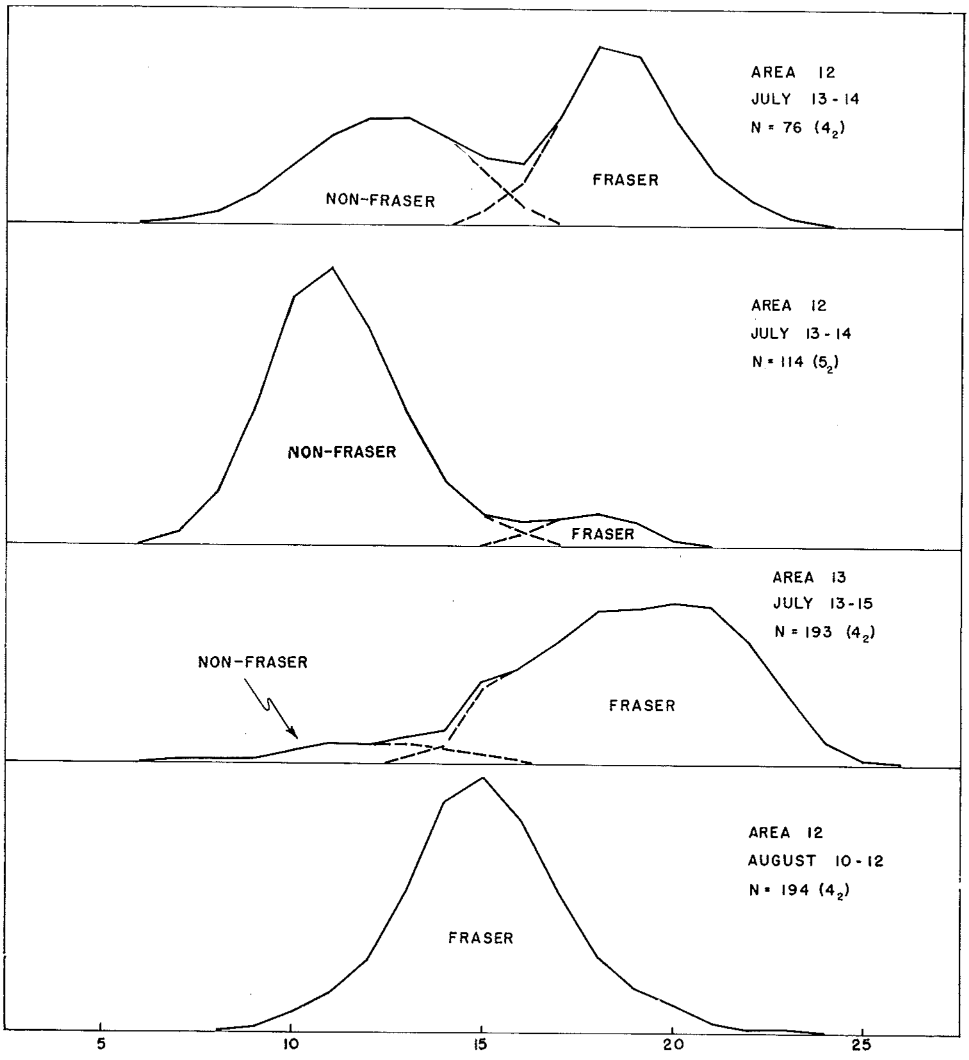

FIGURE 15—Smoothed freshwater scale circuli frequencies from Johnstone Strait sockeye catches, 1959.

later to allow travel time for the run to reach the Puget Sound fishery. In the other two years listed, the catches are compared for the same weeks since the arrival time in the two areas appears to be the same. It is quite apparent from these comparative catches that in 1958 a much greater portion of the Fraser River sockeye run than usual was returning via this northern route. This is even more evident when it is realized that there were only three days of fishing each week for the two weeks of peak catches in Johnstone Strait in 1958, whereas there were seven days a week fishing for the comparable two weeks in Puget Sound.

Gilhousen (1960) has related sun spot activity with periodic large migrations of Fraser River sockeye through Johnstone Strait and states (page 21): "The

TABLE 13—Estimated weekly catch of Fraser River sockeye in Areas 12 and 13, based on scale analysis, 1954 and 1958.

WEEK ENDING	WEEKLY CATCH			
	1954		1958	
	Total Catch[1]	Fraser	Total Catch[1]	Fraser
Before June 27	1,912	—	4,450	—
July 4	3,771	1,408	18,192	7,190
11	17,357	10,546	38,565	29,119
18	26,013	18,758	37,227	27,517
25	25,685	17,898	61,350	44,050
Aug. 1	16,354	14,677	111,000	106,607
8	10,135	8,870	216,224	212,552
15	23	20	303,408	301,174
22	12,110	10,687	976,119	972,649
29	5,543	5,258	1,147,736	1,145,620
Sept. 5	7,237	6,937	1,399,233	1,397,388
12	11,941	11,735	7,618	7,426
19	8,393	8,284	10,029	9,862
26	3,662	3,637	3,694	3,645
After Sept. 26	663	663	44	44
Totals	150,633	119,438	4,334,889	4,264,843

[1] Canada Department of Fisheries Statistics.

TABLE 14—Weekly calculated catches of Fraser River sockeye in Areas 12 and 13, based on scale analysis, compared with weekly catches in Puget Sound in 1954, 1957 and 1958.

WEEK ENDING	WEEKLY CATCH					
	1958		1954		1957	
	Areas 12 & 13	Puget Sound	Areas 12 & 13	Puget Sound	Areas 12 & 13	Puget Sound
Before June 27	—	—	—	83	—	1,546
July 4	7,190	Closed	1,408	13,282	49	35,975
11	29,199	Closed	10,546	52,700	1,657	123,907
18	27,517	14,559	18,818	74,626	68,191	110,487
25	44,050	38,922	17,898	154,266	49,061	226,610
Aug. 1	106,607	54,957	14,677	203,623	83,362	169,648
8	212,552	148,468	8,870	173,543	154,707	380,809
15	301,174	177,729	20	432,224	132,183	361,301
22	972,649	829,804	10,687	236,171	56,534	149,778
29	1,145,620	1,573,053	5,258	807,424	25,227	58,251
Sept. 5	1,397,388	1,419,224	6,937	2,151,702	6,532	52,436
12	7,426	335,878	11,735	423,557	2,916	11,213
19	9,862	324,237	8,284	40,079	893	889
26	3,645	245,166	3,637	5,152	121	61
After Sept. 26	44	63,053	663	1,912	8	—
Totals	4,264,843	5,225,050	119,438	4,770,344	581,541	1,682,911

relationship suggests that unusually heavy migration through Johnstone Strait will occur no more than one or two years out of each ten or eleven, and that an approximate forecast of the event can be made." This is extremely valuable information from a management standpoint and will aid greatly in future regulatory problems. Unfortunately, as stated above, this relationship between sun spot activity and large migrations through Johnstone Strait permits only an approximate forecast, and the 1958 maximum of migration occurred a year or two later than expected on the basis of this relationship. Therefore, in the final analysis, it will be the current scale studies of the Johnstone Strait catches that will determine the extent of the migration of Fraser River sockeye through Johnstone Strait.

In TABLE 15 are listed the calculated weekly catches of Fraser River sockeye in the Johnstone Strait fishery from 1953 through 1959, as well as the total Convention waters catch and escapement. The Johnstone Strait catch of Fraser River sockeye has ranged from 0.98 per cent (1954) to 22.85 per cent (1958) of the total run returning to the Fraser River during these years. The actual proportion of the total run migrating through Johnstone Strait each year would be somewhat higher since these percentages are based only on the number of Fraser fish caught, and the escapement of Fraser River sockeye from this area should be added to these calculated catch figures. Unfortunately, the portion of the total Fraser River escapement coming from Johnstone Strait each year is not known.

Another use of scale identification in management relates to the determination of the area of landfall when the Fraser River sockeye approach the Canadian West Coast on their spawning migration. As pointed out by Gilhousen (1960, page 10), Fraser River sockeye predominate in the troll catches of sockeye off Vancouver Island. In 1958 these troll catches indicated that the Fraser River sockeye approached the coast much farther north than usual. This more northerly approach in 1958 was also associated with the unusually large migration through Johnstone Strait. To be useful to management, information regarding the area of landfall must be available almost immediately during the fishing season, and this is possible by means of scale identification.

In 1959, with the more northerly approach and the large migration of sockeye through Johnstone Strait in 1958 still in mind, the West Coast troll catches were

TABLE 15—Calculated catch of Fraser River sockeye in Areas 12 and 13 based on scale analysis, compared to total run, 1953-1959.

Year	Johnstone Strait Catch of Fraser Fish	Convention Waters Catch Plus Escapement	Total Run	Per Cent of Total Run Caught in Johnstone Strait
1953	422,228	5,407,266	5,829,494	7.24
1954	119,438	12,108,735	12,228,173	0.98
1955	153,272	2,559,506	2,712,778	5.65
1956	123,737	2,742,884	2,866,621	4.32
1957	581,541	4,809,842	5,391,383	10.79
1958	4,341,030[1]	14,658,970	19,000,000	22.85
1959	346,936	4,404,552	4,751,488	7.30

[1] Includes 76,187 fish from Areas 14-16.

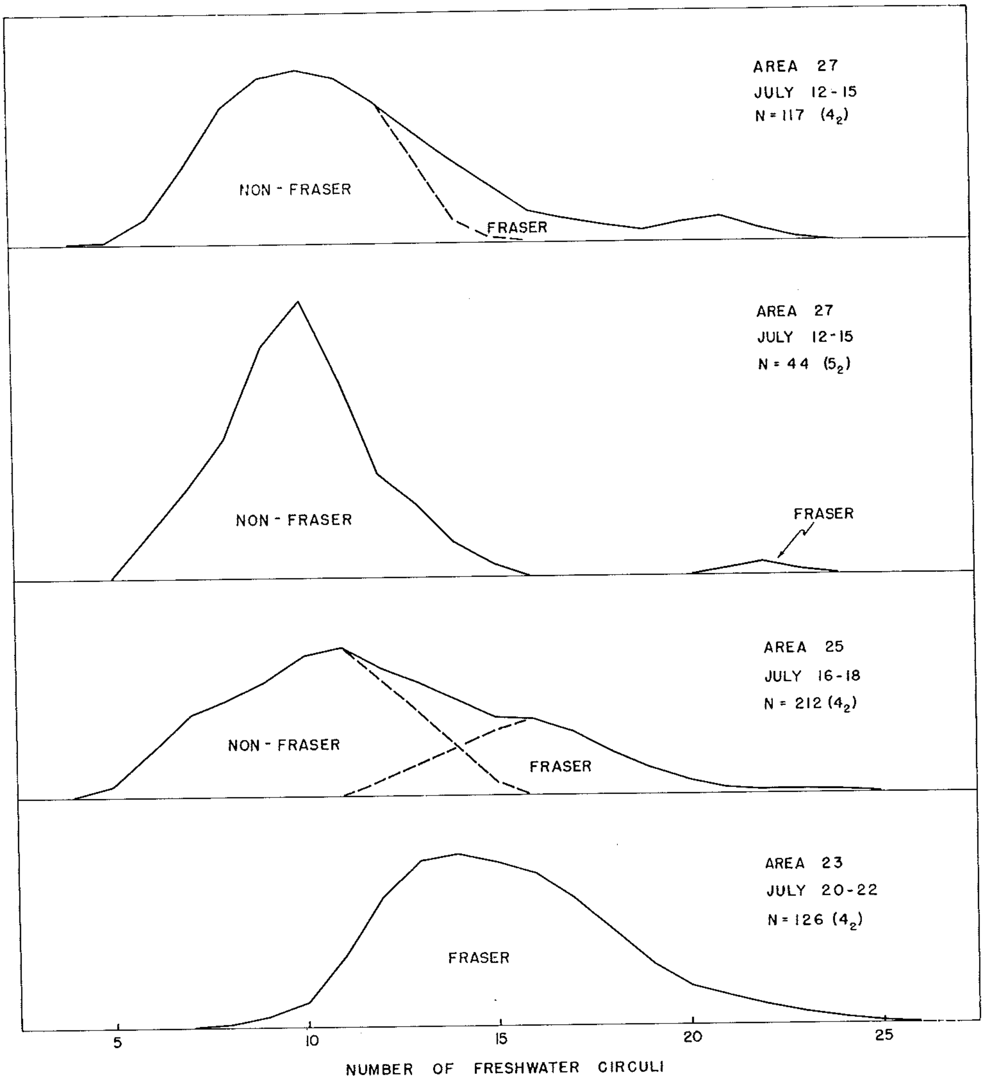

FIGURE 16—Smoothed freshwater scale circuli frequencies from troll catches of sockeye, 1959.

examined very closely for the first possible clue as to the area of the 1959 landfall. In FIGURE 16 are shown the freshwater scale circuli frequencies for certain samples collected from the troll catches during July, 1959. The upper curve represents the freshwater circuli counts for 4_2 sockeye from Area 27 (FIGURE 7) for July 12 to 15. This sample clearly indicates that most of the 4_2 sockeye in Area 27 had low ring counts and were therefore non-Fraser fish. Also, 25.9 per cent of this sample were 5_2 fish; this is a very high percentage for Fraser River fish and would again indicate the presence of a large proportion of non-Fraser fish. The second curve in FIGURE 16 shows the circuli count frequency for the 5_2 fish from the July 12 to 15 sample from Area 27, and this curve also shows almost no Fraser River fish. A sample from Area 25 at about the same time, third curve, shows a considerably larger percentage of 4_2 Fraser River fish and the percentage of 5_2 fish dropped to 20.4 per cent. The fourth curve presents a sample of 4_2 sockeye taken from the Area 23 catch and is almost entirely Fraser River fish. The percentage of 5_2 fish in this Area 23 sample dropped to 13.4 per cent. These data clearly indicated, even at this early date, that the major 1959 landfall was south of that in 1958 and was in the neighborhood of Area 23. The season's troll catches for the various West Coast areas in 1958 and 1959 are listed in TABLE 16. These catch data substantiate the conclusions based on the scale data, particularly in view of the fact that the catches shown for Areas 25, 26 and 27 consisted mainly of non-Fraser fish in 1959, whereas the 1958 catches from these three areas were mainly Fraser fish.

TABLE 16—Troll catches of sockeye in certain fishing areas off the West Coast of Vancouver Island in 1958 and 1959 (Canada Department of Fisheries Statistics).

AREA	1958	1959
27	5,737	2,334
26	4,609	2,809
25	5,584	2,177
24	2,015	3,996
23	3,279	16,132

Time of Saltwater Migration

A knowledge of the timing of races in the fishery is extremely important to the proper management of the fishery. Preliminary fishing regulations must be submitted to the fishing industry several months in advance of the fishing season. These tentative regulations are formulated to obtain the required racial escapements at the proper time on the basis of the expected racial timing. It, therefore, becomes extremely important to determine at the earliest possible date whether the races are timed as contemplated under the original regulations, or whether they are earlier or later than expected, so that the fishing regulations can be modified accordingly.

A specific example of the importance of racial timing data to the proper management of the fishery can be demonstrated by data from the 1957 fishing season. One of the major concerns of management during the season was to give added protection to the Horsefly and Late Stuart races. These races, while they are again becoming major producers after being almost exterminated by the Hell's Gate obstruction (Thompson, 1945, page 169), are still below maximum production. Racial analysis of the daily scale samples from the San Juan Islands fishery indicated the following percentage composition for the Horsefly-Late Stuart races:

July 21 — 18%	July 29 — 74%	Aug. 5 — 79%
July 22 — 28%	July 30 — 71%	Aug. 6 — 78%
July 23 — 40%	July 31 — 76%	

These data, plus the actual daily catches (FIGURE 13), indicated clearly that the August 5 and 6 catches were near the peak of abundance for these races. Consequently, the fishery was closed on August 7 to give added protection to these two races. The additional escapement in this single day amounted to nearly 100,000 fish. Without the immediate information made available by the racial scale method, such close control of the fishery would be impossible.

Data from the 1958 season can be used to demonstrate the value of racial scale identification in the determination of variations in expected racial timing. The 1958 races actually returned ten days later than was anticipated (Internat. Pacific Salmon Fish. Comm., 1959, page 3). Fortunately, racial scale identification for the Early Stuart race, which is the first Fraser River race to appear in the fishery, indicated that this race was later than expected. In view of the lateness of the Early Stuart race, it was anticipated that the Adams River race, which would appear several weeks after Early Stuart and which comprised about 80 per cent of the total 1958 Fraser River sockeye run, might also be late. Therefore, it was possible, fairly early in the fishing season, to properly adjust the tentative fishing regulations, which primarily had been designed for the Adams River race, so that they would be applicable to the anticipated lateness of the Adams fish. This knowledge of a possible change in the expected timing of the run is not only valuable to the management agency, but also to the fishing industry in permitting them to make adjustments to meet the changed timing.

The exact manner in which the lateness of the 1958 Early Stuart race was determined can be seen by examining FIGURE 17, which shows the calculated daily catches of Early Stuart fish in 1954 and 1958 for the Lower Fraser River fishery (below Pattullo Bridge) based on the daily racial scale analysis. At the start of the 1958 fishing season the Early Stuart timing was expected to be about the same as it was in 1954, and the 3_2, or jack, returns in 1957 had indicated increased abundance in 1958 over 1954 (Internat. Pacific Salmon Fish. Comm., *ibid.*). However, the daily calculated catches of Early Stuart fish in early July of 1958 were considerably less than was expected if the timing was the same as in 1954 and if there was the expected increase in the size of the run. These small catches indicated that the 1958 Early Stuart race was either much smaller than the 1954 race or that it was later. The difference between whether the run is smaller than anticipated or merely later than anticipated presents a very serious problem to a salmon management agency. If the race is not late and is smaller than anticipated, then immediate emergency closures of the fishery are required in order to obtain the desired escapement from the smaller than expected run. If additional closures are not put into effect the run will in all probability be overfished. On the other hand, if the run is merely late, additional emergency closures could result in an excessive racial escapement unless additional regulatory adjustments to permit increased fishing are subsequently made.

The calculated catch of Early Stuart fish on July 9, 1958 (FIGURE 17), gave the first real indication that the 1958 run actually was late, because the racial catch of Early Stuart fish was still increasing although the date of the peak catch in 1954 already had passed. The analysis of the July 14 sample clearly showed that the size of the daily Early Stuart catches was still increasing, and it was then obvious that the timing in 1958 was later than it had been in 1954. It was not possible to determine exactly how much later the 1958 run was until the peak racial catch had occurred and the racial catches began decreasing in size.

The 1960 Chilko run represents another example of the management problem that is created when a race is unexpectedly late. It had been anticipated that the timing of the 1960 Chilko run would be approximately the same as the 1952 run, on the basis of alternate migration time in successive generations on a four-year cycle (Gilhousen, 1960), and would reach its peak of abundance in the Puget Sound fishery around August 1. However, when the time for the expected peak abundance arrived and the calculated catches of Chilko fish remained poorer than expected, the problem immediately arose as to whether the run was smaller or later than expected. The analysis of the Early Stuart catches earlier in the season had not indicated that the Early Stuart fish had returned later than anticipated. Therefore, rather than risk overfishing the run, additional emergency closures were put into effect to make certain that the necessary Chilko escapement was obtained. When it was discovered that the Chilko run actually was quite large and merely late, additional fishing was permitted on the latter part of the Chilko run so that the escapement was not excessive. Here again is an example of how improved management of the fishery results from the use of the racial scale identification method.

In FIGURE 18 are depicted the times of passage at the San Juan Islands of the Chilko races in 1956, 1957, 1958 and 1959. These time-abundance curves have been smoothed by eye and approximate the calculated daily racial catches based on scale analysis. The yearly variations in timing and the extreme lateness of the 1958 run are obvious. This variability of timing applies to other races as well. For example, the Lower Adams River race peaked in the San Juan Islands fishery on August 29 in 1954, August 17 in 1955 and September 2 in 1958. With the yearly variations occurring in racial timing in recent years, and because there is as yet no reliable information available as to the cause of these variations, it is impossible to accurately predict when the peak period of racial abundance will occur in any particular year. For this reason some method of currently determining racial timing, such as the method just described, is necessary to effectively manage a salmon fishery on a racial basis.

In TABLE 17 are listed the dates for the normally expected peak of racial abundance, as well as the dates for the normally expected beginning and ending of the racial migrations of Fraser River sockeye at the San Juan Islands, based on racial scale analysis of the daily commercial catch.

Speed of Migration

Knowledge of the speed of migration of various races of sockeye through the different fisheries is very important in management, particularly in determining

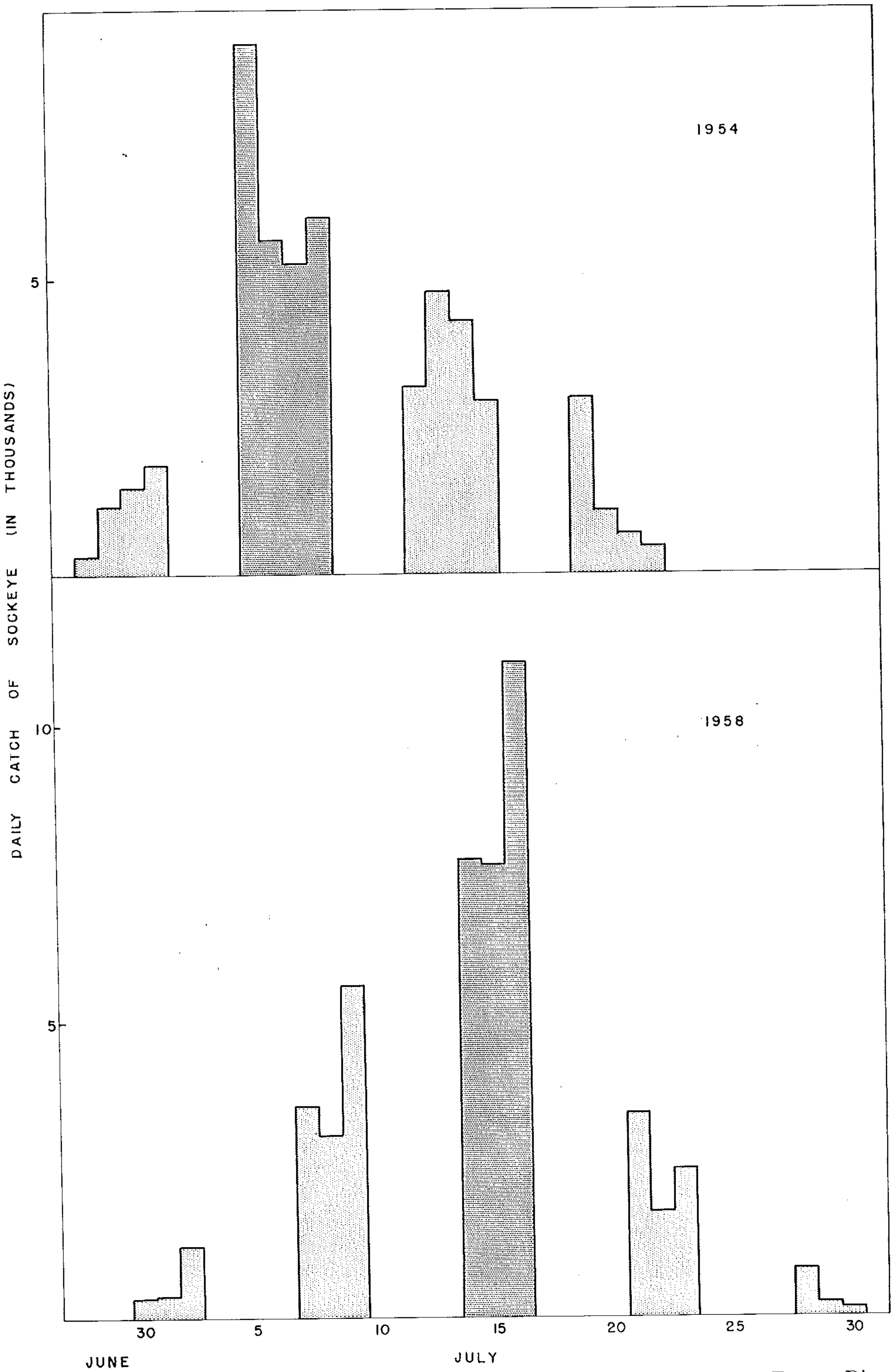

FIGURE 17—Calculated daily catches of Early Stuart sockeye in the Lower Fraser River fishery, based on racial scale analysis, 1954 and 1958.

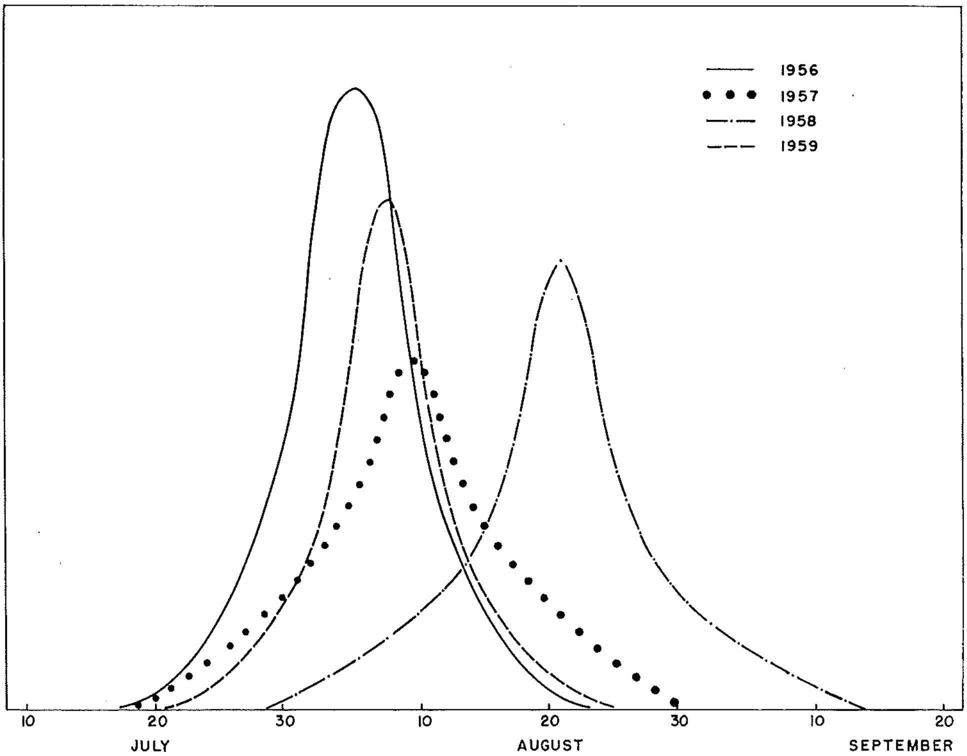

FIGURE 18—Estimated time of passage of Chilko sockeye at San Juan Islands, based on calculated racial catches, 1956-1959.

the time and length of closures to permit additional escapements. Tagging is often used to measure speeds of migration but the results based on tags can be affected by a number of errors. Verhoeven and Davidoff (MS.) discuss factors that could effect the apparent migration speed of tagged sockeye, such as the effect of tagging, and the error in the reported location or time of tag recovery.

The date of occurrence of peaks of abundance, as measured by the catch, has also been used to measure the rate of progress of salmon from one fishery to another. Ward (1959) used this method to estimate migration rates for the 1957 run of Fraser River pink salmon. Since daily racial catches of Fraser River sockeye can now be calculated by the scale analysis method, it is possible to use the date of peak racial catches in the different fisheries as one measure of the speed of migration of individual races of sockeye. However, as will subsequently be demonstrated in the case of sockeye, it is virtually impossible to use date of peak catch alone as a reasonable measure of speed of migration through the fishery, and this is particularly true whenever there are extended closed periods in the fishery. In recent years, the increasing size of the fishing fleet has necessitated shorter periods of fishing in each fishing area, so that it is quite common to have only two or three days fishing a week. Such short fishing periods make it very difficult to follow the peak of abundance from one fishing area to the next. The peak of the run can pass through one area during a closure but be fished in subsequent

TABLE 17—Normal expected times of passage at San Juan Islands of various Fraser River sockeye races, based on scale analysis.

RACE	PEAK DAY	DURATION OF RUN
Early Stuart	July 6	June 20 — July 24
Bowron River	July 20	July 4 — August 5
Pitt River	July 22	July 7 — August 7
Nadina River	July 23	July 5 — August 8
Horsefly River	July 28	July 17 — August 6
Seymour River	August 3	July 21 — August 18
Chilko River	August 2	July 10 — August 31
Stellako River	August 4	July 18 — August 31
Raft River	August 2	July 21 — August 16
Late Stuart	August 3	July 18 — August 21
Birkenhead River	August 10	July 20 — September 4
Weaver Creek	August 16	July 25 — September 5
Lower Adams River	August 22	August 5 — September 12
Cultus Lake	August 21	July 31 — September 20+

areas. Furthermore, there can be significant differences in availability of the fish in the different areas. These factors often result in a false peak in one area being compared to true peaks in succeeding areas. In view of these difficulties, it is therefore necessary that other data be used to modify the results based on peak catches if reasonable estimated speeds of migration are to be obtained. Since racial time-abundance relationships appear to approximate a normal curve, as shown for the Chilko race in FIGURE 16, normal curves can be used to approximate the racial catch curve indicated by the calculated daily catches. The use of these normal curves tends to eliminate the vagaries in the daily catches caused by changes in availability, by changes in fishing intensity, or by the effect of peaks of abundance migrating through an area during a closed period, and permits the migration speeds based on peak days of catch to be reasonably modified.

The calculated 1957 catches of Chilko sockeye in the different fishing areas, progressing from Juan de Fuca Strait to the Lower Fraser River fishery, are shown in FIGURE 19. Arrows joining the peak daily catches in the different fishing areas also are shown. There were many closed periods in that year and any conclusions regarding migration speed based on peak days of catch alone would be erroneous. On the basis of peak catches alone, the migration from Juan de Fuca Strait to San Juan Islands required 15 days, and the peak catch in the San Juan Islands occurred one day later than at Point Roberts. Also, the migration from Point Roberts to the Lower Fraser River required eight days. On the basis of tagging data (Verhoeven and Davidoff, MS.), as well as general knowledge of the fishery, such migration rates appear absurd. Therefore, these speeds of migration were modified on the basis of normal abundance curves approximating the daily catches in the different fishing areas.

The general shape of the daily catches in Juan de Fuca Strait indicate that a normal time-abundance curve approximating the daily catches (FIGURE 19) would have a peak of abundance around August 3, and that the peak catch on July 22 was due to an abnormal increase in availability on that date. Normal curves approximating the daily catches in the other areas indicate peaks about August 6

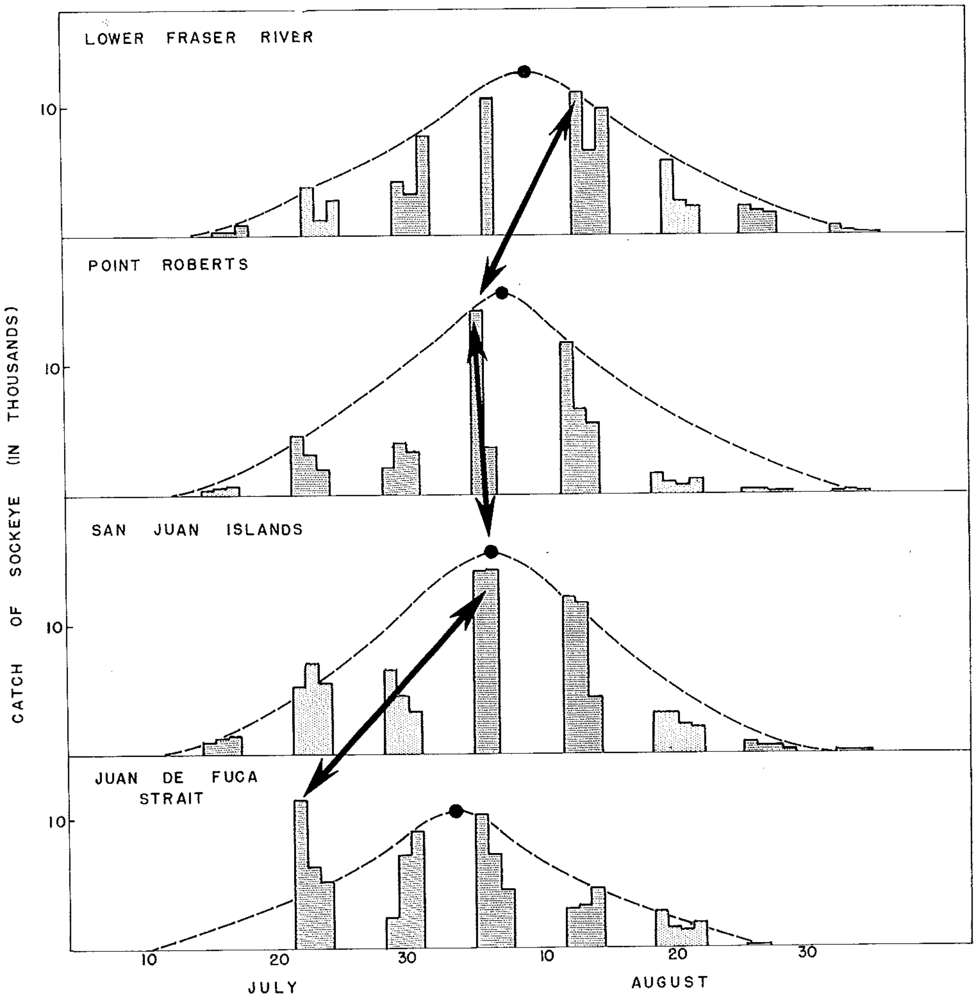

FIGURE 19—Daily calculated catches of Chilko sockeye in various fishing areas in 1957, showing estimated normal-shaped abundance curves (arrows indicate peak catches and dots indicate peaks of abundance on the basis of the normal-shaped catch curves).

in the San Juan Islands, a migration of three days from Juan de Fuca Strait; about August 7 at Point Roberts, a migration of one day from the San Juan Islands; and about August 9 in the Lower Fraser River, a migration of two days from Point Roberts.

In 1959, the Canadian fishery was on strike during the early part of the Chilko run. The United States fleet was permitted to fish 11 straight days with only one day of closure during the peak of the Chilko run. This period of more consistent fishing permitted an improved estimate of the migration time between the two major United States fishing areas, San Juan Islands and Point Roberts. However, again peak catches alone gave erroneous estimates for the speeds of migration.

The daily calculated catches of Chilko sockeye in the different fishing areas in 1959, as well as the estimates of the total daily Chilko escapement at the upper

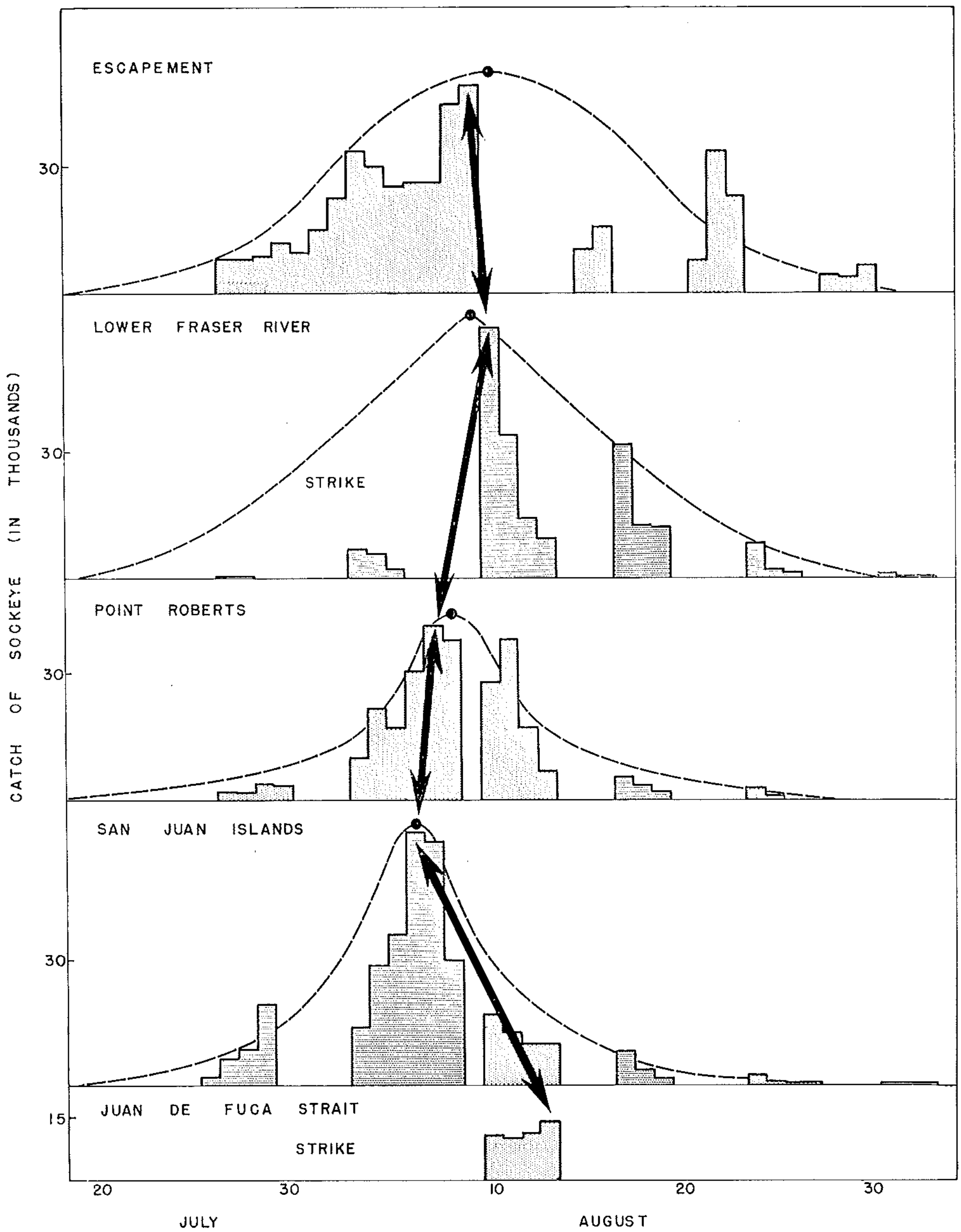

FIGURE 20—Daily calculated catches of Chilko sockeye in various fishing areas and estimated daily escapements from the Fraser River gill net fishery in 1959, showing estimated normal-shaped abundance curves (arrows indicate peak catches and dots indicate peaks of abundance on the basis of the normal-shaped catch curves).

limit of the commercial fishery, are shown graphically in FIGURE 20. Arrows join the peak daily catches. The Canadian strike ended August 10. It is apparent that the Canadian Juan de Fuca Strait fishery missed most of the 1959 Chilko run and did not catch enough Chilko fish to warrant any attempt to estimate a migration time from that fishery. The peak catch in the San Juan Islands on August 6 was followed by a peak catch at Point Roberts one day later. The peak catch in the Lower Fraser River fishery occurred on August 10, or three days later than at Point Roberts, whereas the peak in the escapement occurred one day earlier than the peak catch in the Lower Fraser River. Here again, normal-shaped catch curves are needed to reasonably modify these data based on peak catches, particularly for the Lower Fraser River. When there is almost continuous fishing with no significant closed periods, as occurred in the San Juan Islands and Point Roberts fisheries, the daily catch usually closely approximates the actual abundance curve. Therefore, the peak day of catch, August 6, at the San Juan Islands also appears to be the peak day of abundance on the basis of a normal catch curve. The peak of abundance appears to be August 8 at Point Roberts on the basis of a normal catch curve. This gives a migration time of two days from San Juan Islands to Point Roberts. The Canadian strike makes it difficult to determine exactly when the peak passed through the Lower Fraser River. The August 9 closure at Point Roberts undoubtedly contributed significantly to the size of the August 10 Lower Fraser River catch. When the Lower Fraser River catch and the escapement are considered together, it appears that the peak in the escapement probably would have occurred about August 10 with a peak of abundance in the Lower Fraser River on August 9. This would indicate one day's migration from Point Roberts to the Lower Fraser River, and one day from the Lower Fraser River to the escapement.

Certain other facts important to the management of the 1959 Chilko run can also be discerned from the racial catch data in Figure 20. With the Canadian fishery on strike, the only possible method of avoiding excessive escapement was to permit almost unrestricted fishing in United States waters. Even with this intense United States fishery, considerable escapement occurred prior to the end of the strike on August 10. It is also apparent that this intense United States fishery, with only one day closure during the 11-day period from August 3 to August 13, inclusive, combined with the Lower Fraser River fishery from August 10 to August 13, was capable of almost eliminating all escapement for an eleven day period from August 10 to August 20, inclusive.

It is difficult to establish a migration time originating at the Juan de Fuca Strait fishery on the basis of peak day of racial catch primarily because of the extended periods of closure in recent years. As pointed out previously, the Canadian Juan de Fuca Strait fishery did not begin until August 10 in 1959 because of a strike. In 1957, the shape of a normal catch curve indicated that the day of peak abundance at Juan de Fuca Strait was probably August 3, with approximately a three day migration to the San Juan Islands. In 1958, the Juan de Fuca Strait fishery did not begin until August 20 and missed most of the Chilko run.

The best data for estimating the speed of migration throughout the fishery is available from the 1956 season when fishing in all areas was undisturbed by strikes and remained reasonably consistent throughout the fishing season. The daily calculated catches of Chilko sockeye in the different fishing areas in 1956 are shown graphically in Figure 21. The peak day of catch at Juan de Fuca Strait

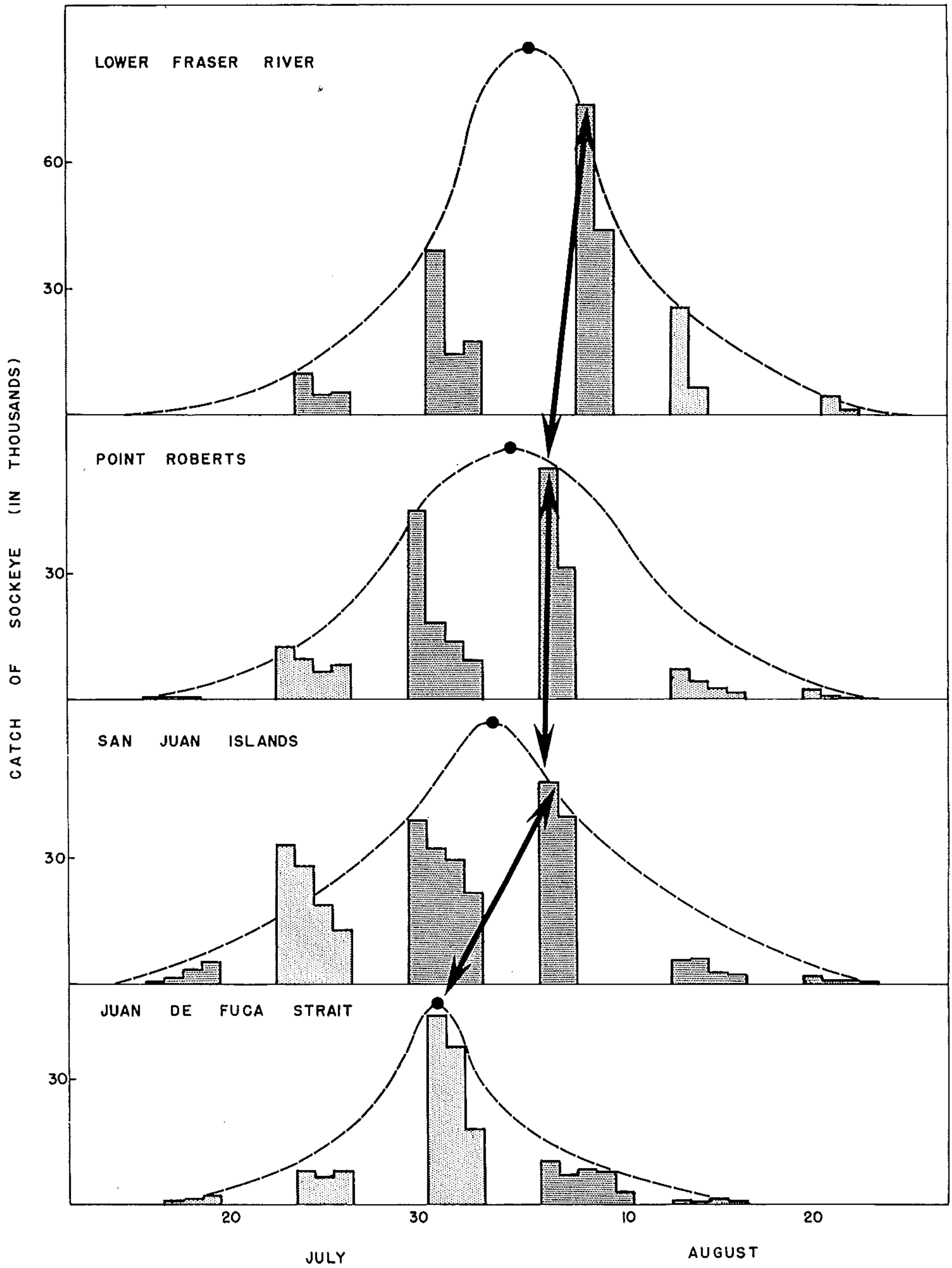

FIGURE 21—Daily calculated catches of Chilko sockeye in various fishing areas in 1956 showing estimated normal-shaped abundance curves (arrows indicate peak catches and dots indicate peaks of abundance on basis of normal-shaped abundance curves).

was July 31. The peak catch in the San Juan Islands occurred on August 6, six days later than the Juan de Fuca Strait peak. The peak catch at Point Roberts also occurred August 6. These data, particularly the occurrence of the peak catches in the San Juan Islands and Point Roberts on the same day, indicate that unusual availability and closed periods in 1956 caused migration times based on the peak day of catch to be misleading. Normal curves approximating these daily catches indicate that the peak of abundance in Juan de Fuca Strait was July 31, with a peak in the San Juan Islands August 3, or a three day migration time between these two areas. The peak abundance at Point Roberts, on the basis of a normal catch curve, appears to be about August 4, one day later than at the San Juan Islands, and August 5 in the Lower Fraser River.

The modified migration times determined in this manner for 1956, 1957 and 1959 are summarized in TABLE 18 together with the migration data determined by Verhoeven and Davidoff (MS.) from tagging experiments. There are certain differences in the areas for which the migration is measured by these two methods. Sooke is closer to the San Juan Islands than the Juan de Fuca Strait fishery. Also, Salmon Banks is the southernmost fishing area in the San Juan Islands fishery, so there would be the greatest possible distance between this portion of the San Juan Islands catches and the Point Roberts catches. There is close agreement between the results from these two different methods.

TABLE 18—Estimated speed of migration for Fraser River sockeye based on normal-shaped catch curves and on tagging.

AREA	Days Migration Based on Normal-Shaped Catch Curves			AREA	Days Migration Based on Tagging[1]
	1956	1957	1959		
Juan de Fuca to San Juan Islands	3	3	—	Sooke to Salmon Banks	2
San Juan Islands to Point Roberts	1	1	2	Salmon Banks to Point Roberts	1-2
Point Roberts to Lower Fraser River	1	2	1	Point Roberts to Lower Fraser River	1

[1] Verhoeven and Davidoff, MS.

Delay

Another problem involved in the management of Fraser River sockeye is created by the fact that certain races of sockeye delay off the mouth of the Fraser River for varying periods before entering into the river. This phenomenon was originally demonstrated in the results from marine tagging experiments (MacKay *et. al.*, 1944 and 1945), and is a factor which at certain seasons of the year has the effect of slowing down the speed of migration. In recent years, racial scale analysis also has been valuable in measuring the extent of this delay and in aiding in the solution of the management problems created by a delay.

The freshwater circuli count frequencies change daily and unless a delay occurs enroute, the pattern of the changes moves progressively from fishing area to fishing area as a function of the racial migration rate through the fishery. Races which do not delay show a normal ring count progression through the various fishing areas. This type of race is demonstrated in FIGURE 22, using the catch data in early August, 1959, when the Chilko race (mean ring count of 15.2), a non-delaying race, represented approximately 45 per cent of the catch. On the basis of the conclusions determined in the preceding section on the speed of the migration of Fraser River sockeye, fish passing the San Juan Islands fishery will arrive in the Lower Fraser River fishery approximately two days later, and approximately three days later in the Upper Fraser River fishery between New Westminster and Mission, British Columbia. The similarity of the circuli frequency curves from samples of the catch for each of these three areas is very evident, clearly indicating a normal progression of the Chilko race through all these areas.

While the Chilko race has a relatively uniform forward movement, the Adams River race, which appears in the fishery in late August, tends to delay in the

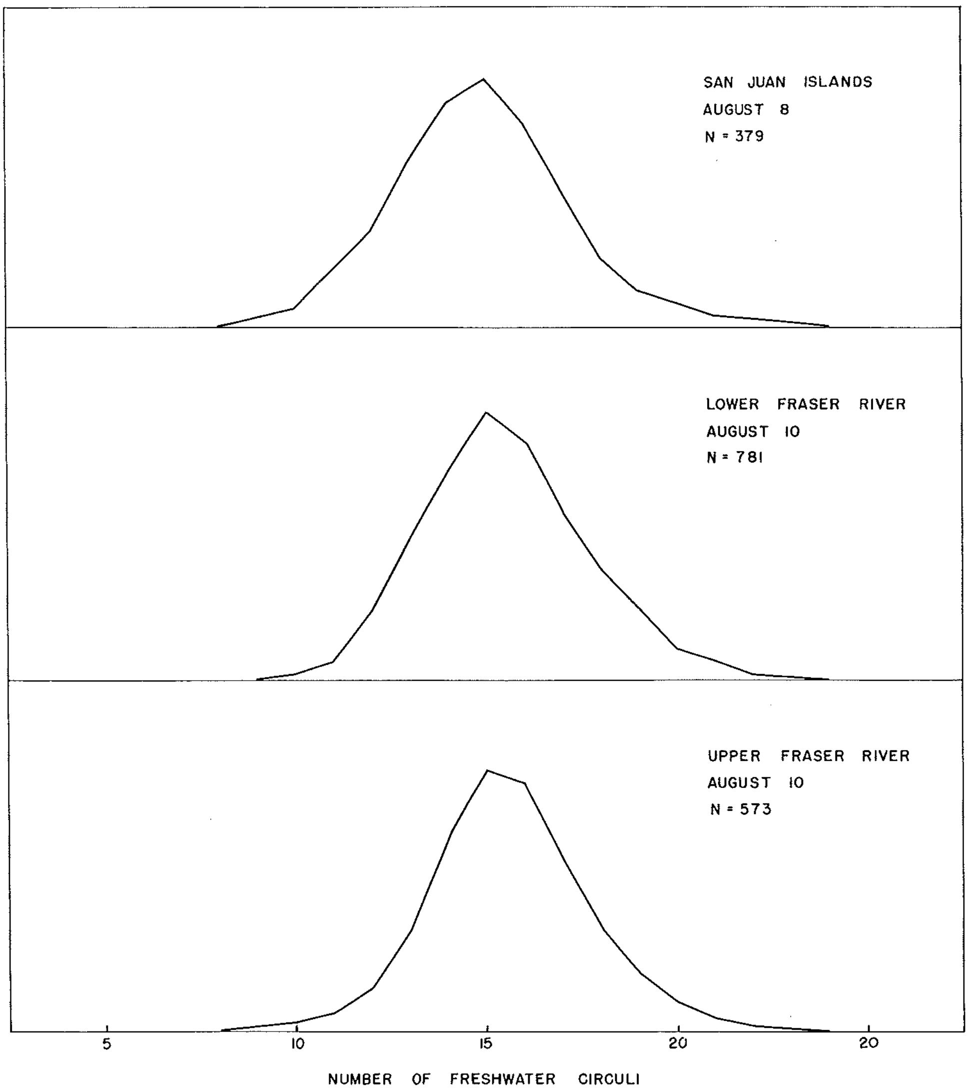

FIGURE 22—Smoothed freshwater scale circuli frequencies for 4_2 sockeye from catches in three different fishing areas, 1959.

estuarial area off the mouth of the Fraser River. The estuarial delay for this race is discussed in considerable detail by Gilhousen (1960). In the case of the Chilko race there is a normal progression of freshwater circuli curves from one fishing area to the next, but during the Adams run the circuli frequency curves have a different relationship in these three areas due to the delaying tendency of Adams River fish.

In FIGURE 23 are shown a series of circuli frequency curves taken from the San Juan Islands catches August 22, August 29 and September 5, 1958. The gradual increasing percentage of the Adams fish (mean ring count of 12.0) during this period, as evidenced by the increasing number of fish with low ring counts, is very noticeable, reaching a calculated 60 per cent of the catch on September 5.

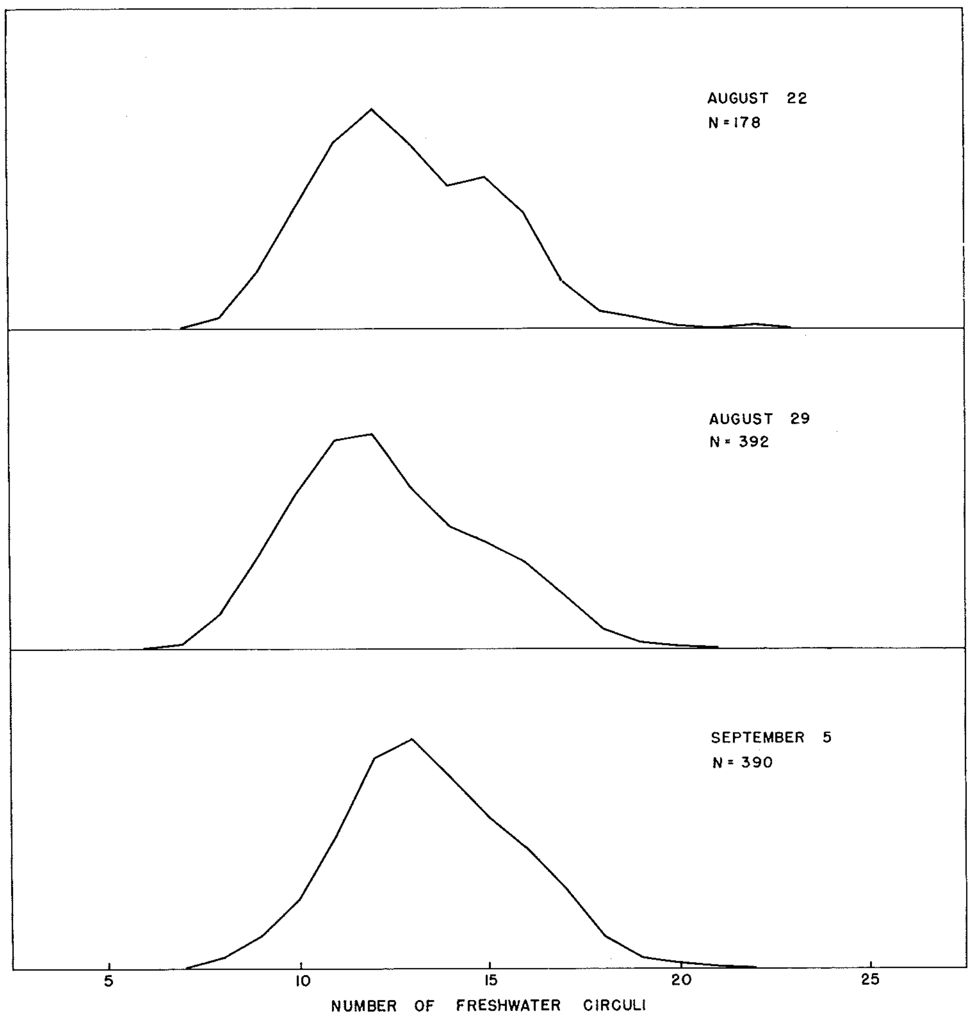

FIGURE 23—Smoothed freshwater scale circuli frequencies for 4_2 sockeye from San Juan Islands catches, 1958.

FIGURE 24 shows a series of circuli frequency curves for the Lower Fraser River-Gulf of Georgia fishery for the period August 22 through September 9, 1958. The differences between these samples and those in FIGURE 23 are very prominent. The fishery in this area is normally concentrated in the mouth of the Fraser River, particularly when non-delaying fish are present. However, when there is a large number of delaying fish in the Gulf of Georgia, as during the Adams run, more effort is expended in fishing farther out into the Gulf away from the river. The samples shown in FIGURE 24 were all taken from catches made in the Gulf of Georgia and do not include any of the fish taken in the Fraser River proper. The circuli count frequency for the August 22 sample in FIGURE 24 is

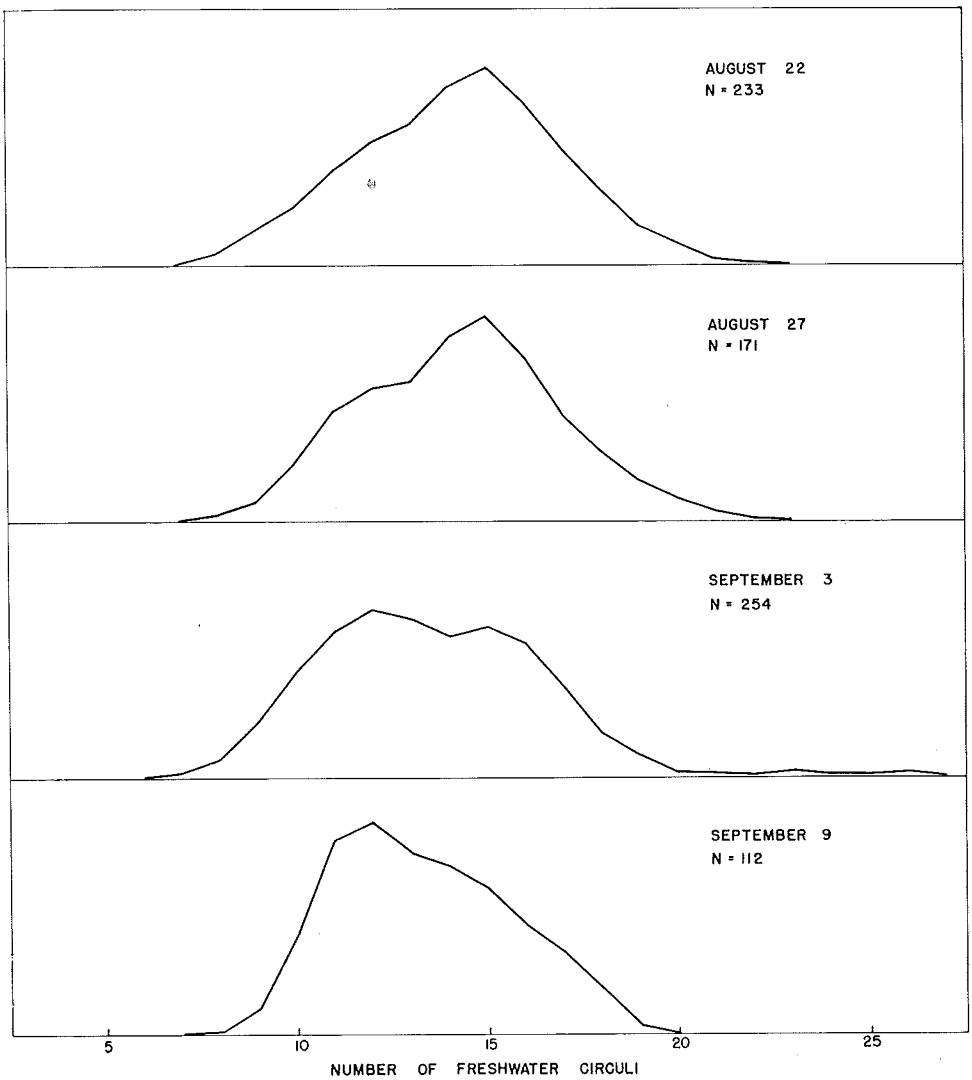

FIGURE 24—Smoothed freshwater scale circuli frequencies for 4_2 sockeye from Gulf of Georgia catches, 1958.

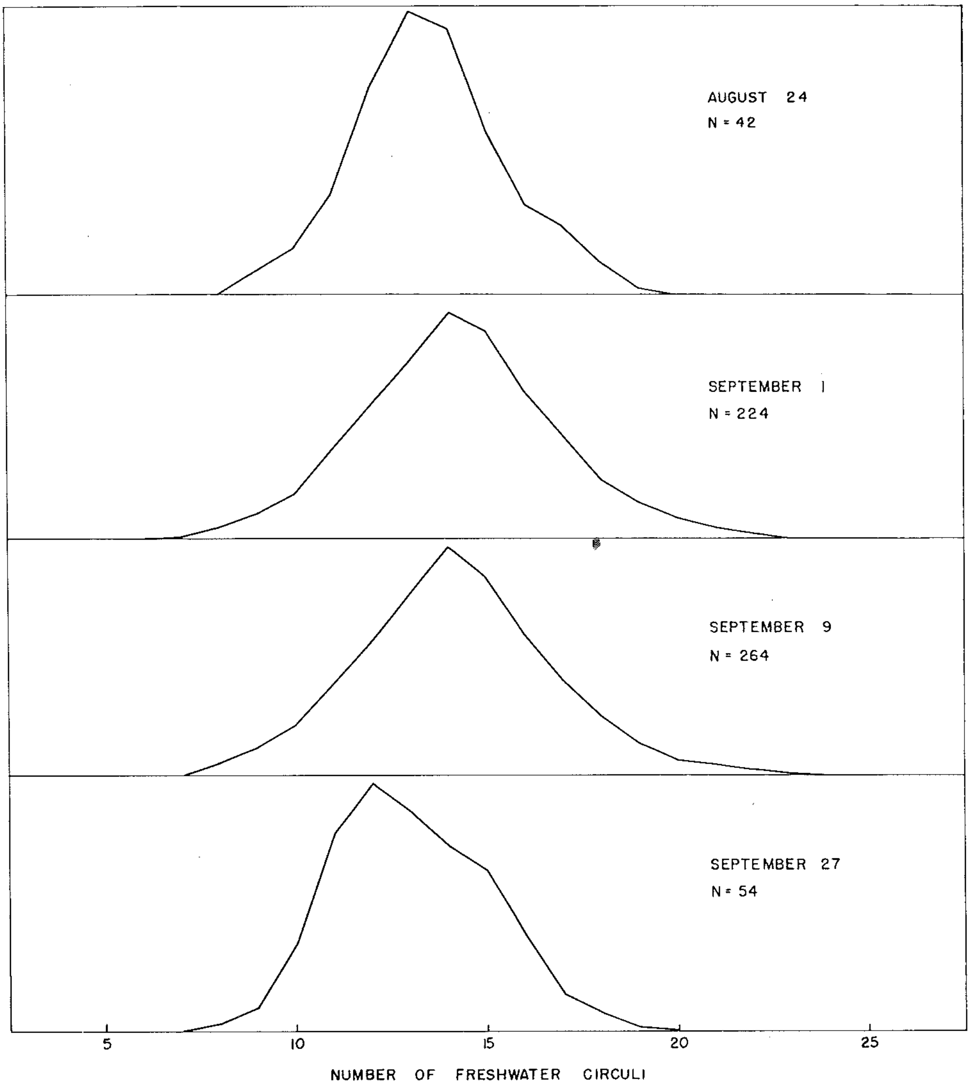

FIGURE 25—Smoothed freshwater scale circuli frequencies for 4_2 sockeye from Upper Fraser River catches, 1958.

very different from the August 22 sample at the San Juan Islands. Instead of Adams being the dominant race, Chilko, Stellako and Seymour still dominate the catch. On the 27th of August, it is apparent that Adams is increasing in importtance in the Gulf of Georgia catches, as shown by the increasing number of low ring count fish, but Adams still constitutes considerably less of the catch than it did on August 22 at the San Juan Islands, whereas the normal migration speed for non-delaying fish between these two areas would be about two days. The sample September 2 shows Adams finally becoming the dominant race but still less important than on August 22 at the San Juan Islands. The September 9 sample shows the increased importance of Adams fish in these catches.

The third area, Upper Fraser River, represents catches of fish that are actively migrating. Samples from this fishery are shown in FIGURE 25. The Upper Fraser River fishing area includes the area from Pattullo Bridge to Mission in the Fraser River. The ring count frequency for the August 24 sample from the Upper Fraser River catch is also quite different from the August 22 samples in the other two areas, because delaying Adams fish are not present in this sample. This sample is composed primarily of Seymour and Chilko fish. There is still no indication of Adams fish in the September 1 sample or even in the sample for September 9. The sample taken on September 27 shows a considerable portion of the catch to be made up of Adams fish (mean ring count 12), indicating that Adams fish finally had commenced their upriver migration in volume.

These differences, or similarities, between samples from the different fishing areas perhaps can be made more evident by superimposing the curves for the different areas as shown in FIGURE 26. In examining these differences, it should be remembered that the normal speed of migration from the San Juan Islands fishery is two days to the Lower Fraser River fishery and three days to the Upper Fraser River fishery. The upper group of three curves in FIGURE 26 represents the samples from the catch on August 22 at the San Juan Islands, the catch on August 22 in the Gulf of Georgia and the catch on August 24 in the Upper Fraser River fishery. The dominance of the low ring count Adams fish in the San Juan Islands sample and their absence in the other samples is very noticeable. In the center group of three curves, the build up of the Adams fish in the Gulf of Georgia catches is very evident as well as the lack of these fish in the Upper Fraser River catches. The lower group of three curves shows the Adams fish obviously becoming dominant in the Gulf of Georgia catches but still not appearing in the Upper Fraser River catches.

On the basis of these data, it can be concluded that the Adams fish pass through the United States fishery and enter the Gulf of Georgia, where they delay and are not available in volume to the fishery for several days. They gradually become more available to the Gulf fishery as the time for their upriver migration approaches.

Another race which appears to delay, at least in certain years, is Stellako. Additional information became available during the 1958 fishing season which substantiated the evidence, based on racial scale analysis, that the Stellako race was delaying.

In FIGURE 27 are shown daily counts of Stellako sockeye arriving at the outlet of Fraser Lake in 1958. These counts were made by the Aluminum Company of Canada. When these daily counts are referred back to the Fraser River fishery on the basis of migration rates by the method established by Killick (1955), it is apparent that the main upriver migration occurred during the month of August. This conclusion was also suggested by the test fishing data.

Referring again to FIGURE 24 and to the samples from the Gulf of Georgia for September 3 and September 9, it will be noted that in addition to the mode for the delaying Adams fish, at about 12 rings, there was another group of fish with a ring count mode about 15. In 1958 the mean freshwater ring count for Stellako

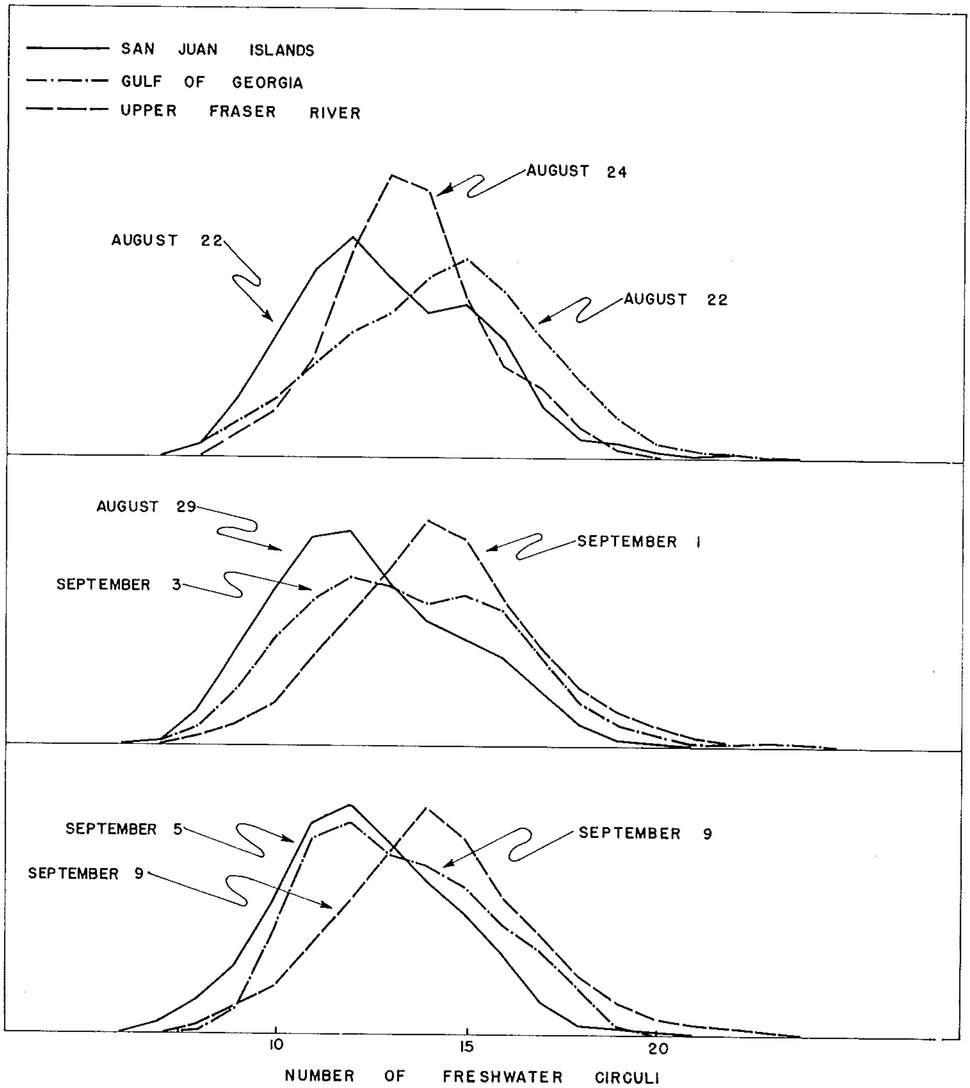

FIGURE 26—Smoothed freshwater scale circuli frequencies for 4_2 sockeye from catches in three different fishing areas, 1958.

sockeye was about 15 (TABLE 2), so these scale samples indicated that there probably still was a relatively large number of Stellako fish delaying in the Gulf of Georgia past the date when the bulk of this race had already migrated up the river.

On October 7, a large number of sockeye were reported ascending the Bridge River Rapids fishway on the Fraser River (FIGURE 1), approximately 50 miles above the confluence of the Thompson River, by an inspector for the Canada Department of Fisheries. The Adams River race migrates up the Thompson River and has never been known to appear at the Bridge River Rapids fishway. The inspector reported that 26 fish a minute entered the fishway and that as many as 60 fish at a time could be observed below the fishway. Sockeye were still passing

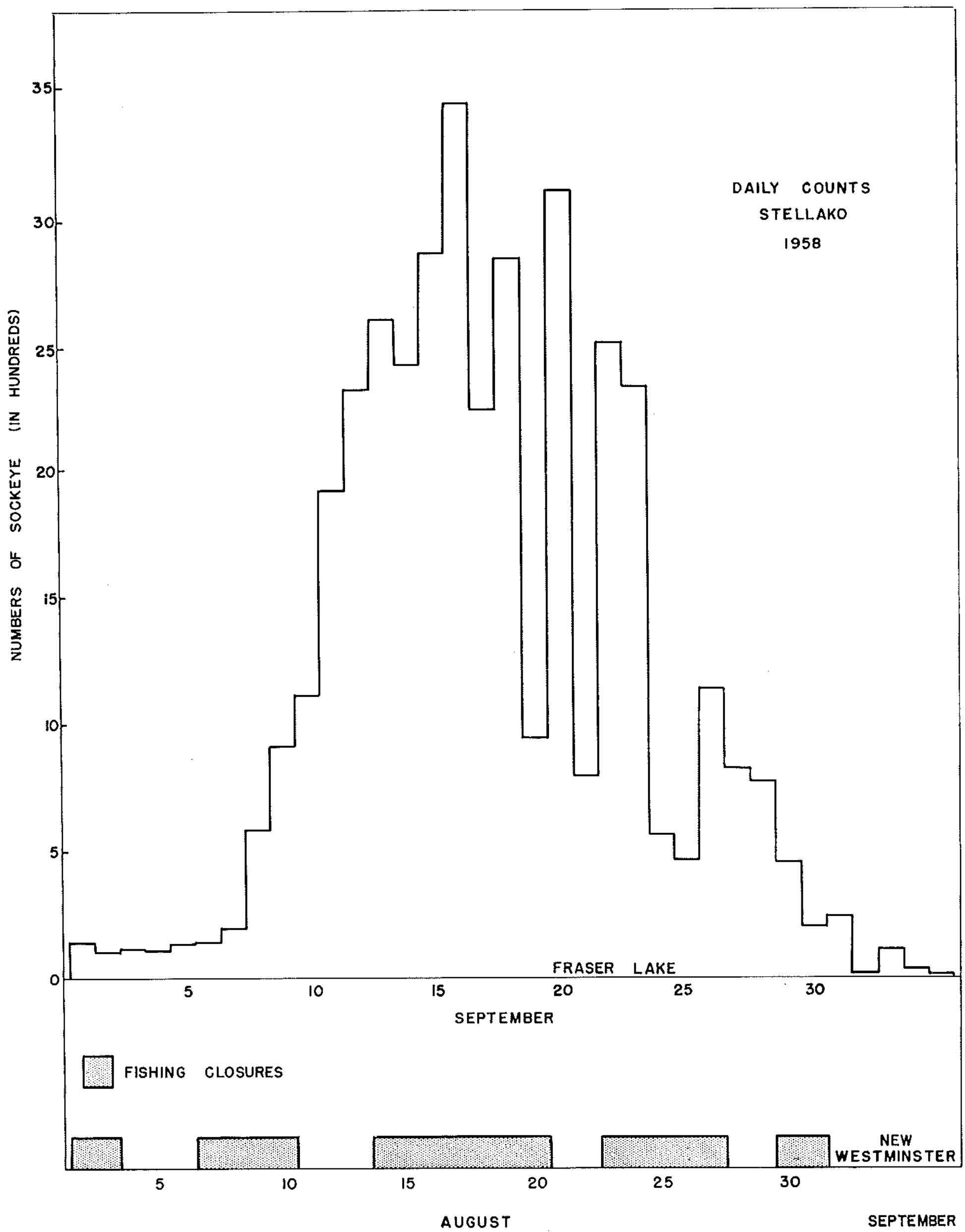

FIGURE 27—Dates of passage of 1958 Stellako sockeye through the Fraser River gill net area and Fraser Lake.

in large numbers two days later at which time a scale sample was obtained. The freshwater ring counts for this sample were:

Ring Count		Number
14		8
15		14
16		2
	Mean	14.8

again indicating very clearly that these were Stellako fish. At the time these fish were reported as "all fish highly colored and physical condition deteriorating in many cases." These fish were reported reaching Soda Creek, approximately 132 miles above Bridge River, October 19, and October 21 the Indians at Soda Creek were reportedly catching 65 sockeye an hour, with the fish being in an advanced stage of maturity. A fair number of sockeye were also reported caught by the Indians October 20 at Marguerite, about 15 miles above Soda Creek. No reports of these fish were received from the area above Marguerite, and they certainly would have been observed by the Salmon Commission staff on the Stellako River or other upriver spawning grounds had they reached any of these areas. It is indicated that they had delayed so long in the Gulf of Georgia that they probably had used up their energy reserves and, consequently, were unable to complete their spawning migration (Idler and Clemens, 1959).

It is estimated that there were between 75,000 and 100,000 fish in this late group. Such a large group of salmon delaying unexpectedly in this manner presents a very serious problem to management. Racial fishing regulations are designed to permit a given number of fish to escape the fishery and to permit the remainder to be caught. Therefore, when a significant portion of the allowed for escapement unexpectedly delays in this manner, this results in an inadequate number of fish on the spawning ground with no possibility of obtaining any additional escapement. Furthermore, fish which delay past their normal migration time would no longer be timed properly to the environmental cycle on their spawning ground, and would not be desirable spawners, or else they would be incapable of reaching their spawning ground. Such delaying fish, if at all possible, should be harvested by the fishery.

Escapement

Racial scale analysis has also been extremely useful to racial management in securing the proper escapements. Certain aspects of this problem were previously discussed in the section explaining the test fishing procedure, but an additional example will emphasize the importance of racial identification in the escapement if proper racial management is to be successful.

In 1958, it was desirable that there be a good escapement to the Stellako River, inasmuch as this is the most productive cycle for this race (Royal, 1953). Analysis of the scale samples from the Puget Sound fishery had indicated that a considerable number of Stellako fish had already passed through that fishery by the middle of August, but the analysis of the escapement past the commercial fishing area in the Lower Fraser River indicated that there had not been sufficient Stellako fish escape to the spawning grounds. A special closure of the Fraser River fishery was put into effect August 18, extending the normal weekly closure for the specific purpose of allowing more Stellako fish to escape (Internat. Pacific Salmon Fish. Comm., 1959, page 16).

In FIGURE 28 are listed the daily estimated racial escapements during this special August closure in 1958, based on test fishing and racial scale analysis, for the Seymour, Chilko and Stellako races. Scale analysis of these test fishing catches indicated that Stellako was not migrating in the expected numbers. Instead, Sey-

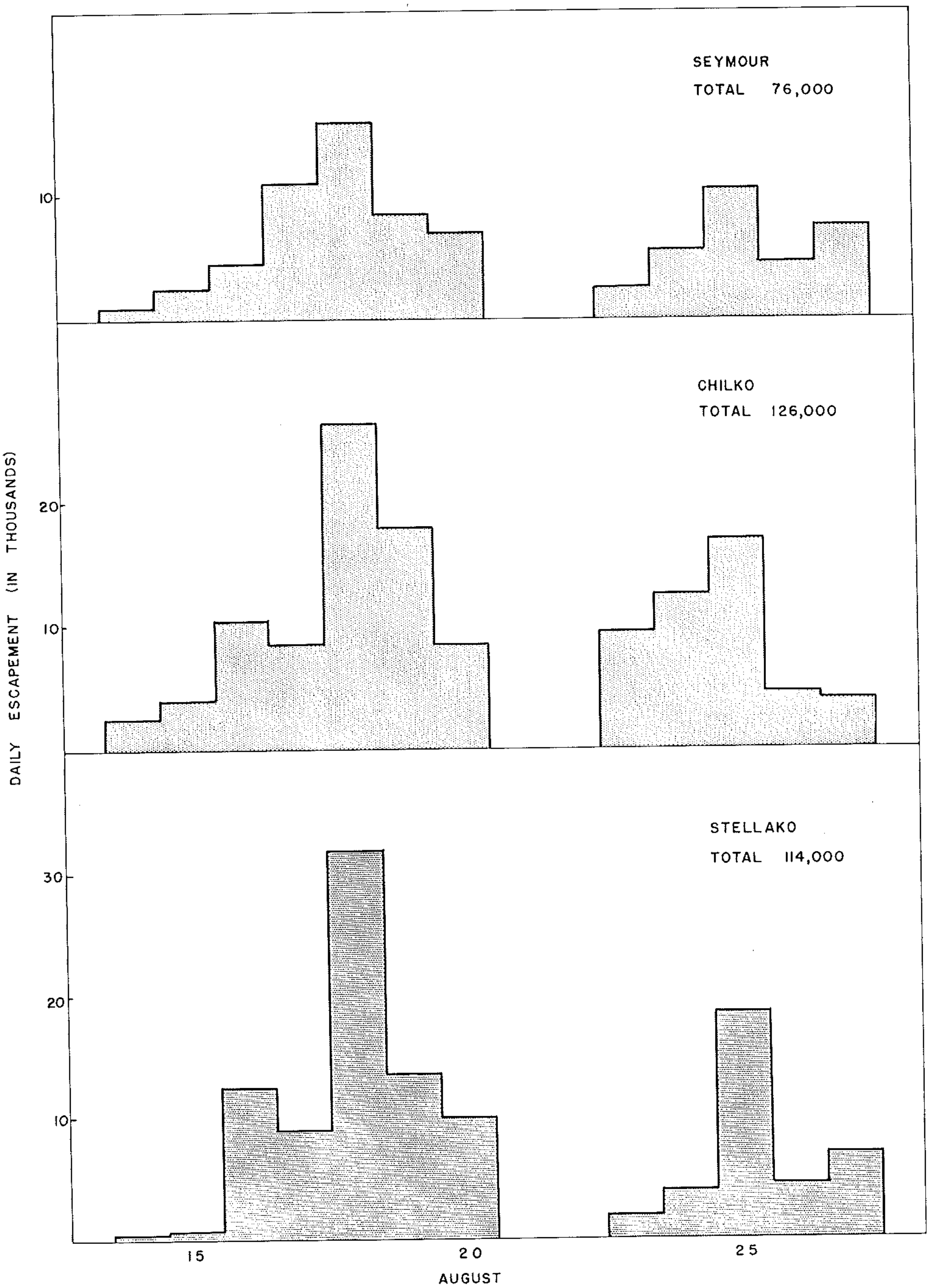

FIGURE 28—Calculated daily racial escapements during special August closure, based on test fishing and racial scale analysis, 1958.

mour, and particularly Chilko, were escaping in large numbers. The large escapement to Seymour was satisfactory, but the escapement to Chilko was considered excessive and undesirable in view of the fact that the 1958 cycle for this race normally is low in productivity. The principle being followed currently by the Salmon Commission in this matter can be stated as follows (Internat. Pacific Salmon Fish. Comm., *ibid.*): "Pending further biological evidence the current principle of management requires that the escapement during the off-years of production in each spawning area be kept at a low level to avoid possible conflict of year classes and possible lowered total yield. The continuous existence of these cycle years of low production has been noted as far back as 1820 long before the existence of a commercial fishery." In view of this established principle, it was not considered practical from a management standpoint to continue this closure for the specific protection of Stellako fish and it was ended on August 21, 1958. The pattern of the racial escapements during the normal weekly closure, after two days of fishing, (FIGURE 28) justified this decision.

Marine Survival and Growth

The ability to distinguish the various races of Fraser River sockeye in the fishery, combined with the enumeration of seaward smolts, has made it possible to obtain estimates of the marine survival based on studies of the Chilko River race. In the discussion to follow, marine survival includes survival from the enumeration of the smolts at the outlet of their lake rearing area to the enumeration of the returning adults.

Not only is it important to be able to measure the marine survival, but even more important from a management standpoint would be the ability to forecast marine survival in future years. It is becoming increasingly important that a management agency be able to forecast the expected magnitude of the returning run, and having the ability to do this would be a tremendous asset, both to the fishing industry in preparing for the fishing season and to the management agency in formulating the necessary fishing regulations.

The need to forecast the size of the returning run of salmon is not restricted to the management of the Fraser River fishery. Royce (1960), speaking of Alaska salmon management, also lists forecasting as one of the five major types of information required to regulate for maximum sustained yield. In a subsequent publication (1961, page 24), Royce estimates that the forecast of the expected magnitude of the 1960 red salmon run to Bristol Bay, Alaska, resulted in five million *more* red salmon being caught, which were worth about $12,000,000 in the can.

Once estimates of marine survival have been obtained, it then becomes possible to examine in more detail various factors which might possibly be related to marine survival and, consequently, used to forecast future survival. One of the factors which has been considered in this respect is the amount of growth occurring during the first year in salt water, as measured by the scales. McAllister (1961) suggests that the inability of young fish to obtain sufficient zooplankton during winters in the ocean, which would certainly be reflected in the growth of the fish, could be critical periods for the survival of young fish.

Scale samples of 4_2 sockeye from the Chilko spawning ground for the years 1953 through 1960 have been examined, and the growth from the outer edge of the freshwater circuli to the outer edge of the first marine annulus measured. The scales were projected from a *Promar* projection microscope as illustrated in Clutter and Whitesel (1956, page 7). The units of measurement are immaterial since the total measurement is dependent upon the degree of magnification. The same person made all the measurements and the same degree of magnification was maintained for all the measurements. The magnification was such that first-year-marine scale growth generally averaged about 90 millimeters. Only sockeye that had spent one year in freshwater were used in this analysis.

Before using the scale growth data it was necessary to establish some criteria as to the sample size required. A method frequently used to determine the size of the sample needed to insure a certain degree of accuracy in the estimates, is to sub-divide systematically a larger sample into various smaller samples and then compare the estimates from among the different sized samples. This is done in TABLE 19 where a sample of 600 scales for 1954 was sub-divided into 12 samples of 50 scales each, six samples of 100 each, three samples of 200 each, two samples of 300 each and finally one sample of 600. The mean relative first-year-marine growth for each sample is listed in this table. It should be realized that probability statements cannot be made concerning these mean values due to their method of selection.

For the 12 samples of 50 scales each, the mean value varied from 84.68 to 91.54, a difference of 6.86 or 7.91 per cent of the mean value for the total sample of 600. For the six samples of 100 each, the mean value varied from 85.14 to 87.14, a difference of 2.00 or 2.31 per cent of the total mean. The mean values for the three samples of 200 each ranged from 85.93 to 87.86, a difference of 1.93 or 2.23

TABLE 19—Comparative means for first-year-marine scale growth among systematic sub-samples of varying magnitude. Chilko spawning ground 4_2 sockeye, 1954.

	NUMBER IN SAMPLE				
	50	100	200	300	600
Mean First-Year-Marine Scale Growth	91.54	88.52	87.86	86.95	86.71
	85.50				
	86.14	87.19			
	88.24				
	84.72	85.14	85.93		
	85.56				
	86.02	86.72		86.48	
	87.42				
	87.58	86.27	86.37		
	84.96				
	84.68	86.46			
	88.24				

per cent of the total mean. The two samples of 300 scales each had means of 86.48 and 86.95, a difference of only 0.47 or 0.54 per cent of the total mean.

These empirical data indicate that a sample of only 100 scales would give a fairly reliable estimate, and that a sample of 300 scales would give excellent results. All the scale samples from the Chilko race contained at least 300 readable scales.

In TABLE 20 are listed the number of one-year-in-the-lake smolts produced from each brood of Chilko sockeye from 1949 through 1956, based on photographic enumeration at the outlet of Chilko Lake, the resulting 4_2 production, based on racial scale analysis of the catch plus the gross escapement, and the 4_2 marine survival. Also listed for each of these years is the relative mean first-year-marine growth, as measured from scales.

TABLE 20—Marine survival of Chilko 4_2 sockeye and mean first-year-marine scale growth.

Year of Return	1 Yr. in the Lake Smolts	Calculated 4_2 Production	Per Cent Marine Survival for 4_2 only	Mean First Year Marine Scale Growth
1953	3,146,830	522,164	16.59	94.05
1954	1,170,490	178,241	15.23	86.71
1955	11,581,930	608,242	5.25	84.68
1956	24,688,406	1,698,767	6.88	88.40
1957	8,316,130	455,918	5.48	88.24
1958	2,997,249	629,862	21.01	87.20
1959	9,409,620	1,378,552	14.65	94.42
1960	28,511,615	2,175,454	7.63	88.65
		Means	11.59	89.04

The annual 4_2 marine survival and mean growth data are plotted in FIGURE 29 for each year of return as actual deviations from their total mean values for these years. For any year where there is a positive deviation in growth there is also a positive deviation in marine survival, and with two exceptions a negative deviation in growth is associated with a negative deviation in survival. In both 1954 and 1958, the growth showed a negative deviation while the deviation for the calculated marine survival was positive.

In FIGURE 30 the mean first-year-marine growth is plotted against the per cent survival. These data also indicate that the mean growth values observed in 1954 and 1958 were less than should have been expected for the relatively high marine survival occurring in these two years, when compared with the relationship between these two factors for the other years. The two years that are in disagreement, 1954 and 1958, are the two years during this period when the dominant Adams River run is present. Considerably more Fraser River sockeye are produced in these two years than in the other years, as can be seen from the data in TABLE 21. Chilko population size does not appear to be related to marine survival since 1956 and 1960 are the years of the two largest Chilko populations.

On the basis of these data, the hypothesis is suggested that the large number of Adams fish in the dominant years is sufficient to depress the first-year-marine

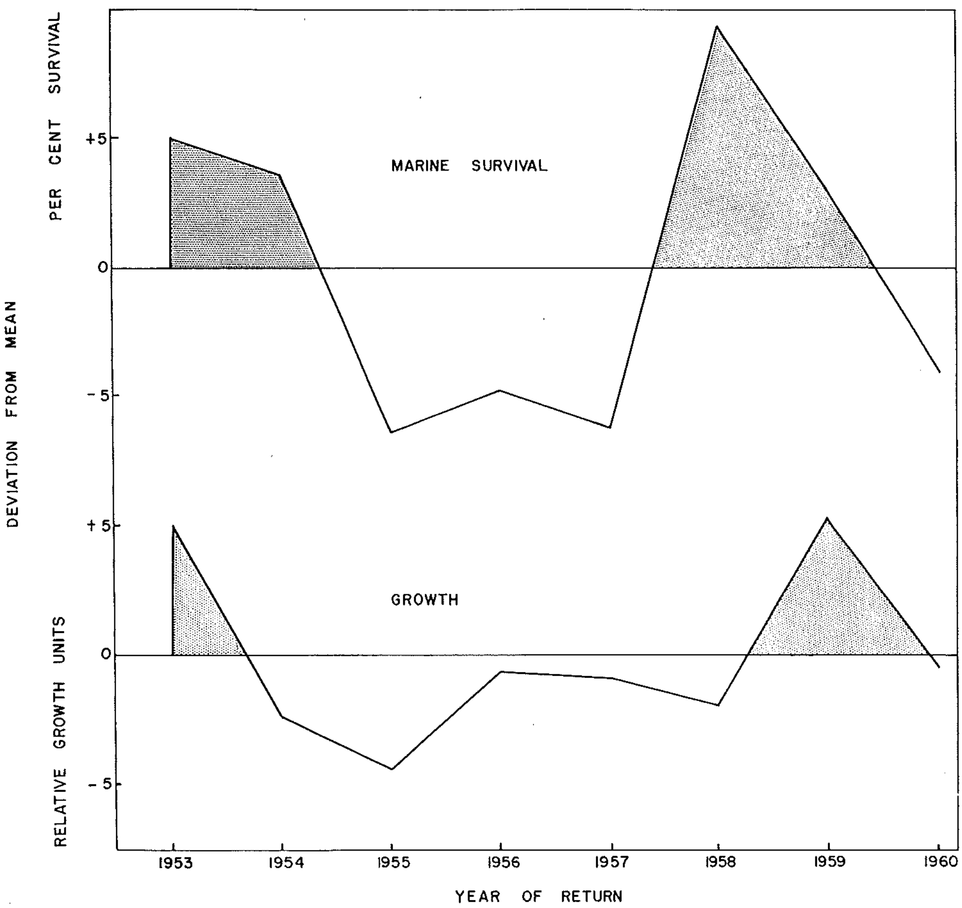

FIGURE 29—Annual deviations from mean values for Chilko 4_2 sockeye marine survival and relative mean first-year-marine scale growth, 1953-1960.

growth in these years, independent of the actual marine survival. In the other years, conditions effecting marine survival are the dominating influence on the growth, so that conditions favoring good survival also favor good growth and the growth will be poorer in years of lower marine survival.

If there is a relationship between the number of Adams fish and the resultant Chilko marine growth, the first-year-marine growth of Adams and Chilko fish would be related, at least in the years of the dominant Adams run. Therefore, the Adams scales were also examined for first-year-marine growth for these years. Unfortunately, the sample sizes were not as large for this race as they were for Chilko so there is more possibility for variability in the calculated means. The comparison between the Chilko and Adams growth measurements as well as the sample sizes are shown in TABLE 22. The Adams fish follow the same growth pattern as the Chilko fish and the correlation coefficient between the two sets of data is $r = 0.860$ (6 d.f.), significant at the one per cent level of confidence.

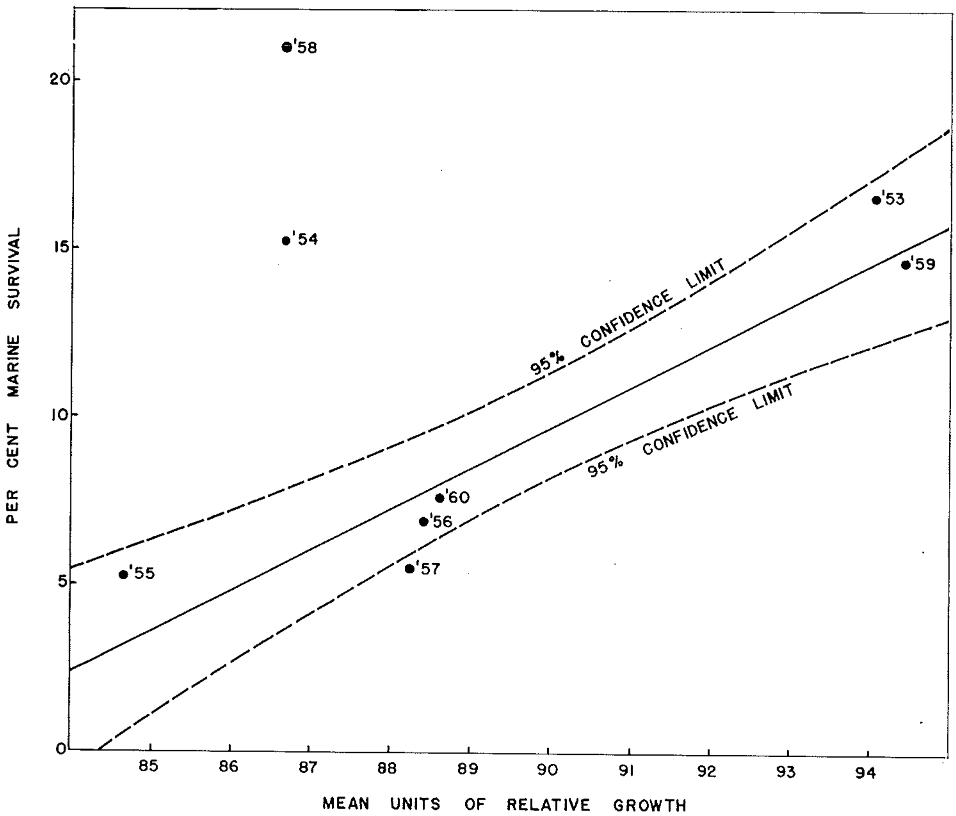

FIGURE 30—Relationship between marine survival and relative mean first-year-marine scale growth for Chilko 4_2 sockeye.

TABLE 21—Total run of Fraser River sockeye based on Convention waters catch plus escapement.

YEAR	TOTAL RUN[1]
1953	5,407,000
1954	12,115,000
1955	2,595,000
1956	2,743,000
1957	4,810,000
1958	19,000,000[2]
1959	4,405,000
1960	3,161,000

[1] Internat. Pacific Salmon Fish. Comm., Annual Reports, 1954-1961.
[2] Includes Johnstone Strait catch of Fraser River sockeye.

Other data were observed during this analysis that definitely proved the close relationship between the marine growth for these two races. In the 1960 Chilko samples, a large number of the scales were noted as having a false annulus during the first year in the ocean. When the Adams scales were examined, this false

TABLE 22—Mean first-year-marine scale growth for Chilko and Adams 4_2 sockeye.

YEAR OF RETURN	CHILKO		ADAMS	
	Mean Growth	Sample Size	Mean Growth	Sample Size
1953	94.05	305	91.75	224
1954	86.71	600	88.21	183
1955	84.68	505	80.86	406
1956	88.40	461	88.18	96
1957	88.24	458	85.31	39
1958	87.20	349	86.68	172
1959	94.42	384	93.81	163
1960	88.65	439	90.75	59

annulus was also noted. A frequency distribution of the growth to this false annulus was made for each of the two races and the mean values computed. For 99 Chilko scales the mean value to the false annulus was 54.48 and for twenty-nine Adams scales it was 54.69. Therefore, on the basis of these data it can be concluded that the same, or at least similar, conditions effect the first-year-marine growth of these two Fraser races.

If the hypothesis suggested earlier is true, then the years 1954 and 1958 should not be included in this comparison. In FIGURE 30 the calculated regression line, omitting 1954 and 1958, is shown. This line has the linear equation:

$$\hat{Y} = -101.0028 + 1.2304\ X \qquad (2)$$

The significance of these data is examined in TABLE 23. The relationship between relative mean first-year-marine 4_2 scale growth (X) and marine survival ($\hat{Y}$) for Chilko sockeye is significant at the one per cent level of confidence with F = 32.29. The total sum of squares was 121.3297 while the sum of squares due to regression was 107.9566. The percentage of the variation accounted for by regression was 88.98 per cent.

TABLE 23—Analysis of variance for the relationship between relative mean first-year-marine scale growth and marine survival for 4_2 Chilko sockeye.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Regression	1	107.9566	107.9566
Error	4	13.3731	3.3433

$$F = \frac{107.9566}{3.3433} = 32.29$$

$$F_{.99\ (1,4)} = 21.20^{1}$$

[1] Snedecor, 1948, Table 10.7.

The 95 per cent confidence limits for equation (2) are also depicted in FIGURE 30. The 95 per cent confidence limits (Y) for any particular value of X in equation (2) can be determined from the following equations:

$$\hat{Y} = -101.0028 + 1.2304\ X \qquad (3)$$

and

$$Y = \hat{Y} \pm 5.0759 \sqrt{1.1667 + \frac{(89.74 - X)^2}{71.3158}} \qquad (4)$$

In order that this relationship be useful as a predictor of future survival rates, it is necessary that there be an estimate for the first-year-marine growth of the 4_2 fish prior to their return from the ocean. The most practical estimate that can be obtained would be from the 3_2 fish which return one year earlier. Therefore, the relationship for the relative first-year-marine growth between 3_2 and 4_2 Chilko sockeye of the same brood has been examined. Unfortunately, the number of usable 3_2 scales was comparatively small. From 50 to 60 per cent of the 3_2 scales could not be used in this study because they were regenerated, absorbed, or of a different age group.

The linear equation equating 3_2 marine growth (X) with 4_2 marine growth ($\hat{Y}$) is:

$$\hat{Y} = 27.9600 + 0.6660\ X \qquad (5)$$

with a correlation coefficient of r = 0.889 (6 d.f.).

The significance of these data is examined in TABLE 24. The relationship between relative mean fist-year-marine growth from scales for 3_2 and 4_2 sockeye is significant at the 2 per cent level of confidence with F = 12.61. The percentage of the variation accounted for by regression was 69 per cent. The 95 per cent confidence limits (Y) for $\hat{Y}$ in equation (5) for any particular value of X can be determined from the following equations:

$$\hat{Y} = 27.9600 + 0.6660\ X \qquad (6)$$

and

$$Y = \hat{Y} \pm 2.1130 \sqrt{1.125 + \frac{(91.71 - X)^2}{147.9447}} \qquad (7)$$

TABLE 24—Analysis of variance for the relationship between relative mean first-year-marine scale growth for 3_2 and 4_2 Chilko sockeye.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Regression	1	56.2819	56.2819
Error	6	26.7883	4.4647

$$F = \frac{56.2819}{4.4647} = 12.61$$

$$F_{.95\ (1,6)} = 5.99^{1}$$

[1] Snedecor, 1948, Table 10.7.

On the basis of the significance of these relationships it would seem feasible to use first-year-marine scale growth from 3_2 fish as a predictor for marine survival. The linear equation relating 3_2 first-year-marine scale growth (X) with marine survival is:

$$\hat{Y} = 0.8947 + 0.9145\ X$$

with a correlation coefficient of $r = 0.807$ (4 d.f.).

The significance of these data is examined in TABLE 25. The relationship between 3_2 first-year-marine scale growth and marine survival has an $F = 7.47$ ($p = .053$). The 95 per cent confidence limits (Y) for $\hat{Y}$ in equation (8) for any value of X can be determined from the following equations:

$$\hat{Y} = 0.8947 + 0.9145\ X \qquad (9)$$

and

$$Y = \hat{Y} \pm 9.0289 \sqrt{1.1667 + \frac{(93.15 - X)^2}{94.4839}} \qquad (10)$$

TABLE 25—Analysis of variance for the relationship between relative mean first-year-marine scale growth for 3_2 Chilko sockeye and marine survival for 4_2 fish.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Regression	1	79.0140	79.0140
Error	4	42.3157	10.5789

$$F = \frac{79.0140}{10.5789} = 7.47$$

$$F_{.95\ (1,4)} = 7.71^{1}$$

[1] Snedecor, 1948, Table 10.7.

These data demonstrate that there is a statistically significant relationship between the relative mean first-year-marine growth, as measured by scales, for 3_2 and 4_2 Chilko sockeye of the same brood year, and also that there is a significant relationship between relative mean first-year-marine growth from scales and marine survival for 4_2 sockeye. The relationship between relative first-year-marine scale growth for 3_2 fish and 4_2 marine survival had a probability of $p = .053$. Therefore, it is statistically practical to estimate the expected marine survival for 4_2 Fraser River sockeye on the basis of relative mean first-year-marine growth from 3_2 scales of the same brood year, provided that the size of the total population is not large enough to interfere with the relationship between these two factors. Calculated marine survival for the 4_2 sockeye returning from 1953 through 1960 has varied from 5.25 per cent to 21.01 per cent, or almost 400 per cent.

Production Curves

An approximate relationship between the spawning escapement and the number of fish produced is used frequently by fishery biologists as a probable measure of the most productive escapement. Ricker (1954 and 1958) depicts this type of relationship for several species of fish including sockeye salmon. Shepard and Withler (1958) show a similar relationship for sockeye of the Skeena River in British Columbia. Royce and Mathisen (1959) discuss this relationship for the red salmon in the Nushagak area of Bristol Bay, Alaska.

Racial scale analysis has made it possible to more closely examine the true relationship between the spawning escapement and the number of fish produced. No attempt is made to discuss this relationship for any area except the Fraser River, since it is impractical and unwise to use published figures to establish relationships and draw conclusions, as is frequently done, without knowing the background as to why and how the figures were obtained or what they truly represent.

The Salmon Commission has been conducting a study of marine survival of Fraser River sockeye salmon using the Chilko River race as a measure of this survival. TABLE 26 lists the production and marine survival data for the 1949 through 1955 broods of Chilko River fish. The 6_3 production for the 1955 brood will not be known until the 1961 run has returned. However, 6_3 fish are numerically so unimportant that the 1961 returns will not alter significantly the calculated percentage survival for the 1955 brood. The marine survival figures listed in TABLE 26 by brood, differ somewhat from survival figures for a given age group or year, but in view of the predominance of the single 4_2 age group among Fraser River sockeye these differences are relatively unimportant. Also, as mentioned in the section on route of saltwater migration, an unusually high percentage of the Fraser River sockeye run in 1958 returned through Johnstone Strait and, therefore, the 1958 calculated catches of Chilko sockeye in Johnstone Strait as well as in Convention waters, for all age groups, have been used in computing these survival figures. Consequently, the survival figure for the 1954 brood is somewhat high relative to the survival figures for the other years shown, which are based primarily on Convention waters catches only. An estimate of the minimum comparable survival figure for the 1954 brood can be obtained from the data in TABLE 15 (page 46), assuming that the data for the entire Fraser River sockeye run apply equally to the Chilko run. If the previous maximum percentage of the Fraser River run, caught in Johnstone Strait, 10.79 per cent in 1957, was applied to the 1958 run and the 1958 Johnstone Strait catch of Chilko sockeye was then excluded from the total production, the estimated survival of the 1954 brood would be reduced only to 18.6 per cent. The calculated catches of Chilko fish in Convention waters for the various age groups in 1958 are also listed in TABLE 26.

As mentioned earlier in the study between scale growth and marine survival, it has been found that marine survival by brood year can vary almost 400 per cent. Therefore, a minimum of almost 400 per cent variation in the size of the returning run can be caused by marine survival alone. Variations in the proportion of the eggs actually deposited, number of fry hatched, and fry to smolt survival could be additive or compensatory to marine survival depending upon the character of

TABLE 26—Production and marine survival, by brood year, for Chilko sockeye.

Brood Year	Adult Spawners[1]	Number of Smolts	Resultant Stock						Total	Marine Survival (Per Cent)
			3_2	4_3	4_2	5_3	5_2	6_3		
1949	58,941	3,198,000	4,600	250	522,164	45,380	10,132	1,315	583,841	18.3
1950	21,123	1,303,875	1,000	500	178,241	14,341	4,382	—	198,464	15.2
1951	100,116	11,791,069	2,650	4,800	608,242	72,288	19,679	3,296	710,955	6.0
1952	486,929	25,089,796	18,900	110	1,698,767	35,210	28,468	506 (893)	1,781,961 (1,782,348)	7.0
1953	197,161	8,451,457	1,100	1,800	455,918	64,961 (87,727)	8,657 (14,004)	735	533,171 (561,284)	6.6
1954	34,714	3,340,476	3,500	1,912 (2,842)	388,286 (629,862)	54,914	4,276	—	452,888 (695,394)	20.8
1955	117,771	9,826,979	25,077 (32,419)	1,250	1,378,552	28,702	43,313	—[2]	1,476,894 (1,484,236)	15.0

1 Internat. Pacific Salmon Fish. Comm., Annual Reports, 1949-1956.

( ) Convention waters plus Johnstone Strait.

2 Returning in 1961.

the interaction that may exist among these factors. FIGURE 31 shows the Chilko marine survival data by brood year for the years 1949 through 1955.

To determine whether the size of the parent escapement was related to the calculated marine survival, the correlation coefficient between these two factors was computed. The linear correlation coefficient of r = 0.562 (5 d.f.) was not significant. Even if the survival of 18.6 is used for the 1954 brood, the correlation coefficient is still not significant (r = 0.566). Since there is no significant linear relationship between the size of the parent escapement and the calculated marine survival, the establishment of any relationship between size of the escapement and resulting production would have to take into consideration the large variation in marine survival.

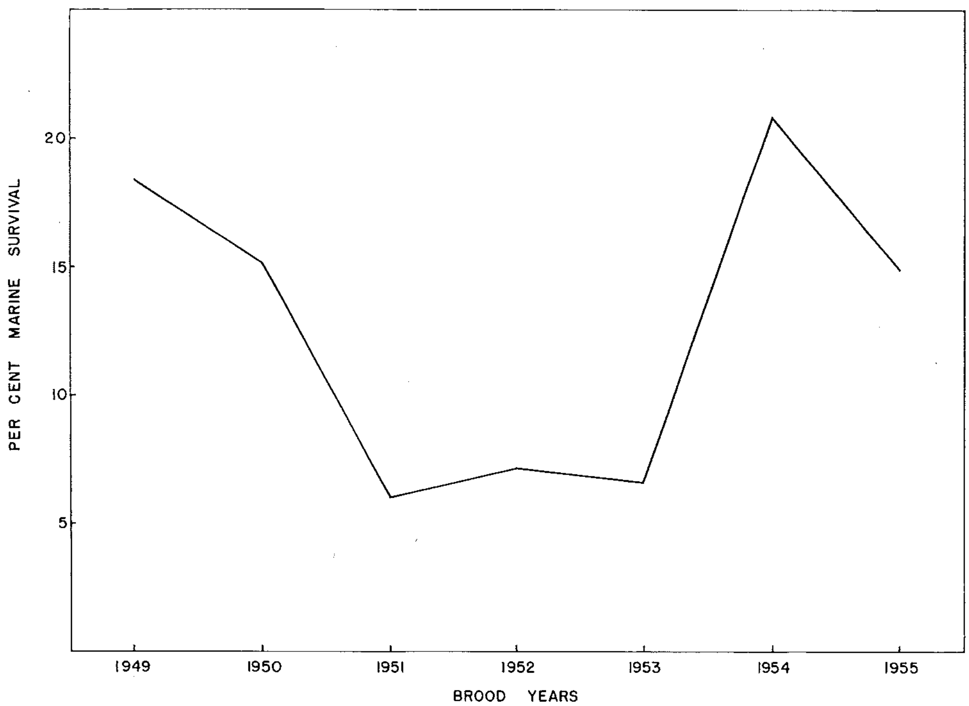

FIGURE 31—Marine survival of Chilko sockeye, by brood year, 1949-1954.

In TABLE 27 are listed, to the closest thousand fish, the actual resultant stock and the possible resultant stock if either the 1951 or 1954 brood year marine survival figures had applied to all of the years listed. The calculated difference in total production, from 3,783,000 fish to 13,105,000 fish, is of great economic and biological significance. With the possibility of such wide variations, it would appear that any relationship between number of spawners and resultant stock would have to be interpreted very liberally, at least for Fraser River sockeye. Thompson's statement for Bristol Bay (1959, page 209), "We seem to have this in Bristol Bay where a measure of the abundance of seaward migrants seems to be providing a usable forecast of returns from the sea," certainly could not be extended to include the Fraser River in light of these marine survival data.

TABLE 27—Actual resultant stock and possible resultant stock, based on the 1951 brood year and 1954 brood year marine survivals, for Chilko sockeye.

Brood Year	Actual Resultant Stock	Based on 1951 Brood Marine Survival	Based on 1954 Brood Marine Survival
1949	584,000	192,000	665,000
1950	198,000	78,000	271,000
1951	711,000	711,000	2,453.000
1952	1,782,000	1,505,000	5,219,000
1953	561,000	507,000	1,758,000
1954	695,000	200,000	695,000
1955	1,452,000	590,000	2,044,000
Totals	5,983,000	3,783,000	13,105,000

Another serious fault that often occurs when production relationships are interpreted without knowledge of biological background of the data, is that racial composition of the catch and the escapement are ignored, and the problem is approached by considering the entire run as a unit. Certain Fraser River sockeye races are more productive in certain years (Royal, 1953), and the escapements have to be considered on a racial basis in so far as is practical each year. As explained earlier, in 1958 it was desirable to get more escapement to the Stellako River. This would have wasted Chilko fish so a compromise between the two extremes was reached to allow practical management of the fishery. Any relationship based on total Fraser River figures for each year cannot show these individual racial requirements, which are the foundation for sound racial salmon management.

Racial Fishing Mortality

The determination of racial fishing mortality, or racial catch, is probably one of the most valuable uses of the scale identification method in management. One of the basic principles of sound management is to obtain the optimum escapement necessary for producing the maximum run. An estimate of what constitutes the optimum escapement is only possible if there is some method of accurately measuring the total production from different magnitudes of escapement. As pointed out previously in the section on production curves, there can be considerable error if racial productions are interpreted on the basis of total production for the entire river. However, the ability to distinguish the races in the fishery makes it possible to measure racial fishing mortality. This calculated racial fishing mortality, combined with the known racial escapements, gives the total production from each particular racial escapement, and it is then possible to determine the magnitude of the racial escapement which produced the maximum run.

Without the ability to measure racial fishing mortality and, consequently, total production, it would not be possible to accurately determine marine survival. Since marine survival for Fraser River sockeye can vary almost 400 per cent, it would be hazardous to predict the expected magnitude of the returning run, as a management agency is now expected to do, if there was no established relationship between marine survival and other factors which could be used as bases for prediction.

Finally, racial fishing mortality data are necessary to calculate racial fishing intensities, or the percentage of the available fish of a particular race caught by a fishery. Knowledge of racial fishing intensities is very important in designing the necessary fishing regulations.

In using the racial scale method to determine racial fishing mortality, the racial composition of the daily catches is estimated for each age group of sockeye, for each type of fishing gear, and for each fishing area. These individual racial catches are systematically consolidated until a final summary is prepared listing the total calculated racial catches. These racial catches are then added to the gross racial escapements to give the total racial production. The racial data for the years 1956 through 1959, excluding jacks, are listed in TABLES 28 through 31. The catches have been grouped into three major fishing areas: Juan de Fuca Strait, Puget Sound and the Fraser River Area.

TABLE 28—Racial catches of Fraser River sockeye, excluding jacks, in the various fishing areas of Convention waters, 1956.

Race	Juan de Fuca Strait	Puget Sound	Fraser River Area	Total Comm. Catch	Gross Escapement	Total Run
Early Stuart	1,186	25,495	31,664	58,345	28,093	86,438
Nadina	679	2,399	2,410	5,488	1,867	7,355
Gates	3,343	11,817	11,870	27,030	9,196	36,226
Bowron	3,725	12,902	10,096	26,723	7,455	34,178
Pitt	8,013	45,142	28,772	81,927	32,258	114,185
Seymour	799	4,503	2,870	8,172	3,218	11,390
Raft	7,102	26,001	14,347	47,450	11,739	59,189
Chilko	195,561	567,868	341,852	1,105,281	683,243	1,788,524
Taseko	603	1,750	1,054	3,407	2,106	5,513
Horsefly	58	183	132	373	111	484
Late Stuart	1,003	3,162	2,278	6,443	1,913	8,356
Stellako	24,762	68,588	48,025	141,375	45,028	186,403
Birkenhead	49,401	83,390	54,290	187,081	58,354	245,435
Harrison	1,907	6,955	3,903	12,765	3,193	15,958
Adams	2,388	5,907	1,634	9,929	8,658	18,587
Weaver	4,588	7,442	8,386	20,416	8,296	28,712
Silver	3,432	5,568	6,273	15,273	6,206	21,479
Widgeon Slough	509	825	926	2,260	919	3,179
Cultus	7,374	16,351	10,127	33,852	14,185	48,037
Totals	316,433	896,248	580,909	1,793,590	926,038	2,719,628

Theoretically, the calculation of racial fishing intensities in each fishing area should be a fairly direct procedure once racial fishing mortality data have been obtained. The racial fishing intensities for the Fraser River Area would be obtained from the following relationship, expressed as a percentage:

$$\text{Fraser River Area Racial Fishing Intensity} = \frac{\text{Fraser River Area Racial Catch}}{\text{Fraser River Area Racial Catch} + \text{Gross Racial Escapement}}$$

The racial fishing intensity for Puget Sound would be obtained by adding the Fraser River Area catch plus the gross escapement to the Puget Sound catch, which would give the total run available to the Puget Sound fishery. The Puget Sound catch is then taken as a percentage of the total run available. Finally, the racial fishing intensity for the Juan de Fuca Strait fishery would be obtained by taking the Juan de Fuca Strait catch as a percentage of the total run available to Puget Sound plus the Juan de Fuca Strait catch. Total fishing intensities would be obtained by following the same procedure using total catches and total escapements.

TABLE 29—Racial catches of Fraser River sockeye, excluding jacks, in the various fishing areas of Convention waters, 1957.

Race	Juan de Fuca Strait	Puget Sound	Fraser River Area	Total Comm. Catch	Gross Escapement	Total Run
Early Stuart	468	210,608	46,477	257,553	258,802	516,355
Nadina	24,841	146,135	49,668	220,644	67,738	288,382
Gates	604	3,551	1,207	5,362	1,646	7,008
Bowron	11,663	28,415	13,492	53,570	12,635	66,205
Pitt	4,870	14,461	8,191	27,522	12,335	39,857
Seymour	7,011	11,129	10,799	28,939	11,000	39,939
Scotch	1,736	2,755	2,673	7,164	2,723	9,887
Raft	5,409	9,671	9,201	24,281	7,647	31,928
Barriere	28	51	48	127	40	167
Chilko	99,417	170,269	99,588	369,274	157,546	526,820
Taseko	2,593	4,441	2,597	9,631	4,109	13,740
Horsefly	76,798	165,090	66,665	308,553	237,399	545,952
Late Stuart	188,278	438,228	215,683	842,189	549,440	1,391,629
Stellako	28,507	53,507	28,287	110,301	42,878	153,179
Birkenhead	30,793	49,663	17,493	97,949	19,974	117,923
Harrison	3,493	6,376	2,793	12,662	3,808	16,470
Adams	6,991	9,254	1,029	17,274	2,877	20,151
Portage	95	125	14	234	39	273
Weaver	47,930	78,099	22,407	148,436	20,339	168,775
Silver	921	1,501	431	2,853	391	3,244
Widgeon Slough	2,743	4,470	1,283	8,496	1,164	9,660
Cultus	30,539	49,624	11,012	91,175	20,456	111,631
Totals	575,728	1,457,423	611,038	2,644,189	1,434,986	4,079,175

The determination of fishing intensities in fishing areas other than the Fraser River Area is complicated by the fact that varying proportions of the sockeye run each year return to the Fraser River via Johnstone Strait. Although the catch of Fraser River sockeye in Johnstone Strait can be calculated on the basis of scale analysis, the Fraser River escapement coming from Johnstone Strait is not known. Therefore, an unknown portion of the gross escapement to the Fraser River, as well as a portion of the catch in the Fraser River Area, is composed of sockeye from the Johnstone Strait escapement. This applies to racial catches and escapements as well as the total catch and escapement. These fish from Johnstone Strait would not have been available to the Juan de Fuca Strait or Puget Sound fisheries and, consequently, should not be included when calculating fishing intensities for

TABLE 30—Racial catches of Fraser River sockeye, excluding jacks, in the various fishing areas of Convention waters, 1958.

Race	Juan de Fuca Strait	Puget Sound	Fraser River Area	Total Comm. Catch	Gross Escapement	Total Run
Early Stuart	4,611	4,167	64,223	73,001	39,095	112,096
Nadina	95	2,926	2,365	5,386	1,701	7,087
Gates	3	107	86	196	62	258
Bowron	886	12,278	17,362	30,526	15,591	46,117
Pitt	824	8,353	13,131	22,308	10,381	32,689
Seymour	19,914	95,442	86,361	201,717	79,825	281,542
Raft	588	10,243	10,085	20,916	10,586	31,502
Chilko	46,944	157,884	125,339	330,167	132,072	462,239
Taseko	2,936	9,876	7,840	20,652	8,262	28,914
Horsefly	2,134	2,296	1,727	6,157	1,931	8,088
Late Stuart	29,220	31,436	23,643	84,299	26,440	110,739
Stellako	115,263	264,008	324,146	703,417	196,813	900,230
Birkenhead	29,230	50,460	31,406	111,096	20,803	131,899
Harrison	19,099	29,697	30,944	79,740	14,716	94,456
Adams	2,499,645	4,403,263	1,571,496	8,474,404	3,346,769	11,821,173
Middle Shuswap	372	655	234	1,261	498	1,759
Lower Shuswap	14,376	14,509	17,585	46,470	9,543	56,013
Portage	4,168	7,746	8,743	20,657	4,873	25,530
Weaver	52,899	63,688	45,653	162,240	35,977	198,217
Widgeon Slough	36	21	597	654	1,086	1,740
Cultus	18,093	35,925	20,127	74,145	13,372	87,517
Totals	2,861,336	5,204,980	2,403,093	10,469,409	3,970,396	14,439,805

these two areas. The fishing intensity for the Fraser River Area is, in general, unaffected by the fact that varying portions of the fish available come from Johnstone Strait since all the fish are considered available to the Fraser River Area fishery whether they come from Johnstone Strait or from Puget Sound. The relationship mentioned above will give the exact fishing intensity for the Fraser River area regardless of the escapement of fish from Johnstone Strait, whereas the fishing intensities for the other areas should be corrected to allow for the escapement of Johnstone Strait fish to the Fraser River area.

In making corrections in the racial fishing intensities to allow for Johnstone Strait fish, certain assumptions had to be made. It was assumed that the Fraser River sockeye races returning through Johnstone Strait are the same races and in the same proportion to one another as in the run returning through Convention waters; in other words, that the character of the portions of the Fraser River sockeye run returning through Johnstone Srait and through Convention waters is the same. Data from 1957 and 1958, the two years in recent history with the largest portion of Fraser River sockeye caught in Johnstone Strait, tend to substantiate this assumption. The calculated average daily catches in 1957 of Fraser River sockeye in Johnstone Strait, compared by weekly periods with the same data

TABLE 31—Racial catches of Fraser River sockeye, excluding jacks, in the various fishing areas of Convention waters, 1959.

Race	Juan de Fuca Strait	Puget Sound	Fraser River Area	Total Comm. Catch	Gross Escapement	Total Run
Early Stuart	307	1,533	3,151	4,991	3,182	8,173
Nadina	280	6,057	2,559	8,896	3,382	12,278
Gates	50	1,074	454	1,578	600	2,178
Bowron	7,066	26,800	17,382	51,248	30,802	82,050
Pitt	4,141	48,728	16,631	69,500	15,731	85,231
Seymour	16,926	163,646	65,177	245,749	55,554	301,303
Raft	2,912	34,262	11,694	48,868	11,061	59,929
Barriere	61	712	243	1,016	230	1,246
Chilko	63,650	590,685	267,202	921,537	495,481	1,417,018
Tesako	2,243	20,812	9,415	32,470	17,458	49,928
Horsefly	21	44	31	96	16	112
Late Stuart	8,574	17,644	12,585	38,803	6,470	45,273
Stellako	115,885	238,467	170,102	524,454	87,447	611,901
Birkenhead	40,738	70,326	75,207	186,271	31,497	217,953
Harrison	38,122	65,811	70,379	174,312	29,475	203,602
Adams	231,055	331,170	112,712	674,937	142,892	817,828
Portage	957	1,367	466	2,790	591	3,381
Weaver	16,078	23,878	21,558	61,514	8,636	70,150
Silver	67	100	90	257	36	293
Widgeon Slough	1,158	1,720	1,553	4,431	622	5,053
Cultus	90,448	130,384	96,840	317,672	48,304	365,976
Totals	640,739	1,775,220	955,431	3,371,390	989,466	4,360,856

for Puget Sound, are shown graphically in FIGURE 32. The similarity of the two curves certainly indicates a similarity in the character of the run in these two areas. Similar data for 1958 are shown in FIGURE 33 and again the agreement between the shapes of the two catch curves indicates very strongly a similarity in the character of the run of Fraser River sockeye in these two areas. In TABLE 31, the weekly estimated racial composition in 1958 of the catch of Fraser River sockeye in Area 12, based on scale analysis, is compared with the weekly estimated racial composition of the San Juan Islands catch one week later. As mentioned previously, the more northerly approach of the Fraser River sockeye in 1958 made it necessary, in that one year only, to compare the weekly Johnstone Strait catches with the Puget Sound catches one week later to allow travel time for the run to reach the Puget Sound fishery. There was no fishing in the San Juan Islands prior to July 20. The racial composition data in TABLE 32 also tend to substantiate the similarity in the character of the run in the two areas.

Finally, it was necessary to assume a certain fishing intensity for the Johnstone Strait fishery. In the following analysis, intensities of 50, 60 and 70 per cent, which appear to cover the range of the possible minimum and maximum intensities, were used to demonstrate the effect of different intensities of this magnitude.

In TABLES 33 and 34 are shown the calculated racial fishing intensities, excluding jacks, for the more important Fraser River sockeye races from 1956 through

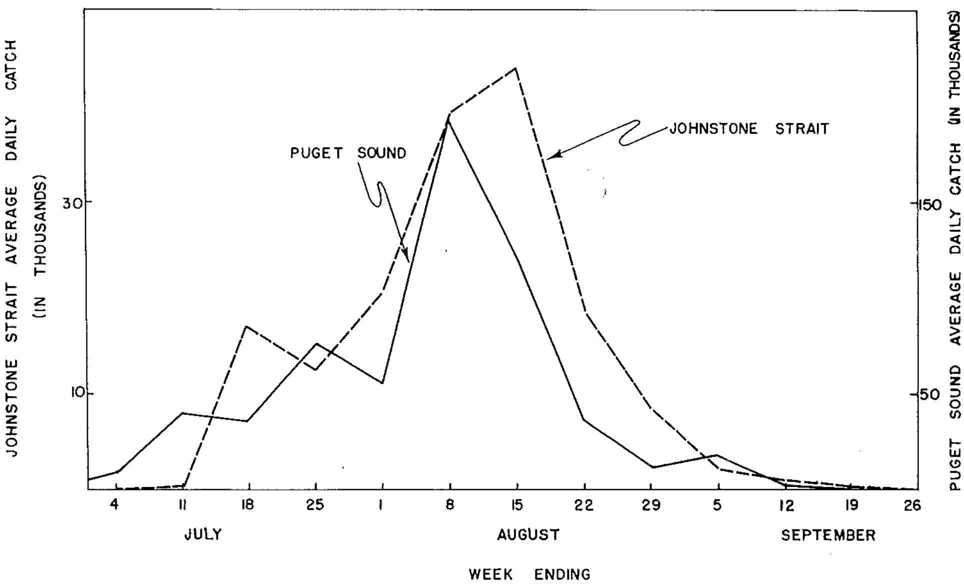

FIGURE 32—Average daily catch, by weekly periods, of Fraser River sockeye in Johnstone Strait and Puget Sound, 1957.

1959. The fishing intensities, uncorrected for Johnstone Strait fish, are shown for the Juan de Fuca Strait, Puget Sound and Fraser River Area fisheries; the fishing intensities corrected for Johnstone Strait fish, assuming 30, 40 and 50 per cent escapements from the Johnstone Strait fishery, also are shown for the Juan de

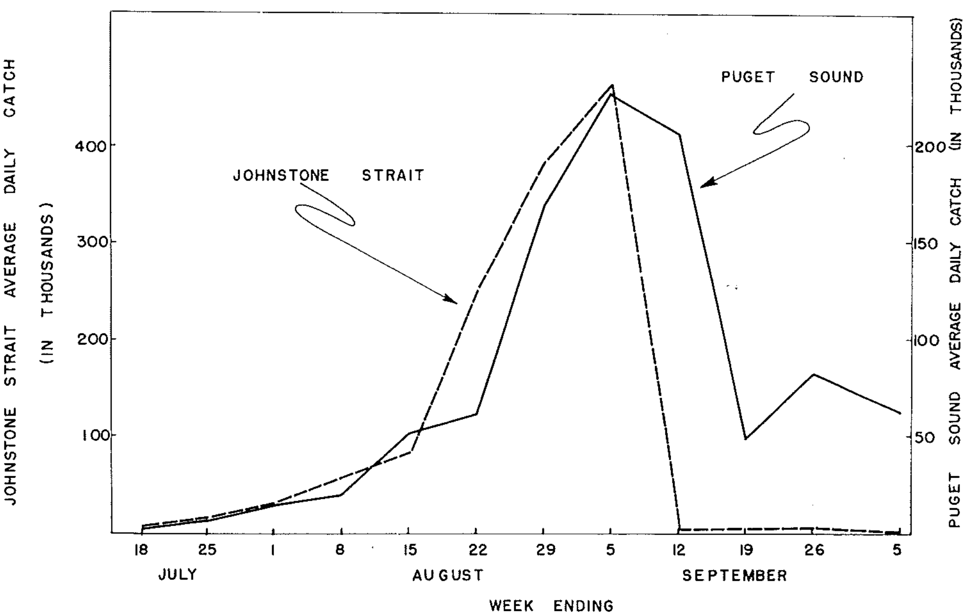

FIGURE 33—Average daily catch, by weekly periods, of Fraser River sockeye in Johnstone Strait and Puget Sound, 1958.

TABLE 32—Estimated weekly racial composition (in per cent) of catches of Fraser River sockeye, excluding jacks, in Area 12 and the San Juan Islands, based on scale analysis, 1958.

Week Ending	E. Stuart		Bowron		Pitt		Seymour		Chilko		Stellako		Birkenhead		Harrison		Adams		Cultus		Other	
	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.	Area 12	San Juan Is.
7-5/12	54.7				8.4				36.9													
7-12/19	90.7				3.3				4.3												1.7	
7-19/26	33.5	26.7	5.8	14.6	24.9	16.4			21.8	24.9			6.8	11.8	5.6	3.5					1.6	2.1
7-26/8-2	8.5		14.0	12.7	12.5	7.7	4.8	18.4	41.6	32.3	5.5	16.6	8.0	5.5	2.6	2.2					2.5	4.6
8-2/9			7.8	5.6	5.3	3.4	21.9	25.1	30.8	31.1	23.2	20.9	4.3	4.6	2.4	2.2					4.3	7.1
8-9/16			2.8				30.0	34.5	29.9	22.0	21.4	18.6	2.7				5.1	12.7			8.1	12.2
8-16/23							10.9	9.1	24.6	29.8	19.9	17.7					37.0	36.2			7.6	7.2
8-23/30									8.7	4.0	12.1	12.0					70.8	76.5			8.4	7.5
8-30/9-6									2.3		8.2	2.0					82.2	92.7			7.3	5.3
9-6/13																	96.3	95.0			3.7	5.0
9-13/20																	97.1	95.7			2.9	4.3
9-20/27																	91.9	81.9	7.2	17.6	0.9	0.5
9-27/10-4																	74.5	36.2	25.2	63.8	0.3	

TABLE 33—Racial fishing intensities, excluding jacks, for certain races of Fraser River sockeye in various fishing areas (per cent caught of fish available) 1956-1957.

Year and Race	Uncorrected for Johnstone Strait			Corrected for Johnstone Strait Assuming Various Fishing Intensities in Johnstone Strait					
				70 Per Cent		60 Per Cent		50 Per Cent	
	Juan de Fuca Strait	Puget Sound	Fraser River Area	Juan de Fuca Strait	Puget Sound	Juan de Fuca Strait	Puget Sound	Juan de Fuca Strait	Puget Sound
1956									
E. Stuart	1.4	29.9	53.0	1.4	30.5	1.4	30.8	1.4	31.3
Pitt	7.0	42.5	47.1	7.2	43.4	7.2	43.9	7.3	44.7
Chilko	10.9	35.7	33.3	11.1	36.4	11.3	36.9	11.5	37.6
Stellako	13.3	42.4	51.6	13.5	43.4	13.7	44.0	13.9	44.8
Birkenhead	20.1	42.5	48.2	20.5	43.6	20.8	44.2	21.1	45.1
Cultus	15.3	40.2	41.6	15.7	41.2	15.8	41.7	16.1	42.5
Total	11.6	37.3	38.5	11.9	38.1	12.0	38.6	12.2	39.3
1957									
E. Stuart	0.1	40.8	15.2	0.1	43.1	0.1	44.4	0.1	46.4
Nadina	8.6	55.5	42.3	9.1	58.8	9.4	60.8	9.8	63.9
Chilko	18.9	39.8	38.7	19.9	42.6	20.5	44.2	21.5	46.8
Horsefly	14.1	35.2	21.9	14.8	37.4	15.3	38.8	16.0	41.0
L. Stuart	13.5	36.4	28.2	14.3	38.7	14.7	40.2	15.4	42.3
Stellako	18.6	42.9	39.7	19.6	45.8	20.2	47.6	21.2	50.4
Birkenhead	26.1	57.0	46.7	27.5	61.3	28.4	64.0	29.7	68.2
Weaver	28.4	64.6	52.4	30.0	69.7	30.9	72.8	32.3	77.8
Cultus	27.3	61.2	35.0	28.9	65.9	29.8	68.8	31.1	73.4
Total	14.1	41.6	29.9	14.9	44.3	15.4	45.9	16.1	48.4

Fuca Strait and Puget Sound fisheries. As mentioned previously, the escapement from Johnstone Strait does not alter the calculated fishing intensities for the Fraser River Area.

The racial fishing intensity figures in these two tables, corrected for that portion of the run escaping from the Johnstone Strait fishery, were determined in the following manner. The percentage of the total run of Fraser River sockeye, excluding jacks, caught in Johnstone Strait each year, based on the calculated catches from scale analysis, was applied equally to each sockeye race to obtain an estimate of the number of each race caught in Johnstone Strait. For each estimated racial catch in Johnstone Strait, the estimated racial escapement from the Johnstone Strait fishery was determined, based on a 50, 60 or 70 per cent fishing intensity. Then, on the basis of the racial fishing intensities in the Fraser River Area, the

TABLE 34—Racial fishing intensities, excluding jacks, for certain races of Fraser River sockeye in various fishing areas (per cent caught of fish available) 1958-1959.

Year and Race	Uncorrected for Johnstone Strait			Corrected for Johnstone Strait Assuming Various Fishing Intensities in Johnstone Strait					
				70 Per Cent		60 Per Cent		50 Per Cent	
	Juan de Fuca Strait	Puget Sound	Fraser River Area	Juan de Fuca Strait	Puget Sound	Juan de Fuca Strait	Puget Sound	Juan de Fuca Strait	Puget Sound
1958									
E. Stuart	4.1	3.9	62.2	4.7	4.5	5.1	4.9	5.9	5.6
Seymour	7.1	36.5	52.0	8.1	42.3	8.8	46.4	10.1	53.7
Chilko	10.2	38.0	48.7	11.6	44.3	12.7	48.8	14.5	56.8
L. Stuart	26.4	38.6	47.2	30.2	46.6	32.9	52.8	37.6	64.7
Stellako	12.8	33.6	62.2	14.7	39.4	16.0	43.5	18.2	51.0
Adams	21.1	47.2	32.0	24.2	56.3	26.4	63.1	30.1	75.9
Weaver	26.7	43.8	55.9	30.6	53.1	33.3	60.1	38.0	73.8
Cultus	20.7	51.7	60.1	23.7	61.7	25.8	69.0	29.4	82.8
Total	19.8	45.0	37.7	22.7	53.5	24.7	59.7	28.2	71.5
1959									
Pitt	4.9	60.1	51.4	5.0	62.3	5.1	63.6	5.3	65.5
Seymour	5.6	57.5	54.0	5.8	59.7	5.9	60.9	6.1	62.8
Chilko	4.5	43.6	35.0	4.6	45.2	4.7	46.1	4.9	47.6
Stellako	18.9	48.1	66.0	19.6	51.9	20.0	51.4	20.6	53.2
Birkenhead	18.7	39.7	70.5	19.4	41.4	19.7	42.5	20.3	44.0
Adams	28.3	56.4	44.1	29.2	59.2	29.8	60.9	30.7	63.4
Cultus	24.7	47.3	66.7	25.6	49.5	26.1	50.9	26.8	52.8
Total	14.7	47.7	49.1	15.2	49.7	15.5	50.8	15.9	52.6

portion of each racial catch in the Fraser River Area and the portion of each racial escapement coming from Johnstone Strait was estimated for each of the three assumed fishing intensities. The portions of the Fraser River Area catch and the escapement estimated to have come from Johnstone Strait were then excluded from the fishing intensity calculations for Puget Sound and the Juan de Fuca Strait fisheries.

As can be seen from the data in the two referenced tables, the higher the estimated fishing intensity in Johnstone Strait and, consequently, the less the escapement to the Fraser River Area and the less fish to be excluded from the subsequent calculations, the smaller the correction for the Puget Sound and Juan de Fuca Strait fishing intensities. The correction to the fishing intensities in the Puget Sound and Juan de Fuca areas is so relatively minor that the uncorrected intensities are sufficiently accurate for practical management purposes except for the occasional year when there is a major migration of Fraser River sockeye through Johnstone Strait.

Although the migration and escapement of Fraser River sockeye through Johnstone Strait had no effect on the calculated fishing intensities in the Fraser River Area, they do have a relatively serious effect on other management problems, such as obtaining equal division of the catch between Canada and the United States and in obtaining proper racial escapements. The fishing regulations are formulated on the basis of a normal relationship between the various fishing areas in Convention waters, so that each country obtains its one half share of the total catch and the proper racial escapements are permitted to reach the spawning grounds. When a substantial portion of the run returns via Johnstone Strait, as occurred in 1957, 1959 and especially in 1958, equal division of the catch between the two countries can be upset. This is the result of increased catches in the Canadian Fraser River Area caused by the availability of large numbers of fish from Johnstone Strait which were not available to the normal Convention waters fisheries. The desired escapements also can be upset seriously by the unexpected decreases or increases in the escapement from the Johnstone Strait fishery.

In Table 35 are listed the calculated Fraser River Area catch and the gross escapement to the Fraser River of fish passing through the Johnstone Strait fishery from 1956 through 1959. Three different fishing intensities have again been assumed for the Johnstone Strait fishery. The data shown are for the total run each year,

Table 35—Calculated Fraser River Area catch and gross escapement of sockeye migrating from Johnstone Strait (assuming 50, 60 and 70 per cent fishing intensity in the Johnstone Strait fishery), 1956-1959.

Year	Fishing Intensity	Calculated Fraser River Area Catch	Calculated Gross Escapement	Per Cent of Total Fraser River Area Catch or of Total Escapement
1956				
	70	20,261	32,364	3.5
	60	31,516	50,345	5.4
	50	47,275	75,517	8.1
1957				
	70	63,223	148,225	10.3
	60	98,347	230,572	16.1
	50	147,520	345,858	24.1
1958				
	70	694,020	1,146,881	28.9
	60	1,079,586	1,784,038	44.9
	50	1,619,379	2,676,057	67.4
1959				
	70	72,264	74,913	7.6
	60	112,410	116,531	11.8
	50	168,615	174,797	17.6

but it is assumed that the percentages shown apply equally to each Fraser River sockeye race. In 1956, when only 4.32 per cent of the total Fraser River sockeye run was calculated as being caught in the Johnstone Strait fishery, 20,261 fish of the total Fraser River Area catch and 32,364 fish in the gross escapement were estimated as coming from Johnstone Strait. This was based on an estimated 70 per cent fishing intensity in Johnstone Strait and a 38.5 per cent fishing intensity in the Fraser River Area. These figures amounted to 3.5 per cent of the total Fraser River Area catch and likewise 3.5 per cent of the total gross escapement. Assuming a 50 per cent fishing intensity for Johnstone Strait, the calculated Fraser River Area catch of sockeye returning through Johnstone Strait would be 47,275 fish with 75,517 fish in the gross escapement, or 8.1 per cent of the totals.

In 1958, with a large migration of Fraser River sockeye through Johnstone Strait, the contribution of fish from this area to the Fraser River Area catch and to the gross escapement was very significant. Assuming a 70 per cent fishing intensity for Johnstone Strait and with a calculated 37.7 per cent fishing intensity for the Fraser River Area, it was calculated that 694,020 fish in the Fraser River Area catch and 1,146,881 fish in the gross escapement migrated through Johnstone Strait. This represented 28.9 per cent of the totals. With an estimated 50 per cent fishing intensity in Johnstone Strait, the portion of the Fraser River Area catch and the gross escapement estimated migrating through Johnstone Strait would jump to 67.4 per cent of the totals. It is obvious that unexpected large portions of the Fraser River sockeye run migrating through Johnstone Strait could seriously upset both division of the catch and desired racial escapement requirements, thus presenting a very serious problem in the proper management of the Fraser River sockeye run. It is apparent from the data in TABLE 35 that the variations resulting from different proportions of the run returning via Johnstone Strait from one year to the next are more significant than the variations achieved by varying the estimated fishing intensities in Johnstone Strait from 50 to 70 per cent within a particular year.

The obvious conclusion that can be derived from these data is that both the gross escapement to the Fraser River and the catch in the Fraser River Area may be largely of sockeye which came through Johnstone Strait, provided the portion of the run migrating through Johnstone Strait is large and the Johnstone Strait fishery is not very intense. Although fishing intensities of 50 to 70 per cent for the Johnstone Strait fishery appear to cover the possible minimum and maximum intensities reasonably, the importance of the Johnstone Strait fishing intensity to the successful management of the Fraser River sockeye runs makes its exact determination imperative.

SUMMARY

This study develops a method of racial identification of Fraser River sockeye based on racial differences in the number of freshwater scale circuli, a characteristic first suggested by C. H. Gilbert.

The methods of racial identification currently used in fishery studies, including blood, parasites, meristic and morphometric characteristics, paper chromatography, otoliths and scales, were examined. These methods, other than the one based on scales, were found to be impractical for racial identification in practical salmon management.

Although the number of freshwater circuli is the basic characteristic used in this scale identification method, racial time of migration, age data and the presence of "spring growth" on the scales also are used to modify the method.

The smoothed freshwater scale circuli frequencies from samples of the daily commercial catch are separated into the racial components by superimposing a series of quasi-normal racial curves on the sample frequency curve. The expected shape and the mean value of these quasi-normal curves is determined by scale samples from jack sockeye the previous year, from downstream migrants, or from scale samples of fish on each racial spawning ground after the fishing season. Each age group is analyzed separately, although over 80 per cent of the returning Fraser River sockeye run normally consists of 4_2 fish. Certain relatively unimportant, unidentified races which may also be present in the daily samples, are initially included in the estimated composition of the major races. After the fishing season, racial time-abundance curves determined from spawning ground data, as well as the comparative size of the escapements of various races migrating at the same time, are used to estimate the contribution of these minor races to the catches. Any portion of the sample frequency credited to these minor races in this manner is subtracted from the estimated catch of the appropriate major race or races.

The accuracy of the racial scale method is examined first on a theoretical basis and then on an empirical basis through paired analyses and results from test fishing. A comparison of the estimated racial percentages of the same samples by two independent observers, based on the racial scale method, indicated that this method gave consistent results that were independent of the observer.

A method of test fishing to measure the daily escapement of sockeye migrating past the commercial fishing area was explained. The calculated racial escapements, based on the test fishing results and scale analysis, were compared with the actual escapement occurring during the same period. The closeness of the estimated escapements and the actual enumerated escapements verified the accuracy of the racial scale identification method.

Two factors which influence age sampling of Fraser River sockeye and can affect the estimated racial catches are discussed:

1. Gear. Size selectivity of commercial fishing gears can affect age composition analyses. A comparison of relative numbers of 5_2 sockeye between concurrent purse seine and nylon gill net catches in 1957, 1958 and 1959, however, showed no significant or consistent difference between the two types of gear for that year class.

2. Smoothing. The daily estimated jack catches are smoothed over a three day period in calculating the total jack catch for the season. The smoothing tended to minimize the total estimated catch of jacks, but not to a serious degree in view of the possible variation in the jack population calculated on the spawning grounds.

The actual application of the scale identification method to a series of freshwater scale circuli frequency curves illustrates the actual method of separating the daily samples into their racial components. The possible use of the scale method in evaluating hatchery production also was demonstrated. The uses of the scale identification method in the solution of a number of current salmon management problems was then considered:

1. Each year varying portions of the Fraser River sockeye run return via Johnstone Strait. The analysis of the freshwater scale circuli frequencies from samples of the Johnstone Strait catches can be used to estimate the total catch of Fraser River sockeye in the Johnstone Strait fishery each year. Also, scale analysis of the West Coast troll catches of sockeye early in the fishing season aid in the determination of the area of landfall for the returning sockeye run.

2. The timing of the sockeye races, which is important to management since fishing regulations are formulated to obtain the required racial escapements at the proper time on the basis of expected racial timing, also can be determined on the basis of daily calculated racial catches from scale analysis.

3. The speed of racial sockeye migrations through the various fishing areas also were determined by applying normal-shaped time-abundance curves to the daily calculated racial catches in the various fishing areas, and then determining the number of days difference between the peaks of abundance in the various areas. Speeds of migration determined in this manner compared favorably with speeds of migration determined from tagging experiments.

4. The fact that certain races of sockeye delay off the mouth of the Fraser River for varying periods before entering into the river also creates a management problem. The use of racial scale identification in determining this delay and in effecting subsequent management decisions concerning the delaying fish is demonstrated.

5. The use of the scale method and test fishing in obtaining the desired racial escapements also is discussed. A situation is examined in which there can be excessive racial escapement, or not enough racial escapement, even though the fishery is managed on a racial basis.

6. Racial identification in the fishery, combined with smolt enumeration at the outlet of Chilko Lake, has permitted the total marine survival to be calculated. These yearly estimated marine survival rates were then compared with first-year-marine 4_2 scale growth and a significant relationship between these two factors was established. A significant relationship between 3_2 and 4_2 first-year-marine scale growth was also established. An ability to predict marine survival for Fraser River sockeye on the basis of 3_2 first-year-marine scale growth was indicated.

7. The production relationship between number of spawners and resultant stock was examined on a racial basis. The linear relationship between number of spawners and marine survival was examined and was found to be not significant. On the basis of this non-significant relationship and a possible 400 per cent varia-

tion that can occur in marine survival, the establishment of any relationship between the size of the parent escapement and resulting production would have to take into consideration the large variation in marine survival.

8. Racial fishing mortalities, or racial catches, were determined by the scale method for the years 1956 through 1959. On the basis of these racial catches, racial fishing intensities were calculated for three major fishing areas, Juan de Fuca Strait, Puget Sound and the Fraser River Area. The importance of the fish returning via Johnstone Strait in the calculation of the fishing intensities was examined. Johnstone Strait fish had no effect on the calculation of fishing intensity in the Fraser River Area, but the intensity in the other areas tended to be increased when a correction was made for the fish from Johnstone Strait. Even with estimated fishing intensities of from 50 to 70 per cent in the Johnstone Strait fishery, the uncorrected fishing intensities in Puget Sound and Juan de Fuca Strait were accurate enough for practical management purposes except in years when there was a large migration through Johnstone Strait.

The sockeye returning through Johnstone Strait had the greatest effect on the division of the catch between the United States and Canada and on obtaining the proper escapements. In years of large migration through Johnstone Strait, the Fraser River Area catch and the escapement to the Fraser River were increased significantly over what was expected on the basis of the usual migration path through Convention waters. The variations resulting from different proportions of the run returning via Johnstone Strait from year to year were much more significant than the variations resulting from varying the fishing intensity estimates in Johnstone Strait within each year from 50 to 70 per cent. Although the estimated fishing intensities used in this analysis for the Johnstone Strait fishery of from 50 to 70 per cent appear to reasonably cover the possible minimum and maximum intensities, the importance of the fishing intensity in this area to the successful management of the Fraser River sockeye run makes it imperative that the actual fishing intensity in Johnstone Strait be determined.

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