INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

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BETWEEN CANADA AND THE UNITED STATES FOR THE
PROTECTION, PRESERVATION AND EXTENSION
OF THE SOCKEYE SALMON FISHERIES IN
THE FRASER RIVER SYSTEM

BULLETIN VII

THE CHRONOLOGICAL ORDER OF FRASER RIVER SOCKEYE SALMON DURING MIGRATION, SPAWNING AND DEATH

BY

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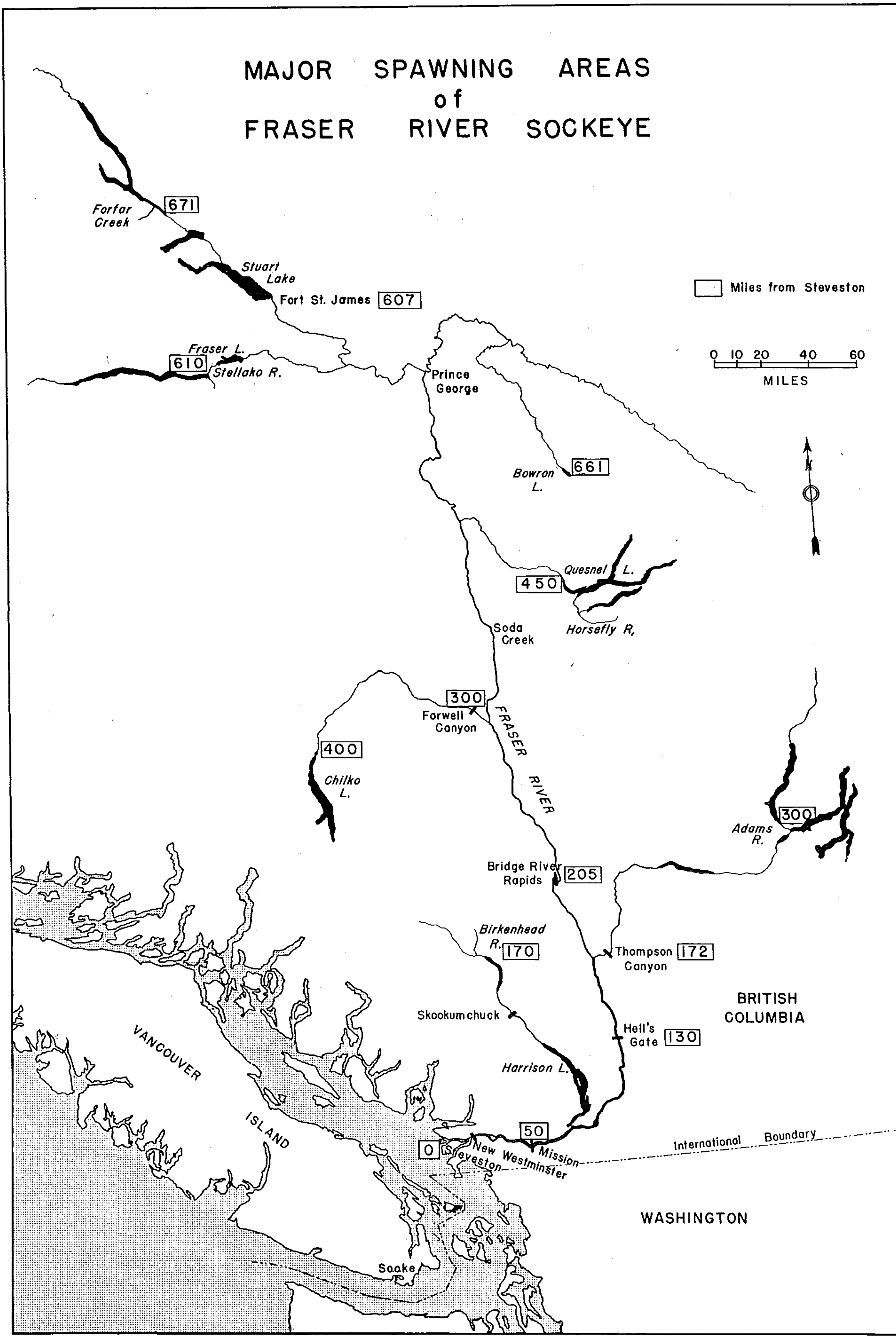
MAJOR SPAWNING AREAS of FRASER RIVER SOCKEYE



ABSTRACT

In the regulation of the sockeye salmon fishery of the Fraser River by the International Pacific Salmon Fisheries Commission, it was important to know whether selected escapements of particular parts of a given run would maintain their chronological order during subsequent migration, spawning and death. The consistency of the time taken for tagged sockeye to migrate and the similarity of the shape of the arrival curve of untagged sockeye at the time of escapement and at the time of arrival on the spawning grounds showed that in general the original *order was retained* during migration over distances as great as 600 miles or more. The order in which individual sockeye spawned was closely related to that of their arrival at the stream but there was significant variation in their life-span after spawning was completed.

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THE CHRONOLOGICAL ORDER OF FRASER RIVER SOCKEYE SALMON DURING MIGRATION, SPAWNING AND DEATH

INTRODUCTION

The annual run of sockeye salmon *(Oncorhynchus nerka)* to the Fraser River watershed is composed of discrete units, each migrating from the sea at its own specific time and spawning in a specific area in accordance with its own individual requirements for survival. Within each unit the numerical frequency of migrants, spawners or deaths, when related to time, tends to form a normal curve with a range of approximately 30 days. These units are commonly referred to as populations, runs or races and are usually identified by the area in which they spawn. Royal (1953) defined such a unit as a race if it consisted of one homogeneous population, every member of which spawned in a particular area that offered a generally uniform reproductive environment. On the basis of the above he developed the concept that only the central part or peak of the migration curve was composed of fish that were properly related to the normal environmental cycle in the reproductive area and that the beginning and end consisted of variants whose migration was not properly timed for maximum reproduction. Whether or not true homogeneity does exist in such a population has never been determined but it is a well-established fact, at least in certain cases, that the first and last migrants of a unit migration do not spawn as successfully as those from the peak.

Royal observed also that some of the spawning migrations seriously affected during the period of the Hell's Gate block are now composed of only the early segments of formerly much larger migrations and that these segments were currently spawning only in the areas most suited environmentally for their reproduction. In such cases the original migration prior to its decimation may have consisted of several units whose migration and spawning periods overlapped. It is possible that the later units were completely destroyed so that only the early unit remains. It is also possible that the presence of small residual segments of the late-migrating units is obscured by the variants of the early-migrating unit.

It is a major task of the International Pacific Salmon Fisheries Commission to regulate the fishery in such a manner that the original sockeye reproductive potential again be realized and the maximum production from a minimum escapement be obtained. To achieve this it is essential that an effort be made to aid in the restoration of the later migrants so that spawning areas no longer used can be brought into production again. It is also essential that consideration be given to providing escapement from that part of the unit migration which appears to be timed to spawn in the most favorable reproductive environment.

Whatever the genetic structure of a unit migration may be and whatever may be required in the character of the escapement in order to accomplish the rehabilitation and maintenance of the Fraser River sockeye populations it is important to know whether *selected escapements* have a value in reaching the desired accomplishment. If selected groups of sockeye from a given unit migration are allowed to escape the fishery and they *maintain their chronological order* during subsequent migration and during the spawning act, regulatory selection may be beneficial. If sockeye do not retain a chronological order within practical limits during their upstream migration and during spawning then any chosen objective cannot be obtained by providing selected escapements.

It is the purpose of this report to determine whether the chronological order of Fraser River sockeye runs is maintained during the migration, spawning and death of the fish. Migrations to the spawning grounds, some of which involve distances of over 600 miles, are given first consideration. This is followed by studies of the order of spawning and death as they occur within the spawning grounds. An analysis of the three phases combined is presented in the final section of this report.

CHRONOLOGICAL CONSISTENCY DURING MIGRATION

To study the problem of chronological consistency during migration it was first necessary to have accurate data on the travel rates of individual sockeye. It was found that such data were provided by the days-out of tagged sockeye from the date of tagging to the date of recovery; therefore, the results of all tagging experiments conducted by the International Pacific Salmon Fisheries Commission on the Fraser River sockeye were re-examined. Saltwater tagging at Sooke (1938-1948), originally intended for racial analysis, and tagging of sockeye at Hell's Gate (1939-1948) and Bridge River Rapids (1942-1946) for migration obstruction studies, provided a large volume of data. The study of the consistency of migration rates might not have been possible if these extensive tagging programs, designed for other purposes, had not been conducted. Careful consideration of which tag returns would provide accurate measures of migration rates was necessary and a very critical examination of the location of tagging, method and recovery of tags was made, as misleading and erroneous conclusions could result if careful consideration were not given to these points. Important problems that arose in the search for accurate tagging data and the criteria that were consequently established in the investigation are reviewed below. In addition to the analysis of tagging data, a second method of assessing the consistency of migration was developed whereby the dates and general configuration of the escapement upon leaving the commercial fishing areas was compared with the dates and configuration of the escapement upon arrival at the spawning grounds.

PROBLEMS INVOLVED IN THE ANALYSIS OF TAGGING DATA

Availability of Tags from Suitable Locations

Theoretically the ideal location for tagging is at some position along the path of the adult spawning migration prior to the major commercial fishing areas. Sooke, in the Strait of Juan de Fuca, is such a site and extensive sockeye tagging was conducted there by the International Salmon Commission from 1938 to 1948. Unfortunately, about ninety-nine per cent of the Sooke tag returns were recovered in the commercial and Indian fisheries and only small numbers, recovered on individual spawning grounds, were available for this study.

As there were not sufficient samples from the Sooke tagging for complete analysis, the results of tagging at Hell's Gate were examined. Hell's Gate is located in a canyon of the Fraser River, 130 miles from the river mouth and 81 miles beyond the upper limits of the commercial gillnet fishery. Tagging conducted here annually from 1939 to 1948 was designed at first to measure how the river obstruction affected the sockeye migrations and then to test the efficiency of the fishways built in 1945. Part of the analysis of these tagging experiments by Thompson (1945) and Talbot (1950) revealed that before the fishways were constructed many sockeye died below the Gate during block periods or were greatly delayed in arrival time at the spawning grounds, whereas after the fishways were built delays in migration to the spawning grounds no longer occurred. Obviously only the undelayed tagged sockeye returns since 1945 could be used to describe the normal migration rate of sockeye above Hell's Gate; these were available for four years, 1945 to 1948 inclusive.

The consistency and rate of migration in the 81 miles below Hell's Gate, the distance travelled after leaving the commercial fishery, must also be known. No tagging data were available for this region, except for small samples of Sooke tags; therefore a migration time of five to six days, derived by Talbot (1950), was used. This time was obtained from his study of the fluctuating numbers of net-marked sockeye taken on different days of the week by the tagging crews at Hell's Gate. Detailed tagging records indicated that there was a persistent low percentage of net-marked sockeye each Friday during July and most of August and high percentages of net-marked sockeye during the other six days of the week. It was concluded that this difference was caused by the weekend closures in the commercial fishery at the mouth of the Fraser River. The period of five or six days from the Saturday-to-Sunday closure to Friday when there were least net-marked fish represents the migration time from the commercial fishery to Hell's Gate. A distinct chronological order of migrating sockeye below Hell's Gate was shown by the consistency of the variation between non-marked and net-marked fish; had the sockeye from days of fishing and those from days of closure intermingled en route to Hell's Gate, the marked differences in percentages of net-marks would have been obscured.

The varying daily catches at Hell's Gate provided further evidence that the sockeye from weekend closures in the gillnet operations remained in compact groups and appeared at separate and regular intervals at Hell's Gate. High catches and low percentages of net-marked sockeye on Fridays at Hell's Gate were thus a standard pattern after the fishways were built in 1945.

As it had been established that sockeye tagged at Hell's Gate after 1945 were not obstructed (Talbot, 1950) and the travel time of the escapement to Hell's Gate was known, it was feasible to analyse migration rates from this location to the spawning grounds. Unlike tags from Sooke, a large percentage of Hell's Gate tags were recovered at the separate spawning areas, and provided large samples for examination.

Physical Effects of Tagging

It was essential that the physical effects of tagging be critically examined. It was possible that the tagging operation alone could so alter the migration of a salmon that it would no longer be representative of the behavior of an untagged individual. This problem was considered by Schaefer (1951) when he tested the effects of tagging of sockeye in the Harrison Lake district. The migration rate of *tagged sockeye* was measured by their days-out to recovery over a known distance while the migration rate of *untagged sockeye* was obtained by measuring the times of peak abundance of the run at various places along the path of migration. The peaks were indicated as a result of trapping or netting portions of the passing run, but the precise timing of the peaks was uncertain and only large differences between rates of migration of tagged and untagged fish would have been distinguishable by this method. However, Schaefer concluded that there was no good evidence that the tagged fish which reached the spawning stream were delayed in their migration by tagging.

The respective arrival dates of tagged and untagged sockeye at the spawning grounds provided a second approach to the problem of possible differential behavior of tagged sockeye. Daily counts at the Bowron River weir located at the outlet of Bowron Lake illustrated the relative occurrence of the two groups. In the four years, 1945 to 1948, the dates of arrival of the sockeye were similar. Since the numbers of sockeye tagged were roughly proportional to the numbers present at the time of tagging, the data for the four years have been grouped to provide a larger sample and the percentage frequency distributions of all the tagged and untagged sockeye counted at the weir are shown in Figure 1. The tagged sockeye, starting at Hell's Gate, migrated the distance of 531 miles in an average time of 21.4 days. There was ample distance and time available for possible digression and differential behavior between tagged and untagged sockeye, yet the two groups demonstrated a remarkable similarity in both percentages and dates of arrival. Large numbers of untagged sockeye did not precede the tagged sockeye nor did large numbers of belated tagged sockeye arrive at the end of the run. There was some overall indication that the tagged sockeye were slightly later in arriving at the weir than the untagged sockeye; however, it appears that the lateness of tagged sockeye was not confined to any particular segment of the run but was common to all tagged members. (This slight slowness of tagged sockeye was borne out by subsequent comparison of the rates of migration calculated from tagging, with rates obtained by fitting dates of peak weekend escapements to peaks of abundance of sockeye at the various spawning grounds.) Even if they had been delayed, the chronological order maintained by tagged sockeye would not have differed from that of untagged sockeye provided that all the tagged fish were similarly affected.

The error introduced by using tag returns to estimate the migration rates of sockeye may vary with the distance between the place of tagging and the place of recovery. The percentage error would probably be greater over small distances; a delay of one or two days is probably caused by tagging *any* sockeye during its spawning migration. Consequently calculations of migration rates, as measured

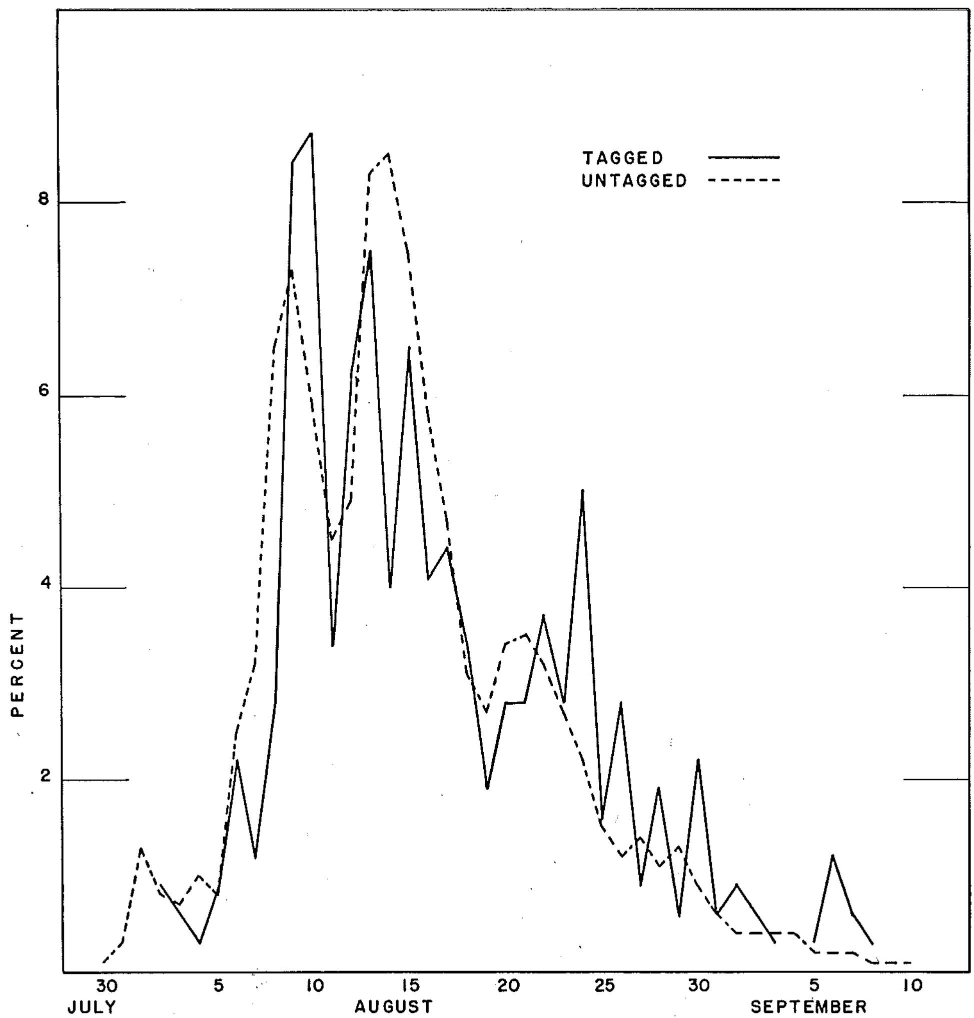

FIGURE 1. The percentage frequency distribution of tagged and untagged sockeye at the Bowron weir, 1945 to 1948.

by distance divided by time of travel, over short distances above the tagging site would produce rates much slower than those computed over greater distances. The errors introduced by migration rates calculated over short distances would be even more serious if tagging caused some sockeye to migrate at a rate considerably below normal and then die a few days after tagging. The recapture of such slow-migrating sockeye would be possible near the tagging site and would provide completely erroneous migration rates. (Such results are undoubtedly obtained from any saltwater tagging experiment conducted for the purpose of measuring the migration rate of various salmon populations.) The solution to this problem was to calculate migration rates only from those recoveries that were obtained at the greatest distance from the tagging site; sockeye seriously injured or weakened by tagging were thus eliminated from the recovery data and more accurate rates of migration obtained. The greater the distance involved, the

TABLE 1

TESTS OF SIGNIFICANCE BETWEEN THE MIGRATION TIMES OF MALE AND FEMALE SOCKEYE FROM HELL'S GATE AND THE BRIDGE RIVER RAPIDS TO THE BOWRON WEIR

Tagging Location	Recovery Location	Year	MALES Mean Time	MALES Sample	FEMALES Mean Time	FEMALES Sample	Values of "t"	Degrees of Freedom	Significant Difference
Hell's Gate	Bowron Weir	1945	23.2	(22)	24.4	(5)	1.0235	25	None
Hell's Gate	Bowron Weir	1946	21.3	(38)	19.7	(26)	.8799	62	None
Hell's Gate	Bowron Weir	1947	19.7	(54)	20.4	(60)	1.7450	112	None
Hell's Gate	Bowron Weir	1948	22.3	(63)	22.4	(44)	.0410	105	None
Bridge River Rapids	Bowron Weir	1945	20.1	(30)	19.8	(15)	.3712	43	None
Bridge River Rapids	Bowron Weir	1946	16.4	(59)	16.8	(37)	1.1125	94	None

less adverse effect tagging would have had on determining accurate rates of migration.

Effect of Delays Along the Path of Migration

A breakdown of chronological order and resultant mixing of various portions of the escapements is inevitable below any obstruction which creates an accumulation of salmon. Such a circumstance occurred each season at Hell's Gate prior to the installation of the fishways in 1945. Detailed descriptions of the effect of delays and subsequent mortalities of blocked sockeye below Hell's Gate are given in reports by Thompson (1945) and Talbot (1950). No attempt has been made to calculate migration rates of sockeye affected by the Hell's Gate block because it was impossible to assess how long the individual sockeye were delayed. Only tagging since 1945 has been considered and, unless otherwise stipulated, the following analysis of migration rates will include only those runs which appeared relatively free from delay en route. This does not imply that the sockeye migrations proceed uninterrupted day and night and at a constant rate throughout all regions of the path of migration, as such is most unlikely; instead, the tagging data have been chosen to deliberately exclude unnatural delay periods such as formerly existed below Hell's Gate. In general, it is proposed that the results of these studies will represent migrations that exist at present with no serious obstructions being in effect.

Effect of Differences Between the Sexes

As it is common for male sockeye to be more numerous at the start of a run and for females to be more abundant at the end, it was necessary to investigate whether the sexes travel at the same rate; otherwise, an apparent lack of chronological order (change in migration rate) in combined data might merely have been the result of changes in the proportions of the two sexes. Schaefer (1951) analysed the data for Harrison male and female sockeye migrations separately and concluded that, where the number of cases involved was sufficient to give a reliable average, there was no evidence of any appreciable difference in the speeds of migration. In the present investigation the possibility of different speeds for male and female sockeye was tested using adequate numbers of tags that were accurately recorded both during tagging at Hell's Gate and the Bridge River Rapids and during recovery at the Bowron weir. The distances involved were 531 and 455 miles respectively. Tests of significance between the migration times of males and females are given in Table 1. Data from four consecutive years of tagging at Hell's Gate from 1945 to 1948 demonstrated a probability of less than one per cent that male and female sockeye had different rates of migration. Two additional tests made from Bridge River Rapids in 1945 and 1946 confirmed the Hell's Gate results.

Two years of tagging at Hell's Gate in 1947 and 1948 were considered in more detail to determine whether the total mean value for each sex was developed from unlike daily means occurring through the duration of the runs. The mean

TABLE 2

A COMPARISON OF THE DAILY MIGRATION TIMES OF MALE AND FEMALE SOCKEYE FROM HELL'S GATE TO THE BOWRON WEIR IN 1947 AND 1948

Dates of Tagging at Hell's Gate	Daily Mean Migration Times as Days-Out From Dates of Tagging to Recovery			
	1947		1948	
	Males	Females	Males	Females
July 12			22.0 (1)	
13			22.0 (1)	
14				23.5 (2)
15		28.0 (1)	20.0 (1)	
16			21.0 (1)	
17			23.0 (2)	
18			21.3 (6)	21.8 (4)
19	22.0 (1)	22.0 (1)	21.0 (5)	
20			22.9 (8)	22.8 (8)
21	23.0 (1)	20.4 (5)	21.1 (8)	20.9 (8)
22	20.0 (3)	23.0 (1)	21.3 (3)	22.0 (1)
23	20.0 (2)	18.4 (5)	21.4 (5)	21.0 (1)
24	17.0 (1)	20.5 (2)		
25	18.8 (7)	18.1 (6)	20.0 (1)	22.0 (4)
26	19.0 (3)	20.0 (1)	26.0 (3)	21.0 (3)
27	19.0 (3)	19.5 (2)	24.5 (4)	23.0 (4)
28	19.0 (9)	20.9 (8)	24.1 (8)	22.0 (3)
29	19.0 (2)	20.5 (3)	23.5 (2)	23.0 (2)
30	17.5 (2)	19.7 (6)	26.5 (2)	25.7 (3)
31	19.0 (1)	19.0 (1)	24.0 (1)	
August 1	20.0 (2)	21.0 (1)		
2	20.8 (4)	23.0 (1)		
3		20.7 (6)		
4	21.0 (4)	20.0 (2)	27.0 (1)	25.0 (1)
5		21.3 (4)		
6	18.0 (1)			
7	20.3 (3)			
8		21.0 (1)		
9	19.5 (2)	21.0 (1)		
10				
11				
12				
13	25.0 (1)	22.0 (2)		
14				
15	20.5 (2)			
Season Means	19.7 (54) days	20.4 (60) days	22.3 (63) days	22.4 (44) days

Sample sizes in parentheses.

numbers of days before recovery for each day's tagging of males and females are shown in Table 2. The two sexes had such similar speeds of migration that, even though the males and females may have occurred in varying abundance throughout the period of the run, their respective migration rates could be treated as one.

Accuracy of Tag Recovery Dates

The accuracy of calculated rates of migration of tagged sockeye depends greatly upon the accuracy of the recovery data. Unmeasured delay in recovery of available tags, has been the most common source of error in the calculation of the true speeds of travel. This problem confronted Thompson (1945) at Adams River in 1942 when Indians recovered Hell's Gate tags from live sockeye on the spawning grounds. Thompson noted that the spawning ground recoveries included salmon which apparently migrated at different rates, or which were recovered at very different intervals after arrival; however, there was no way of distinguishing between the two. He used the first decile values representing the fastest recoveries to reduce the delay in recovery after arrival to a minimum. Still it was very probable that the effort exerted by the Indians was not continuous; it seems that they may not have begun their search until a reasonable number of tags had already arrived on the spawning grounds, then made an intense recovery until the tags became scarce. Such uneven effort applied to tag recovery could have produced the following results assuming some variation from a common mean existed for every date of tagging. The first tagged sockeye after arrival at Adams River would not be recovered immediately and a slow migration would be obtained from their days-out to recapture; even the use of the first decile would not fully compensate for these belated returns of the early arrivals. The centre groups of arriving sockeye would be sampled through all variations of their arrival period in the river and a first decile value of tag returns for this group would represent a reasonably accurate measure of the fastest migration time. Tagged sockeye which arrived late would be sampled with the central group and only the fastest migrants of this group recorded; and, unless an extended search was continued even when the tags were few, the slowest of the late migrants would not be included in the recovery data. The inevitable overall result would be a faulty impression of a progressive speed-up of migration between the first and the last fish of the run. Talbot (1950) also mentioned that there was no way of determining how long the tagged fish were present on the spawning grounds before the tags were recovered and so they could not be used to determine migration rates. The recovery of such tags were not considered in the present analysis.

Some other source of tag recovery was needed to measure migration rates accurately. Counting fences or weirs located in streams containing only one run offered the best solution. Of those available the Bowron weir, located below Bowron Lake about 12 miles from the spawning grounds, provided the most accurate data because all sockeye were examined immediately upon arrival. Other weirs in the Stuart Lake district had been used for tag recovery but it was found that weirs located at the immediate entrance to the spawning grounds seemed to delay the migration of the first arrivals. The various circumstances concerning the accuracy of tag recoveries are discussed for each run.

It should be borne in mind that possible adverse effects of tagging and delays in tag recovery both tend to interfere with the recognition of the correct order of migration and therefore, since it was not possible to completely evaluate these effects, estimates of the degree of mixing as measured by inconsistencies in the chronological order may be unduly high.

The criteria for securing accurate migration rates for tagged sockeye were not met by many of the tagging data collected by the Commission. However, valuable data for some runs of Fraser sockeye were available. The runs to the Bowron and the Stuart areas have been given first consideration as their migrations are longer than those of other runs of Fraser River sockeye, each being over 600 miles, and in each of these areas weirs had been installed from which accurate dates of tag recovery were obtained.

METHODS OF STATISTICAL ANALYSIS

Analysis of chronological order during migration by examination of the travel times of *tagged* sockeye is followed by consideration of the order of migration of groups of *untagged* sockeye, and the results from the two methods compared. The procedures and their relative merits are as follows:

Analysis of Tagging Data

The order of migration of tagged sockeye was assessed by measuring the degree of consistency of the individual travel times as recorded from the date of tagging to the date of recovery. Tag returns were classified by separate runs and tested against the following hypothesis: *each sockeye of a particular run required the same number of days to travel between the place of tagging and recovery.* It is probable that such an exact relationship did not exist, especially when long migrations were involved. Measures of the extent of agreement with the hypothesis therefore had to be established. Any inconsistencies in the chronological order during the migration of a run result in mixing, and the expression *mixing* will be used henceforth in the sense that the chronological order has been inconsistent.

Schaefer's concern (1951) with the chronological order of Harrison sockeye during their migration, was not with respect to the ultimate character of escapements, but with population enumeration. He wished to determine whether tagged fish in particular parts of a population would mix throughout the recovery period in a more or less homogeneous manner. To measure the degree of mixing he plotted the dates of recovery for each date of tagging. For the sum of all tag returns, statistics were calculated which he defined as follows:

n—the number of recoveries represented.

d—the average days between dates of tagging and dates of recovery of all recoveries.

r—the product moment correlation coefficient, measuring the amount of mixing between tagging and recovery.

b—the coefficient of mean square linear regression of date of recovery on date of tagging, which may be taken as an indication of the change in speed of migration. ($b = 1$ denotes no change; $b > 1$ denotes slowing of the migration and $b < 1$ denotes an acceleration of migration through the period of the run.)

These statistics have been used in parts of the present analysis. In addition the Standard Deviation from Regression, or Standard Error of Estimate (SEE), has also been calculated to measure the degree of dispersion about the regression line.

Analysis of the tag returns *en masse* can adequately illustrate whether mixing occurs and, if so, to what degree; details as to the behavior of parts of a run however, are difficult to abstract from the summed data. The regression line is a function of both the position and frequency of the member tags and is mostly controlled by that part of the run where the tag concentration is heaviest. The derived values of "r" and "b" may not apply to the smaller samples of tagged sockeye which occur early and late in the run. Possible differences of behavior in different parts of the run can only be determined by considering each part separately.

To assess the chronological order of all *parts* of a run, the tagging data in the present analysis have been dealt with in the following manner. For each tagging day, the numbers of *days-out* from date of tagging to dates of recovery were tabulated and daily arithmetic mean times of migration calculated. These means were examined for their degree of consistency throughout the complete period of tagging. If the daily means showed no trends or significant differences then a seasonal mean was used to express the time of travel of any part of the run. Daily means consistent with the season mean were not always the case; therefore, the period of tagging (30 to 40 days) was divided into three equal parts—early, central and late—and each analysed separately. For these parts, means were calculated and examined for consistency between themselves and the season mean. Mixing occurred when the means indicated a progressive speed-up throughout the run; whereas an extension of the period of arrival occurred when the means indicated a progressive slowness throughout the run. Changes in rate, either by acceleration resulting in mixing, or by slowness resulting in extension, are of concern when it is desired to place selected escapements on the spawning grounds at particular periods of the environmental cycle.

In addition to considerations of changes in the means, standard deviations were calculated. This was not done on a daily basis as the numbers of tags recovered for any one day were seldom sufficient. Instead the standard deviation of the group and season means were calculated and, where the samples were adequate, the means tested by an analysis of variance. The standard deviation of the season mean for each run was used as a measure of the degree of mixing unless marked differences between the group means were apparent. To facilitate comparisons between runs, coefficients of variation were calculated. (This statistic is the standard deviation expressed as a percentage of the mean.)

It was observed that the frequency distribution of the days-out of tagged sockeye usually formed a moderately asymmetrical curve tending towards positive skewness. Skewness of the tag recovery curve sometimes caused discrepancies between the positions of the statistical mean and the mode. It may be that the mode was closest to the time taken by untagged fish. Excessively late recoveries of tagged members would have the effect on the curve of shifting the mean travel time to the right of the mode and the mean would indicate too many days of travel and a slow migration. (This effect is confirmed in later comparisons of the travel rates of tagged and untagged sockeye migrations.) In any case, in a skewed frequency distribution equal intervals of time on either side of the mean do not include equal proportions of the run. Nevertheless the skewness of the frequency distribution was not considered to be sufficiently great to invalidate the use of the standard deviation as being generally representative of the degree of mixing.

Analysis of the Migration Pattern Without Tagging

The indication that sockeye were delayed by tagging and that the calculated mean travel times of tagged sockeye were consequently slower than would be expected for untagged sockeye led to the need for further study. Migration patterns without the use of tags have already been discussed in the measurement of chronological order through the 81 miles of river below Hell's Gate (see page 3). Escapements of untagged sockeye were also traced hundreds of miles above Hell's Gate to the spawning grounds. Details of the pattern of these movements are dealt with in the text but it is noted here that the travel times of untagged sockeye were a function of group behavior and could not be readily tested for degrees of dispersion because the exact times for *individual* sockeye were not known. Deviations from constant mean travel times were indicated by depression of the escapement peak and slight extension of the period of arrival of the groups at the spawning grounds.

THE BOWRON SOCKEYE MIGRATION

The most extensive and accurate data were available for a study of the Bowron run and their analysis serves as a model for other runs of the Fraser. Two years of tagging at Sooke in 1946 and 1947 provided thirty tag recoveries which, although few in number, were representative of various parts of the runs and were particularly valuable because they traced a migration pattern through the lengthy distance of 785 miles. Four years of tagging data at Hell's Gate from 1945 to 1948 were also used to study the migration of Bowron sockeye through the last 531 miles. These data throughout a four-year cycle were especially valuable for determining possible annual variations in rates of migration and degrees of mixing. Results from analysis of these data were confirmed by analysis of abundance curves for other years.

Analysis of Tagging Data

Sooke to Bowron, 1946 - 1947

Regression coefficients were not calculated for the Sooke data of 1946 and 1947 because the numbers of tag recoveries were insufficient; instead, the individual days-out from dates of tagging were tabulated for the two years as shown in Tables 3 and 4. The daily means were calculated and examined for consistency through the run. Limited sample sizes restricted the conclusions with respect to changes in rate throughout the period of the run; however, the general symmetry of the daily means permitted a reasonable assessment of the degrees of mixing to be obtained from the standard deviations of the season means.

Eight sockeye tagged at Sooke in 1946 were recovered at the Bowron weir (Table 3). The fastest sockeye arrived in 25 days and the slowest in 33 days with a mean travel time of 29.75 days for all eight recoveries. The daily means showed

TABLE 3

THE MIGRATION TIMES OF SOCKEYE FROM SOOKE TO THE BOWRON WEIR IN 1946 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Sooke	Number of Days-Out to Recovery at Bowron													Daily Mean Number of Days	Number Recovered
	24	25	26	27	28	29	30	31	32	33	34	35	36		
July 10															
11									1					32.0	1
12															
13															
14															
15				1										27.0	1
16															
17															
18		1				1				1				29.0	3
19															
20															
21															
22							1	1						30.5	2
23															
24															
25								1						31.0	1

Number Recovered = 8
Season Mean Days-Out = 29.75
Standard Deviation = 2.68
Coefficient of Variation = 9.01
Mean Rate (Miles per Day) = 27.3

no particular tendency to change through the period of the run; however, a slight degree of mixing was attributed to differences in the individual days of travel as signified by the standard deviation of 2.68 days.

Twenty-two Sooke-tagged sockeye were recovered at the Bowron weir in 1947 (Table 4). The extreme times of the fastest and slowest sockeye were 24 to 36 days with a mean of 29.41 days for all recoveries. This mean was nearly identical to that of 1946 but slightly more mixing was indicated by the larger standard deviation value of 3.13. The higher value of the standard deviation was largely due to two slow-moving sockeye tagged on July 10 and 14 that took 35 and 36 days respectively. The average speed of travel from Sooke to Bowron in 1947 was 27.6 miles per day as compared with 27.3 in 1946. (The days-out given in Tables 3 and 4 are inclusive of both date of tagging and date of recovery, therefore, they are reduced by one day to calculate speed in miles per day.)

For each of the two years of 1946 and 1947, coefficients of variation were calculated; they were 9.01 in 1946 and 10.64 in 1947. The fact that only small deviations in individual migrations occurred demonstrated that quite an orderly passage of sockeye existed along an extremely long migration route from Sooke to the Bowron weir.

Hell's Gate to Bowron, 1945 - 1948

Tagging of Bowron sockeye at Hell's Gate from 1945 to 1948 provided sufficiently large samples of tag returns to permit the calculation of statistics of

TABLE 4

THE MIGRATION TIMES OF SOCKEYE FROM SOOKE TO THE BOWRON WEIR IN 1947 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Sooke	Number of Days-Out to Recovery at Bowron													Daily Mean Number of Days	Number Recovered
	24	25	26	27	28	29	30	31	32	33	34	35	36		
July 10												1		35.0	1
11															
12															
13															
14					1			1					1	31.6	3
15				1				1		1				30.3	3
16															
17								1						31.0	1
18				1	1		2	1						29.2	5
19															
20															
21		1	2											25.6	3
22															
23															
24								1						31.0	1
25															
26															
27															
28			1			1		1						28.6	3
29															
30															
31	1													24.0	1
Aug. 1															
2															
3															
4								1						31.0	1

Number Recovered = 22
Season Mean Days-Out = 29.41
Standard Deviation = 3.13
Coefficient of Variation = 10.64
Mean Rate (Miles per Day) = 27.6

TABLE 5

STATISTICS DERIVED FROM LINEAR REGRESSION OF THE FREQUENCY DISTRIBUTION OF TAGGED SOCKEYE FROM DATES OF TAGGING AT HELL'S GATE TO DATES OF RECOVERY AT THE BOWRON WEIR
1945 TO 1948

Year	Place of Tagging	n	d	r	b	SEE
1945	Hell's Gate	26	23.2	.9182	1.044	3.36
1946	Hell's Gate	64	21.5	.9534	1.007	2.70
1947	Hell's Gate	114	20.1	.9403	1.039	2.30
1948	Hell's Gate	107	22.3	.9151	1.158	2.37

n = number of recoveries
d = average days from tagging to recovery
r = product moment correlation of date of tagging with date of recovery
b = regression coefficient of mean square linear regression of date of recovery on date of tagging
SEE = Standard Error of Estimate

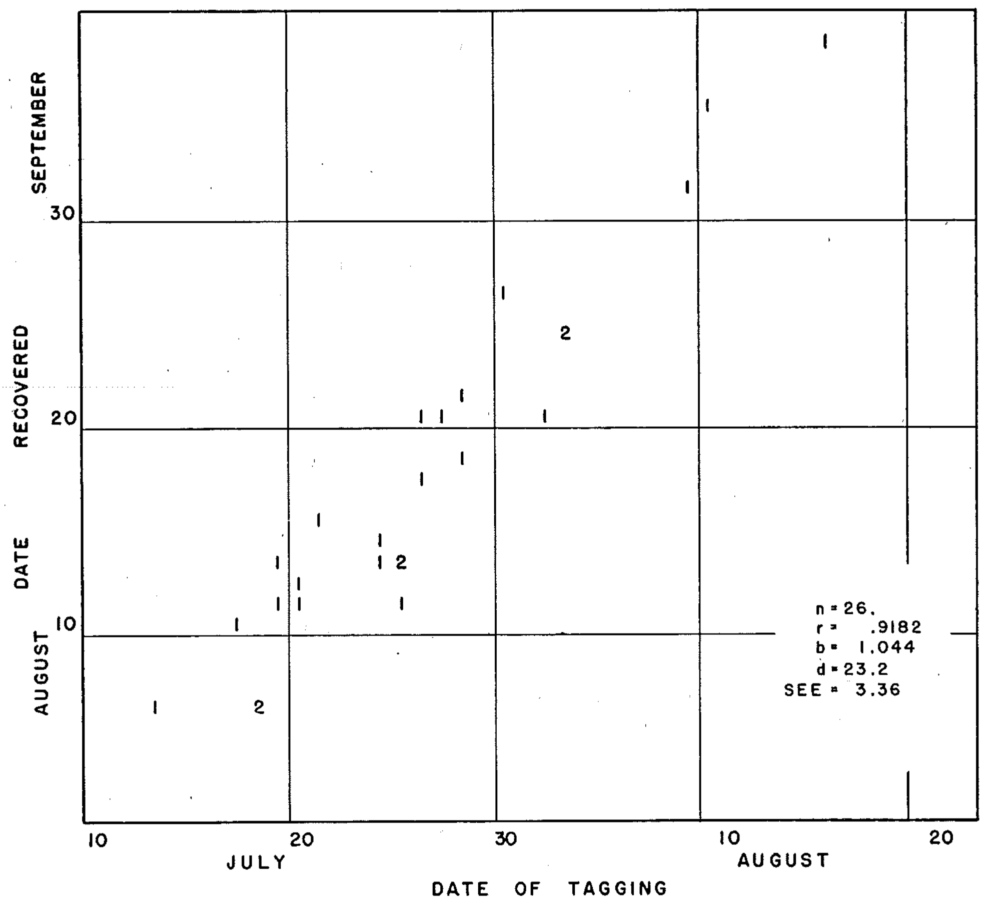

FIGURE 2. Recoveries by dates of tagging and recovery of sockeye tagged at Hell's Gate and recovered at the Bowron weir, 1945.

regressions similar to those presented by Schaefer for the migration of runs within the Harrison system. The distribution of tag recoveries and the statistical values of n, d, r, b and the SEE (see page 10) are shown in Figures 2 to 5 and summarized in Table 5. The differences between years do not appear to be great and, as there were relatively few recoveries in 1945 and 1946, only the recoveries in 1947 and 1948 need be considered in detail.

In 1947, 114 sockeye tagged at Hell's Gate were recovered at the Bowron weir. The dates of tagging and the recovery distribution are plotted in Figure 4. An average time of 20.1 days was required for the sockeye to travel between the location of tagging and recovery. The 1947 "b" value was very close to 1, being 1.039; this indicated that a consistent rate of migration of tagged sockeye occurred throughout the run above Hell's Gate.

Accepting the regression line as representing all parts of the run, sockeye leaving Hell's Gate on July 15 would have reached the Bowron weir 19.5 days later between August 2 and 3. Sockeye migrating a month later would have taken 20.5 days. Thus the first and last fish would have had a difference in mean

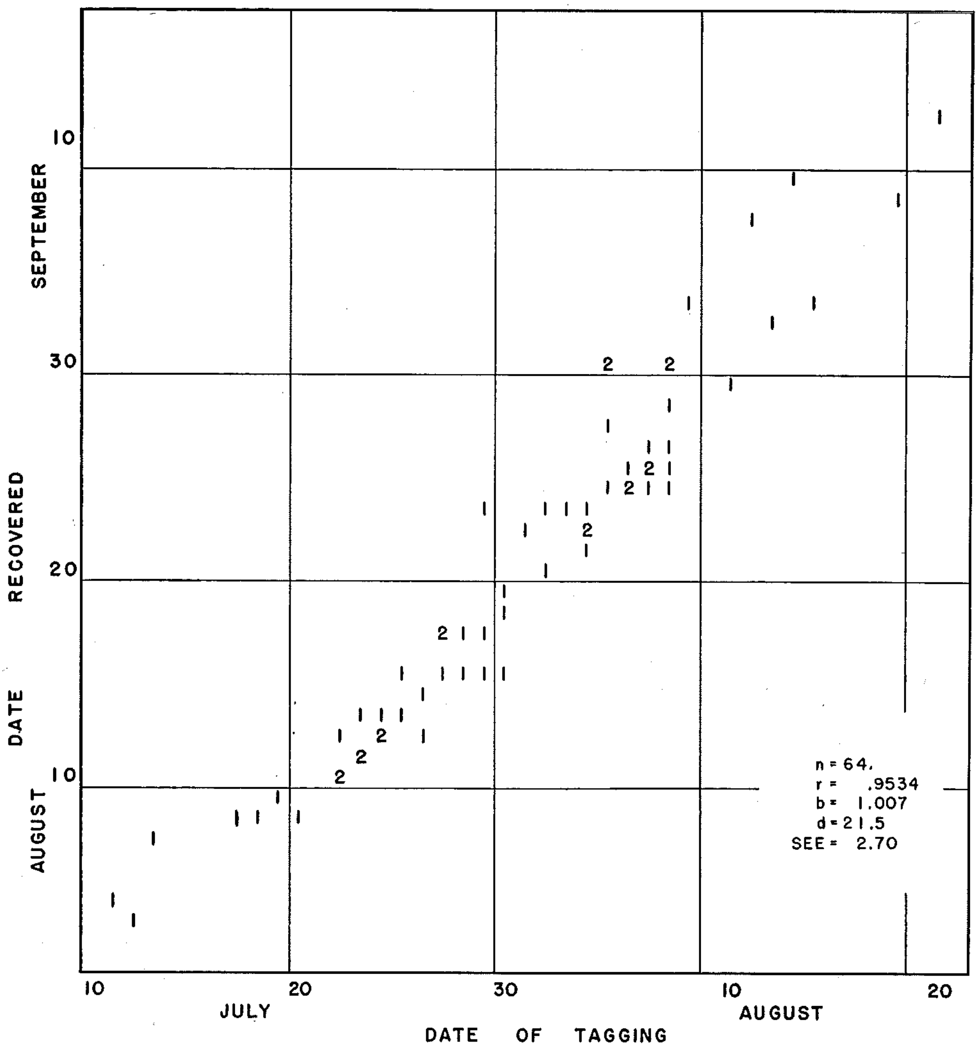

FIGURE 3. Recoveries by dates of tagging and recovery of sockeye tagged at Hell's Gate and recovered at the Bowron weir, 1946.

migration time of only 1 day. Such a small variation in migration times between early and late-migrating sockeye would be negligible.

Some mixing of the 1947 tagged sockeye did occur as indicated by the "r" value of .9403. The extent of the dispersion indicated by the standard error of estimate was 2.3 days.

The 1948 tagging at Hell's Gate provided a sample of 107 tag recoveries at the Bowron weir. The average migration time was 22.3 days (Figure 5). The degree of mixing indicated by the "r" value of .9151 and the standard error of estimate value of 2.37 was very limited. The "b" value was 1.158 indicating a progressive slowing of the migration towards the end of the run. While the degree of mixing appeared to be nearly the same as that for the previous three years, the change

TABLE 6

THE MIGRATION TIMES OF SOCKEYE FROM HELL'S GATE TO THE BOWRON WEIR IN 1945 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Hell's Gate	Number of Days-Out to Recovery at Bowron											Daily Mean Number of Days	Number Recovered
	18	19	20	21	22	23	24	25	26	27	28		
July 10													
11													
12													
13								1				25.0	1
14													
15													
16													
17								1				25.0	1
18			2									20.0	2
19							1		1			25.0	2
20						1	1					23.5	2
21									1			26.0	1
22													
23													
24				1	1							21.5	2
25	1		2									19.3	3
26						1			1			24.5	2
27								1				25.0	1
28					1			1				23.5	2
29													
30											1	28.0	1
31													
August 1			1									20.0	1
2						2						23.0	2
3													
4													
5													
6													
7													
8							1					24.0	1
9										1		27.0	1
10													
11													
12													
13													
14													
15							1					24.0	1

Number Recovered	= 26
Season Mean	= 23.23
Standard Deviation	= 2.55
Coefficient of Variation	= 10.98
Mean Rate (Miles per Day)	= 23.89

in time required for migration through the duration of the 1948 run was more apparent. A difference of 3.5 days was indicated between the migration time of fish tagged on July 12 and August 4. No mixing was created by this change through the run; in fact, an extension of the recovery period would tend to separate the day-populations.

Regression analysis of the Bowron tag recoveries demonstrated that in general the chronological consistency was closely retained throughout the runs of 1945 to 1948. More details on the migratory order of various parts of each run were obtained from tabulations of the days-out from dates of tagging to dates of recovery either on a daily basis or by subdividing the total period of the run into three

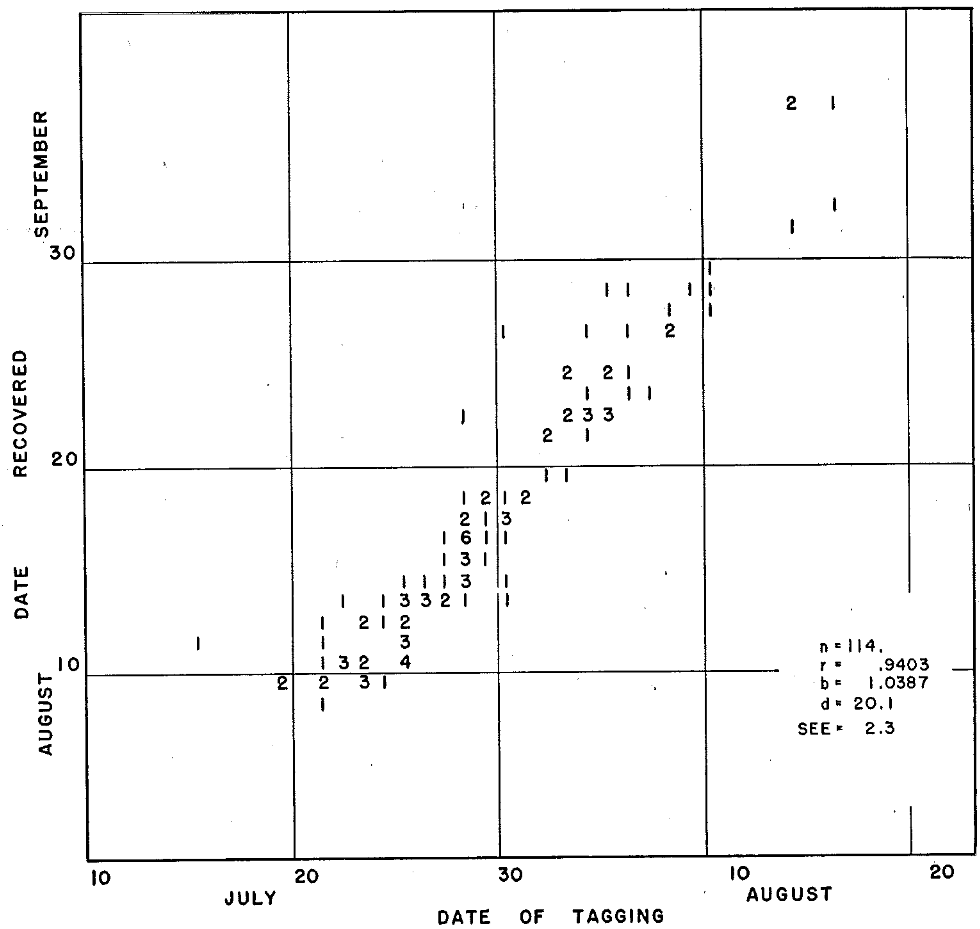

FIGURE 4. Recoveries by dates of tagging and recovery of sockeye tagged at Hell's Gate and recovered at the Bowron weir, 1947.

parts of early, central and late sockeye. Such data are shown in Tables 6 to 13 for the four years of 1945 to 1948.

In 1945, the daily mean times of travel (days-out) showed no definite trend of increase or decrease during the 34 days of the run; however, the numbers in the daily samples were small. Division of the run into three periods of tagging (Table 7) gave larger sample sizes although still not large enough to give great confidence. There were no large variations in the mean times of travel or degrees of mixing for the three periods, the means being 23.66, 22.57 and 25.0 days and the standard deviations 2.29, 2.74 and 1.73 days respectively. The run was adequately represented by the seasonal values of 23.23 mean days of travel and 2.55 days of dispersion about the mean. The coefficient of variation for the total recoveries was 10.98.

Inspection of the daily means of the 1946 Bowron tags, revealed a slight tendency towards a change in migration throughout the run and this was more

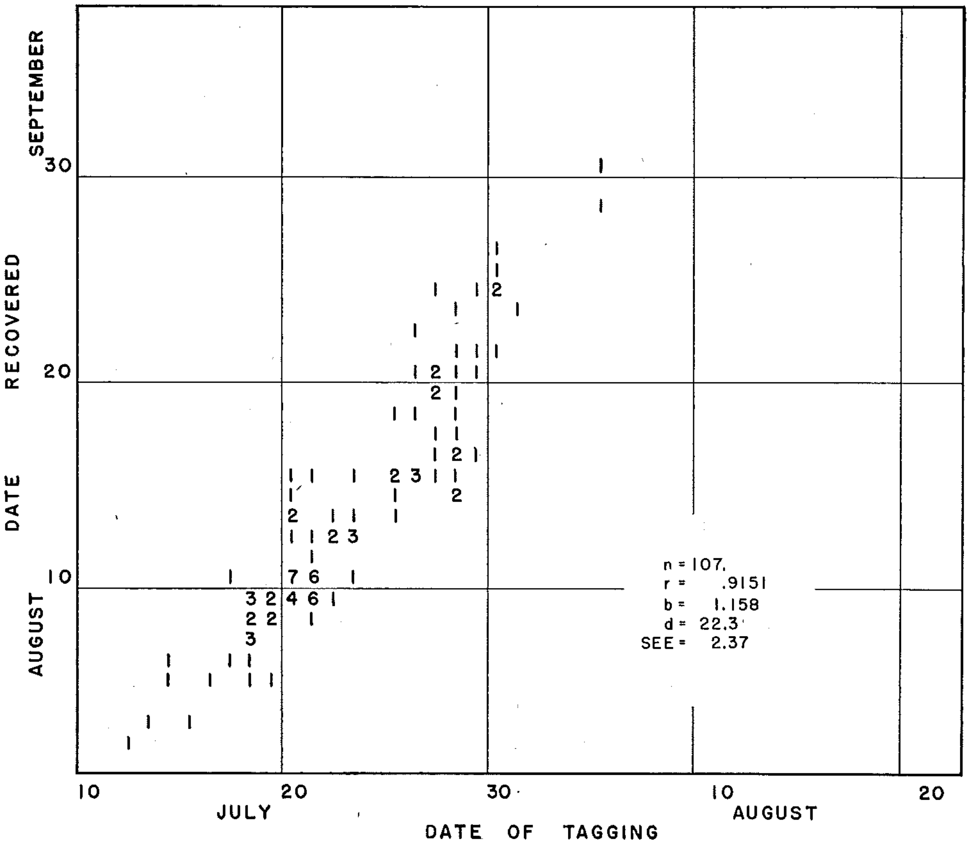

FIGURE 5. Recoveries by dates of tagging and recovery of sockeye tagged at Hell's Gate and recovered at the Bowron weir, 1948.

TABLE 7

A COMPARISON OF THE DAYS-OUT OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE MIGRATING FROM HELL'S GATE TO THE BOWRON WEIR IN 1945

No. of Days-Out	Early Group (A) July 13 - 23	Central Group (B) July 24 - August 3	Late Group (C) August 4 - 15	All Groups July 13 - August 15
15				
16				
17				
18		1		1
19				0
20	2	3		5
21		1		1
22		2		2
23	1	3		4
24	2		2	4
25	2	2		4
26	2	1		3
27			1	1
28		1		1
No. Recovered	9	14	3	26
Means	23.66	22.57	25.0	23.23
Standard Deviation	2.29	2.74	1.73	2.55
Coef. of Variation	9.68	12.14	6.92	10.98

TABLE 8

THE MIGRATION TIMES OF SOCKEYE FROM HELL'S GATE TO THE BOWRON WEIR IN 1946 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Hell's Gate	Number of Days-Out to Recovery at Bowron											Daily Mean Number of Days	Number Recovered
	17	18	19	20	21	22	23	24	25	26	27		
July 10													
11									1			25.0	1
12							1					23.0	1
13										1		26.0	1
14													
15													
16													
17							1					23.0	1
18						1						22.0	1
19						1						22.0	1
20				1								20.0	1
21													
22				2		1						20.7	3
23				2		1						20.7	3
24				2	1							20.3	3
25				1		1						21.0	2
26		1		1								19.0	2
27				1		2						21.3	3
28			1		1							20.0	2
29		1		1						1		21.3	3
30	1			1	1							19.3	3
31							1					23.0	1
August 1				1			1					21.5	2
2						1						22.0	1
3			1	2	1							20.0	4
4					1			1			2	24.8	4
5				2	1							20.3	3
6			1	2	1							20.0	4
7		1	1	1		1		2				21.2	6
8										1		26.0	1
9													
10				1								20.0	1
11											1	27.0	1
12					1							21.0	1
13											1	27.0	1
14				1								20.0	1
15													
16													
17													
18					1							21.0	1
19													
20							1					23.0	1

Number Recovered	=	64
Season Mean	=	21.44
Standard Deviation	=	2.39
Coefficient of Variation	=	11.15
Mean Rate (Miles per Day)	=	25.98

apparent from the group means of 21.63, 21.03 and 23.13 which indicated that the later migrants travelled more slowly (Table 9), although the small sample of 8 tagged sockeye for the last group may not have provided a very reliable value. The degree of dispersion through various parts of the run also increased slightly according to the standard deviations of 1.89, 2.31 and 3.09 and coefficients of variation of 8.74, 10.98 and 13.36. In general the values for the season, a mean time of 21.44, deviation of 2.39 and a coefficient of variation of 11.15 per cent, were considered adequately representative in view of the small numbers in the early and late groups.

TABLE 9

A COMPARISON OF THE DAYS-OUT OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE MIGRATING FROM HELL'S GATE TO THE BOWRON WEIR IN 1946

No. of Days-Out	Early Group (A) July 11-23	Central Group (B) July 24-August 7	Late Group (C) August 8-20	All Groups July 11-August 20
15				
16				
17		1		1
18		3		3
19		4		4
20	7	13	2	22
21	1	6	2	9
22	4	5		9
23	2	2	1	5
24		3		3
25	1			1
26	1	1	1	3
27		2	2	4
28				
No. Recovered	16	40	8	64
Means	21.63	21.03	23.13	21.44
Standard Deviation	1.89	2.31	3.09	2.39
Coef. of Variation	8.74	10.98	13.36	11.15

The larger sample of 114 tag returns in 1947 is shown in Table 10. For these tags, the daily means showed only a slight tendency for the later sockeye to travel more slowly. This transition agrees with the evidence obtained from the regression line. The dates of tagging were divided into three groups of which the means were 19.81, 20.03 and 20.77 days. Analysis of variance tests made on the group means indicated that differences in their travel times were not significant. The standard deviations of the groups were similar, being 2.27, 2.15, and 2.32, while that for the season was 2.19 days. The coefficients of variation for the early, central and late sockeye were 11.46, 10.73 and 11.17 and for the season was 10.93, which agreed closely with the values of 10.98 and 9.15 calculated for the years 1945 and 1946.

The daily group and seasonal means and standard deviations of the 1948 Bowron tag data are given in Tables 12 and 13. While there appeared to be slightly more dispersion than occurred in 1947, the daily means were similar throughout the passage of the run. The means of the early, central and late portions of the run were 21.65, 22.23 and 23.30 while that for the season was 22.34. An analysis of variance test on the group means showed significant differences at the 2.5 per cent level but not at the 5.0 per cent level. The change in travel time was only of the order of one-tenth of a day per day and, inasmuch as the later fish travelled more slowly, the change decreased the degree of mixing.

The standard deviations were 1.47, 2.23 and 3.17 for the three groups. The increased dispersion as the season progressed was more important than the increase in the mean length of time from Hell's Gate to the Bowron weir; however, even

TABLE 10

THE MIGRATION TIMES OF SOCKEYE FROM HELL'S GATE TO THE BOWRON WEIR IN 1947 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Hell's Gate	Number of Days-Out to Recovery at Bowron														Daily Mean Number of Days	Number Recovered
	15	16	17	18	19	20	21	22	23	24	25	26	27	28		
July 15														1	28.0	1
16																
17																
18																
19								2							22.0	2
20																
21					1	2	1	1	1						20.8	6
22						3			1						20.8	4
23				3	2		2								19.1	7
24			1			1	1								19.3	3
25			4	3	2	3	1								18.5	13
26					3	1									19.3	4
27				2	1	1	1								19.2	5
28			1	3	3	6	2	1				1			19.9	17
29				1	1	1	2								19.8	5
30	1	1		1	3	1								1	19.3	8
31					2										19.0	2
August 1					1		2								20.3	3
2				1			2		2						21.2	5
3					1	3	1			1					20.7	6
4					3		2				1				20.7	6
5					1	1		1		1					21.3	4
6				1											18.0	1
7						2	1								20.3	3
8							1								21.0	1
9					1	1	1								20.0	3
10																
11																
12																
13					1						2				23.0	3
14																
15				1					1						20.5	2

Number Recovered	= 114
Season Mean	= 20.04
Standard Deviation	= 2.19
Coefficient of Variation	= 10.93
Mean Rate (Miles per Day)	= 27.89

though there was a variation in mixing of the different groups, the maximum deviation for the majority of the tagged sockeye was of the order of only three days. The coefficients of variation for early, central and late sockeye were 6.79, 10.03 and 13.60 while that for the season was 10.65.

Comparison and Combination of the Bowron Tagging Data, 1945 - 1948

Comparative statistics of the sockeye migrations to the Bowron weir from Hell's Gate for the four years of 1945 to 1948 are shown in Table 14. Tag recoveries differed in number each year according to the size of the runs but the conclusions from each year's returns were fairly consistent. The mean number of days between date of tagging and date of recovery varied from 20.04 to 23.23 days for different years. Whether sampling errors, or water-level or other physical conditions of the Fraser River caused most of the three-day differential was not

TABLE 11

A COMPARISON OF THE DAYS-OUT OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE MIGRATING FROM HELL'S GATE TO THE BOWRON WEIR IN 1947

No. of Days-Out	Early Group (A) July 15 - 25	Central Group (B) July 26 - August 5	Late Group (C) August 6 - 15	All Groups July 15 - August 15
15		1		1
16		1		1
17	5	1		6
18	6	8	2	16
19	5	19	2	26
20	9	14	3	26
21	5	12	3	20
22	3	2		5
23	2	2	1	5
24		2		2
25		1	2	3
26		1		1
27				0
28	1	1		2
No. Recovered	36	65	13	114
Means	19.81	20.03	20.77	20.04
Standard Deviation	2.27	2.15	2.32	2.19
Coef. of Variation	11.46	10.73	11.17	10.93

TABLE 12

THE MIGRATION TIMES OF SOCKEYE FROM HELL'S GATE TO THE BOWRON WEIR IN 1948 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Hell's Gate	Number of Days-Out to Recovery at Bowron												Daily Mean Number of Days	Number Recovered
	18	19	20	21	22	23	24	25	26	27	28	29		
July 10														
11														
12					1								22.0	1
13					1								22.0	1
14						1	1						23.5	2
15			1										20.0	1
16				1									21.0	1
17				1				1					23.0	2
18		1	1	3	2	3							21.5	10
19		1		2	2								21.0	5
20				4	7		1	2	1	1			22.8	16
21		1	6	6	1	1			1				21.0	16
22		1			2	1							21.5	4
23		1		3	1		1						21.3	6
24														
25			1	1	2			1					22.0	5
26				3			1		1		1		23.5	6
27			1	1	1		2	2				1	23.8	8
28	2	1	2	1	1	1	1	1		1			21.5	11
29		1				1	1			1			23.3	4
30						1			2	1	1		26.0	5
31							1						24.0	1
August 1														
2														
3														
4								1		1			26.0	2

Number Recovered = 107
Season Mean = 22.34
Standard Deviation = 2.38
Coefficient of Variation = 10.65
Mean Rate (Miles per Day) = 24.88

TABLE 13

A COMPARISON OF THE DAYS-OUT OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE MIGRATING FROM HELL'S GATE TO THE BOWRON WEIR IN 1948

No. of Days-Out	Early Group (A) July 12 - 19	Central Group (B) July 20 - 27	Late Group (C) July 28 - August 4	All Groups July 12 - August 4
15				
16				
17				
18			2	2
19	2	3	2	7
20	2	8	2	12
21	7	18	1	26
22	6	14	1	21
23	4	2	3	9
24	1	5	3	9
25	1	5	2	8
26		3	2	5
27		1	4	5
28		1	1	2
29		1		1
No. Recovered	23	61	23	107
Means	21.65	22.23	23.30	22.34
Standard Deviation	1.47	2.23	3.17	2.38
Coef. of Variation	6.79	10.03	13.60	10.65

apparent. The standard deviations measuring the degree of mixing were nearly identical for each year, ranging from 2.19 to 2.55 and were roughly proportional to their means, giving a coefficient of variation close to 11 per cent in each case. It is considered that the analysis of these four years of data on migrations of the Bowron sockeye has not only established the general migration pattern but has also indicated the extent of the annual variation.

In order that the results of the tag analysis might be applied to or compared with other Bowron runs since 1948, it is necessary to decide on a *mean time of travel* and an *average degree of mixing*. A weighted mean time of 21.4 days was calculated from the annual means given in Table 14. Mixing although measured by dispersion from the annual means could not be measured by the standard deviation from the weighted mean of 21.4 days, since the annual means differed.

TABLE 14

STATISTICS DERIVED FROM THE ANNUAL MEANS AND STANDARD DEVIATIONS OF THE TIMES OF TRAVEL OF SOCKEYE BETWEEN HELL'S GATE AND THE BOWRON WEIR, 1945 TO 1948

Year	Number of Recoveries	Mean Number of Days-Out	Standard Deviation	Coefficient of Variation
1945	26	23.23	2.55	10.98
1946	64	21.44	2.39	11.15
1947	114	20.04	2.19	10.93
1948	107	22.34	2.38	10.65

TABLE 15

DISPERSION TABLE MEASURING THE DEGREE OF MIXING OF ALL HELL'S GATE TAGS RECOVERED AT THE BOWRON WEIR DURING 1945 TO 1948

	Days Different from Annual Means	Frequency	Per Cent Frequency	Cumulative Frequency Per Cent
Fast-Migrating Sockeye	5 days or more	2	.6	
	4	4	1.3	
	3	21	6.8	
	2	33	10.6	
	1 day early	77	24.8	
Average	0	60	19.3	57.6 — 75.9 — 88.5 — 92.7%
	1 day late	42	13.5	
	2	24	7.7	
	3	18	5.8	
	4	9	2.9	
Slow-Migrating Sockeye	5 days or more	21	6.7	

To obtain an overall measure of mixing, each year mean was classed as zero, disregarding its actual numerical value, and the number of tags recovered in 1, 2, 3, 4, 5 or more days different from the mean number of days were summed for the four years and shown in Table 15. The cumulative percentage frequency of deviations showed the dispersion. In summary, the tagging data indicated that mixing during migration was mostly confined to a range of two to three days or 9 to 13 per cent of the average time required to complete the spawning migration.

Analysis of Other Data

On the basis of the results of the tagging analysis, it should follow that when a near-constant rate of migration exists for all portions of a given sockeye run, the time distribution and relative abundance of the peaks of escapement from the commercial fishery should correspond to the arrival pattern on the spawning grounds. To test this hypothesis, the dates of the weekend closures for the Fraser River gillnet fleet have been compared with fluctuations in the daily counts of sockeye through the Bowron weir and travel times deduced.

Alternate periods of fishing and closures of the Fraser River gillnet fishery caused the curve of daily abundance of sockeye to take on a characteristic pattern briefly described as follows. Under normal circumstances, regulations of sockeye catches in the Fraser River permitted four days of fishing on Monday, Tuesday, Wednesday and Thursday and three days of closure on Friday, Saturday and Sunday. Part of the gillnet fleet operating in a three-mile section of the Fraser River at New Westminster, shown in Plate I, reflects the concentration of gear during the four days of fishing. Royal (1953) stated that current findings indicated that ninety-eight per cent of the migrating fish during the open-fishing periods

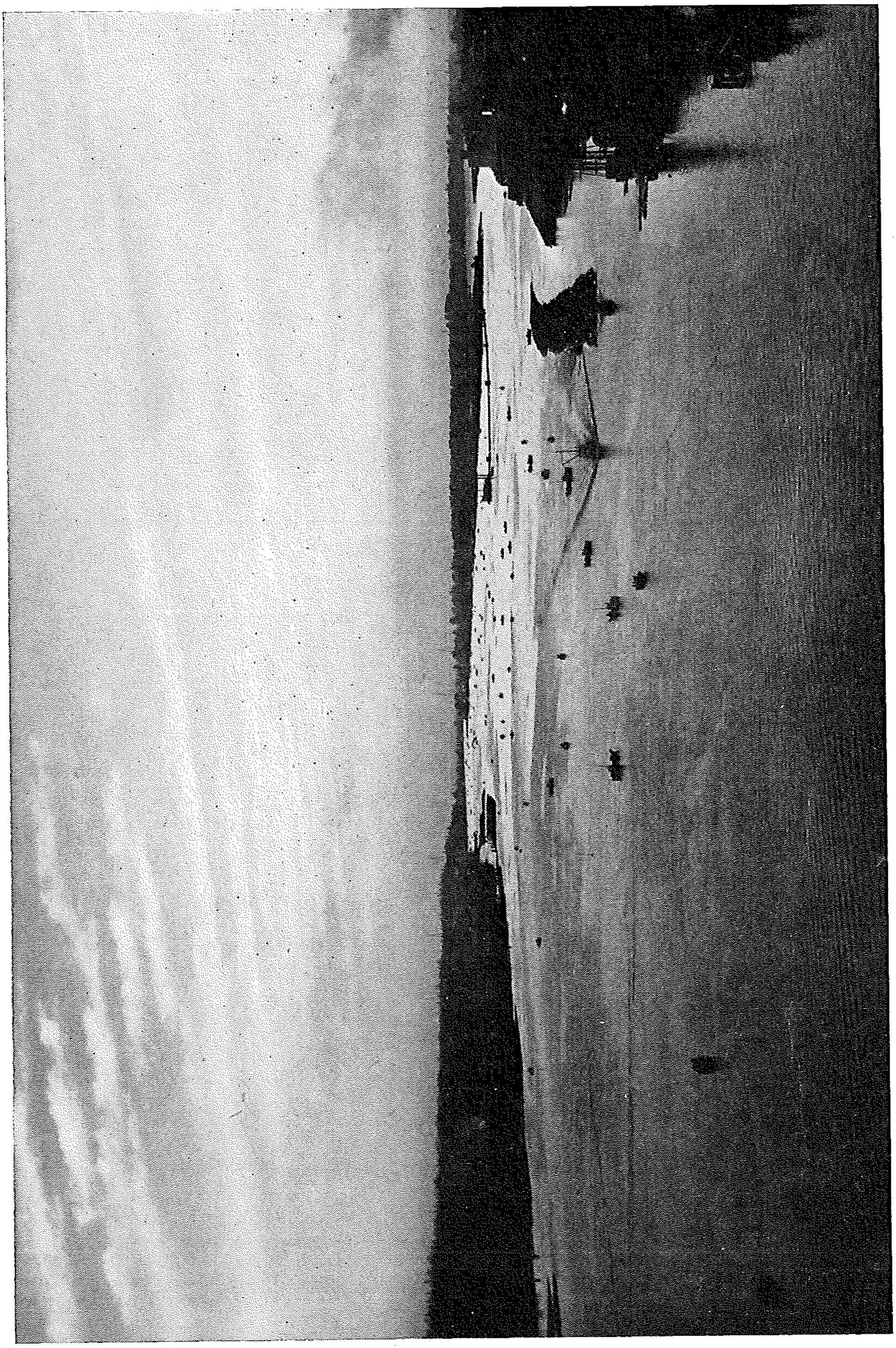

PLATE I. Gillnet boats fishing in the main channel of the Fraser River at New Westminster in September, 1954.

were caught; therefore, the sockeye escapement consisted mainly of those fish which migrated through the fishing area on the days of closure.

However, even though there were three days of closure, there were only about forty-six hours of escapement that were not fished to some degree. At the beginning of the weekend closure there is a transition period when the numbers escaping increase slowly from the estimated two per cent that prevailed during the fishing period. After the heavy escapement period of forty-six hours, the percentage escapement does not drop immediately to the two per cent level since the fishery is not capable of reducing the migrating population to that level for at least twenty-four hours after fishing commences. Rectangular blocks of weekend escapements do not occur and should not be anticipated at the spawning grounds.

It is not proposed to describe further the complexities of the pattern of the escapement but only to point out that as a result of the alternating fishing and closure periods, the escapement consisted of separate groups or peaks which migrated at relatively short, discrete intervals. Talbot (1950) noted that the regular fluctuations in the catch-per-hour records and the percentage of net-marked sockeye caught at Hell's Gate after 1945 were the direct result of gillnet closures in the lower Fraser River in the previous 5 to 6 days (see page 3).

Unfortunately, the 1945 Bowron run was small and no commercial fishing was allowed on this run in the three years from 1946 to 1948 and no tagging was conducted after 1948 at Hell's Gate. Consequently, no direct comparison of the migration rates obtained from tagged sockeye with those obtained by tracing waves of escapement could be made. Commercial fishing on the Bowron run was resumed in 1951 and this year was therefore chosen for comparison with the values obtained by tagging in earlier years. The 1952 escapement of Bowron sockeye was also analysed as it contained an unusual form of extended escapement caused by a fishermen's strike during the peak of the run.

The 1951 Bowron Migration

In 1951, a pattern of four days of fishing followed by three days of closure permitted waves of Bowron sockeye to escape up the Fraser. Under the most stringent conditions of a constant rate of migration for all individuals, these intermittent modes of abundance would have been identically reflected in the Bowron weir counted some 600 miles upriver. The weir counts for 1951 were examined and it was seen that the sockeye *did* arrive in a wave pattern composed of three major peaks or modes (see Figure 6 and Table 16).

The next problem was to relate the weir counts to the correct dates of passage by Hell's Gate and thence to the dates of closure at the fishing area from which they had escaped. This was accomplished graphically by drawing rate lines, the date being represented by the horizontal axis and the distance travelled by the vertical axis. The period of peak abundance at the Bowron weir of August 10 to 12, was considered first. If the travel time between Hell's Gate and the weir were 20 days as recorded for tagged sockeye in the cycle year of 1947, then the peak abundance of August 10 to 12 would have left the Gate on

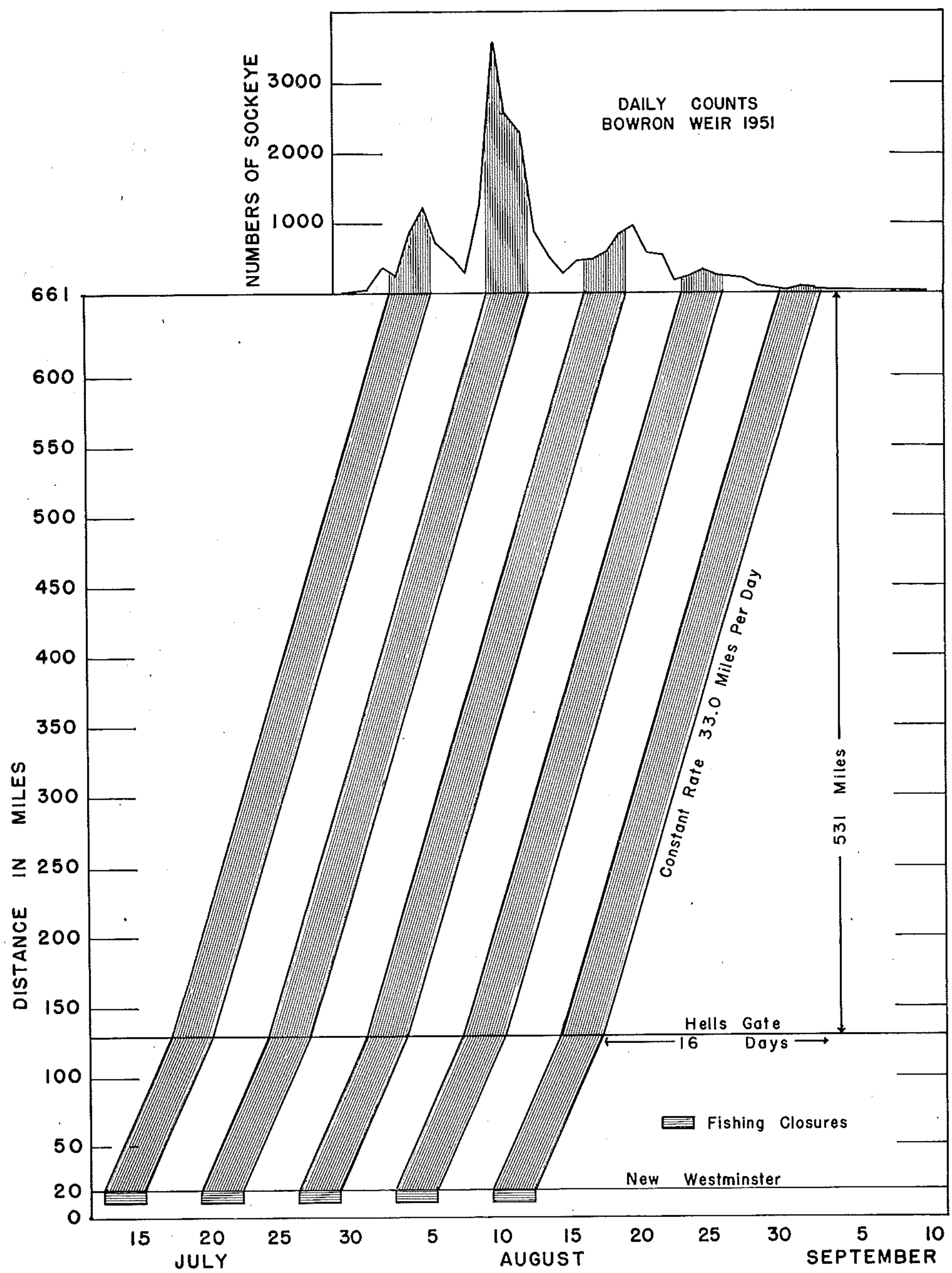

FIGURE 6. Dates of passage and migration rates of the 1951 Bowron sockeye through the Fraser River gillnet area, Hell's Gate and the Bowron weir.

TABLE 16

DAILY COUNTS OF SOCKEYE THROUGH THE BOWRON WEIR IN 1951 AND 1952

Date	Number of Sockeye 1951	1952	Date	Number of Sockeye 1951	1952
July 24	3	0	August 19	838	387
25	7	0	20	959	241
26	10	0	21	565	177
27	18	0	22	531	156
28	1	2	23	172	83
29	19	1	24	234	107
30	4	5	25	317	99
31	27	80	26	230	101
August 1	72	133	27	201	89
2	349	50	28	186	125
3	236	70	29	94	102
4	879	800	30	62	69
5	1,189	461	31	30	71
6	707	443	September 1	82	21
7	514	175	2	56	54
8	287	135	3	37	38
9	1,246	1,476	4	31	20
10	3,545	1,038	5	15	12
11	2,535	3,111	6	17	12
12	2,289	1,682	7	13	1
13	856	1,869	8	7	3
14	508	1,785	9	1	1
15	280	1,494	10	1	3
16	445	648	11	8	0
17	485	640	12	2	0
18	570	542	13	0	0
			Totals	21,770	18,612

July 22 to 24. These July dates in 1951 occurred on Sunday, Monday and Tuesday but an abundance of sockeye at Hell's Gate on these days was unusual—the peak days there being normally on Thursday and Friday. Furthermore, the percentage of net-marked sockeye at Hell's Gate always indicated a 5 to 6-day interval between the fishing zone and Hell's Gate, in which case sockeye at Hell's Gate on July 22 to 24 would have escaped around July 17 to 20, which were Tuesday, Wednesday, Thursday and Friday. No plausible reasoning could account for a peak escapement occurring during days of intense gillnet fishing. Therefore, it was concluded that the 1947 time of 20 days for tagged sockeye from Hell's Gate or 25 to 26 days from the commercial fishing area to the Bowron weir was not correct for the 1951 run. The peak escapement must have left the fishery during one of the three weekends of July 13 to 15, July 20 to 22 or July 27 to 29. The respective days-out to the Bowron weir from these weekends would have been 29, 22 or 15 days. The central weekend of July 20 to 22 was chosen as being the most likely; this gave a travel time of 22 days between the fishery and the weir. Sockeye leaving an arbitrary point at New Westminster on Saturday July 21 would be at Hell's Gate on Thursday July 26 after 6 days and at the Bowron weir on August 11, 17 days after leaving Hell's Gate. This 1951 migration was faster than those previously indicated by tagging but, as it was obtained without handling the fish, it is believed to be the more accurate estimate of the usual speed of travel. The rates in miles per day obtained from the various estimates would be as follows:

	*Days-Out	Distance	Rate as Miles Per Day
New Westminster to Hell's Gate	5	110	22
New Westminster to Bowron weir	21	641	31
Hell's Gate to Bowron weir	16	531	33
Hell's Gate to Bowron weir	19	531	28
(Tagging - cycle year 1947)			

* As the days-out are inclusive in the text to agree with previous practice, one day has been subtracted to calculate miles per day.

The three-day difference in the migration times established by tracing modes of abundance and by tagging was considered to be partly attributable to errors in the tagging method. Tagging no doubt had a delaying effect on the sockeye to the extent of one to two days; moreover, in calculating seasonal rates from tag recoveries, the majority or mode of the returns was nearly always at least one day less than the mean. (See Tables 8 to 13 and text page 11.) The conclusion that tagged sockeye migrated slightly more slowly than untagged sockeye is of particular importance and should receive careful consideration in all similar migration studies. It does not, however, change the prior conclusions regarding mixing provided all tagged sockeye reacted to the tagging in a like manner.

After the migration times for the 1951 Bowron run had been established as 6 days to Hell's Gate and a further 17 days to the Bowron weir, each weekend closure was projected to the curve of daily weir counts using the same rate of travel for all parts of the run and the arrival days determined. Since practically no escapement occurred during the four days of fishing and if no dispersion or mixing had occurred en route then sockeye would have been expected at the weir only on the determined days of arrival. However, tagging indicated that 38.3 per cent would deviate one day from a constant mean and 18.3 per cent two days (see Table 15) so it was to be expected that all the weekend escapements would not fall exclusively within the narrow confines plotted in Figure 6. Some sockeye did in fact appear at the weir every day but, in spite of this, the peaks in the weir counts were apparent and corresponded to respective gillnet closures. This general retention of the wave pattern of the escapement over more than 600 miles from the Fraser River gillnet fishery to the Bowron weir confirmed the prior conclusions of the tagging analysis that for all practical purposes, a consistent chronological order of migration was maintained.

The 1952 Bowron Migration

Accurate daily counts were again kept at the Bowron weir in 1952. These are listed in Table 16 and plotted in Figure 7. The method of projecting weekend escapements was repeated with the data. It was found that a travel time of 18 days from Hell's Gate to the weir provided a better fit than one of 17 days. The starting position of the escapement within the 50 miles of the gillnet area was not precise and 1 day more or less could not be considered decisive.

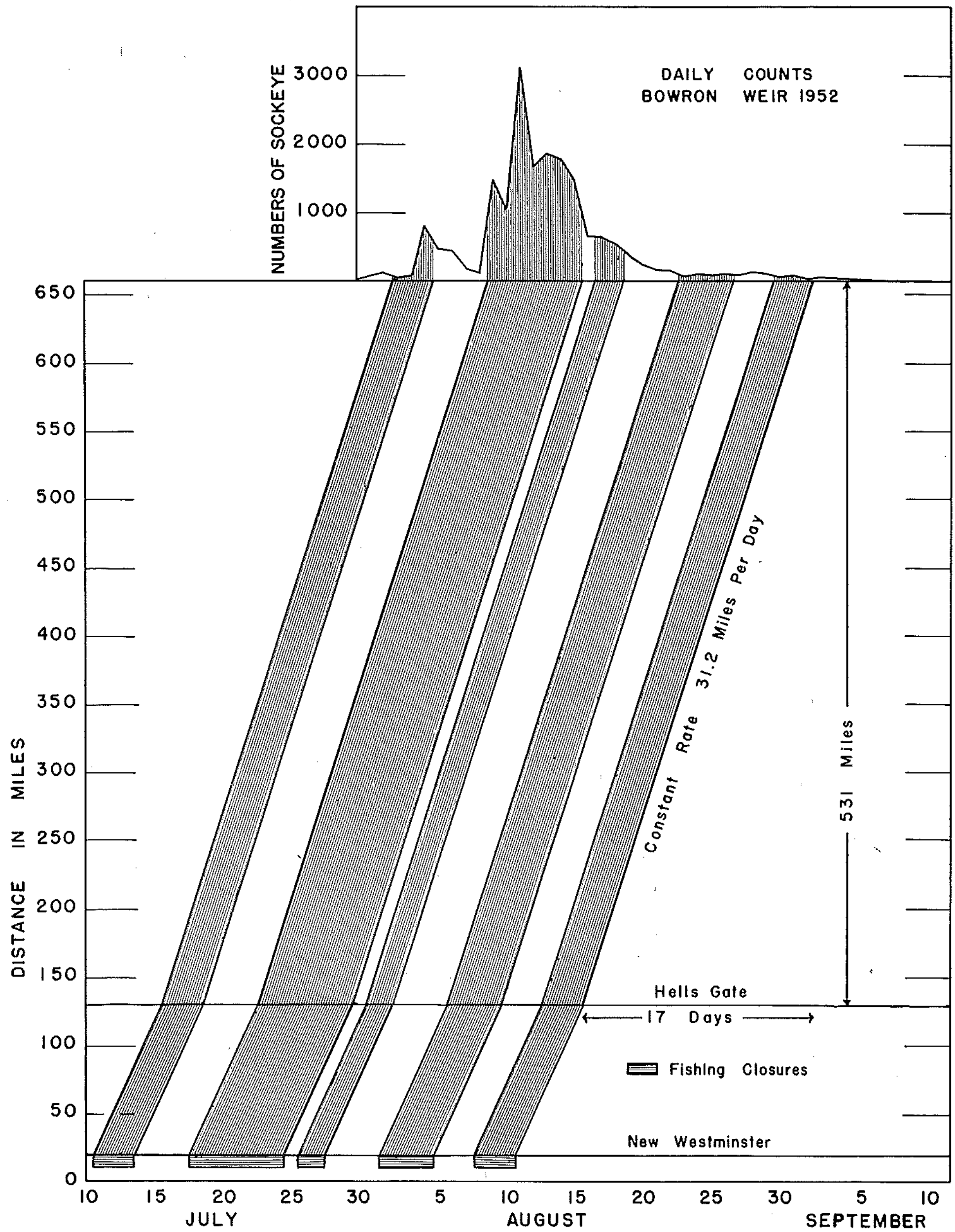

FIGURE 7. Dates of passage and migration rates of the 1952 Bowron sockeye through the Fraser River gillnet area, Hell's Gate and the Bowron weir.

The migration rates in miles per day for the 1952 Bowron run were as follows:

	Days-Out	Distance	Rate as Miles Per Day
New Westminster to Hell's Gate	5	110	21
New Westminster to Bowron weir	22	641	29
Hell's Gate to Bowron weir	17	531	31
Hell's Gate to Bowron weir (Tagging - cycle year 1948)	21	531	25

In the discussion of the 1951 run, the weekend of July 20 to 22 had been chosen as the source of the peak escapement to the Bowron weir. This choice was guided to some degree by the rates of tagged sockeye; however, there was nothing unusual in the closure patterns upon which the correct choice of weekends could be conclusively decided. Fortunately, from the point of view of this analysis, a fishermen's strike in 1952 from July 20 to July 23 extended the normal period of weekend escapement of the Bowron run. The strike period and extended escapement was reflected in the high weir counts over a longer period than that expected from a normal 3-day weekend closure. The subsequent re-appearance of this extended escapement at the Bowron weir correctly established the weekend positions used in 1952 and confirmed the choice previously made for 1951.

From the foregoing analysis of the Bowron sockeye run the following conclusions were drawn:

(1) Tagging at Hell's Gate during the four consecutive years of 1945 to 1948 demonstrated that sockeye from all portions of the Bowron run migrated at a near-constant rate and mixing during migration only extended to 2 or 3 days for the major portion of the run.

(2) Tag recoveries indicated that the mean annual migration times of tagged sockeye were 23.23, 21.44, 20.04, and 22.34 days from Hell's Gate to the Bowron weir for the four consecutive years 1945, 1946, 1947 and 1948.

(3) The mean migration times of 17 and 18 days calculated for untagged populations in 1951 and 1952 were less than those calculated for the four years of 1945 to 1948. The times of 17 and 18 days, giving rates of 33.2 and 31.2 miles per day from Hell's Gate to the Bowron weir, were considered to be the more reliable. The apparent slowness of tagged sockeye was attributed mostly to the physical effects of tagging and the use of the arithmetic mean rather than the mode.

(4) The peaks of weekend escapements of untagged sockeye from the Canadian gillnet fleet retained their chronological order, confirming the conclusion reached from the tagging analysis.

THE STUART SOCKEYE MIGRATION

The migration of sockeye salmon to the spawning grounds of the Stuart Lake district represents one of the longest distances travelled by this species in the Fraser River watershed, the distance from Sooke to Middle River being 800 miles. An "early" and a "late" run compose the Stuart district sockeye populations.

The "early" Stuart sockeye are the first sockeye to pass through the commercial fisheries and the first to reach their parent streams; they originally spawned mostly in four small cold-water streams tributary to the large Middle River. The second or "late" Stuart run is present in the commercial fishery in the latter part of July and early August; these sockeye spawn in the Middle River draining Takla Lake and in the Tachie River draining Trembleur Lake. Only the "early" run has been studied for chronological order during migration because accurate dates of tag recovery were not available for the "late" run. The methods of analysis were similar to those used for Bowron sockeye in that the days-out of tagged members were used to measure the mean time of travel and range of dispersion about the mean. These data were then compared with the results of a second study using untagged populations that were traced from the commercial fisheries to the spawning grounds by comparing closure dates and peaks of abundance.

Analysis of Tagging Data

In 1945, sufficient tags were returned from the early Stuart run to provide a reasonable picture of the migration pattern. The order of passage of sockeye tagged at Hell's Gate and the Bridge River Rapids was compared with their subsequent order of arrival at an Indian fishing station near the outlet of Stuart Lake and at a weir on Forfar Creek, one of the main spawning streams of the early run.

Hell's Gate to the Outlet of Stuart Lake, 1945

At the outlet of Stuart Lake, the Indians captured sockeye in gillnets as the mainstay of their food requirements. Both tagged and untagged sockeye were caught from a migration that was passing continuously into Stuart Lake. There was thus no problem of unmeasured delay in the recovery of tags as may happen when tagged sockeye are speared from a non-migrating population on the spawning ground. There was however a limitation to the recovery data in that the Indians fished only five days a week and two days of closure provided no tag returns. Closures are evident by the diagonal blank zones, regularly spaced between periods of recovery in Table 17. Obviously the same time for migration was not taken by all the tagged sockeye. Some sockeye travelled quickly and some slowly, the overall time ranging from 12 to 28 days. The daily means, despite periods of no fishing, were however quite uniform throughout the run.

Mixing created by deviations from the mean travel time was measured after grouping the day-populations into early, central and late portions of the run. The principal statistics for the three groups and the total recoveries are given in Table 18. The mean days-out were 18.41, 19.74 and 16.75 for the groups while that for all recoveries was 18.37. The mode for the whole run was 16 days. The group means indicated a quicker migration at the end of the run; however, the daily tag recovery table showed no slow tag recoveries for the late portion of the run and it was considered probable that the Indians ceased fishing when the run declined, in which case the mean of 16.75 days was unduly low. Coefficients

TABLE 17

THE MIGRATION TIMES OF SOCKEYE FROM HELL'S GATE TO THE OUTLET OF STUART LAKE IN 1945 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Hell's Gate	Number of Days-Out to Recovery at Stuart Lake																	Daily Mean No. of Days	Number Recovered
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28		
July 3							1											18.0	1
4					4	6			1	2		1						17.9	14
5					8												1	17.3	9
6				1			4	1							2			19.8	8
7						4			2					1				19.0	7
8								2										19.0	2
9			1					1				1						18.7	3
10							1											18.0	1
11					1	2							2					19.6	5
12					2				1	2	1							19.3	6
13									1	2								20.7	3
14							1	1	2	2				1				20.6	7
15	1					1		1										16.0	3
16								1									1	23.5	2
17						2												17.0	2
18				2	4	2												16.0	8
19				3	4				1	1								16.7	9
20						1		1										18.0	2
21							1			1								19.5	2
22																			
23																			
24				1														15.0	1

Number Recovered = 95
Season Mean = 18.37
Standard Deviation = 3.1
Coefficient of Variation = 16.88
Mean Rate (Miles per Day) = 27.46

TABLE 18

A COMPARISON OF THE DAYS-OUT OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE MIGRATING FROM HELL'S GATE TO THE OUTLET OF STUART LAKE IN 1945

No. of Days-Out	Early Group (A) July 3 - 9	Central Group (B) July 10 - 16	Late Group (C) July 17 - 24	All Groups July 3 - 24
12		1		1
13				0
14	1			1
15	1		6	7
16	12	3	8	23
17	10	3	5	18
18	5	2	1	8
19	4	3	1	8
20	3	4	1	8
21	2	6	2	10
22		1		1
23	2			2
24		2		2
25	1	1		2
26	2			2
27				0
28	1	1		2
No. Recovered	44	27	24	95
Means	18.41	19.74	16.75	18.37
Standard Deviation	3.18	3.28	1.98	3.10
Coef. of Variation	17.27	16.62	11.82	16.88

of variation of 17.3, 16.6 and 11.8 for the three groups and 16.88 for the total recoveries indicated that mixing of the Stuart tagged sockeye was slightly greater than for Bowron sockeye. The speed of travel was 27.5 miles per day based on the arithmetic mean and 29.8 from the position of the mode of the frequency distribution.

Hell's Gate to the Forfar Creek Weir, 1945

Tags applied at Hell's Gate were recovered each day at a weir near the mouth of Forfar Creek. The distribution of tag recovery times and mean speed of travel of these tagged sockeye may be compared with those obtained from tags taken by the Indians at Stuart Lake. The daily frequency distribution of days-out from tagging to recovery and the daily means of the Forfar tag recaptures are recorded in Table 19. It was noteworthy that the first part of the run took longer to reach the weir than later parts of the run. Whereas the complete range in days-out extended from 17 to 35 days, none of the tagged sockeye from the first three dates of tagging at Hell's Gate reached the weir until after 22 days. Some accumulation of at least the first part of the run was indicated by the slowness of the earliest fish.

When the run was divided into the same group periods as were used for Stuart Lake Indian fishing recoveries, it was calculated that the early sockeye reached the Forfar weir after a mean of 23.96 days and the central groups after 22.63 days whereas the last group of the run required 20.6 days (Table 20). The

TABLE 19

THE MIGRATION TIMES OF SOCKEYE FROM HELL'S GATE TO FORFAR CREEK IN 1945 RECORDED AS DAYS-OUT FROM DATES OF TAGGING TO DATES OF RECOVERY

Dates of Tagging at Hell's Gate	Number of Days-Out to Recovery at Forfar Creek 17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Daily Mean No. of Days	Number Recovered
July 3						1		1			2									25.0	4
4						1	1		1	1		2								25.3	6
5						2	8	1	1				1						1	24.4	14
6				1		5	2	1			1									22.7	10
7				2	1		3	1		1			1							23.2	9
8				1									1							24.5	2
9								1												24.0	1
10				1		2	1	1												22.2	5
11			1	2																19.7	3
12				1	1		1					1	1			1				25.5	6
13			1	1	2	1														20.6	5
14									1						1					28.0	2
15						1														22.0	1
16			1	1																19.5	2
17	1			1																18.5	2
18													1							29.0	1
19			1	1		3														21.0	5
20	1		2		1			1												20.0	5
21																					
22																					
23																					
24																					
25	1																			17.0	1
26					1															21.0	1

Number Recovered	= 85
Season Mean	= 22.99
Standard Deviation	= 3.42
Coefficient of Variation	= 14.88
Mean Rate (Miles per Day)	= 24.60

TABLE 20

A COMPARISON OF THE DAYS-OUT OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE MIGRATING FROM HELL'S GATE TO FORFAR CREEK IN 1945

No. of Days-Out	Early Group (A) July 3 - 9	Central Group (B) July 10 - 16	Late Group (C) July 17 - 26	All Groups July 3 - 26
17			3	3
18				
19		3	3	6
20	4	6	2	12
21	1	3	2	6
22	9	4	3	16
23	14	2		16
24	5	1	1	7
25	2	1		3
26	2			2
27	3			3
28	2	1		3
29	3	1	1	5
30				
31		1		1
32		1		1
33				
34				
35	1			1
No. Recovered	46	24	15	85
Means	23.96	22.63	20.60	22.99
Standard Deviation	2.93	3.76	3.11	3.42
Coef. of Variation	12.23	16.62	15.10	14.88

frequency distributions of the groups of tags upon arrival at the Forfar Creek weir are plotted in Figure 8. A mean of 22.99 days was calculated for all recoveries. The mean speed over the 541 miles was 24.6 miles per day. A distinct mode in the frequency array was not apparent and a modal speed was not calculated. The reduction in mean speed from 27.5 miles per day below the Indian fishery to 24.6 miles a day between the Indian fishery and the Forfar weir indicated either that the migration through the lakes and rivers above the outlet of Stuart Lake was slower than for the first part of the journey or that the sockeye delayed somewhere along the path of migration.

The mean migration times to the two recovery locations are shown in Table 21. The difference of 5.55 days in travel time was greatest for the early sockeye which were 2 to 3 days slower in arrival at the weir compared with those from later portions of the run. Similar data were available from the Bridge River Rapids tagging in 1945. These rapids are 75 miles or 3 to 4 days' travel time above Hell's Gate. A summary of the mean migration times of tag returns from this location are found in Table 22.

It was suspected that the recovery of the Hell's Gate tags by the Indians at the outlet of Stuart Lake was incomplete; the recovery of Bridge River tags was similarly affected by cessation of fishing before the last tags arrived. It is believed that the difference between mean travel times to Stuart Lake and Forfar Creek of 4.87 days for the late group was unduly large because of this. From the other groups it was apparent, as from the Hell's Gate tags, that the early

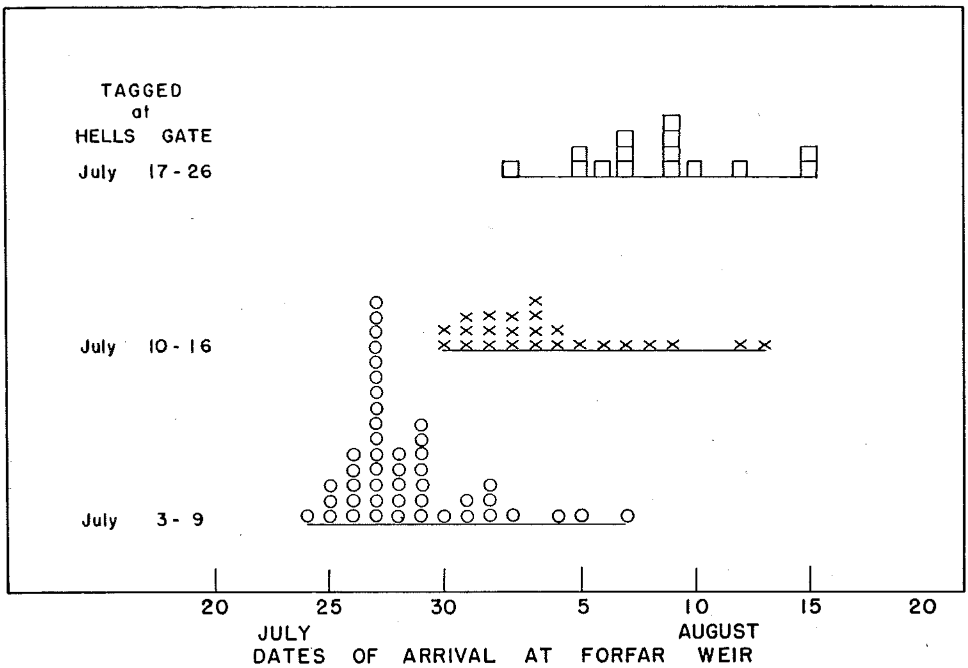

FIGURE 8. Distribution of early, central and late groups of Hell's Gate tagged sockeye upon arrival at the Forfar Creek weir, 1945.

TABLE 21

A COMPARISON OF THE MEAN MIGRATION TIMES OF TAGGED SOCKEYE BETWEEN HELL'S GATE AND THE OUTLET OF STUART LAKE AND FORFAR CREEK

Tagged at Hell's Gate	GROUPS Early	Central	Late	All Groups
Recovered at Forfar Weir	23.96	22.63	20.60	22.99
Recovered at Outlet of Stuart Lake	18.41	19.74	16.75*	18.37
Difference	5.55	2.89	3.85	4.62

* Probably low.

TABLE 22

A COMPARISON OF THE MEAN MIGRATION TIMES OF TAGGED SOCKEYE BETWEEN THE BRIDGE RIVER RAPIDS AND THE OUTLET OF STUART LAKE AND FORFAR CREEK

Tagged at Bridge River Rapids	GROUPS Early	Central	Late	All Groups
Recovered at Forfar Creek	19.00	17.67	17.78	18.15
Recovered at Outlet of Stuart Lake	14.89	15.92	12.91*	14.66
Difference	4.11	1.75	4.87	3.49

* Probably low.

TABLE 23

DAILY COUNTS OF SOCKEYE THROUGH THE FORFAR CREEK WEIR IN 1945

Date	Count	Date	Count
July 20	0	August 11	80
21	0	12	127
22	0	13	112
23	0	14	70
24	211	15	46
25	295	16	41
26	334	17	11
27	580	18	12
28	443	19	4
29	625	20	9
30	696	21	4
31	538	22	9
August 1	334	23	3
2	392	24	6
3	238	25	3
4	262	26	1
5	319	27	4
6	216	28	0
7	293	29	1
8	262	30	0
9	179	31	1
10	135	September 1	0
		Total	6,896

segment of the run was slow in traversing the intervening distance between Stuart Lake and Forfar weir as compared with the central portion.

Thus, tag returns from both Hell's Gate and the Bridge River Rapids indicated that sockeye from the early part of the run took 2 to 3 days longer than would be expected to cover the distance between the outlet of Stuart Lake and Forfar Creek weir. The location of delay at the immediate entrance to the spawning grounds is indicated by the daily weir counts into Forfar Creek which are listed in Table 23. They show that no sockeye were counted through the weir until July 24, on which date the count was 211. When subsequent counts were considered, this sudden influx on the first day was found to be higher than would have been expected. Field reports provided an explanation. The weir was installed July 19 when no sockeye were in the stream. On July 21, sockeye of unknown numbers were seen in Middle River off the mouth of Forfar Creek, the next day one sockeye was seen immediately below the weir and about 200 reported to be off the creek mouth, and by July 23 the creek was full of sockeye below the weir but there were still none in the trap. On the following day, July 24, the 211 sockeye were captured at the weir. Thus, from both visual observation of sockeye below the weir and from the belated returns of early tagged sockeye it was evident that at least the first 2 to 3 day-populations at Forfar Creek did not enter the stream immediately on arrival but accumulated at the stream mouth and entered as a group on about the fourth day.

Summarizing the above data, it appeared from both Hell's Gate and Bridge River Rapids tag returns that the chronological order of migration of the "early"

TABLE 24

DAILY CATCHES OF SOCKEYE BY THE INDIANS AT THE OUTLET OF STUART LAKE IN 1952

Date	Number of Sockeye Caught	Number of Nets	Average Catch per Net
July 17	1	11	.1
18	2	12	.2
19	No fishing	—	—
20	No fishing	—	—
21	4	16	.3
22	47	17	2.8
23	136	34	4.0
24	309	28	11.0
25	378	28	13.5
26	No fishing	—	—
27	No fishing	—	—
28	276	35	7.9
29	164	31	5.3
30	135	24	5.6
31	235	27	8.7
August 1	133	26	5.1
2	No fishing	—	—
3	No fishing	—	—
4	14	13	1.1
5	18	9	2.0
6	4	1	4.0
7	18	6	3.0
8	12	7	1.7
9	No fishing	—	—
10	No fishing	—	—

Stuart run was retained quite consistently as far as the outlet of Stuart Lake but beyond the outlet of Stuart Lake a change in the migration consistency was noted; it was observed that the first of the run delayed at the mouth of Forfar Creek. An accumulation of at least the first two to three day-populations of sockeye was evident at this location after which the sockeye seemed to enter the stream in their order of arrival. The weir may have been partly responsible for the delay in entering the stream as sockeye entered adjacent non-weired streams two to three days prior to the date of the first weir count in Forfar Creek.

Analysis of Other Data

The 1952 Stuart Migration

In the analysis of the migration of the Bowron sockeye it was found that, while tagging provided a practical measure of the degree of mixing along the path of migration, the arithmetic mean values of days-out for tagged sockeye were larger than the migration times of untagged sockeye. The same difference would probably apply to sockeye destined for the Stuart area and, since it was pertinent that the most accurate mean rates be provided wherever possible, the abundance curves of the early Stuart sockeye run of 1952 were studied to obtain a migration rate without the use of tags. Dates of the periods of escapement through the Canadian gillnet fleet, daily Indian catch records at Stuart Lake and weir counts at Forfar Creek have been compared and are shown in Figure 9. The daily Indian catches and the weir counts are given in Tables 24 and 25 respectively.

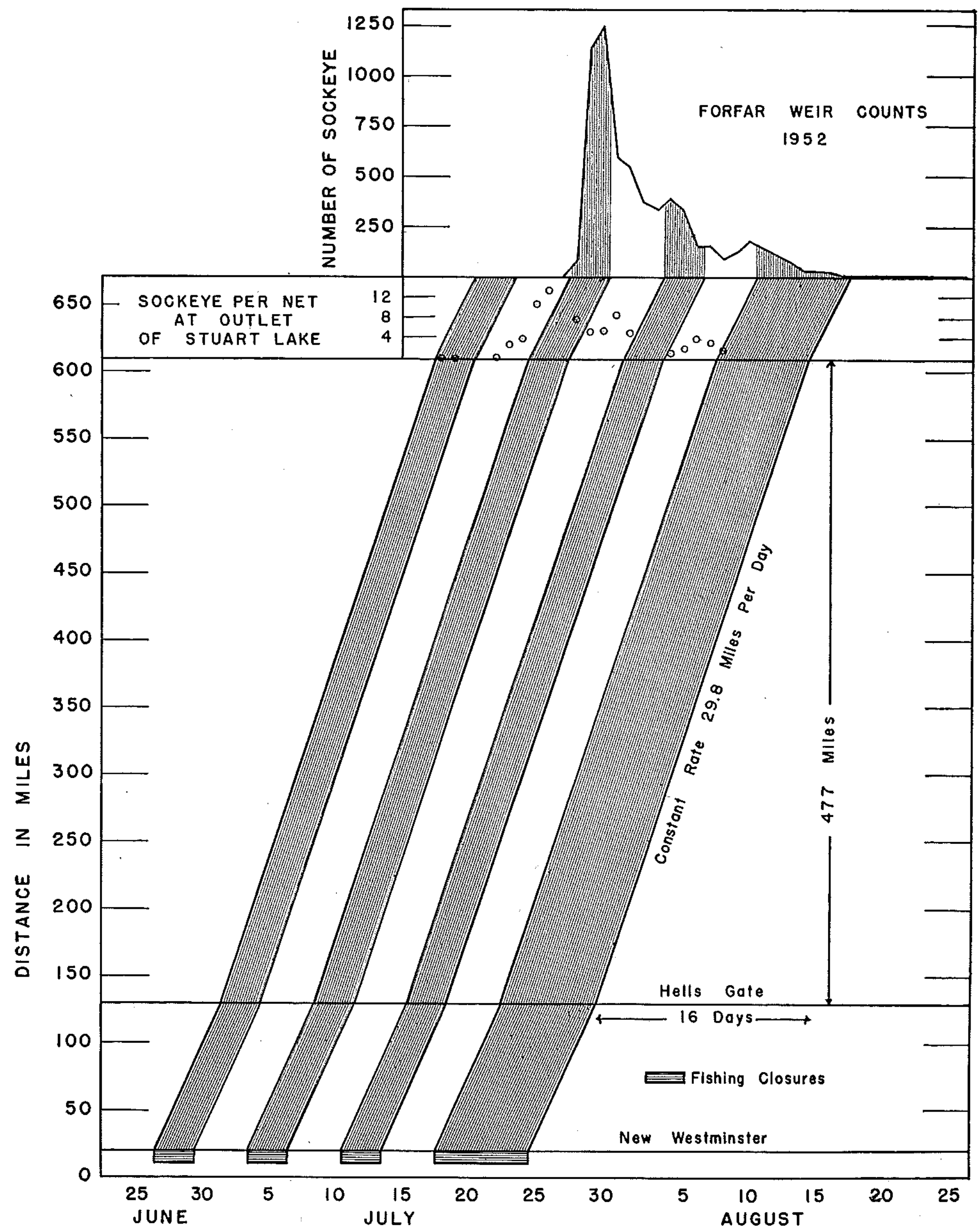

FIGURE 9. Dates of passage and migration rates of the 1952 Early Stuart sockeye through the Fraser River gillnet area, Hell's Gate, Stuart Lake Indian fishery and the Forfar Creek weir.

TABLE 25

DAILY COUNTS OF SOCKEYE THROUGH THE FORFAR CREEK WEIR IN 1952

Date	Count	Date	Count
July 20	0	August 9	123
21	0	10	189
22	0	11	149
23	0	12	112
24	0	13	78
25	0	14	32
26	0	15	29
27	0	16	26
28	81	17	9
29	1,138	18	11
30	1,247	19	3
31	598	20	1
August 1	548	21	5
2	369	22	4
3	330	23	1
4	381	24	3
5	331	25	2
6	150	26	2
7	162	27	2
8	83		
		Total	6,199

The dates of passage of the Early Stuart run through the zone of the Canadian gillnet fishery have been definitely established over a number of years from analysis of the commercial catch data, readings of scales taken at the mouth of the Fraser River, and hourly catches and percentage of net-marked sockeye at Hell's Gate. In 1952, the early portion of the Stuart run escaped from the gillnet zone during the closed weekend of June 27 to 29, the central or peak escapement occurred from July 4 to 6 and the tail escapement occurred mostly from July 10 to 12. Presuming a constant mean travel time, these three segments would be at Hell's Gate 6 days later on July 2 to 4, July 9 to 11 and July 16 to 18 respectively. The projection of the run above Hell's Gate to Stuart Lake was based on the dates of peak sockeye catches in the Stuart Indian fishery 477 miles upstream. It was assumed that the peak escapement from the gillnet zone on Saturday July 5 provided the peak upstream catch of July 26. This was substantiated by the corresponding dates of June 27 in the gillnet zone and July 18 at the fishery for the earliest sockeye. The time interval of 22 days from the gillnet zone or 17 days from Hell's Gate gave a rate of travel above Hell's Gate of 29.8 miles a day. In 1945, the mean time from all Hell's Gate tag returns was 18.37 days or 27.5 miles a day. It appears that the migration time of the untagged 1952 Early Stuart run was 1.37 days less than that shown by the tagged sockeye in 1945.

Following the examination of the Indian catches at the outlet of Stuart Lake, the dates of arrival on the spawning grounds were considered. The most probable speed was obtained by relating the peak Forfar Creek weir count of 1,247 sockeye on July 30 to the Stuart Lake Indian closure of July 27. This gave an interval of 4 days inclusive and parallel times were assumed for the early and late sockeye. If this assumption were correct the first sockeye would have been counted at the weir on July 21 followed by low counts until July 26, then the counts would have increased on July 27 and 28 to a normal peak on July 30. However, no sockeye were counted at the weir until 81 passed on July 28, followed by a sudden influx of 1,138 on July 29 and a peak passage of 1,247 on July 30. It therefore appeared that the early sockeye of the 1952 run may have been delayed as long as 8 days from their proper chronological date of arrival. Confirmatory visual evidence of delay was reported by observers at the stream mouth; a few sockeye were seen there on July 21 and in schools in the channel below the weir by July 25. In the opinion of resident biologists this early delay was apparent at most of the early Stuart streams for 2 to 3 days at the start of the run but was extended to 6 or 8 days when a weir was installed. These findings at the weir were similar to those of 1945 except that in 1952, the very early sockeye delayed a longer period of time before reaching the weir.

The 1953 Stuart Migration

It was apparent in the analysis of the 1945 and 1952 Stuart runs that the presence of a weir at the immediate entrance to the spawning area may have been partly or completely responsible for the reluctancy of early sockeye to enter the stream. This problem was studied in 1953 when the Forfar weir was removed and the sockeye passed unobstructed into the stream. In lieu of weir counts, daily live and dead counts were made throughout the duration of the run. Daily arrival counts were obtained by the subtraction of preceding daily live counts: for instance, on July 16, 6 live sockeye were the first seen in Forfar Creek, on July 17, 122 sockeye were counted which included the 6 from the previous day; therefore 116 sockeye must have entered on the second day. This procedure was applied to the arrivals each day until the first dead recoveries were made. From that date, dead counts were cumulated and added to the live counts, to give the total numbers of sockeye present in the stream each day. These totals were then subtracted day by day to give the daily arrivals. When these live-plus-dead totals no longer increased, it was concluded that the total population had entered the stream and the daily arrival number was zero. This method of developing an arrival curve required adjustment for the fact that only about 70 per cent of the live fish present on any one day were counted and only 70 per cent of the dead fish were recovered. The accuracy of live counts in Forfar Creek has been substantiated by checks against known weir counts for many years and found to be so consistent that the total population number can be derived by multiplying the peak live count plus accumulated dead by a factor of 1.8.

In addition to the calculated arrival counts, the 1953 sockeye catches by Indians at Stuart Lake and the closed weekends for both Indians and the Canadian gillnet fishery are shown in Figure 10. Starting with the commercial fishery at New Westminster, the normal three-day weekend closures were effected as in 1952; however, they occurred one day earlier in 1953. The projection to Hell's Gate and to the outlet of Stuart Lake was made at the same rate as determined in 1952. Three-day Indian fishing closures in 1953, compared with two days in 1952, made it difficult to relate the pattern of wave escapement from the gillnet zone to the catch-curves at the Indian fishery, as the peak escapements mostly arrived at

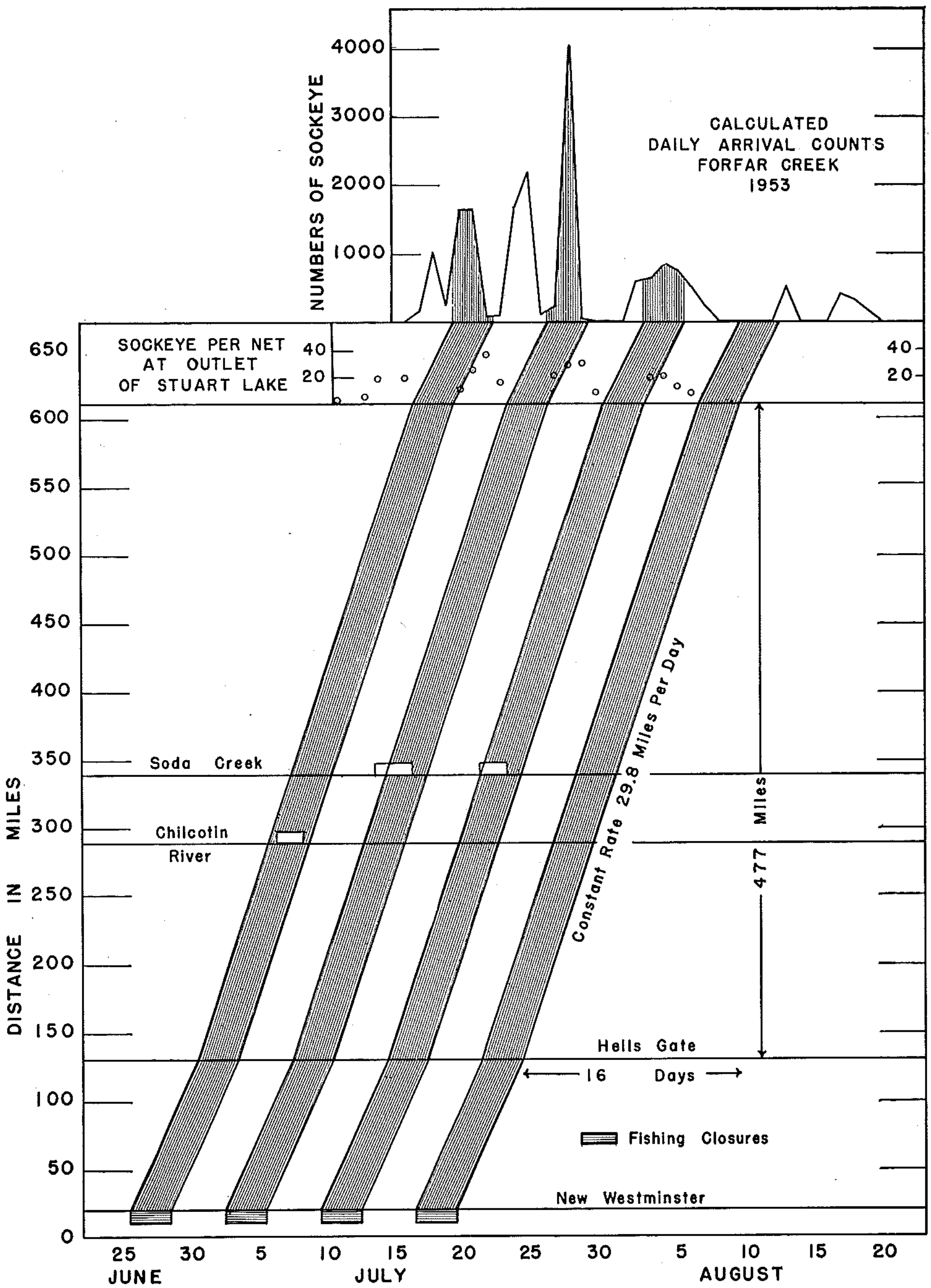

FIGURE 10. Dates of passage and migration rates of the 1953 Early Stuart sockeye through the Fraser River gillnet area, Hell's Gate, Fraser River and Stuart Lake Indian fisheries and Forfar Creek.

Stuart Lake on the days when the Indians were prohibited from fishing. An unfished peak passing through Stuart Lake caused sharper and higher peaks of abundance at the spawning grounds. The first important commercial weekend escapement of June 26 to 28 was reflected by a peak at Forfar Creek on July 20 to 21. The peak escapement of July 3 to 5 formed a high peak day on July 28 at the spawning grounds and the late escapement of July 10 to 12 entered the stream between August 3 and 5. The arrival counts at Forfar Creek subsequent to the above dates showed no significant peaks. Earlier, one exceptional peak occurred in the stream on July 24 and 25 which was not associated with the normal commercial weekend escapements. It also occurred in significant numbers in the Indian fisheries at Fort St. James and Tachie on July 22. More complete analysis of the commercial fishing data during the week of June 29 to July 2 may reveal the cause of this midweek escapement but for the present no reason is apparent. The most significant feature of the 1953 Forfar Creek run was the fact that sockeye first entered the stream on July 16 as compared with July 28 in 1952 and live counts of over 3,000 sockeye were made on July 21 and 22. No delay of arriving sockeye was noted at the mouth of the stream in 1953. It was therefore concluded that, whereas the early portion of the Forfar Creek run had delayed as much as 3 days in 1945 and 8 days in 1952 when a weir was constructed in the stream, there was no delay in 1953 when the weir was removed.

The constant speed of migration and the consistency of the wave pattern of the 1953 escapement was also illustrated by the fluctuations in Indian catches in the Fraser River en route to the Stuart Lake system. Dependable counts of Indian catches and numbers of sockeye per hour were made by Dominion Fisheries Inspector J. E. Kew (1953) at the mouth of the Chilcotin River and at Soda Creek approximately 160 and 210 miles respectively above Hell's Gate. Kew noted that a moderately good run passed the mouth of the Chilcotin River on July 7 and 8. This early peak was not reported at Soda Creek but a heavy migration was counted at Soda Creek on July 14, 15 and 16 followed by a lesser peak of passage on July 22 to 23. These three peaks are plotted on Figure 10 to test whether they fell within the bracket zones of escapement originating from weekend closures at New Westminster. The early peak at the mouth of the Chilcotin was located exactly within the expected dates set at the 30 miles per day rate. The peak at Soda Creek on July 14 to 16 appeared one day sooner than scheduled by the constant rate and the third peak of July 22 and 23 at Soda Creek was placed exactly as anticipated. Three separate peaks of escapement at a seven-day interval travelling at 30 miles a day were definitely evident along the long migration path of the most northern Fraser sockeye run. These data further substantiated the conclusion that the 1953 escapement of Early Stuart sockeye retained an orderly time sequence over 600 miles from the area of the Canadian gillnet fishery to entry into the spawning streams.

THE HARRISON SOCKEYE MIGRATION

Sockeye runs to Bowron and Stuart Lake have shown that mixing during migration was restricted to two or three days deviations from a constant rate. Both of these upper Fraser runs migrated through the commercial fishing areas in June and July and each had a river migration of over 600 miles. Tagging data and curves of abundance were also considered for the August run of Birkenhead sockeye into the Harrison system. This run is located in the lower section of the Fraser and has a relatively short migration of 170 miles to the spawning grounds.

Analysis of Tagging Data

Schaefer (1951) analysed the migration of tagged sockeye in the Harrison River System and concluded that while some mixing was evidenced it was by no means complete. However, in view of the criteria found necessary to study the migrations of the Bowron and Stuart runs, the data available for the Harrison sockeye runs have been re-examined.

Some of the tag recoveries that he analysed were applied at Skookumchuck and recovered at a trap on the Birkenhead River (ref. map). On re-examination of these, it was found that the days-out of tag returns were not exact measures of the time required for sockeye to migrate from Skookumchuck to the Birkenhead River because parts of the sockeye migration were undoubtedly delayed below the Skookumchuck Rapids for unknown periods of time before and after being tagged. The fluctuating water levels caused different lengths of delay and mixing of various parts of the run was inevitable. The Skookumchuck Rapids were described by Schaefer as follows:

> "The swift, fast-dropping water at this point (Skookumchuck) offers a difficult passage to upstream salmon migrants and offers to their migration a partial blockade, the effectiveness of which is a function of the volume of flow of the river."

The method of recovery of Skookumchuck tags at the Birkenhead spawning grounds was also closely scrutinized. Schaefer reported that the trap built on the Birkenhead River was not a total barrier and permitted sockeye to pass both up and down; therefore, tagged sockeye may not have been recovered on their first arrival. Some portion of the population spawned below the trap site and were thus not available for capture. Furthermore, during the periods of flood, especially in 1940, the trap was completely out of operation for much of the recovery period. These circumstances all tend to invalidate any conclusions as to the migration time taken between Skookumchuck and the spawning grounds.

Analysis of Other Data

In 1939, a spiller-type trap was erected in the Harrison River approximately one mile upstream from the Fraser. The daily catches of sockeye at the trap in 1939, 1940 and 1941 are shown in Figure 11. These catches represent sockeye from a number of runs of which the Birkenhead, present from mid-August to approximately September 20, is the most important. The periods of closure in the Canadian gillnet fleet have been associated with the peak trap counts and it was found that three days were required for the migration. From a mid-point at New Westminster, the distance travelled in the three days was 52 miles giving a rate of 17.3 miles a day. The same migration rate was plotted for all parts of the sockeye run for the journey between the commercial fishery and the Harrison

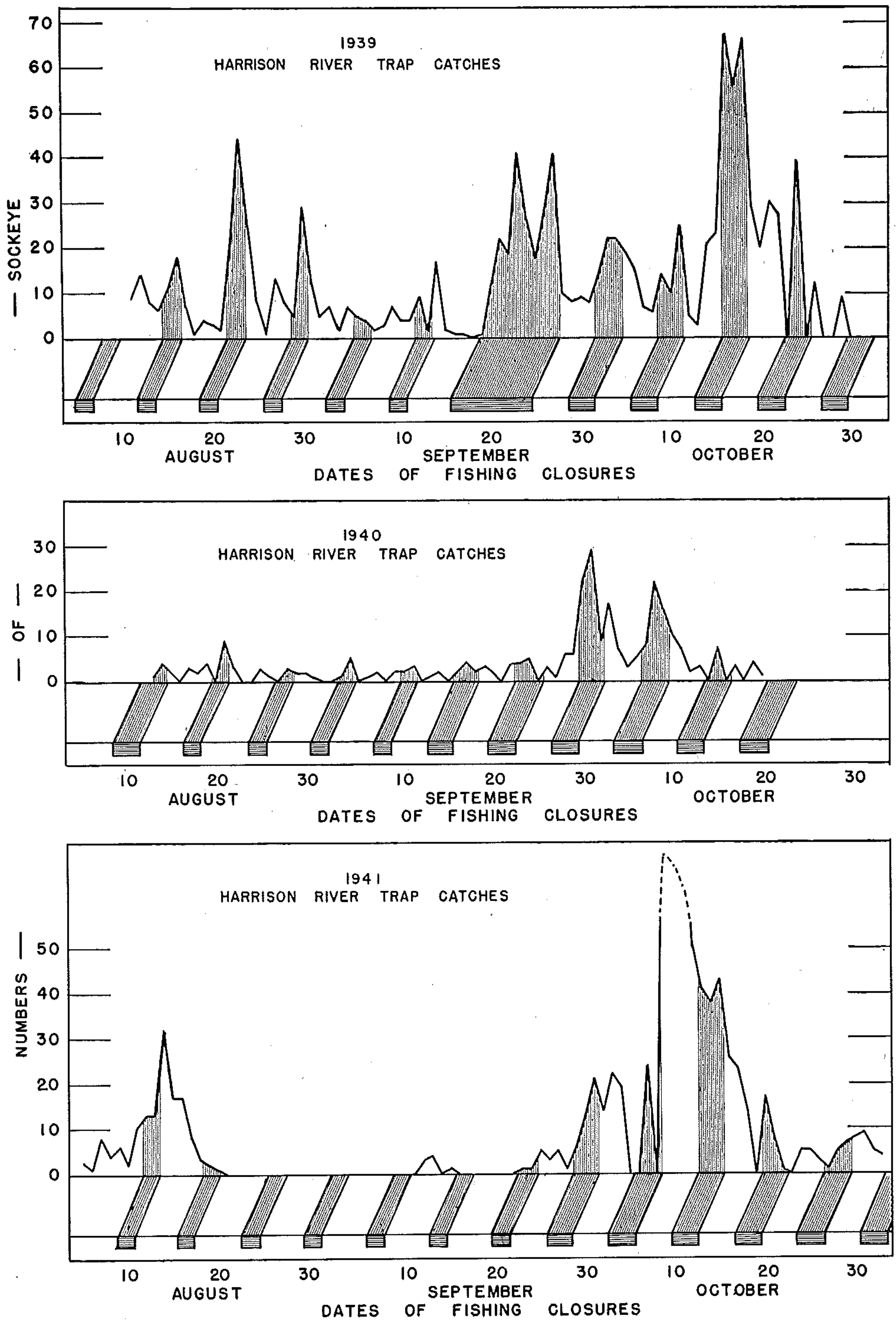

FIGURE 11. Dates of passage of the 1939, 1940 and 1941 Harrison District sockeye through the Fraser River gillnet area and the Harrison River trap.

trap, and the peaks compared. The regular association of escapement with closures was beyond dispute in 1939, peaks occurring at the traps between Monday and Thursday. The presence of considerable sockeye on Thursdays was most probably caused by the extension of the Saturday-Sunday closure to noon Monday above the Pattullo Bridge. From these data it was concluded that, irrespective of the ultimate form of the escapement, the sockeye left the zone of commercial fishing in waves caused by the periods of closure and maintained this pattern during their migration up the Fraser at least as far as the Harrison River.

In 1940 and 1941, the Harrison trap catches through August and September were insufficient to justify any conclusions as to the form of the escapement. Weeds, debris and mechanical difficulties forced the trap out of operation for long periods of the sockeye passage. However, two peaks were apparent in the October trap catches of 1940 and they confirm the three-day rate of migration. In 1941, the abundance of sockeye captured at the trap could not be related to particular weekend closures because unknown numbers of sockeye, whose migration was obstructed at Hell's Gate, dropped down the Fraser and entered the Harrison River in September and October. These sockeye, some of which bore tags affixed at Hell's Gate, were injured, near sexual maturity and quite different in appearance from the native sockeye of the Harrison system. It was evident that these "Hell's Gate" sockeye were sufficient in numbers in 1941 to obscure the appearance of the peak weekend escapements in the trap catches that were shown clearly in 1939 and to a lesser degree in 1940. Other than for the relationship of the 1939 catches to the dates of closures in the Canadian gillnet fleet, data from the Harrison River trap did not assist in studies of the sockeye migration.

The next location from which a measure of the migration pattern might have been obtained was at the Skookumchuck Rapids on the Lillooet River, 65 miles upstream from the Harrison trap and 35 miles downstream from the Birkenhead spawning grounds. In 1940 and 1941, tagging crews were stationed at Skookumchuck and their catches of sockeye are plotted in Figures 12 and 13. The curves of abundance were examined to see whether they showed distinct peaks. In 1940, only a few sockeye were caught at Skookumchuck before August 24. The run was large between August 24 and September 3, but between August 29 and September 1 catches for tagging and enumeration were purposely restricted because too high a percentage of the run had been caught at the beginning of the peak. If the catches had not been restricted it is assumed that the catch curve would have indicated a peak of abundance on the four days of August 28 to 31. Since apparently there was a sharp peak of abundance at Skookumchuck, the configuration of the run from the time of escapement to the time of arrival at the Rapids had not been distorted by slow- and fast-swimming sockeye.

In 1941, peak catches of sockeye were made between September 1 and 9 although after September 5 the numbers of sockeye caught for tagging were restricted to reduce the tag ratio during a partial blockade. The true peak was estimated to have occurred between September 3 and 5; such a peak would not have persisted if extensive mixing had been in effect between the date of escapement in the Fraser River and the date of capture at Skookumchuck. The conclusions

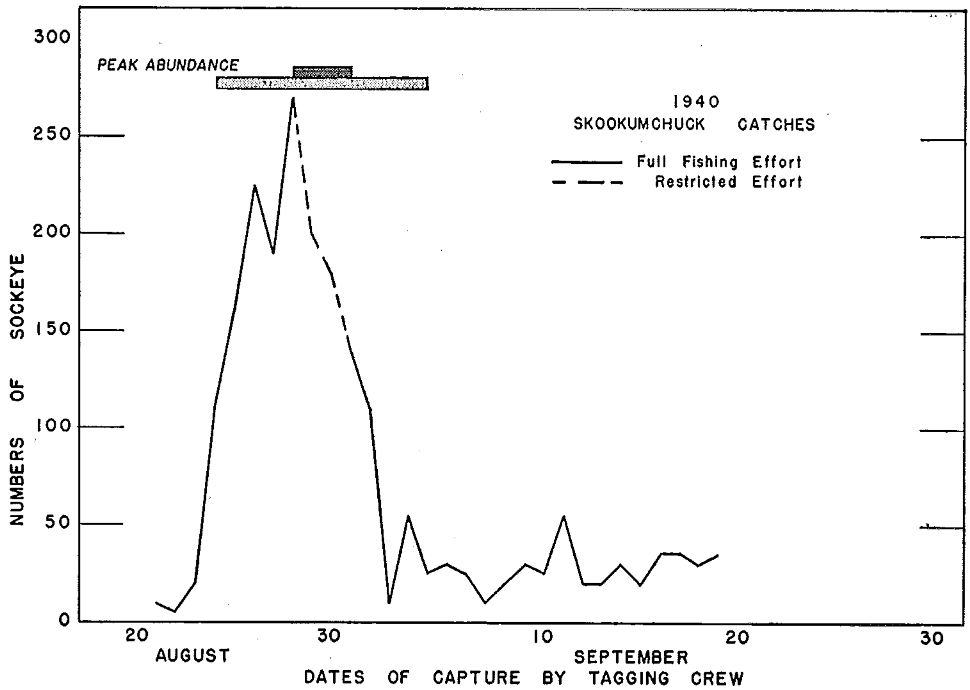

FIGURE 12. Daily sockeye catches by the tagging crew at the Skookumchuck Rapids, Harrison district, 1940.

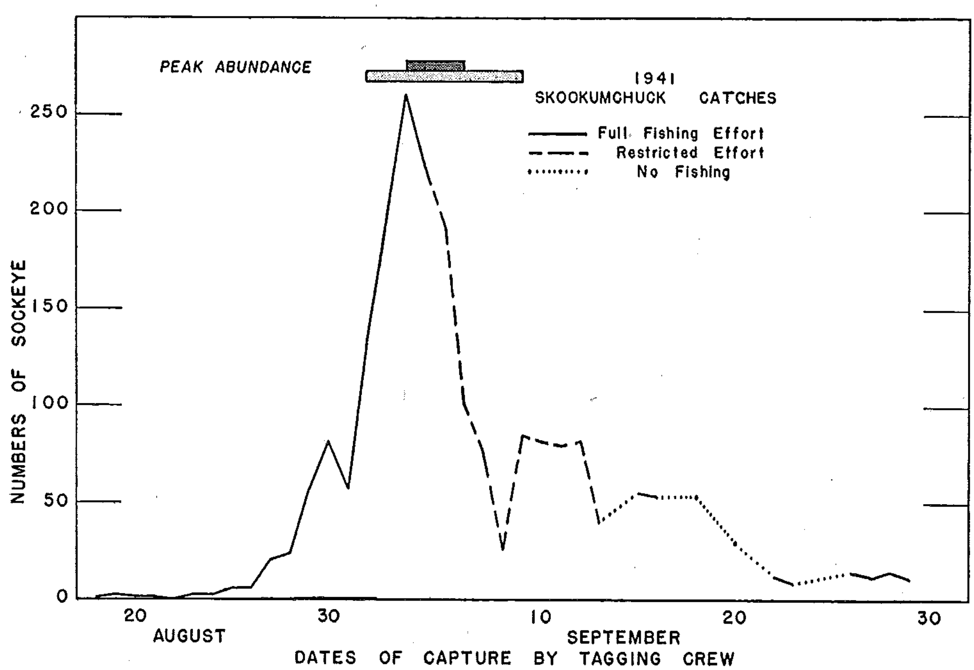

FIGURE 13. Daily sockeye catches by the tagging crew at the Skookumchuck Rapids, Harrison district, 1941.

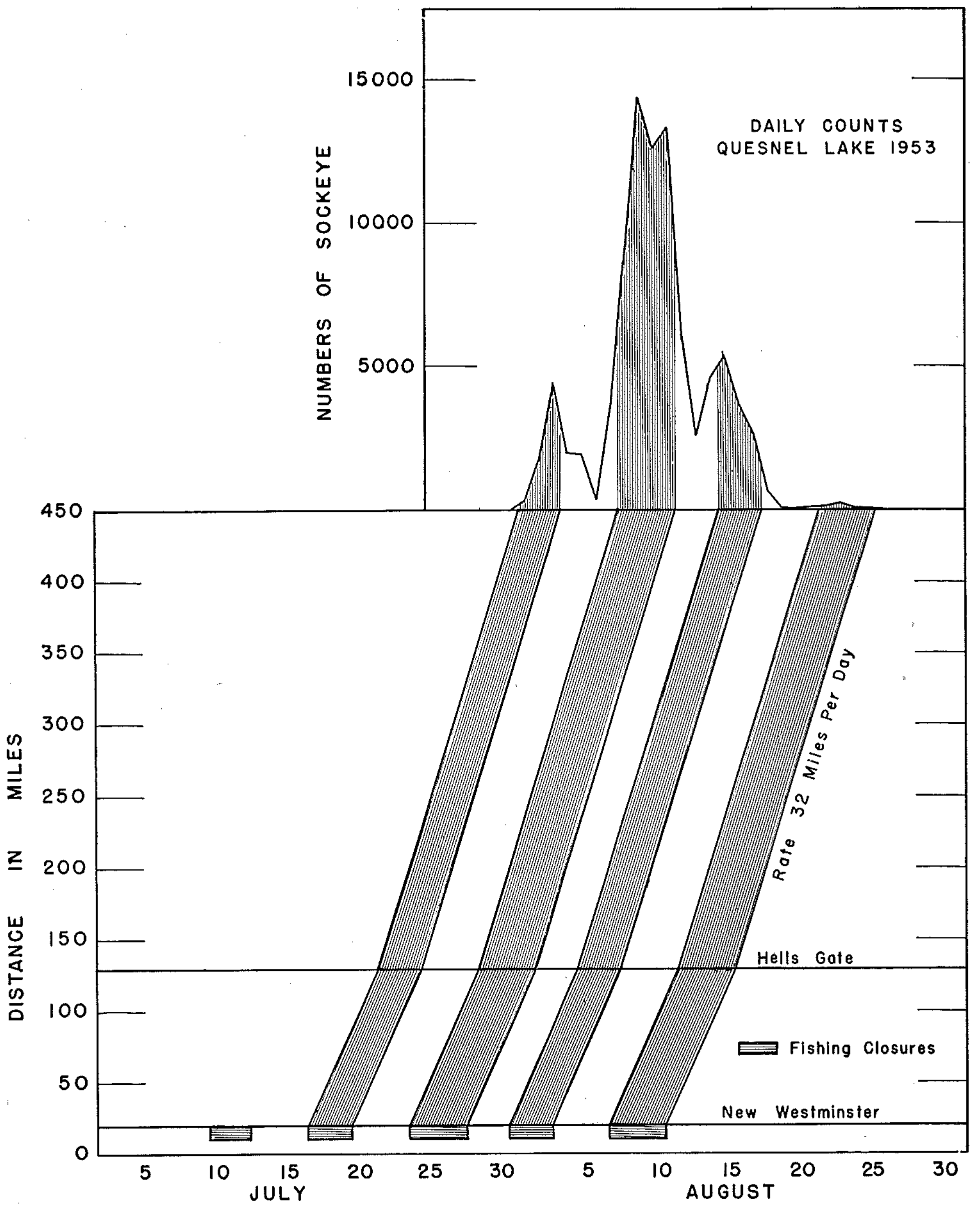

FIGURE 14. Dates of passage and migration rates of the 1953 Quesnel sockeye through the Fraser River gillnet area, Hell's Gate and Quesnel Lake.

based on the data for the two years are somewhat circumstantial as the restricted fishing effort could not be weighted accurately.

It was not practical to attempt a further analysis of the migration of Birkenhead sockeye because of unmeasurable delays at the location of tagging and in tag recoveries. Only the reflection of the closures of the Canadian gillnet fishery in the Harrison trap catches and, to a lesser degree, in the catches at Skookumchuck justify the conclusion that the chronological order was maintained as far as Skookumchuck but there was probably considerable mixing beyond that point caused by the physical character of the river system.

THE QUESNEL SOCKEYE MIGRATION—HORSEFLY RIVER

The sockeye runs to the Quesnel district were so small during the years of tagging at Sooke and Hell's Gate that analysis of the few tag returns was of little value in measuring the consistency of the migration. The first sizeable escapement since 1913 occurred in 1953 when 105,000 sockeye spawned in the Horsefly River and the configuration of the arrival curve of these sockeye related to dates of closure in the Fraser River gillnet fishery was used to measure the consistency of the chronological order.

It is noteworthy that prior to the 1953 sockeye season, the Commission proposed regulations to provide two extra days of closure, namely July 27 and August 3, in addition to the usual three-day closed weekends during the passage of the Horsefly run. The first closure of July 24 to 27 was to insure an adequate escapement from the peak while that of July 31 to August 3 was to provide an increased escapement from the late portion of the run as a step towards the possible rehabilitation of lower sections of the Horsefly River. Later in the fishing season, the August closure of four days had to be modified to a three-day period to permit equalization of the catch taken by fishermen of Canada and the United States. At the entrance to the spawning area, counts of sockeye were taken each day to determine (1) whether the closures were effective in permitting the desired escapements, and (2) whether these selected escapements migrated in their respective chronological order.

The period of passage of the run through the Fraser gillnet zone and the configuration of the escapement upon arrival at the spawning area is plotted in Figure 14. The periods of gear closure were marked at New Westminster, the mid-point in the 50 miles of gillnet fishing area in the lower Fraser. From the periods of weekend closures, the escapement peaks were projected to Hell's Gate at a constant 6-day travelling time previously established for the Bowron and Stuart runs. Above Hell's Gate, another set of parallel lines associated the main peak in the daily counts of sockeye as they entered Quesnel Lake with the extended closure of July 24, 25, 26 and 27. This gave ten days for the 320-mile river migration above Hell's Gate, requiring a speed of 32 miles a day. This rate of migration was almost identical with the rates of 33 and 31.2 miles per day for the Bowron runs of 1951 and 1952 and slightly faster than the rate of 29.8 miles per day for the 1952 Early Stuart run. Additional confirmation of the validity of this fit was given by the association of the two adjacent peaks of arrival at the spawning grounds with the weekend closures immediately before and after the extended weekend.

THE CHILKO SOCKEYE MIGRATION

The study of the pattern of migration of the Chilko sockeye has been difficult, mostly because of the inability to secure accurate arrival counts at the spawning grounds. The waters of this system are large, glacial-fed rivers and sockeye can

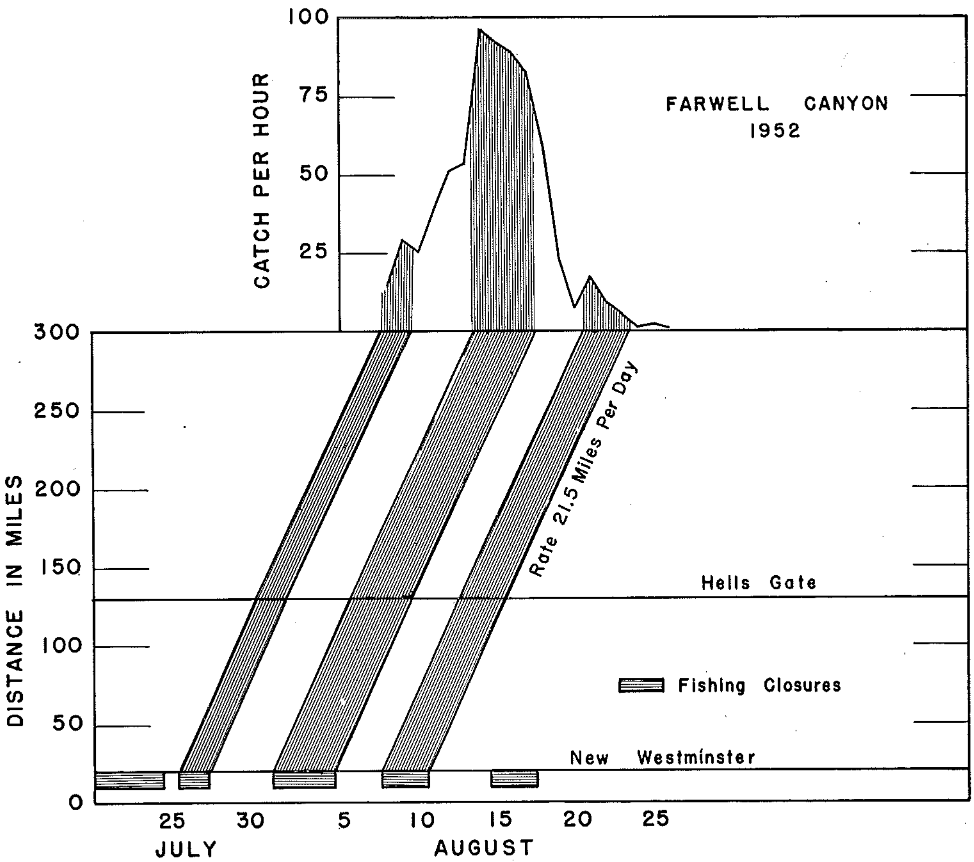

FIGURE 15. Dates of passage and migration rates of the 1952 Chilko sockeye through the Fraser River gillnet area, Hell's Gate and Farwell Canyon.

seldom be seen in the murky waters. As visual counts were impossible, it was necessary to establish netting crews at Farwell Canyon, located 10 miles up the Chilcotin river and 300 miles upstream from the mouth of the Fraser. The daily catch-per-hour of these crews can be regarded as a relative index of the numbers of passing sockeye, with some reservation as to the exact relationship during the passage of large numbers of sockeye. Most probably a greater percentage of sockeye were caught when the migrating population was small since catches during the peak passage were restricted by the physical netting capacity of the crews.

In 1952, a special effort was made to establish the dates of passage of the Chilko run and to determine whether the weekend escapement of this run retained an orderly migration pattern to the spawning grounds. The daily average catches-per-hour of the netting crew at Farwell Canyon are plotted in Figure 15. The four-day period of greatest abundance at Farwell Canyon was directly associated with a four-day closure in the Fraser gillnet fleet from August 1 to 4, although weekly fluctuations in the catches at Farwell Canyon were not clearly defined. The extended peak escapement was especially important as the extra closure of August 4 was an emergency one made particularly to permit a greater escapement to Chilko.

TABLE 26

THE MIGRATION TIME PLUS LIFE-SPAN ON THE SPAWNING GROUNDS OF **MALE** SOCKEYE TAGGED AT FARWELL CANYON AND RECOVERED FRESH DEAD AT CHILKO IN 1948

Date of Tagging	Number of Tag Recoveries	Individual Times Fastest	Individual Times Slowest	Daily Mean Time All Recoveries
August 16	3	36.0	42.0	38.0
17	0	—	—	—
18	7	29.0	35.0	33.7
19	15	29.0	47.0	34.7
20	14	29.0	39.0	33.4
21	8	26.0	41.0	32.0
22	5	26.0	37.0	32.2
23	23	25.0	43.0	34.0
24	27	26.0	46.0	33.7
25	9	27.0	39.0	32.1
26	6	26.0	40.0	34.7
27	3	31.0	41.0	34.7
28	2	37.0	39.0	38.0
29	0	—	—	—
30	1	28.0	28.0	28.0
31	0	—	—	—
September 1	1	22.0	22.0	22.0
2	1	33.0	33.0	33.0
3	0	—	—	—
4	1	21.0	21.0	21.0
5	2	23.0	26.0	24.5
6	1	31.0	31.0	31.0
Mean Days-Out		28.1	36.1	33.4 days
Standard Deviations		4.38		4.76
Coefficient of Variation		15.59		14.25

These 1952 data for the Chilko sockeye traced the run to Farwell but not to the actual spawning grounds which are located 100 miles further upstream. There were no netting locations immediately below the spawning area and the river water was so opaque that it was impossible to obtain accurate daily live counts; however, it was possible to check the chronological order beyond Farwell by analysing the days-out of "fresh-dead" tagged sockeye recovered at the Chilko spawning grounds. Such data were available from tagging conducted at Farwell Canyon in 1948. The time-interval from tagging to recovery at death included therefore both the period of migration and the life-span on the spawning grounds; however, it was hoped that inclusion of the life-span would not completely mask chronological consistency during migration if it existed.

The analysis of the tag recoveries from dead fish dealt with those from males and females separately as there was an average difference of three days between them. The days-out from tagging to dates of fresh-dead recovery are shown in Tables 26 and 27. For both males and females the fastest times, slowest times and daily means were listed. The season means for the fastest recoveries and all recoveries were calculated together with their respective standard deviations and coefficients of variation.

TABLE 27

THE MIGRATION TIME PLUS LIFE-SPAN ON THE SPAWNING GROUNDS OF **FEMALE** SOCKEYE TAGGED AT FARWELL CANYON AND RECOVERED FRESH DEAD AT CHILKO IN 1948

Date of Tagging	Number of Tag Recoveries	Individual Times Fastest	Individual Times Slowest	Daily Mean Time All Recoveries
August 16	1	39.0	39.0	39.0
17	0	—	—	—
18	4	30.0	40.0	35.8
19	14	36.0	47.0	40.0
20	13	32.0	42.0	38.0
21	12	33.0	42.0	36.5
22	5	35.0	41.0	37.2
23	18	23.0	43.0	36.4
24	27	24.0	50.0	37.0
25	13	28.0	41.0	35.7
26	17	28.0	48.0	38.2
27	11	29.0	43.0	36.9
28	8	25.0	47.0	36.0
29	2	39.0	40.0	40.0
30	3	35.0	47.0	40.3
31	1	28.0	28.0	28.0
September 1	6	23.0	38.0	31.8
2	2	28.0	42.0	35.0
3	0	—	—	—
4	1	33.0	33.0	33.0
5	2	20.0	26.0	23.0
6	4	19.0	24.0	22.3
7	3	27.0	36.0	31.0
8	0	—	—	—
9	1	34.0	34.0	34.0
Mean Days-Out		29.5	39.6	36.4 days
Standard Deviation		5.73		5.64
Coefficient of Variation		19.42		15.49

For male sockeye, neither the times of the fastest nor the mean times for each day-population showed any trend for different dates of tagging; however, the time intervals of the slowest sockeye indicated considerable variation between individuals. The coefficient of variation of 14.25 for all male tag recoveries indicated that while some mixing occurred between the time of tagging at Farwell and the time of death on the spawning grounds, it was by no means complete. For instance, male sockeye tagged on August 16 were recovered after an average of 33.4 days and the majority of these within 29 to 38 days; they would therefore, with few exceptions, be recovered separately from those tagged on August 21. Similarly, male sockeye tagged during the peak of the run on August 24 would be mostly recovered separately from tags applied before August 20 or after August 28.

The female day-populations were similarly distinct; however, there was a tendency throughout the run towards progressively shorter time intervals to dates of recovery which increased the degree of mixing. The increased mixing of female sockeye was indicated by the higher coefficient of variation values of 19.42 for fast tag recoveries and 15.49 for all recoveries as compared with equivalent values of 15.59 and 14.25 for males.

It was quite probable, as will be shown later, that a considerable portion of the apparent mixing was caused by different time intervals to death within the spawning grounds and a lesser portion by differences in individual migration times from Farwell to the spawning grounds.

THE STELLAKO SOCKEYE MIGRATION

In 1952, a record of the daily numbers of Stellako sockeye arriving at the outlet of Fraser Lake was maintained by the Aluminum Company of Canada. These counts were taken to ascertain the dates of passage of the sockeye into the Fraser-Francois district as part of a study connected with the stoppage of water

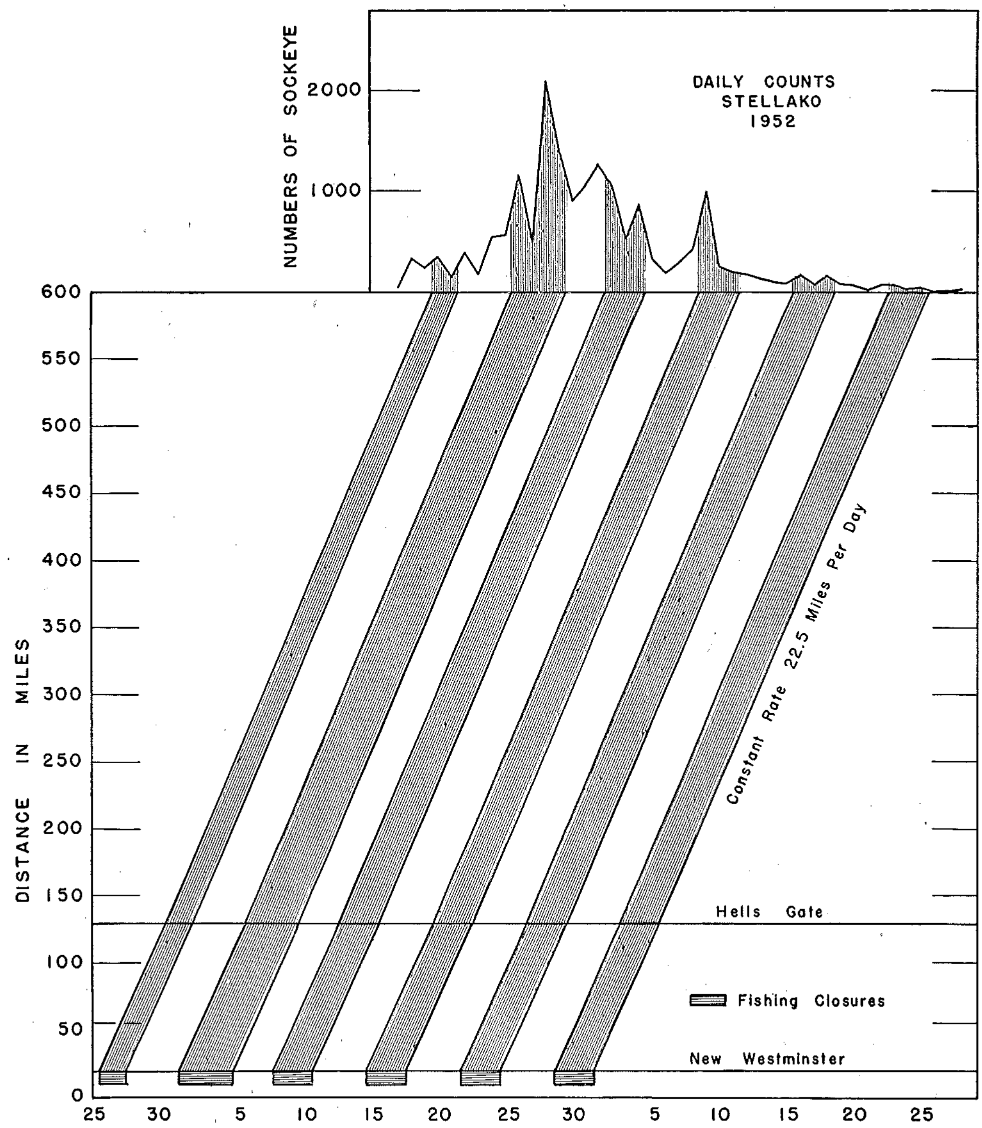

FIGURE 16. Dates of passage and migration rates of the 1952 Stellako sockeye through the Fraser River gillnet area, Hell's Gate and Fraser Lake.

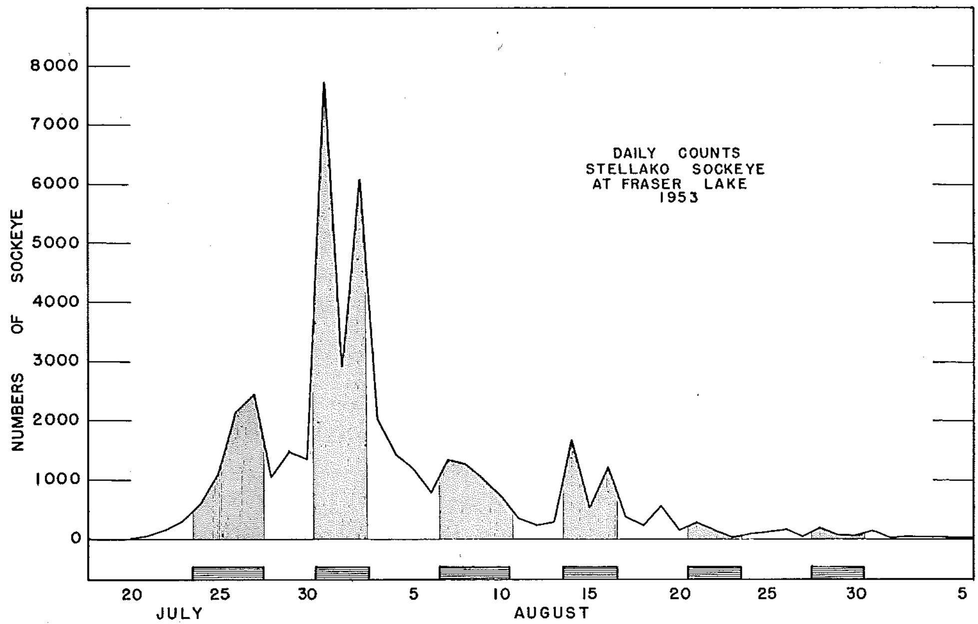

FIGURE 17. Dates of passage of the 1953 Stellako sockeye through the Fraser River gillnet area and Fraser Lake.

in the Nechako River. The data have been generously made available to the Salmon Commission and have been of value as they showed peaks which could be related to closure dates in the commercial fishing areas at the Fraser mouth.

The association of fishing closures at the Fraser River mouth and counts of Stellako sockeye at the outlet of Fraser Lake is shown in Figure 16. While separate peaks of escapement occurred, it was apparent that the depressions between the peaks, resulting from the effect of commercial fishing, were not as distinct as would be expected if a constant chronological order had been maintained. Some difficulty in the counting of sockeye during the first year of study may have been responsible for the lack of pronounced variation. Apart from the configuration of the escapement it was noted that the speed of migration of 22.5 miles a day above Hell's Gate was almost the same as 21.5 for Chilko and slower than the 30 miles a day rate of the July runs.

Daily counts of migrating Stellako sockeye were also made in 1953 at the outlet of Fraser Lake. These counts and the periods of gillnet fishing and closure in the lower Fraser River are given in Figure 17 which shows the effect of fishing and the discrete intervals of escapement very clearly. Considering that 600 miles were traversed between the commercial fishing areas and Fraser Lake, it is remarkable that such an effect persisted. Regulation of the closures in the fishery to secure selected escapements at the spawning grounds becomes a possibility when mixing is so limited that peaks of arrival are as clearly retained throughout the run as those of the Stellako sockeye in 1953.

THE ADAMS SOCKEYE MIGRATION

Unlike the early runs of the Fraser River, the Adams sockeye do not migrate upstream until they have delayed about three weeks at the mouth of the Fraser. Whether the time sequence of various portions of the run is retained during this delay period is not known; however, it is considered essential to secure an escapement at the proper time to insure the peak arrival of the run at the spawning grounds from approximately October 3 to 15—the period of optimum temperature for spawning. Studies of the migrations of the larger runs to Adams River indicate that the peak of abundance at the Fraser River mouth occurs about August 28 and migrates upstream about September 16. The migration time is 18 days of which 8 days are required to reach Hell's Gate and 10 days to reach the spawning grounds located 170 miles upstream (rate—17 miles a day). Based on a migration time of 18 days, the escapement from the commercial fishery at the Fraser mouth should occur between September 16 and 28.

The 1954 Adams Run

The 1954 run to the Adams River was unique in its pattern of migration; instead of migrating up the Fraser for a normal period lasting about thirty days, the bulk of the run, comprising some two million sockeye, made a mass movement into the Fraser in a period of two and a half days from September 17 to 19 as shown in Figure 18. The starting time was established by two gillnetting experiments in the lower areas of the Fraser and by daily estimates of the numbers of sockeye jumping or finning between Steveston and Mission. The next checking station was at Hell's Gate where relative counts of the daily numbers of sockeye were made. At Hell's Gate the run lasted 6 days as compared with the initial 2.5 days of passage at the mouth. This extension of the run resulted from the congestion which developed when hundreds of thousands of sockeye were forced into limited passageway at the Gate. The period of the Adams run was further extended to 14 days of passage at the Thompson Rapids, located on the Thompson River 10 miles above Lytton, where the fish were still too concentrated to pass the swift, turbulent waters in their correct order of arrival. Beyond the Thompson Rapids, there were no further places of difficult passage and the period of migration into the Adams River should have been complete in 14 days from October 5 to 19. Counts of sockeye at Adams River showed that 80 per cent of the run *did* arrive between the above dates; however, most of the remaining 20 per cent continued to arrive for a further 8 days. This 8-day delay at the end of the run may have been related to the crowded condition on the redds. The final period of the run extended over 22 days as compared with the starting time of 2.5 days as a result of consecutive delays created by the congestion of a very large run migrating in a short period of time. This phenomenon had not occurred for any of the other runs considered in this report.

SUMMARY OF MIGRATION PATTERNS

Three main types of migratory behaviour were revealed by studying the consistency of chronological order during migrations of Fraser River sockeye. The *first* consisted of the June and July runs of Early Stuart, Bowron and Horsefly

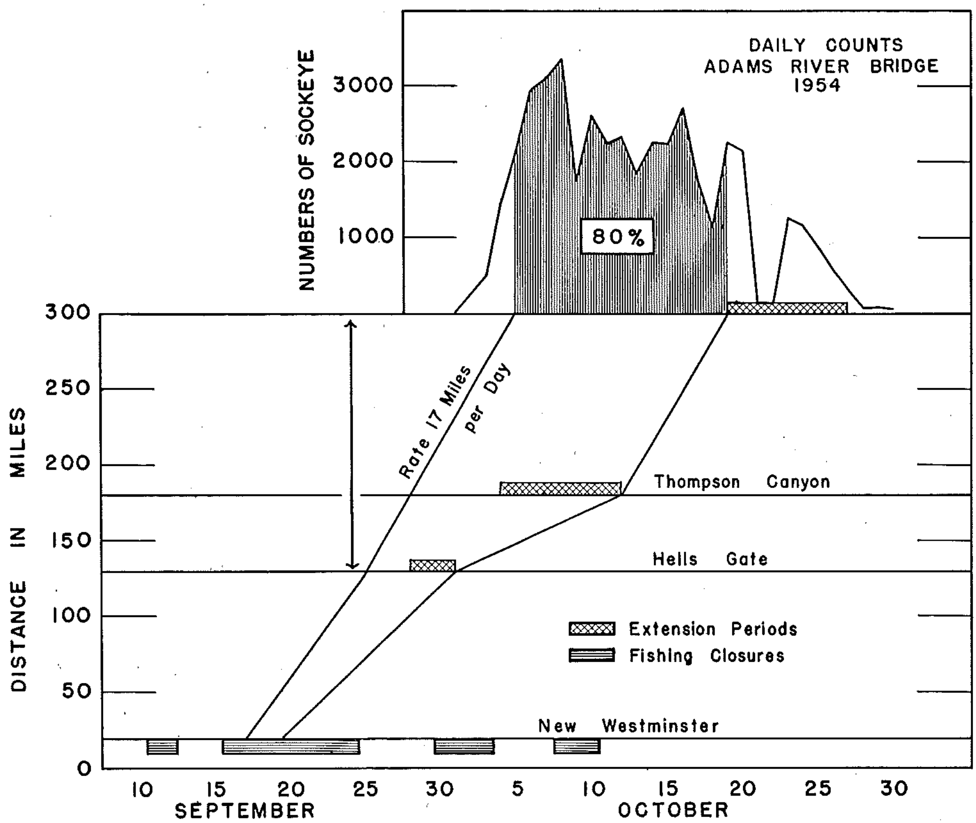

FIGURE 18. Dates of passage and migration rate of the 1954 Adams sockeye through the Fraser River gillnet area, Hell's Gate, Thompson Canyon and Adams River.

sockeye which migrated at 30 miles a day and were timed to arrive on their respective spawning grounds just prior to their time of spawning. The order of migration of various portions of these runs was constantly maintained. The peaks of two later sockeye runs, Chilko and Stellako, usually entered the Fraser in early August and represented a *second type*; for they migrated at a slower rate of 21 to 22 miles a day and arrived at the spawning ground well in advance of their spawning time. The Chilko run for instance had a peak escapement at Steveston about August 3 in 1952; yet, the peak of spawning was not until 50 days later on September 22. Allowing 6 or even 10 days for the sockeye to reach sexual maturity and prepare the redds prior to spawning there were 40 to 44 days left for migration. The distance from Steveston to the Chilko spawning grounds is 400 miles and would require 19 days at a rate of 21.5 miles per day. A balance of 21 to 25 days remained for delay before the sockeye began nest preparation. The Stellako run also peaking at Steveston on August 3 in 1952, did not spawn until September 28; and applying its rate of 22.5 miles per day over 612 miles only 27 days out of the total period of 56 days were used for migration. A *third type* of migration was represented by the Adams run which arrived at the Fraser mouth in late August but did not begin its river migration until mid-September and then at a rate of 17 miles a day.

Through July, August and into September there was a progressive reduction in the speeds of migration and extensions of the periods of delay. Associated with the slower migrations and longer delay periods, there was a slight tendency towards increased mixing of the various portions of the individual runs; however, for every run examined, it was demonstrated that the chronological order was retained so closely that the escapements from closures in the Fraser River gillnet fishery were clearly identified as discrete peaks of abundance upon arrival at the respective spawning grounds.

CHRONOLOGICAL CONSISTENCY DURING SPAWNING

The migrations of sockeye have been traced from the commercial fishing zones to the spawning streams and the extent to which the various segments of the individual runs mixed en route has been discussed. However, extensive mixing may conceivably occur after the sockeye enter the spawning grounds. Spawning is considered to be critically related to the environmental cycle but it was not known whether it took place at a constant time after arrival for all individuals of the run or whether the spawning population constituted a mixed assembly, membership of which was unrelated to date of arrival. Special experiments were conducted with groups of sockeye to assess the chronological order of spawning as related to the sequence established on arrival.

METHODS OF STUDY

The spawning sequence study was conducted at Forfar Creek in the Stuart Lake district in 1952. Forfar Creek was chosen because it is small, relatively free from flash floods, and easily fenced at its entrance. Prior to the start of the sockeye run, a weir was constructed through which all the sockeye passed. The daily numbers and sex could thus be recorded. As various day-populations of sockeye could not be distinguished within the spawning stream it was necessary to devise a method of recognition. It was first proposed that numbers of sockeye should be tagged and passed through the fence to mix at liberty with the untagged population; then, at subsequent regular time-intervals, they would be netted and examined by tag-number for date of stream entry, state of maturity and time of spawning. Although such a plan had the advantage that the salmon would have a free choice of redds and mates, it was considered beyond the physical capacity of the field crew to patrol the length of the stream, locate, net and examine the tagged sockeye as often as required. As an alternate proposal, selected groups of sockeye were captured upon arrival at the weir and confined in a large wire-screened pen containing 212 square yards of suitable spawning gravel. By this means, the fish were easily observed and caught for examination. (See Plate II.)

Three sample lots representing early, central and late arriving sockeye were transferred from the counting weir to the pen area on July 29, August 3 and August 8 respectively, each lot of sockeye being distinguished by distinctive coloured tags. One hundred sockeye, 50 of each sex, composed each of the early

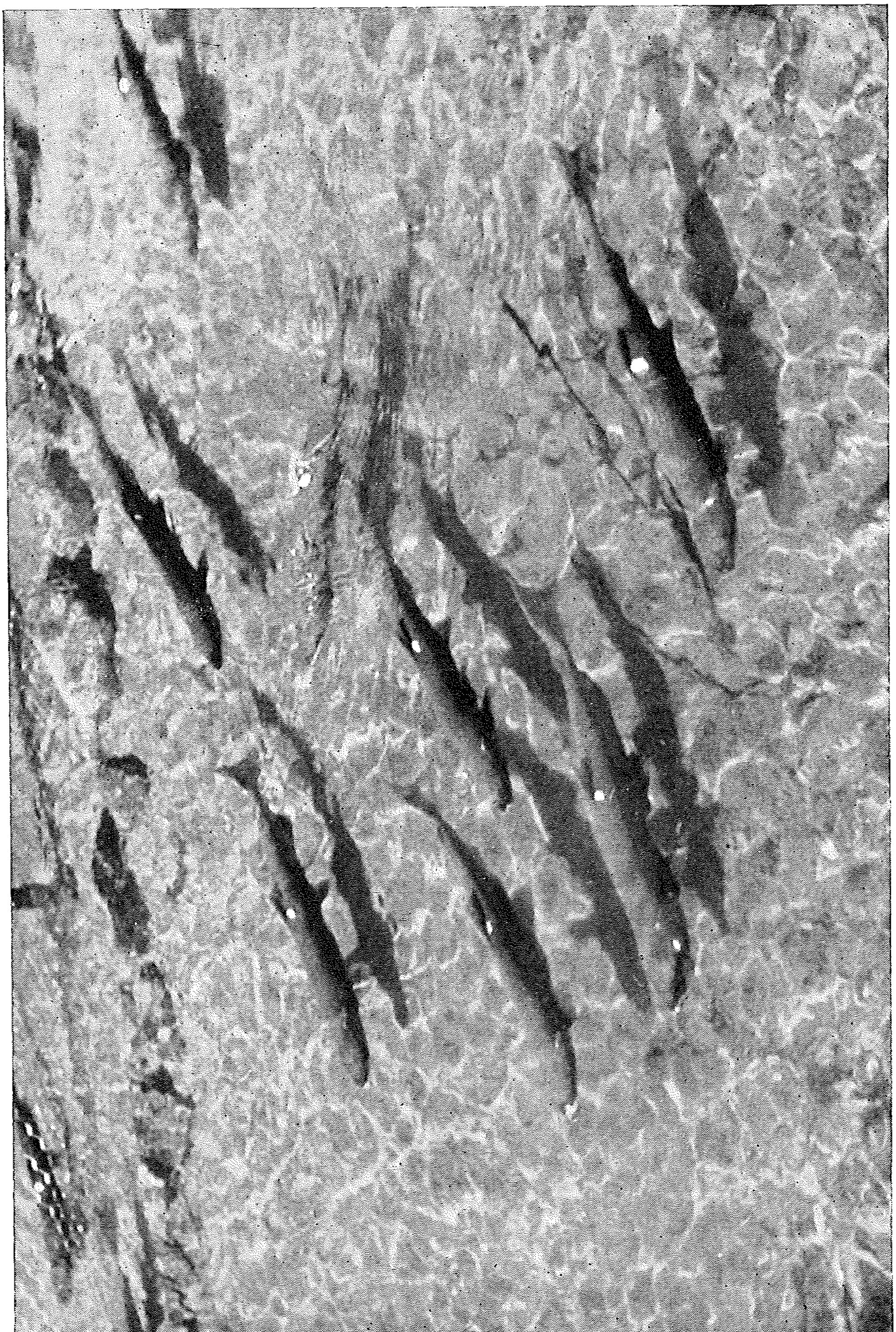

PLATE II. Male and female sockeye marked with various coloured tags in the experimental pen area at Forfar Creek, 1952.

and central groups but, because of the reduced numbers of sockeye arriving later in the run, only 87 sockeye including both sexes were taken on August 8.

Two methods were employed in recording the spawning times of the penned individuals.

1. *Visual counts* of the numbers of sockeye which appeared to be spawning each day.
2. *Manual examination* of 50 per cent or more of the number of penned female sockeye every second day to record the degree of sexual maturity. The maturation of live male sockeye was estimated also, but this estimate was not considered sufficiently accurate to indicate the period of functional spawning. During the manual examination of the females, an estimate was made of eggs already emitted to the nearest 25 per cent.

RESULTS

Visual Observations of Spawning Sockeye

The primary objective of visual observations was to ascertain the period and peak of the spawning activity of the confined sockeye without causing the disturbance in the pen area that was necessary for manual examinations. Counts of spawners seen each day are listed in Table 28. As spawning of individuals required two days, on the average, the totals represent numbers of "spawning-days" and not individual sockeye. The peak day of spawning is noted for each group.

TABLE 28

DAILY VISUAL COUNTS OF THE NUMBERS OF SOCKEYE SPAWNING IN THE EXPERIMENTAL PEN IN FORFAR CREEK, 1952

Date	Early Group Confined July 29	Central Group Confined August 3	Late Group Confined August 8
July 29	0		
30	No Record		
31	No Record		
August 1	6		
2	20		
3	50*	0	
4	30	2	
5	4	0	
6	0	6	
7	10	20	
8	6	40*	0
9	0	36	No Record
10	2	20	2
11	0	15	6
12		8	4
13		6	12
14		4	12
15		4	21
16		4	23*
17		2	7
18		0	5
19			3
20			0
* Peak Date of Spawning (From Mode)	August 3	August 8	August 16

TABLE 29

A COMPARISON OF THE SPAWNING FREQUENCY DISTRIBUTIONS OF EARLY (E), CENTRAL (C) AND LATE (L) GROUPS OF SOCKEYE MEASURED AS DAYS-OUT FROM DATES OF CONFINEMENT TO THE EXPERIMENTAL PEN AREA FORFAR CREEK 1952

(Data based on Visual Observation)

	Visual Counts				Counts as Percentages			
	Groups				Groups			
Days-Out	E	C	L	ECL	E	C	L	ECL
1	0	0	0	0	0	0	0	0
2	—	2	—	2	0	1.2	0	.5
3	—	0	2	2	0	0	2.1	.5
4	6	6	6	18	4.7	3.6	6.3	4.6
5	20	20	4	44	15.6	12.0	4.2	11.3
6	50	40	12	102	39.1	24.0	12.6	26.1
7	30	36	12	78	23.4	21.5	12.6	20.0
8	4	20	21	45	3.1	12.0	22.1	11.5
9	0	15	23	38	0	8.9	24.2	9.7
10	10	8	7	25	7.8	4.8	7.4	6.4
11	6	6	5	17	4.7	3.6	5.3	4.4
12	0	4	3	7	0	2.4	3.2	1.8
13	2	4	0	6	1.6	2.4	0	1.7
14	0	4	0	4	0	2.4		1.0
15	0	2	0	2		1.2		.5
Totals	128	167	95	390	100.0	100.0	100.0	100.0
Mean Days-Out	6.7	7.5	7.8	7.3				
Standard Deviation	1.8	2.5	2.0	2.2				

The sockeye did not all spawn at an equal length of time after they entered the stream; instead, the numbers of spawners seen each day formed a frequency distribution curve. Similar frequency distribution curves, tending towards positive skewness, were apparent for early, central and late groups of sockeye. Hardly any spawning was observed until the sockeye had been in the pen area for at least three days and only a little by the fourth day. On the fifth day the numbers of spawners increased and a peak of spawning activity occurred on the sixth, seventh and eighth days. Following the peak, the numbers of spawners declined until by the eleventh day nearly all the sockeye were spent.

The occurrence of spawning measured as "days-out" from the dates of arrival is presented in Table 29 and Figure 19. The respective means of the frequency distributions were 6.7, 7.5 and 7.8 days, which showed a slight tendency for early sockeye to spawn more quickly than later groups. Such a tendency separated the periods of spawning; however, there was sufficient variation in the days-out to indicate that some mixing had occurred. The standard deviations of 1.8, 2.5, 2.0 days for the groups and 2.2 for all penned sockeye measured the general variation in the times of spawning. The degree of mixing developed by the dispersion of two and a half days from a single peak day of spawning, similar to that which occurred during migration, was considered of little consequence.

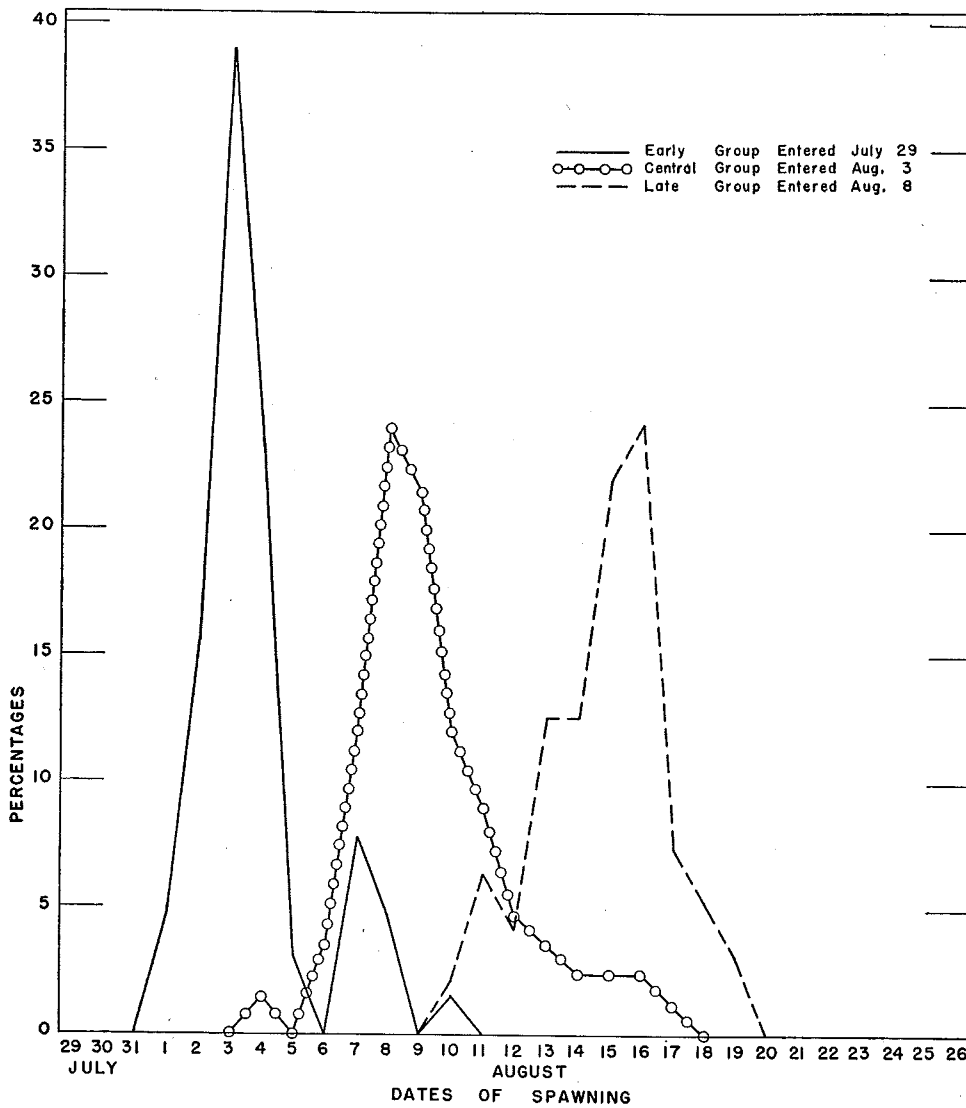

FIGURE 19. Percentage frequency distributions and dates of spawning of early, central and late groups of sockeye confined to the experimental pen area at Forfar Creek, 1952. (Data obtained from *visual* observations of female sockeye.)

Manual Examination for Time of Spawning

Upon analysis of the data obtained from manual examination, two difficulties in the experimental design became apparent. Handling the females had been scheduled for every second day as it was suspected that spawning would occur over a period of three to five days for each fish. Subsequent examinations showed that individual spawnings took place in slightly less than two days and, as a result, half the spawning was missed. This void in the data is apparent in Tables 30 to 32. In these tables, it was necessary to assume that a female sockeye found to be 25 per cent spawned on the day of examination would be 75 per cent spawned on the

TABLE 30

RECORD OF DATES WHEN THE EARLY GROUP OF FEMALES WERE FOUND TO BE 25 AND 75 PER CENT SPAWNED

Tag Numbers	July 29	30	31	August 1	2	3	4	5	6	7	
					Dates of Examination for Spawning						
8903				(25)	75						
8916						(25)	75				
8920						(25)	75				
8922						(25)	75				
8928					25	(75)					
8929			25	(75)							
8937									25	(75)	
8945									25	(75)	
8953			25	(75)							
8955				(25)	75						
8957					25	(75)					
8958				(25)	75						
8960					25	(75)					
8961			25	(75)							
8963			25	(75)							
8965					25	(75)					
8968			25	(75)							
8970				(25)	75						
8974			25	(75)							
8989						(25)	75				
8990							25	(75)			
8998			25	(75)				(25)	75		
Daily Totals at 25%	0	0	7	4	4	4	1	1	2	0	Total 23
Daily Totals at 75%	0	0	0	7	4	4	4	1	1	2	Total 23
Daily Total of Spawners	0	0	7	11	8	8	5	2	3	2	Total 46

following day and similarly a reversed extrapolation was applied to those found to be 75 per cent spawned. A second difficulty resulted from handling only half the number of sockeye in the penned area. Examination of tag-numbers showed that some sockeye were missed consistently for as many as eight days and their spawning periods were never reported. Missing some of the spawning periods resulted in the sample sizes being considerably less than was anticipated.

The detailed results of the manual examinations given in Tables 30, 31 and 32 are summarized as to "days-out" from dates of arrival into the stream in Table 33 and plotted in Figure 20.

The first spawning of the early group occurred on July 31, three days after their stream arrival. Spawning increased until the fifth and sixth days and thereafter the numbers of spawners decreased until by the tenth day spawning had ceased. The mean number of days from date of entry to the stream was 5.5 days and may be compared to 6.7 days recorded during visual observations.

Twenty-seven of the 50 females of the central group were handled during their period of spawning. Again, spawning commenced on the third day and increased to a moderate peak lasting from the sixth to the eighth day and then gradually decreased to the completion of spawning on the fourteenth day. The

TABLE 31

RECORD OF DATES WHEN THE CENTRAL GROUP OF FEMALES WERE FOUND TO BE 25 TO 75 PER CENT SPAWNED

Tag Numbers	Dates of Examination for Spawning August 5	6	7	8	9	10	11	12	13	14	15	16	
10-402				25	(75)								
10-405				25	(75)								
10-408					(25)	75							
10-414				25	(75)								
10-416				25	(75)								
10-418										25	(75)		
10-422					(25)	75							
10-423											(25)	75	
10-426		25	(75)										
10-431		25	(75)										
10-436				25	(75)								
10-437			(25)	75									
10-441					(25)	75							
10-442		25	(75)										
10-446	(25)	75											
10-450				25	(75)								
10-453					(25)	75							
10-455						25	(75)						
10-457				25	(75)								
10-460								25	(75)				
10-462								25	(75)				
10-464	(25)	75											
10-471			(25)	75									
10-472							(25)	75					
10-479									(25)	75			
10-483						25	(75)						
10-489						25	(75)						
Daily Totals at 25%	2	3	2	7	4	3	1	2	1	1	1	0	Total 27
Daily Totals at 75%	0	2	3	2	7	4	3	1	2	1	1	1	Total 27
Daily Total of Spawners	2	5	5	9	11	7	4	3	3	2	2	1	Total 54

TABLE 32

RECORD OF DATES WHEN LATE GROUP OF FEMALES WERE FOUND TO BE 25 AND 75 PER CENT SPAWNED

Tag Numbers	Dates of Examination for Spawning August 8	9	10	11	12	13	14	15	16	17	18	19	20	
60-106								(25)	75					
60-108					25	(75)								
60-119								(25)	75					
60-128						(25)	75							
60-146						(25)	75							
60-150						(25)	75							
60-156											25	(75)		
60-158								(25)	75					
60-162							25	(75)						
60-165					25	(75)								
60-173									25	(75)				
Daily Totals at 25%	0	0	0	0	2	3	1	3	1	0	1	0	0	Total 11
Daily Totals at 75%	0	0	0	0	0	2	3	1	3	1	0	1	0	Total 11
Daily Total of Spawners	0	0	0	0	2	5	4	4	4	1	1	1	0	Total 22

TABLE 33

A COMPARISON OF THE SPAWNING FREQUENCY DISTRIBUTIONS OF EARLY (E), CENTRAL (C) AND LATE (L) GROUPS OF SOCKEYE MEASURED AS DAYS-OUT FROM DATES OF CONFINEMENT TO THE EXPERIMENTAL PEN AREA, FORFAR CREEK 1952

(Data based on Manual Examination of Female Sockeye)

	Manual Examination Counts Groups				Counts as Percentages Groups			
Days-Out	E	C	L	ECL	E	C	L	ECL
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	7	2	0	9	15.2	3.7	0	7.4
4	11	5	0	16	23.9	9.2	0	13.1
5	8	5	2	15	17.4	9.2	9.1	12.3
6	8	9	5	22	17.4	16.7	22.7	18.0
7	5	11	4	20	10.9	20.4	18.2	16.4
8	2	7	4	13	4.4	13.0	18.2	10.7
9	3	4	4	11	6.5	7.4	18.2	9.0
10	2	3	1	6	4.3	5.5	4.6	4.9
11		3	1	4	0	5.5	4.5	3.3
12		2	1	3		3.7	4.5	2.5
13		2		2		3.7	0	1.6
14		1		1		2.0		.8
Totals	46	54	22	122	100.0	100.0	100.0	100.0
Mean Days-Out	5.5	7.4	7.7	6.7				
Standard Deviation	2.0	2.6	1.9	2.5				

weighted mean and standard deviation of the central group of spawners was 7.4 and 2.6 as compared with 7.5 and 2.5 for the visual observations. It is possible that, whereas some of the early spawning in the first group were not recognized by the observers, by the time the central group was confined, the observers were more experienced and the signs of spawning were detected immediately. This would explain the closer agreement of the means obtained by both methods for this group as compared with those of the early group.

In the last group, only 11 females were successfully examined for spawning yet the mean and standard deviation values were again consistent with those recorded visually. The peak of spawning occurred after a mean of 7.7 days with a standard deviation range of 1.9 days. These times are nearly identical to values of 7.8 and 2.0 recorded from visual observations.

The results of the visual and manual studies of spawning sockeye were sufficiently similar for confidence to be placed in either method (see Table 34). The manual examinations provided data on individuals and, because of more careful scrutiny of the females, are believed to be the more accurate of the two procedures. From the analysis of the mean spawning times of 5.5, 7.4, 7.7 days for early, central and late groups of sockeye respectively, it was concluded that there was no general tendency for later sockeye to spawn more quickly after arrival than fish which arrived early. Indeed, the contrary seemed to be indicated but it is quite probable that the difference of two days between the means for the early arrivals and the later groups was caused by a delay of the first arrivals below the weir.

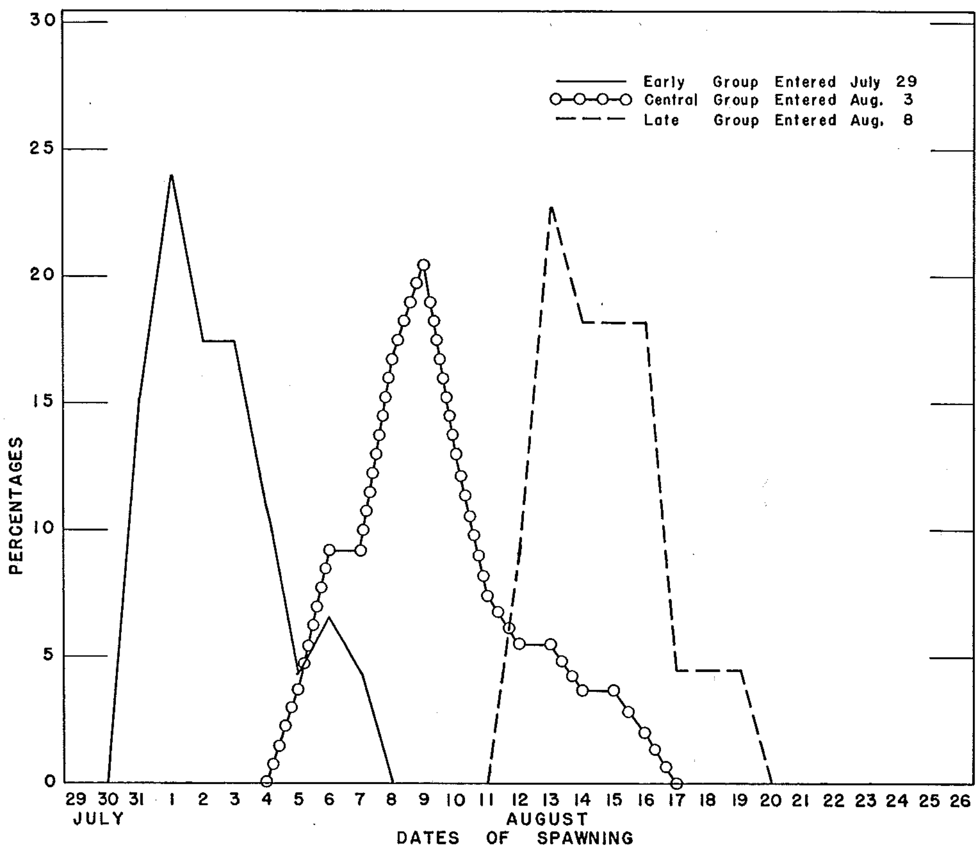

FIGURE 20. Percentage frequency distributions and dates of spawning of early, central and late groups of sockeye confined to the experimental pen area at Forfar Creek, 1952. (Data obtained from *manual* examinations of female sockeye.)

TABLE 34

A COMPARISON OF THE MEANS AND STANDARD DEVIATIONS OF THE DAYS-OUT TO THE PEAK OF SPAWNING OF EARLY, CENTRAL AND LATE GROUPS OF FEMALE SOCKEYE AS RECORDED BY VISUAL AND MANUAL OBSERVATIONS AT FORFAR CREEK, 1952

Method	Early Group July 29	Central Group August 3	Late Group August 8	All Groups
Mean Days-Out—				
Visual	6.7	7.5	7.8	7.3
Manual	5.5	7.4	7.7	6.7
Standard Deviation—				
Visual	1.8	2.5	2.0	2.2
Manual	2.0	2.6	1.9	2.5

This delay before entering a weir immediately below the spawning grounds was discussed previously. Although the means showed that there was no tendency for various sections of the run to converge into one spawning population, the standard deviations of two to three days showed that there was some mixing, but this was not considered sufficient to mask the general maintenance of chronological order from the time of arrival to the time of spawning in the stream.

CHRONOLOGICAL CONSISTENCY DURING DEATH

A study of the times of death of sockeye salmon may provide important basic data on the success or failure of reproduction of this species. It is apparent that the time of death is governed by the amount of stored energy in the body tissues which must be sufficient for both migration and the successful completion of the reproductive act. Feeding ceases just before the migrating sockeye enter the Fraser estuary, and therefore, since no supplementary energies are available, it appears that each sockeye has a predetermined and relatively non-adjustable time of death. Prior to death the food storage must provide for a period of migration and a balance of time for life within the spawning grounds. If the time normally allotted for migration were exceeded because of unnatural delays then it is probable that the time available on the spawning grounds will be proportionally reduced. In support of this, Thompson (1945) and Talbot (1950) found that tagged sockeye did not reach the spawning grounds if they had been delayed at Hell's Gate more than 12 to 15 days. Data collected in this report will show that the average life-spans within the spawning grounds are 12 to 19 days; a time similar to that calculated to be the limit of delay at Hell's Gate. The significance of extended delay periods which eliminate any available time or energy for spawning is readily appreciated; however, it may be equally important to understand the effects of lesser delays. It is probable that many sockeye, delayed less than 12 days at Hell's Gate, were able to reach the spawning grounds but, because of the reduced time of life remaining, were unable to spawn with a normal degree of success. The much larger returns-per-spawners since the fishways were built in 1945 certainly indicate that the former Hell's Gate delays reduced the spawning efficiency of those sockeye that did reach the spawning grounds. As it seems that the time spent on the spawning grounds is related to the success of spawning, it is important to measure this time and to record the order of occurrence of the spawning ground deaths. This analysis will provide the mean life-span after arrival on the spawning grounds for different parts of various runs; however, the physiological significance of long or short life-spans—important though it may be—has not been assessed in this report.

A study of the times of death is also desirable to establish whether the daily abundance and sex ratio of the dead can be used as a measure of the numbers and sex ratios of the live sockeye upon arrival on the spawning grounds. For instance, in larger streams or rivers where counts of arriving sockeye are impossible to obtain it may be practical, provided the life-spans of the sockeye are reasonably consistent for all parts of the run, to use a curve derived from the daily numbers of dead carcasses as being representative of the arrival curve. Also, when the sex ratios of sockeye entering the grounds cannot be secured, the daily sex ratios

TABLE 35

LIFE-SPAN OF MALE AND FEMALE SOCKEYE IN THE EXPERIMENTAL PEN, FORFAR CREEK, 1952
(All Sockeye listed were "Fresh" dead, 100 per cent spawned.)

	FEMALES			MALES		
Days-Out to Death	Early Group	Central Group	Late Group	Early Group	Central Group	Late Group
1						
2						
3						
4						
5			1			
6	1	1				
7	1	1	3			1
8	3	3	1			
9	10	5	2		4	3
10	8	12	5	2	2	3
11	11	8	3	6	3	3
12	3	2	2	7	3	7
13	7	4	3	6	5	4
14		2	1	4	4	1
15		1		2	3	
16		2		1	2	
17		1		2	1	
18						
19				1		
20						
21				1		
22				1		
Totals	44	42	21	33	27	22
Means	10.3	10.9	10.1	13.5	12.0	11.2 days

of the dead may represent the proportions of the two sexes during various parts of the run, provided the life-spans of male and female sockeye are equal.

Two separate spawning grounds were selected for the death sequence studies; the first being Forfar Creek where accurate data of the daily numbers and sex ratios of arriving sockeye were recorded at a weir and the second being Adams River where somewhat less accurate data on arrival were available. At Forfar Creek in 1946 and 1952, 521 tagged sockeye were assessed by time of death from dates of stream arrival, while at Adams River the order of dying of 1,453 sockeye for the years 1946, 1950, 1951 and 1954 have been tabulated. These examples, representing conditions in small and large spawning grounds and early and late runs within the Fraser River watershed, should indicate the range that may occur on most Fraser spawning grounds.

FORFAR CREEK

Tagging of Forfar Creek sockeye in 1952 provided the most complete data in which the order of dying was measured first from the life-span on the spawning grounds of the sockeye used for assessing dates of spawning in the experimental pen and secondly from the life-span of 427 sockeye that were tagged upon arrival at a weir. The data for the order of death of the penned sockeye are shown in Table 35. The mean life-spans of females for the three experimental lots were 10.3, 10.9 and 10.1 days respectively. No significant differences in the average length of life were evident for different dates of stream entry but the range in days-out to death was extensive, especially in the central lot of August 3 where one female was dead after 6 days while another died after 17 days. Most of the females in each part of the run were dead after 9 to 11 days. The males lived consistently longer than the females in each of the pen lots although late-arriving males died sooner than the early males as shown by the respective lot means of 13.5, 12.0 and 11.2 days. The dispersions from the means were extensive with the greatest spread occurring in the early lot for the males and the central lot for females. If the penned sockeye were representative of the total run, mixing of the dead male carcasses must have been considerable because it would have been caused by both deviations from the daily means and changes in average life-span as the season progressed. Females, on the other hand would have been mixed only to the extent of the dispersion from relatively stable means. The results derived from these data have not been applied to the total run because it was considered probable that handling the fish to determine their state of spawning advanced the date of death.

As the penned sockeye probably died prematurely, a second measure of the death sequence at Forfar Creek was obtained by tagging approximately every fifth male and female as they passed through the counting fence. In conjunction with the tagging, a daily recovery of dead carcasses was made throughout the length of the stream. Each dead sockeye was examined for sex, tag-number, per cent spawned and extent of decomposition. The record of decomposition was necessary to permit the separation of "fresh" dead from "old" fish that may have been missed on the date that they actually died.

A summary of the mean days-out to recovery of dead sockeye at various stages of decomposition and levels of spawning is provided in Table 36. The inclusion of tainted and rotten carcasses would have indicated a longer mean life-span for females of 13.2 days as compared with 12.7 obtained by using fresh dead only. Similarly, males unclassified as to condition would have given a mean of 12.3 days compared with 12.0 for fresh dead. These differences were not too

TABLE 36

SUMMARY OF THE MEAN DAYS-OUT TO RECOVERY OF DEAD SOCKEYE AT VARIOUS DEGREES OF DECOMPOSITION AND LEVELS OF SPAWNING, FORFAR CREEK, 1952

	Per Cent Spawned	Fresh	Tainted	Rotten
Females	100	12.7 (228)	13.5 (80)	15.4 (43)
	75	8.6 (7)	10.2 (8)	14.0 (2)
	50	11.2 (13)	10.6 (7)	7.5 (1)
	25	7.0 (3)	9.0 (1)	12.0 (1)
	0	8.9 (12)	8.4 (10)	12.5 (2)
Males	100	12.0 (199)	12.9 (43)	15.5 (21)
	75	11.0 (47)	10.2 (11)	14.6 (8)
	50	10.1 (31)	11.4 (5)	14.0 (2)
	25	7.9 (8)	13.0 (1)	7.0 (1)
	0	7.8 (18)	7.3 (4)	5.0 (1)

Sample sizes in parentheses.

TABLE 37

TIME OF DEATH OF TAGGED FEMALE SOCKEYE RECORDED AS DAYS-OUT FROM DATES OF ARRIVAL TO DATES OF DEAD RECOVERY OF "FRESH," 100 PER CENT SPAWNED SOCKEYE. FORFAR CREEK, 1952.

Dates of Tagging	Number of Days-Out to Recovery																				Daily Mean No. of Days	Number Recovered
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
July 29						1		3	2		2	5	2	5	1			1			13.8	22
30						4	4	4	2	9	11	12	5	4	4	6	3	2		1	13.8	71
31					1	1	1	5	2	5	6	3	4	2		1	1		1		12.9	33
August 1							1	1	2	4	2		1	2	2	1	2				14.0	18
2				1				2	1	2	2	1			1		2				13.0	12
3						1	1				1	2	1								12.2	6
4					1		4	2	2	5	4	1	4	1							12.0	24
5						1	1		2	4	2				1						11.8	11
6					1				1	1		1			1						12.2	5
7						1		2	1	2											10.5	6
8							1	3													9.8	4
9																						
10	2					3		1	1		1										8.0	8
11		1				2	2		1												8.2	6
12				1																	6.0	1
13								1													10.0	1

TABLE 38

FREQUENCY DISTRIBUTION OF THE DAYS-OUT TO DEATH (LIFE-SPAN) OF EARLY, CENTRAL AND LATE GROUPS OF FEMALE SOCKEYE IN FORFAR CREEK, 1952

Days-Out to Death	Numbers of Dead Groups A	B	C	ABC	Percentages Groups A	B	C
1							
2							
3			2	2			10.00
4			1	1			5.00
5			0	0			0.00
6	1		1	2	.64		5.00
7	1	2	0	3	.64	3.85	0.00
8	6	3	5	14	3.85	5.77	25.00
9	6	6	3	15	3.85	11.54	15.00
10	15	4	5	24	9.62	7.69	21.00
11	9	6	2	17	5.77	11.54	14.00
12	20	12	0	32	12.82	23.07	0.00
13	23	7	1	31	14.74	13.46	5.00
14	21	4		25	13.46	7.69	
15	12	5		17	7.69	9.62	
16	13	1		14	8.33	1.92	
17	8	2		10	5.13	3.85	
18	8			8	5.13		
19	8			8	5.13		
20	3			3	1.92		
21	1			1	.64		
22	1			1	.64		
Totals	156	52	20	228	100.00	100.00	100.00
Means	13.59	11.81	8.40	12.73			
Standard Deviation	3.17	2.45	2.64	3.34			

important because the numbers of dead other than fresh were small and did not influence the mean values excessively. Errors in computing the life-span of the sockeye unclassified as to decomposition would have been greater if a *daily* recovery of dead carcasses had not been maintained.

It was also considered that the most representative estimate of life-span would be obtained if only fully-spawned sockeye were included since the success of spawning is greater than ninety-five per cent for most Fraser River populations. Knowledge of the dates of tagging and recovery, together with the classifications of sex, condition and per cent of spawning, made it possible to tabulate the daily frequency distributions of dead sockeye and to apply the results to the total population.

Death Schedule of Female Sockeye, 1952

The schedule of female deaths in Forfar Creek is presented in Table 37. All the tagged females from any single arrival date did not subsequently die on a single day but were recovered over a wide range of days. This variation in life-span prevailed throughout the whole of the run but was greatest during the period of peak abundance. The total mean life-span was 12.73 days with a standard deviation of 3.34 days. The rather large standard deviation was developed from the combined

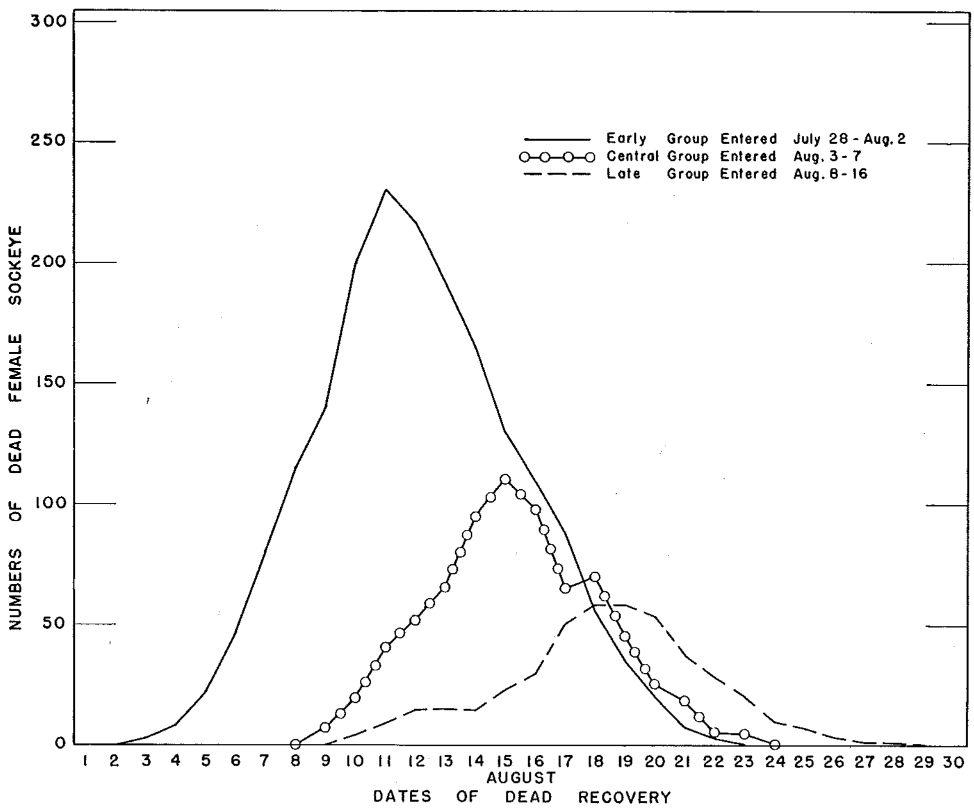

FIGURE 21. Calculated frequency distributions and dates of death of early, central and late groups of female sockeye in Forfar Creek, 1952.

effect of daily deviations and a tendency throughout the season for the later sockeye to die more quickly; the progressive shortening of the life-span from about 14 to 8 days caused the period of arrival to be compressed into a shorter period of dead recovery and mixing of adjacent day-populations of female sockeye was inevitable.

To illustrate graphically the degree of mixing that existed between dates of arrival and dates of death, the total period of arrival was divided into early, central and late parts corresponding approximately with the experimental groups used to measure the spawning sequence. Early sockeye (A) were those arriving from July 28 to August 2, central sockeye (B) from August 3 to 7, and the late arrivals (C) from August 8 to the end of the run on August 16. The group frequency distributions of the dead females are shown in Table 38. The mean life-span for the early group of females was 13.59 days with a standard deviation of 3.17 days; the life-spans ranged from 6 to 22 days but were mostly between 11 and 17 days. The central group died after a mean of 11.81 days with a standard deviation of 2.45 days; they lived a shorter length of time and showed less variation than the early arrivals. The late females were few in number but, of the sample secured, death occurred after a mean of 8.40 days with a standard deviation of 2.64 days.

To measure the total effect of mixing for all female sockeye, tagged and untagged, the frequency distributions of the tagged groups were converted to percentages. These group percentages were then applied to each daily arrival count. (Daily percentage distributions were also applied to their respective daily weir counts and the results were very similar to those obtained by using the group frequencies.) The calculated distributions of dead females of the early, central and late arrivals are plotted in Figure 21. The early female sockeye which entered the stream July 28 to August 2 were available for almost the full period of the dead recovery. The central and late females showed less random variation in life-span but, mostly because of their progressively shorter mean life-spans, they became mixed with each other and the early group. For females, there was extensive mixing and the separate recognition of the initial groups of arrivals at the time of death was almost impossible.

The accuracy of using the frequency distribution of the dead tagged samples to convert the total arrival curve into a dying frequency curve was tested by comparing the period and configuration of the total *calculated* dead recovery curve with the *actual* dead recovery curve. (In the previous analysis of the spawning sequence, the results of tagged samples were not applied to the total population because a check curve of the actual frequency of spawning of the total population was impossible to obtain.) The actual and calculated death curves of female sockeye are given in Figure 22. They differed in size because the actual dead recovery included only about 70 per cent of the run; the remaining 30 per cent was removed by predators or lost in deep holes and log jams. The dates marked with an asterisk were days of incomplete dead recovery when the total length of the stream was not patrolled. The two curves were considered to be sufficiently alike in dates of recovery and general configuration to confirm the methods used in calculating a total dead recovery of female sockeye.

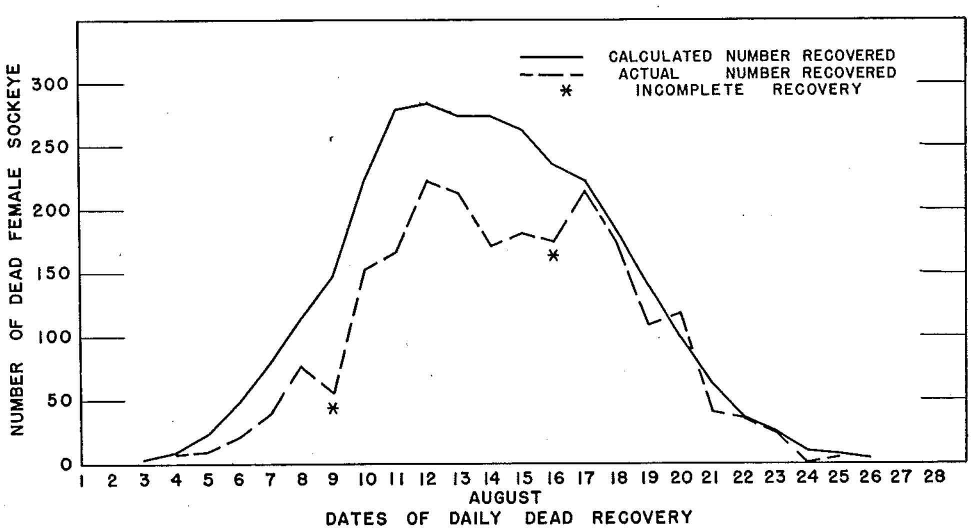

FIGURE 22. Comparison of the total, calculated and actual daily numbers of dead female sockeye in Forfar Creek, 1952.

TABLE 39

TIME OF DEATH OF TAGGED MALE SOCKEYE RECORDED AS DAYS-OUT FROM DATES OF ARRIVAL TO DATES OF DEAD RECOVERY OF "FRESH," 100 PER CENT SPAWNED SOCKEYE FORFAR CREEK, 1952.

Dates of Tagging	Number of Days-Out to Recovery																			Daily Mean No. of Days	Number Recovered
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
July 29							1	2	2		2	6	3	1	1					12.3	18
30						1	1		1	6	7	19	13	3	2	1	2		1	13.2	57
31						1		2	4	7	13	7	7	1	4	1				12.4	47
August 1					1	1	1	5	4	5	4	4	1		2					11.0	28
2						1		2				1	1		1					11.3	6
3					1					1		1		1						11.3	4
4								1	3	1		3	2	2		1				12.6	13
5			1							1			1							9.7	3
6	1								1			1		1						10.0	4
7																					
8						2														7.0	2
9																					
10								1	3		1				1					11.2	6
11							1	2		1	2	1								10.6	7
12						2	1													7.3	3
13																					
14																					
15								1												9.0	1

TABLE 40

FREQUENCY DISTRIBUTION OF THE DAYS-OUT TO DEATH (LIFE-SPAN) OF EARLY, CENTRAL AND LATE GROUPS OF MALE SOCKEYE IN FORFAR CREEK, 1952

Days-Out to Death	Numbers of Dead Groups A	B	C	ABC	Percentages Groups A	B	C
1							
2		1		1		4.17	
3		0		0		0	
4		1		1		4.17	
5		0		0		0	
6	1	1		2	.64	4.17	
7	4	0	4	8	2.56	0	21.05
8	3	0	2	5	1.92	0	10.54
9	11	1	4	16	7.05	4.17	21.05
10	11	4	3	18	7.05	16.66	15.79
11	18	3	1	22	11.54	12.50	5.26
12	26	0	3	29	16.67	0	15.79
13	37	5	1	43	23.72	20.83	5.26
14	25	3	0	28	16.03	12.50	0
15	5	4	0	9	3.21	16.66	0
16	10	0	1	11	6.41	0	5.26
17	2	1		3	1.28	4.17	
18	2			2	1.28		
19	0			0	0		
20	1			1	.64		
Totals	156	24	19	199	100.00	100.00	100.00
Means	12.39	11.58	9.79	12.05			
Standard Deviation	2.34	3.61	2.42	2.64			

Death Schedule of Male Sockeye, 1952

The same method of analysis was applied to male sockeye in Forfar Creek. The daily frequency distributions of the days-out to death are shown in Table 39. The males died over a wide range of time, the extremes for the season being 2 and 20 days. The season mean of 12.05 days was nearly identical with that of 12.73 days for females but a study of the means of different arrival groups revealed considerable differences between the two sexes *within* the total period of dying. The standard deviation from the mean was 2.64 for males as compared with 3.34 for females, indicating that less mixing occurred among the males. Whereas the early females lived about 14 days compared with 8 days for late entries, the early males lived 12 to 13 days and the late entries 9 to 10 days. Differences in the times of dying between male and female sockeye is important in measuring sex ratios and will be considered in more detail following the discussion of males alone.

After the tagged males were divided into three groups, representing early, central and late arrivals, the frequency distributions of the life-spans of each group were calculated and given in Table 40. These counts were then converted to percentages and applied to the daily weir counts of all males to provide the calculated group frequency curves shown in Figure 23. Group A, having a mean of 12.39 days, remained fairly distinct from Group B which had a similar mean

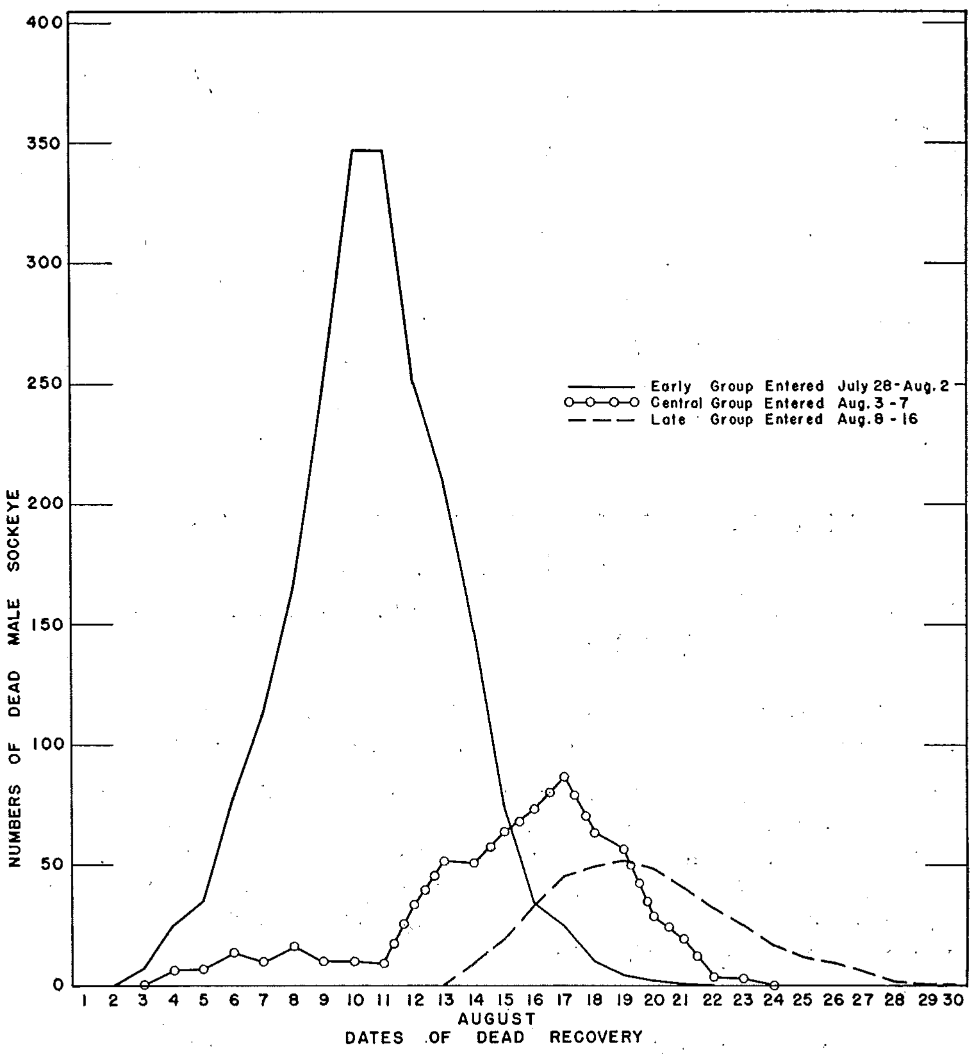

FIGURE 23. Calculated frequency distributions and dates of death of early, central and late groups of male sockeye in Forfar Creek, 1952.

of 11.58. The mixing between these two groups was caused almost entirely by the dispersions apparent for any one day. Group C on the other hand was largely mixed with B not only because of daily dispersion but because of a shorter mean life-span of 9.79 days.

The degree of mixing of the males shown in Figure 23 may be compared with that of females in Figure 21. Considerable group overlap was evident for both sexes, but whereas the females formed an almost completely mixed mass of dead carcasses, the males remained fairly distinct for the early and central groups although the late male sockeye mixed considerably with the central arrivals.

The reliability of the method of calculating the dates of death of all male sockeye was also tested by comparing the *calculated* death curve with the *actual*

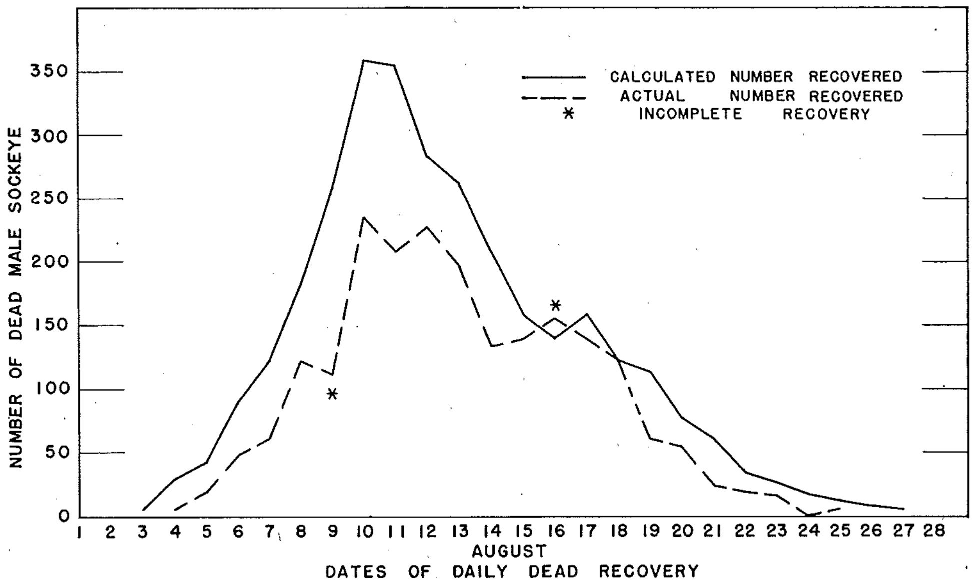

FIGURE 24. Comparison of the total, calculated and actual daily numbers of dead male sockeye in Forfar Creek, 1952.

male dead recovery in Figure 24. As was found for females, the two curves were sufficiently similar in shape and date to verify the method of analysis used.

Additional data measuring the life-spans of male and female sockeye were available for the 1946 run within the spawning grounds of Forfar Creek. A comparison of the days-out to time of death from dates of tagging at a weir for the years 1946 and 1952 indicated that the pattern of shorter life for later arrivals was substantially the same for both years and probably is the normal case for Forfar Creek sockeye (Table 41).

TABLE 41

A COMPARISON OF THE LIFE-SPANS OF EARLY, CENTRAL AND LATE GROUPS OF SOCKEYE IN FORFAR CREEK FOR THE YEARS 1946 AND 1952

		Early Arrivals Days	Central Arrivals Days	Late Arrivals Days
Females	1946	12.7	12.0	8.8
	1952	13.6	11.8	8.4
Males	1946	12.0	11.3	9.7
	1952	12.4	11.6	9.8

Comparisons of the Daily Abundance Curves and Sex Ratios Between the Dates of Arrival and Death

To illustrate the results of variations in life-span, the curves of daily abundance at the times of arrival and death for the separate sexes are provided

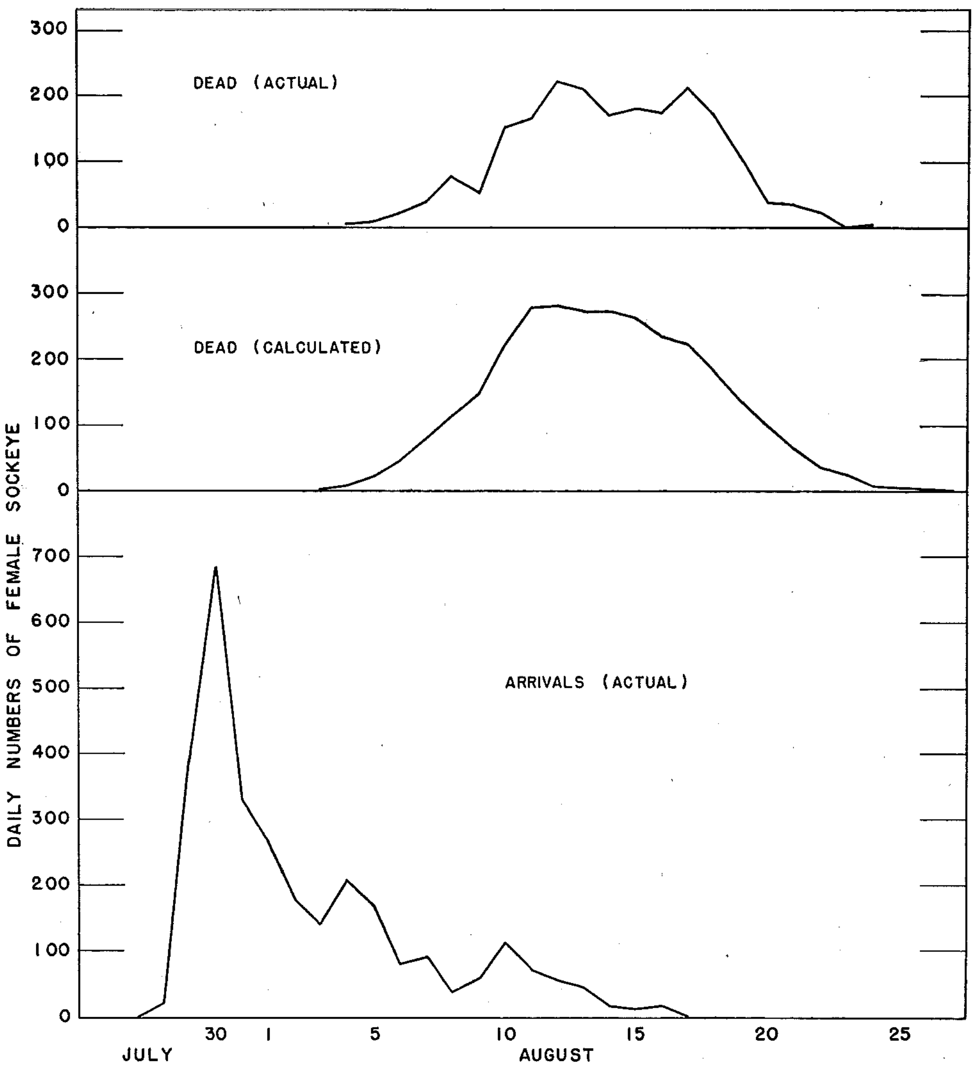

FIGURE 25. Comparison of the frequency curves of daily abundance of female sockeye at the times of arrival and death at Forfar Creek, 1952.

in Figures 25 and 26. Considering females first, it may be seen from Figure 25 that the daily arrival curve had a peak of abundance at the start of the run with a slow subsequent decline; whereas, the curves of dead female sockeye obtained from both the calculated and the actual dead recoveries showed a peak abundance at the centre of the recovery period and differed markedly from the original arrival curve. Equivalent curves were plotted for males in Figure 26 and the results were nearly identical although there was more similarity between the arrival and death curves for the males than was apparent for the females. In either case, it was apparent that because of extensive mixing the daily abundance of dead carcasses was not a reliable measure of the daily numbers of sockeye that

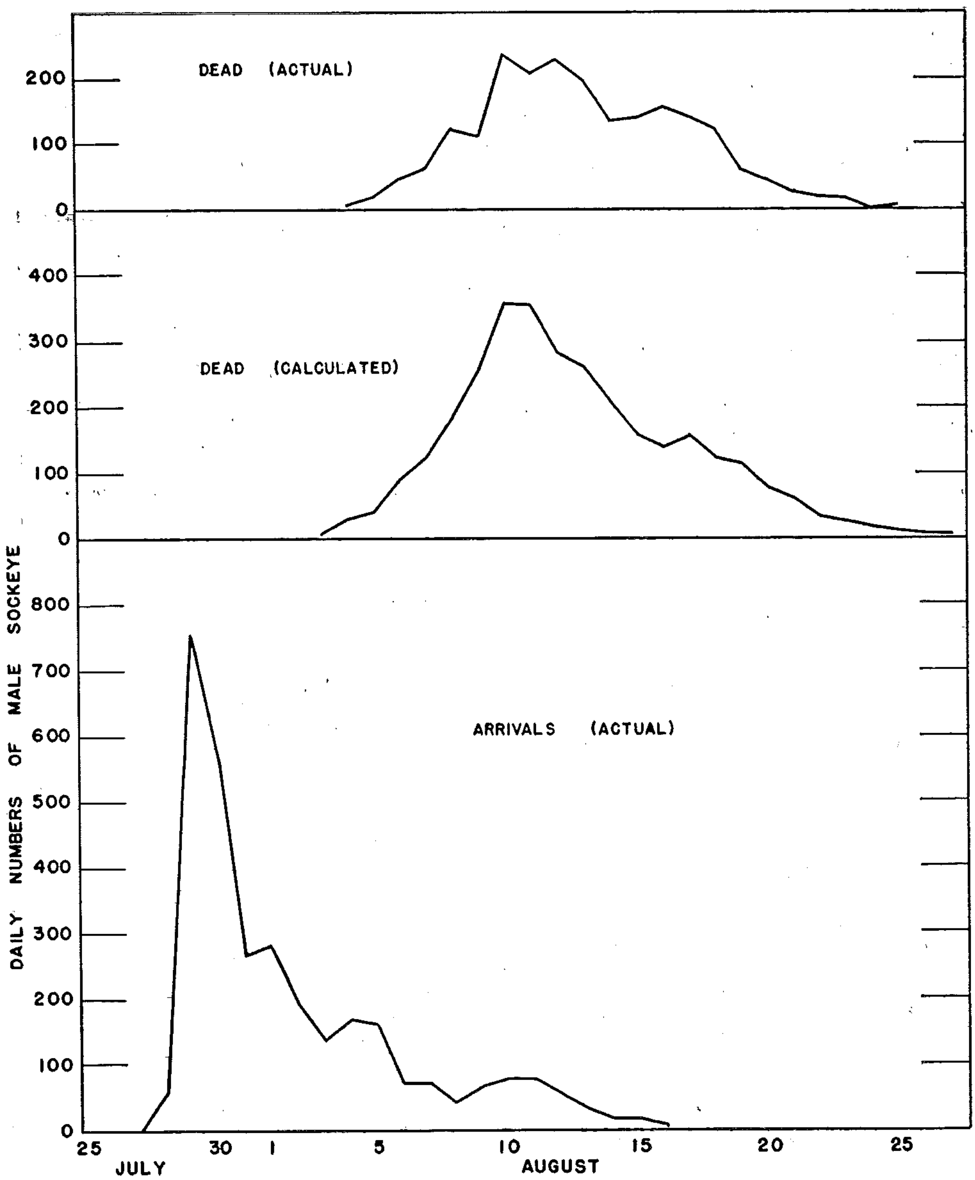

FIGURE 26. Comparison of the frequency curves of daily abundance of male sockeye at the times of arrival and death at Forfar Creek, 1952.

entered Forfar Creek unless considerable correction was made for differences in the times of death of the two sexes.

Sex ratios at the times of arrival and death were calculated and shown in Table 42 and Figure 27. The totals for the season showed an almost 50-50 ratio for sockeye arriving in Forfar Creek. (The reduction of the percentage of males to 48.75 in the actual dead recovery indicated that more males than females were missed in the dead recovery.) While knowledge of the sex ratio for the season

TABLE 42

SEX RATIOS AT FORFAR CREEK SHOWN AS PERCENTAGE OF MALES DURING ARRIVAL AND AT DEATH, 1952

(Percentages from counts smoothed by moving averages of 3)

Date	Arrival (Weir Count)	Dead (Calculated)	Dead (Actual)
July 28	66.6		
29	55.7		
30	53.0		
31	46.3		
August 1	48.9		
2	49.0		
3	46.3	75.0*	
4	45.1	70.2*	
5	46.7	67.5	66.7
6	47.4	63.0	64.0
7	47.3	62.0	62.6
8	48.9	62.0	62.8
9	47.3	62.0	62.2
10	48.4	59.9	59.7
11	48.0	55.9	55.3
12	50.0	52.0	51.2
13	48.6	47.4	47.9
14	50.0*	43.5	45.4
15	51.7*	39.4	44.8
16	52.9*	38.5	43.3
17		37.6	42.6
18		41.9	39.6
19		42.6	37.1
20		45.7	34.6
21		46.8	33.7
22		50.0	37.7
23		53.1*	40.0
24		57.5*	
25		66.7*	
26		69.2*	
Seasonal Sex Ratio	50.76	50.65	48.75

* Sample less than 50.

has some value for annual comparisons of one stream or for comparing various streams it is not necessarily of value in assessing the success of spawning throughout the various periods of a run. Daily sex ratios are much more significant in relation to the success of reproduction.

The daily sex ratios of *arriving* sockeye showed a predominance of males for three days at the start of the run; henceforth, until the end of the run, the number of males was slightly less than that of females. By contrast, the sex ratios at the time of *death* showed a preponderance of males throughout the *first half* of the run and a reciprocal lack of males in the *second half*. Calculation of the daily sex ratio of live sockeye in Forfar Creek from the relative proportions of males and females in the daily dead recovery would only be correct if special provisions were made for the difference in the life-spans of the two sexes.

The study of the order of dying of male and female sockeye at Forfar Creek in 1952 demonstrated that considerable mixing of the day-populations defined on arrival at the spawning grounds had occurred by the time the sockeye were taken in the dead recovery. The shorter life-spans of late arriving sockeye in

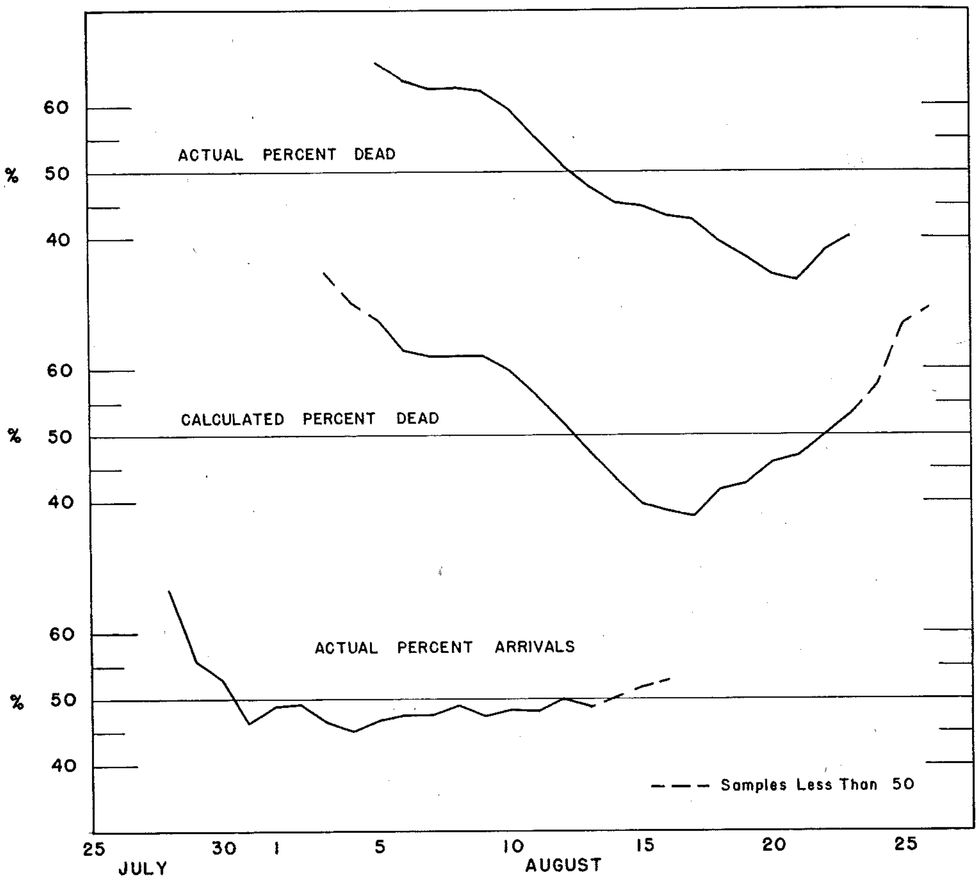

FIGURE 27. Comparison of the sex ratios (shown as per cent males) at the times of arrival and death at Forfar Creek, 1952.

1946 would also result in mixing equal to that of 1952. As the days-out to spawning were found to be relatively constant throughout the run, the greater differences between individuals from date of arrival to date of death must have occurred after completion of spawning; that is, *mixing occurred during the spent period.* Among the females, the early-arriving sockeye remained alive about eight days after spawning was complete; whereas, spent females from the last of the run remained alive for only one day. This variation in the life-period of spent females may have some biological significance although proof of such has not been attempted in this report.

ADAMS RIVER

At present the largest spawning populations of sockeye in the Fraser River watershed are located in the Adams River and knowledge of the order of dying of sockeye in this system would be particularly valuable. Unlike Forfar Creek, the Adams River is so large and swift that it has been impossible to construct a counting fence for determining the daily arrival curve. Instead, live counts of

TABLE 43

THE MEAN LIFE-SPANS OF EARLY, CENTRAL AND LATE GROUPS OF FEMALE AND MALE SOCKEYE IN ADAMS RIVER IN 1946, 1950, 1951 AND 1954. ("FRESH" DEAD ONLY.)

FEMALE SOCKEYE Dates of Entry into Adams River					
Year	Oct. 1 - 8	Oct. 9 - 14	Oct. 15 - 22	Oct. 23 - 28	Oct. 1 - 28
1946	—	16.3 (63)	15.4 (99)	12.7 (80)	14.8 days
1950	20.1 (9)	18.0 (43)	19.5 (25)	—	18.7 days
1951	18.0 (7)	16.9 (27)	14.1 (15)	—	16.2 days
1954	18.0 (58)	18.4 (201)	17.7 (101)	—	18.1 days

MALE SOCKEYE Dates of Entry into Adams River					
Year	Oct. 1 - 8	Oct. 9 - 14	Oct. 15 - 22	Oct. 23 - 28	Oct. 1 - 28
1946	—	19.2 (64)	17.1 (56)	14.8 (20)	17.7 days
1950	20.4 (31)	19.3 (41)	19.3 (20)	—	19.5 days
1951	17.6 (17)	18.0 (9)	18.0 (3)	—	17.8 days
1954	19.8 (94)	19.7 (268)	18.5 (91)	—	19.5 days

migrating sockeye have been made of a portion of the run each day from a bridge located about two miles upstream from the river mouth. It was impossible to determine the sexes from live counts taken in this way, therefore data on the daily variations in sex ratio could only be obtained from the dead recovery. It was thought that an analysis of the order of dying might indicate that the daily abundance of dead could provide an alternative, and possibly a better, index of the arrival pattern.

To establish whether the dead recovery data could represent the arrival counts and sex ratios, it was necessary to measure the life-span of sockeye within the spawning grounds. Tabulations were made of the days-out from dates of tagging of sockeye caught with a beach seine at the mouth of Adams River to dates of recovery of "fresh" dead, tagged carcasses. From these, mean life-spans for early, central and late groups were obtained and are listed for each sex in Table 43 for the years 1946, 1950, 1951 and 1954.

Mean Life-Spans of Female Sockeye

There was a noticeable variation in the mean length of life of female sockeye on the spawning grounds in different years. In 1950 and 1954 the mean life-spans were 18.7 and 18.1 days respectively; whereas in 1946 and 1951 death occurred after shorter time intervals of 14.8 and 16.2 days. The 1946 data were supported by substantial numbers of recoveries and the shorter life-span appeared to be associated with the late arrival of the run to the spawning grounds. (In this

TABLE 44

TIME OF DEATH OF TAGGED FEMALE SOCKEYE RECORDED AS DAYS-OUT FROM DATES OF ARRIVAL TO DATES OF "FRESH" DEAD RECOVERY IN ADAMS RIVER, 1954

Dates of Tagging	Number of Days-Out to Recovery																						Daily Mean No. of Days	Number Recovered
		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
October	4																								
	5						2	1	3				1	2										17.0	9
	6					3	4	1	1	1		2	1	2				1						16.8	16
	7				1	1	1				1	1	2							1			1	19.2	9
	8					4	1	2		2	4	4			2			2	1	2				18.8	24
	9			2	2	1			5	1	5		2	2	1	1	2	1	4					19.0	29
	10		1	3		2		2	1	4	8		5	1	2	4	1	4	2	1				19.2	41
	11						2	2	6	1	3	4	2	2	3		2			1				18.7	28
	12					2	2	3	5		2	2	1	1	7							1		18.4	26
	13		1		4	1	8	5	3	3	4	5	5		4	1		2			2			17.5	48
	14					5	3		3	4	2	3	2	3	2	1	1							17.6	29
	15					3	1	2	3	2	4	2	7	1	1	3								18.2	29
	16				1			4	2	3		8	2	1	6			1						18.8	28
	17							2			8			2				1						18.5	13
	18					2	4			7	3	1	3											16.7	20
	19																								
	20																								
	21																								
	22	1			1	2		1	5			1												14.6	11

Group	Dates of Arrival	Mean Time of Death	Standard Deviation
Early	October 4 - 8	18.0 days	4.41
Central	October 9 - 14	18.4 days	4.09
Late	October 15 - 22	17.7 days	3.02
Season	October 4 - 22	18.1 days	3.89

instance, the mean life-span may prove to be a practical index of the normality of the timing of the run.) When the relationship between the order of arrival and the order of dying of female sockeye was considered, two different patterns were apparent in the four years. In 1946 there was a progressive reduction in life-spans towards the end of the run ranging from 16.3 to 12.7 days. A similar reduction occurred in 1951 when the mean life-spans throughout the run changed from 18.0 to 14.1 days. By contrast, in both 1950 and 1954, there was no significant change in the life-span of females from the first to the last of the runs; the mean days-out to death for early, central and late arrivals being 20.1, 18.0, and 19.5 days in 1950, and 18.0, 18.4, and 17.7 days in 1954. A possible explanation for the differences in the lengths of life and degrees of consistency for different years at Adams River may be that in 1950 and 1954 the major portions of the runs entered the Fraser River mouth in a period lasting 2.5 to 5 days; whereas in 1946 and 1951, the runs lasted for the usual 30-day period that was required for most earlier runs to other areas.

Mean Life-Spans of Male Sockeye

In each of the four years of 1946, 1950, 1951 and 1954, the male sockeye lived on an average one to two days longer than the females. This difference in life-span was not considered to be sufficient to seriously upset the sex ratio in the dead recovery. The mean life-span of males in both 1950 and 1954 was 19.5 days compared with shorter times of 17.7 and 17.8 in 1946 and 1951 respectively. Consistency in time of death through various parts of the run was apparent for male sockeye in three of the four years studied. Only in 1946 was there any indication that the later male sockeye died more quickly than earlier arrivals.

Daily Analyses of Life-Span in 1954 and 1950

The 1954 Adams run provided a particularly large sample of 813 "fresh" dead tagged recoveries which have been analysed in detail to establish the degree of variation in times of dying for any day or group of days. Tables 44 and 45 show the daily frequency distributions and mean days-out to the recovery of dead male and female sockeye. It was apparent that, even though the daily and group means were fairly consistent throughout the total period of the run, there was still considerable individual variation to time of death for both sexes. The standard deviations of the grouped data provide an assessment of the dispersion about the mean times of death. For females, the standard deviations were 4.41, 4.09 and 3.02 respectively for early, central and late arriving sockeye while that for the total period was 3.89 days. For males, the standard deviations were 3.88, 3.91, 2.30 for the various segments of the run and 3.72 for the total period. The standard deviation values of three to four days at Adams River indicated that some mixing had occurred between the dates of sockeye arrival and death on the spawning grounds; however, it was general throughout all parts of the run.

Even though the standard deviations indicated that some mixing from dates of arrival to death had occurred, the group mean times of death remained fairly constant throughout all parts of the Adams run in 1954 and it was expected

TABLE 45

TIME OF DEATH OF TAGGED MALE SOCKEYE
RECORDED AS DAYS-OUT FROM DATES OF ARRIVAL TO
DATES OF "FRESH" DEAD RECOVERY IN ADAMS RIVER, 1954

Dates of Tagging	Number of Days-Out to Recovery																					Daily Mean No. of Days	Number Recovered
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
October 4								1														17.0	1
5					1	3	2	1			1											16.0	8
6				1	2	2	1	1		3	1	6		1	1		2					19.3	21
7					2	2			5		3		3	1	1			1			1	19.9	19
8				2		1		1	4	10	8		8	5	1		1		2	1	1	20.8	45
9			1		1		6	2	3	6	1	1	1	2	3	1	3	1	1	1		20.4	34
10			2	1	3	1	6	4	3	1	8	7	2	9		5	1	2	2			20.2	57
11	2				1				4	11	6	5	7	1	4	1	2	3				20.7	47
12				2	3	6	6	2	4	4	5	2	2	4	1	5				1		19.0	47
13	1		1		2	7	2	9	4	4	4	1	4	3	3	3				1		18.8	49
14					3	1	4	3	3	3		6	4	4	2			1				19.5	34
15				2			4	4	7	1	7		4	3				1				19.0	33
16			1	1		1	2	3		9	3	5	4									18.9	29
17			1			2	1		6	1	1											17.1	12
18			1					3	1	2	6											18.4	13
19																							
20																							
21																							
22						1	3															15.8	4

Group	Dates of Arrival	Mean Time of Death	Standard Deviation
Early	October 4 - 8	19.8 days	3.88
Central	October 9 - 14	19.7 days	3.91
Late	October 15 - 22	18.5 days	2.30
Season	October 4 - 22	19.5 days	3.72

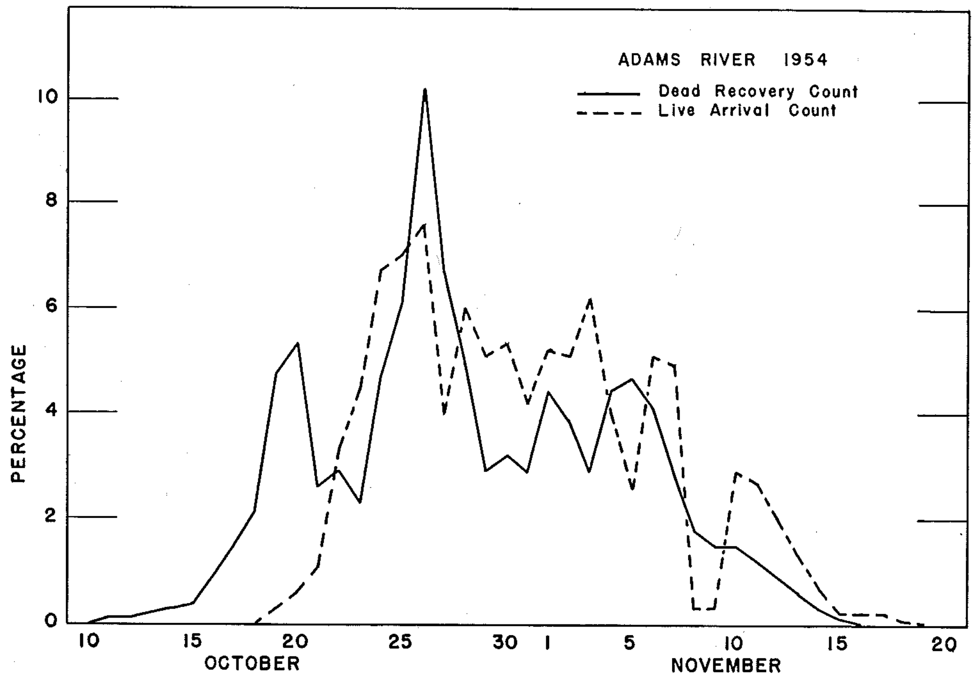

FIGURE 28. Comparison of the percentage frequency curves of daily abundance of sockeye at the times of arrival and death at Adams River, 1954.

that the curves of the daily numbers of dead and the live counts at the Adams River bridge would be quite similar. To test the fit of the arrival and dead recovery data, the daily bridge counts and dead recovery curves were plotted in Figure 28; the arrival curve was offset 19 days—the mean life-span for both sexes combined—to compare with the period of dying. In general, the curve of the dead was similar to the curve of arriving sockeye; the main exception being an early peak of dead on October 19 to 20 that was not present in the arrival counts. Tables 44 and 45 showed that very early male and female sockeye tagged on October 4 and 5 died two to three days sooner than the mean time of death (16-17 days compared with 19). Had these early sockeye also died after 19 days the two curves would have been very nearly the same.

For the 1950 run, data available for 169 "fresh" dead, tagged sockeye are presented in Table 46. Males lived an average of 19.52 days compared with 18.74 days for females so that the sex ratio upon arrival and death must have been very similar. The times of death for both sexes were fairly uniform throughout all parts of the run although more variation was apparent than occurred in 1954; this was indicated by the larger standard deviation values of 4.51 and 4.28 for males and females respectively as compared with 3.72 and 3.89 in 1954. The dispersions from a constant time of death for all individuals would tend to smooth the peaks in the arrival pattern and would also extend the beginning and ends of the run by four to five days; however, it was still thought that the consistency in the daily means would insure that the frequency curve of dead sockeye would represent the arrival

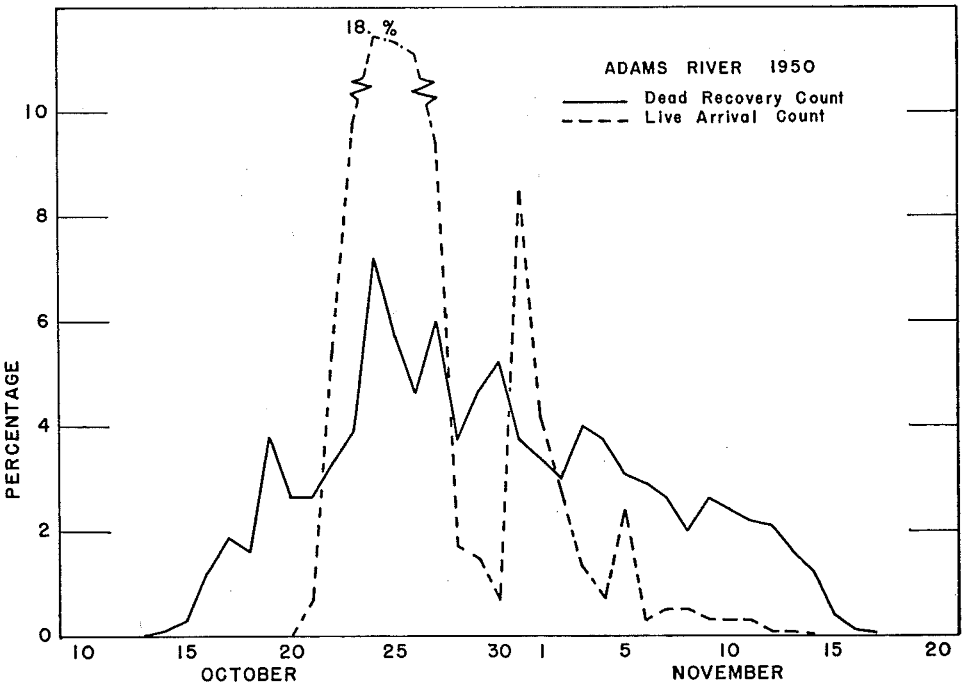

FIGURE 29. Comparison of the percentage frequency curves of daily abundance of sockeye at the times of arrival and death at Adams River, 1950.

TABLE 46

THE DAILY MEAN TIMES OF DEATH OF MALE AND FEMALE SOCKEYE IN THE ADAMS RIVER IN 1950

Dates of Arrival	Males	Females
October 2	18.0 (1)	
3	18.9 (13)	19.0 (2)
4	23.0 (4)	19.3 (3)
5	20.0 (7)	21.0 (2)
6	22.3 (6)	21.5 (2)
7		
8		
9	21.8 (5)	19.3 (7)
10	19.0 (8)	18.7 (11)
11	16.8 (5)	22.5 (2)
12	19.3 (6)	14.8 (10)
13	18.6 (16)	17.9 (11)
14	24.0 (1)	22.0 (2)
15	20.7 (7)	16.7 (3)
16	19.4 (5)	24.8 (4)
17	20.3 (4)	18.6 (7)
18		20.0 (3)
19		
20	16.0 (2)	18.6 (5)
21	14.0 (2)	18.3 (3)
Totals	19.52 (92)	18.74 (77)
Standard Deviation	4.51	4.28

curve almost as well as in 1954. When the two curves were plotted in Figure 29 it was found that they did not agree well either by relative abundance or duration of the run. The early abundance of dead sockeye resulting from the slightly earlier deaths of the first of the run was comparable with 1954 but there was further disagreement in the latter segments of the run. The bridge counts showed a main sharp peak and a second subordinate peak both within a span of about 10 days, whereas the death curve indicated an extended but gradually declining abundance over a period of about 18 days. As the run of 1950 was smaller than that of 1954, it was probable that the late 1950 arrivals found suitable spawning areas in the lower two miles of Adams River below the bridge and so were not seen by the counters on the bridge. If this were true then the frequency curve of dead recoveries would be more representative of the arrival curve than that indicated by the bridge counting.

SUMMARY OF DEAD RECOVERY ANALYSIS

It was concluded from the analysis of the death sequences of sockeye within the spawning grounds, that in no instance was the mixing of the dead complete and except in those cases where there was a definite change in times of death for various segments of the run, as at Forfar Creek, the chronological order was generally maintained. The curve of the abundance of dead and the sex ratio in the dead recovery would therefore be reasonably representative of the abundance pattern and sex ratio of the sockeye upon their arrival at the spawning grounds. At Forfar Creek in 1946 and 1952 and at Adams River in 1946 and 1951, the late-arriving sockeye died sooner after their arrival at the spawning grounds than sockeye which arrived earlier in the run; the shorter life-span of the last of these runs may have affected the spawning efficiency.

COMBINED EFFECT OF MIXING DURING MIGRATION, SPAWNING AND DEATH

In the preceding sections of this report, the degree of chronological consistency maintained by sockeye salmon during their period of migration, spawning and death has been measured. In each instance, some deviation from an exact orderly sequence was evident. During migration to the spawning grounds, deviations were on an average two to three days, and during spawning, further deviations of two to three days occurred. By the date of death, the original chronological order was almost totally lost at Forfar Creek but was reasonably well retained at Adams River in 1950 and 1954. Mixing during the migrations to the spawning grounds and after arrival up to the time of spawning may be especially important in designing commercial gear regulations for selected escapements; and, because the mixing during migration and spawning is additive, an estimate of the combined effect was required. An example of the total deviation to be expected to time of spawning has been calculated in simple form.

It was postulated that, during the Fraser River gillnet closure of July 18, 19 and 20 of 1952, 1,000 sockeye per day escaped to the Bowron weir. At a constant mean travel time of 22 days, these three day-populations would have arrived at the weir on August 9, 10 and 11. However, the recovery of tagged sockeye showed that a constant travel time for all sockeye does not occur; instead, during the 22-day migration, dispersion would take place as noted in Table 15, recapitulated as follows:

.6%	would arrive after 22 days less 5 days or more
1.3%	would arrive after 22 days less 4 days
6.8%	would arrive after 22 days less 3 days
10.6%	would arrive after 22 days less 2 days
24.8%	would arrive after 22 days less 1 day
19.3%	would arrive after 22 days
13.5%	would arrive after 22 days plus 1 day
7.7%	would arrive after 22 days plus 2 days
5.8%	would arrive after 22 days plus 3 days
2.9%	would arrive after 22 days plus 4 days
6.7%	would arrive after 22 days plus 5 days or more

These percentages of dispersion, when applied to the original escapements of 1,000 sockeye per day, would provide the weir counts shown in Table 47. The daily weir counts would be expected to disperse further before the dates of actual spawning were reached. The amount of this dispersion for the Bowron was not known but the dispersion from the mean spawning time at Forfar Creek was given in Table 33:

7.4%	spawned after 3 days
13.1%	spawned after 4 days
12.3%	spawned after 5 days
18.0%	spawned after 6 days
16.4%	spawned after 7 days
10.7%	spawned after 8 days
9.0%	spawned after 9 days
4.9%	spawned after 10 days
3.3%	spawned after 11 days
2.5%	spawned after 12 days
1.6%	spawned after 13 days
.8%	spawned after 14 days

These percentages were applied to each of the newly-calculated Bowron weir counts for August 4 to 16 to obtain the spawning dates. The daily numbers of spawners were summed and the totals are also given in Table 47. It can be seen that the three-day escapement would have been extended to spawn over a 23-day period; however, the bulk of the spawning remained confined to a relatively restricted time-period as follows:

35%	spawned in a 3 day period (Original time period of escapement)
55%	spawned in a 3 day period plus or minus 1 day
70%	spawned in a 3 day period plus or minus 2 days
82%	spawned in a 3 day period plus or minus 3 days

Thus it was calculated that 82 per cent of a population escaping from the Fraser gillnet fishery in three days would eventually spawn during a nine-day period. The results of this example using Bowron sockeye would apply particularly to

TABLE 47

CALCULATED DISPERSION OF THREE THOUSAND SOCKEYE FROM THEIR DATES OF ESCAPEMENT FROM THE COMMERCIAL FISHERY THROUGH THE MIGRATION PERIOD TO DATES OF SPAWNING

Dates of Arrival at Bowron Weir	Escapement Dates July 18	July 19	July 20	Daily Weir Count	Dispersion of Weir Counts to Dates of Spawning	
August 1						
2						
3						
4	6			6		
5	13	6		19		
6	68	13	6	87		
7	106	68	13	187	2	
8	248	106	68	422	9	
9	193	248	106	547	28	
10	135	193	248	576	70	
11	77	135	193	405	138	
12	58	77	135	270	219	
13	29	58	77	164	290	
14	67	29	58	154	340	
15		67	29	96	358	—35% —55% —70% —82%
16			67	67	344	
17					303	
18					253	
19					204	
20					152	
21					110	
22					75	
23					47	
24					27	
25					15	
26					8	
27					5	
28					2	
29					1	
Totals	1,000	1,000	1,000		3,000	

other June and July runs; slightly less precision during migration might be expected for August and September runs which delay prior to or at the completion of their migrations to the spawning grounds.

The pattern of migration and the time required to date of spawning were both sufficiently consistent to warrant the conclusion that sockeye salmon did retain their chronological order from the dates of escapement from the commercial fishing areas to dates of arrival and spawning at the respective spawning grounds. The chronological sequence of dying was not maintained at Forfar Creek in 1946 and 1952 whereas at Adams River, when the run entered the Fraser in a very short time interval and arrived at a normal time for spawning, the sockeye died in the order established at the time of arrival.

SUMMARY

1. The purpose of this report was to determine whether chronological consistency was maintained during the migration, spawning and death of individual runs of Fraser River sockeye. The three phases were considered separately.

2. It was proposed that chronological order was maintained if every individual sockeye of a particular run took exactly the same number of days to migrate to the spawning grounds.

3. The consistency of migration-time was first measured by the days-out of tag returns, and secondly by associating dates of closures of the commercial fishing gear with peaks of arrival of sockeye at the spawning grounds.

4. Prior to the presentation of the tagging results, criteria governing the methods of analysis of the tagging data were established and the following possible sources of error considered.

   (a) When the physical effect of tagging was assessed by recording the relative occurrence of tagged and untagged sockeye in the recovery area, only slight differences of one to two days were indicated. However, subsequent analysis of totally untagged populations showed that the migration times calculated from tag returns were slower to the extent of three to four days in a twenty-day migration.

   (b) The spans of distance and time involved were important factors when the significance of delay caused by tagging was assessed. A delay of one day would introduce a serious percentage error in an analysis of a three to four-day migration but would be much less significant in a thirty-day 750-mile passage.

   (c) To establish reliable rates of migration, the presence or absence of unnatural delays en route had to be considered. Mixing could occur at the location of any delay which caused an accumulation of salmon.

   (d) Tests of male and female sockeye migration times revealed that, for the areas considered, the migration times of the two sexes were so similar that, even though the males and females occurred in varying abundance, it was unnecessary to treat them separately.

   (e) The recovery of tags immediately upon arrival was essential. Counting fences or weirs just below the individual spawning areas offered the best means of recovering tags and data from these were used for most of the tagging analysis.

5. For the Bowron sockeye, Hell's Gate tagging data demonstrated that all parts of the run migrated at almost the same speed. The tagged sockeye required means of 23.23, 21.44, 20.04 and 22.34 days for the respective years of 1945 to 1948 inclusive whereas 17 and 18 days were calculated for the 1951 and 1952 migrations for total runs of untagged sockeye. The latter travel times of 17 and 18 days (33.2 and 31.2 miles per day) were considered to be more accurate.

6. The Early Stuart sockeye migration was analysed by the tagging method in 1945 and by comparing peaks of abundance in 1952 and 1953. Tag returns from Hell's Gate and Bridge River Rapids in 1945 showed a fairly consistent chronological order of migration to the outlet of Stuart Lake but the first part of the run delayed for two to three days before entering the spawning streams. The beginning of the 1952 run showed a delay of six to eight days but in 1953 the counting fence was removed and no delays occurred. The mean rate of migration was 27.5 miles per day in 1945 and 29.8 in 1952 and 1953.

7. An attempt was made to measure the migration sequence of the sockeye runs to the Harrison system but as the necessary criteria for tagging were not fulfilled no positive conclusions were obtained.

8. The daily abundance of sockeye arriving in Quesnel Lake in 1953 illustrated that a substantial escapement was obtained from the peak of the Horsefly run because of a special closure of the commercial fishery and that the order of migration was retained throughout 450 miles of travel. These sockeye entered the Fraser in July and travelled at a speed of 32 miles a day.

9. The Chilko sockeye that entered the Fraser in early August migrated more slowly than other earlier runs. Their speed was 21.5 miles a day. The success of an emergency closure to increase the size of the escapement of the Chilko run in 1952 was shown by the configuration of the escapement curve.

10. The 1952 August run to Stellako migrated at 22.5 miles a day and distinct peaks of abundance at this spawning area were closely associated with closures in the fishery at the mouth of the Fraser River.

11. The 1954 Adams sockeye migration was presented as a special case in which the run was extended; although it took 2.5 days to pass through the mouth of the Fraser, its arrival at the entrance to the spawning grounds was spread over 14 days. A further 8 days elapsed before the last of the run entered the spawning grounds. Apart from periods of delay en route and at the spawning grounds, the Adams sockeye migrated up the Fraser and Thompson Rivers at a rate of 17 miles a day.

12. The consistency of chronological order during migration was most precise for the June and July sockeye runs which travelled at a rapid rate of 30 to 32 miles a day. August runs travelled more slowly at 22 miles a day and some delayed a considerable time at the entrance to the spawning grounds. The latest runs, which entered the Fraser in September after having delayed at the river mouth prior to migration, travelled even more slowly at 17 miles a day.

13. It was necessary to extend the study of chronological order beyond the dates of arrival on the spawning grounds as it was conceivable that extensive mixing could occur even there before spawning took place. Special experiments were designed whereby the order of spawning was related to the dates of arrival of the sockeye into the stream.

14. Sockeye were grouped as early, central or late according to their time of arrival and two methods of recording their spawning times were used. According to daily visual counts, spawning was at a peak after 6.7, 7.5 and 7.8 days for early, central and late sockeye respectively: manual examinations gave means of 5.5, 7.4 and 7.7 days. Separate peaks of spawning were associated with the three groups of early, central and late-arriving sockeye showing that the chronological order had been retained to the times of spawning.

15. The chronological order of death was studied to determine whether the daily abundance curve and sex ratio of the dead was representative of the daily abundance curve and sex ratio on arrival on the spawning grounds.

16. At Forfar Creek in 1952 the order of dying was measured by tag-returns which showed that there was a progressive reduction in the mean life-span of females from 13.59 to 8.40 days, the season mean being 12.73. Males were more consistent, only varying from 12.39 to 9.79 days. Their average of 12.05 days was similar to that of the female sockeye. This variation in times of death throughout the duration of the run combined with the daily dispersions from the means so affected the daily numbers of dead that their frequency curve no longer reflected the shape of the arrival curve. Similarly, daily sex-ratios in the dead recovery did not correspond with daily arrival ratios.

17. The analysis of the time of death of Adams River sockeye for the years 1946, 1950, 1951 and 1954, revealed that the life-spans were shorter at the ends of the runs in 1946 and 1951 when the migration into the Fraser was extended over the usual 30-day period whereas in 1950 and 1954, when the main concentration of Adams sockeye entered the river in 2.5 to 5 days, the mean times of death on the spawning grounds were the same throughout all parts of the run. In 1950 and 1954 the daily numbers and the sex ratio of the dead sockeye at Adams River was considered a reliable measure of the daily numbers and sex ratio that occurred at the time of arrival.

18. As the effect of dispersion during migration and spawning was additive, a hypothetical three-day escapement of 1,000 sockeye per day was traced from the Fraser River commercial fishery and converted to spawners on the spawning grounds of the Bowron River. After allowing for variations from constant mean migration and spawning times it was calculated that eighty-two per cent of the original three-day population would eventually spawn within a nine-day period.

19. Consideration of all of the main runs of Fraser River sockeye showed that, in general, the duration of the run and the order of the component sockeye was unchanged from the time of escapement from the commercial fishery at the river mouth to the time of spawning, even though many hundreds of miles were travelled before the spawning grounds were reached.

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