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 X

CHARACTER OF THE MIGRATION OF PINK SALMON TO FRASER RIVER SPAWNING GROUNDS IN 1957

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ABSTRACT

The characteristics of the migration of pink salmon to the Fraser River system in 1957 are related, in this study, to the requirements of scientific management of the fisheries. Analysis of catch, tagging and escapement data indicated that populations of pink salmon spawning in particular streams, which are defined as races of pink salmon, could be classified into early and late migrating groups. It is suggested that fishing mortality rates affecting the early groups were greatest, particularly in Fraser River fishing areas. Pink salmon delayed off the mouth of the Fraser River for a considerable period but migration through the remaining fishing areas was rapid and direct. Two early migrating races moved directly to respective spawning areas but the two major late races delayed in the lower sections of their spawning streams for considerable periods. Although chronological order of migration was maintained from passage through Fraser River commercial areas until death, races which delayed lost chronology but regained it during residence on the spawning grounds. Total escapement of pink salmon to the Fraser River system was enumerated by the use of tagged individuals. The abundance of fish spawning in individual streams was estimated by a number of methods. Sources of error affecting each method are discussed.

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INTRODUCTION

A protocol amending the Sockeye Salmon Fisheries Convention to provide for the conservation of the pink salmon fisheries of the Fraser River system was ratified by the governments of Canada and the United States on July 3, 1957. According to the terms of this protocol the responsibilities of the International Pacific Salmon Fisheries Commission were extended to include the management of these pink salmon fisheries.

Since ratifications were exchanged just prior to the appearance of the run in commercial fishing areas, it was possible to initiate a number of investigational programs. Detailed catch statistics were collected from the various fishing areas of Convention waters. Tagging was carried out to determine the times of passage of individual runs through the commercial fishing areas located in the lower Fraser River. The total escapement and the escapements of individual races were enumerated. Information on the migration rate of fish in the Fraser River were collected. Times of arrival, spawning and dying were determined for fish on individual spawning grounds.

The primary purpose of this report is to present the results obtained from these programs, to appraise methods of investigation and to evaluate results as aids in management.

TIMES OF PASSAGE OF PINK SALMON MIGRATING THROUGH THE COMMERCIAL FISHERIES

Analysis of data collected during the 1957 season showed that the pink salmon run to the Fraser River system was composed of a number of individual spawning populations. Since, as shown by Pritchard (1939) the majority of pink salmon return to the parent stream it seemed probable that these populations could be called races. This term was applied to sockeye by Thompson (1945) and was defined by Royal (1953) as follows: "The term 'race' as used here assumes that homogeneity exists in each population spawning in a particular area which is subject to the same general reproductive environment". As defined above, the term race will be applied in this report to a population of pink salmon spawning in a particular area. The race will bear the name of the area.

The assumption that the run is composed of a number of self-perpetuating populations is an important management concept. Since a race is assumed to be discrete, it is possible for each race to be differently affected. For this reason, management regulations must be designed, as far as possible, for application to individual races or groups of similarly affected races. It is important, therefore, to identify the races composing the commercial catch and to determine the abundance of each race in both catch and escapement. It is obvious that knowledge is required regarding the times of passage of individual races or groups of similarly timed races through each of the various fisheries.

In this section data are presented pertaining to the identification of races in the escapement, to the timing of the total escapement, and to the timing of individual racial escapements. An assessment of the effect of the river fishery on the escapement is made and the shape of the migration curve of the run entering the river is considered. The times of passage of defined segments of the run through the fisheries in Convention waters other than the Fraser River are discussed.

Timing of the Escapement

Time of escapement of individual races was determined from data obtained from a tagging and recovery program. Tags were placed on migrating pink salmon captured by beach seines. One site which was fished throughout the run was located at the Glen Valley bar on the left bank of the Fraser nine miles below Mission Bridge, which marks the upper limit of the commercial fishery. The other fishing site was located five miles further upstream at the Silverdale bar, also on the left bank and was fished by an additional seine during the peak of the run. Tags were recovered from dead spawned fish examined throughout the period of dying on the individual spawning grounds of the Fraser River system (FIGURE 1). These recoveries (TABLE 1) were weighted in proportion to the daily average number of hauls made with the seines at the tagging sites. The average of 7.5 was obtained by summing the daily number of hauls and dividing by the number of days of tagging. The total number of beach seine hauls made was 249 and tagging was conducted for a total of 33 days (TABLE 1). Weighting of recoveries to fishing effort was attained by adjusting actual recoveries to the number that would have been made from a fishing effort of 7.5 hauls. Compared with Glen Valley, a slightly different portion of the run was sampled at Silverdale. This fact necessitated additional adjustments to recoveries made from tags applied during the period September 13 to 17 inclusive, when tagging was conducted at Silverdale. Recoveries shown in TABLE 1 have been corrected for this difference in fishing efficiency. As an example of the corrections applied, on September 15, 1514 fish were tagged and 146 tags were recovered. If 7.5 hauls had been made instead of the actual 10, recoveries would have been reduced to 109.6. Since catch per haul at Silverdale was 1.59 per cent less than at Glen Valley, total recoveries required an upward adjustment from 109.6 to 111.3. It is logical to assume that these adjustments resulted in recoveries being proportional to a constant fishing effort. Any daily changes in the number of recoveries were the result of variations in catch, not in tagging effort. The further assumption was made that these weighted daily recoveries, when corrected to the rate of sampling which applied to each spawning stream, were representative of the daily number of fish migrating past the fishing sites.

Tagging was not conducted during the periods September 2 to 5 inclusive and September 10 to 12 inclusive because commercial fishing was allowed in the area. It was unlikely that any significant escapement could have occurred

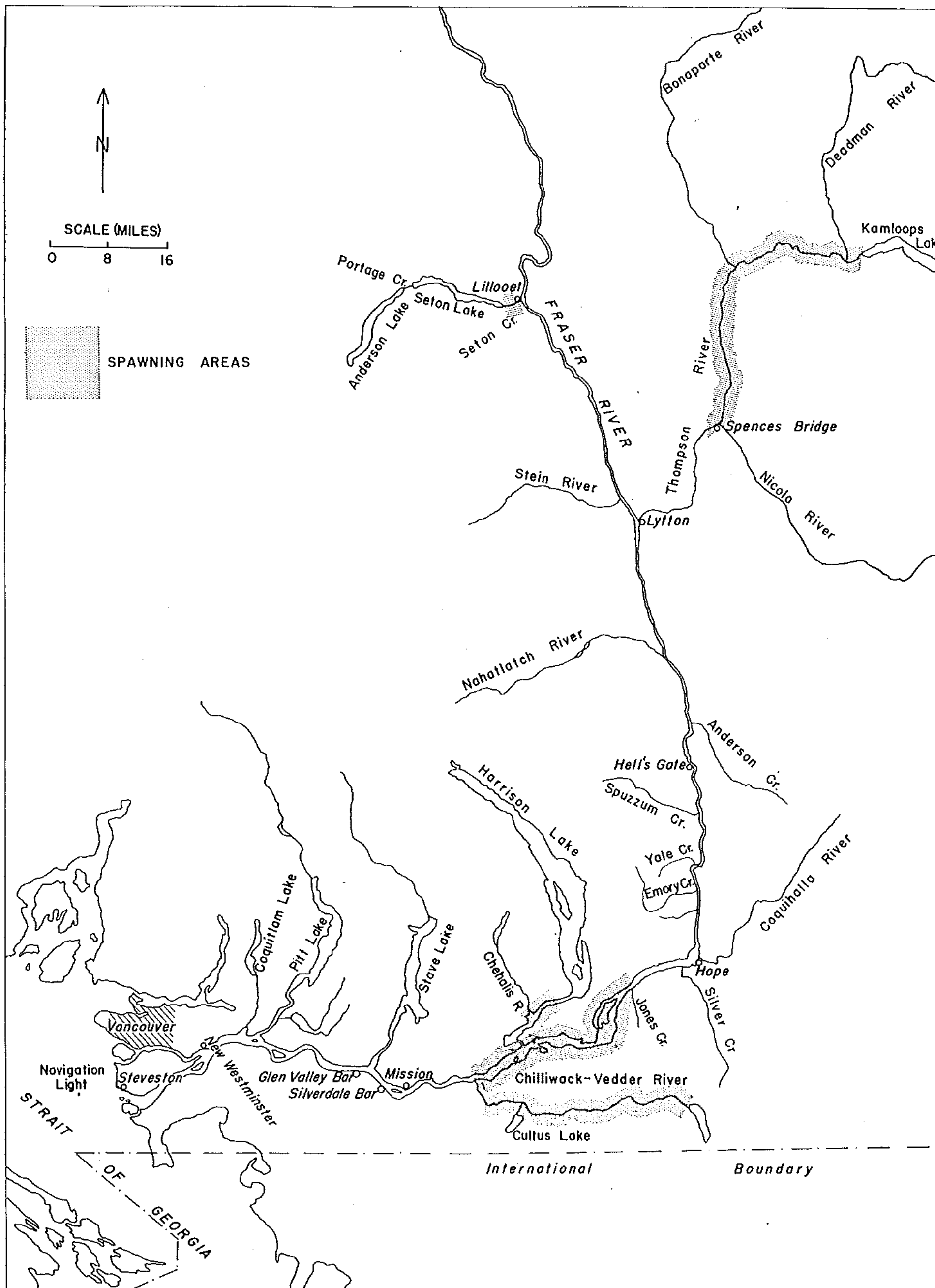

FIGURE 1—Principal pink salmon spawning areas of the Fraser River system.

TABLE 1—Numbers of pink salmon tagged at the Glen Valley and Silverdale fishing sites and the number of tags recovered (weighted to the average daily number of hauls) in the spawning areas in 1957.

DATE OF TAGGING	NUMBER TAGGED	NUMBER OF HAULS	WEIGHTED NUMBER OF RECOVERIES						
			Harrison River	Vedder River	Fraser River	Seton Creek	Thompson River	Misc. Streams	Total
Aug. 31	41	6	0	0	0	0	0	1.3	1.3
Sept. 1	63	6	0	0	6.3	0	0	1.3	7.6
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	195	7	0	0	5.4	4.3	2.2	2.2	14.1
7	416	7	1.1	0	22.5	5.4	4.3	5.4	38.7
8	447	6	0	0	15.0	17.5	7.5	2.5	42.5
9	548	4	0	0	24.4	13.1	11.3	11.3	60.1
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	252	17	0	0	5.4	2.9	2.5	0	10.8
14	1277	10	0.7	1.1	36.1	13.7	16.5	6.3	74.4
15	1514	10	0	3.4	44.8	30.8	23.2	9.1	111.3
16	1560	8	16.2	6.2	54.0	30.7	30.7	8.2	146.0
17	1520	7	17.5	10.1	55.1	20.9	15.7	5.9	125.2
18	279	6	10.9	2.4	9.7	4.8	6.1	2.4	36.3
19	34	7	1.1	0	0	0	0	1.1	2.2
20	70	9	0	1.7	0.8	5.0	0	0	7.5
21	177	9	3.3	1.7	5.8	8.3	4.2	0.8	24.1
22	171	8	3.5	0.9	3.5	1.8	2.6	0.9	13.2
23	244	8	9.7	1.9	7.5	2.8	5.6	0	27.5
24	329	8	4.7	5.5	11.3	4.7	3.8	3.8	33.8
25	331	8	16.5	4.6	8.3	8.3	3.7	0.9	42.3
26	594	6	36.6	17.0	15.9	12.2	10.1	2.5	94.3
27	372	7	24.2	13.7	7.4	2.1	5.2	3.2	55.8
28	262	8	11.9	11.9	10.6	2.7	2.7	2.7	42.5
29	95	7	12.8	5.3	4.3	0	1.1	1.1	24.6
30	189	9	12.9	6.1	2.5	0.6	0	1.2	23.3
Oct. 1	204	8	23.5	6.0	1.8	0	0	0.6	31.9
2	421	6	55.7	23.8	2.0	0	0	1.0	82.5
3	455	7	27.5	57.2	4.3	0	0	0.2	89.2
4	78	8	14.1	1.4	0.5	0	0	0	16.0
5	227	8	29.5	4.5	2.7	0	0	1.8	38.5
6	298	7	26.0	34.7	0	0	0	1.4	62.1
7	184	7	2.4	26.1	4.8	0	0	0	33.3
8	32	6	0	2.5	0	0	0	0	2.5
9	31	4	0	3.8	0	0	0	0	3.8
Totals	12910	249	362.3	253.5	372.7	192.6	159.0	79.1	1419.2

during these two periods because the efficiency of the fishery is so high that relatively few fish escape during the fishing periods to reach the "Above Pattullo Bridge" area. Many years of experience have shown, that on the first day of fishing after a closure, catches of sockeye are good in the Above Bridge area but decline abruptly on succeeding days. The reason for good catches on the first day is that escaping fish are available for capture in the Above Bridge area but on the second and subsequent days there is very little recruitment from the "Below Pattullo Bridge" area because the intense fishery allows little escapement. It has been stated (Royal, 1953) that the Fraser River gill net fishery can take 98 per cent of the available sockeye salmon. It seems probable that a similar situation applies to pink salmon.

Catches of pink salmon in the Fraser River areas are shown in TABLE 2. On September 2 almost 14,000 pink salmon were caught in the Above Bridge area; however the catch declined to about 2,400 on September 3 and to less than 1,200 on September 4. After the next closed period, the catch was high on the first day of fishing (September 10) but dropped from 27,000 to about 7,000 on the second day. The Below Bridge catches followed a very different pattern. During the fishing period September 2 to 4 inclusive the catch on the first day was lower than catches on the two succeeding days. During the

TABLE 2—Catches from the commercial fishing areas of the Fraser River system, 1957.

DATE	ABOVE PATTULLO BRIDGE		BELOW PATTULLO BRIDGE	
	Units	Fish	Units	Fish
Sept. 1				
2	278	13,918	904	68,373
3	122	2,445	805	96,674
4	66	1,156	765	73,134
5				
6				
7				
8				
9				
10	320	27,367	1,021	68,294
11	142	7,323	823	76,831
12				
13				
14				
15				
16				

next fishing period the first day's catch was lower than the second day's catch. These results indicated that Above and Below Bridge catches varied for different reasons. The size of the Below Bridge catch depends on the number of fish accumulating at the mouth of the river and on the number of fish entering the river. Catches in the Above Bridge area depend entirely on escapement from the Below Bridge fishery. Immediately after a closed period catches were good but thereafter depended on the limited escapement from the Below Bridge fishery.

It can be concluded that escapement during periods when fishing was conducted in the Below Bridge area was negligible. Since this fishery operated during the two periods when tagging was not conducted, it can also be concluded that escapement was negligible during these periods and recov-

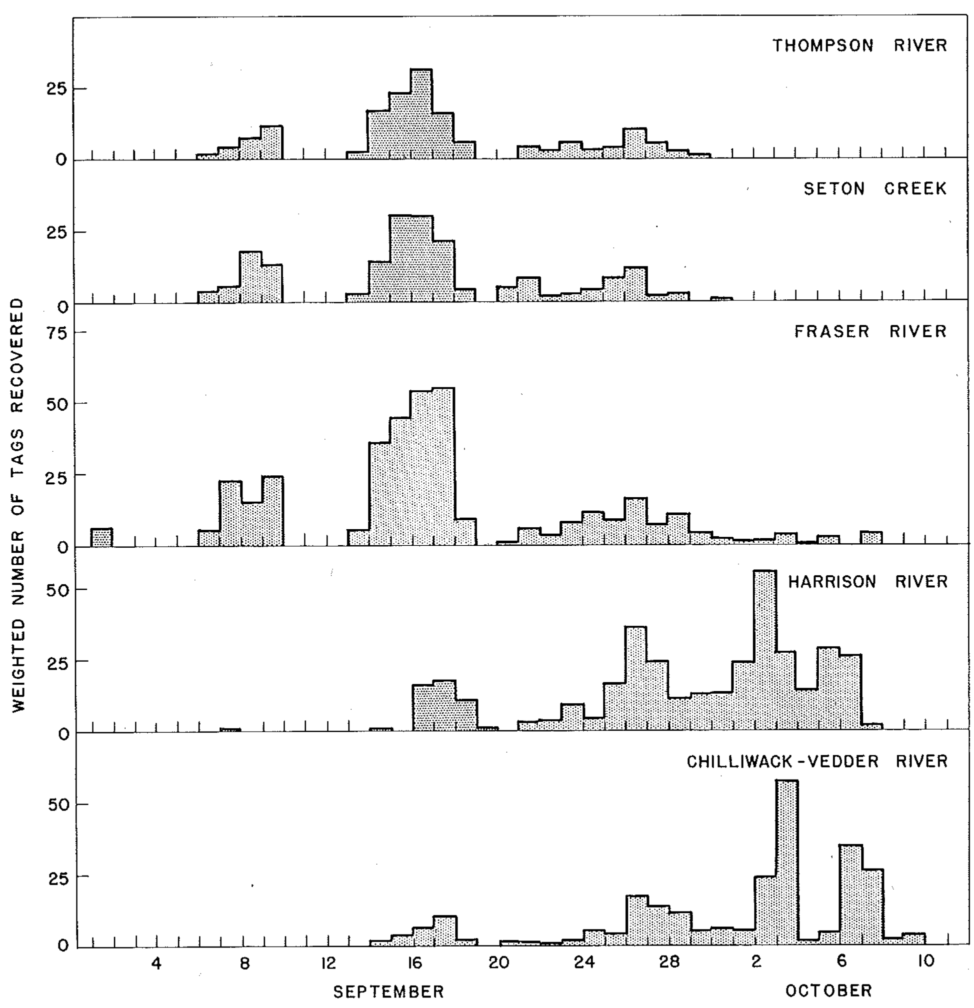

FIGURE 2—Times of passage of five major races of pink salmon through the 1957 Fraser River gill net fishery.

eries of tags, weighted to constant fishing effort, made from each major spawning area when plotted according to date of tagging (FIGURE 2) represented the migration curve of the particular race at the upstream limit of the fishery.

The five races, according to their periods of passage and peaks of passage, could be divided into two groups. The Thompson River, Seton Creek and Fraser races (FIGURE 2) were early. Fish of these races first appeared in significant numbers in the commercial fishing areas of the Lower Fraser during the first week of September and the great majority migrated upstream during the period September 14 to 17 inclusive. Very few pink salmon destined for the Thompson, Fraser and Seton spawning grounds were available in the lower river after the first of October. Fish of the two late races, the Harrison River race and the Chilliwack-Vedder race; were not present in the tagging area in significant numbers until after the middle of September (FIGURE 2). According to weighted tag recoveries eighty per cent of the

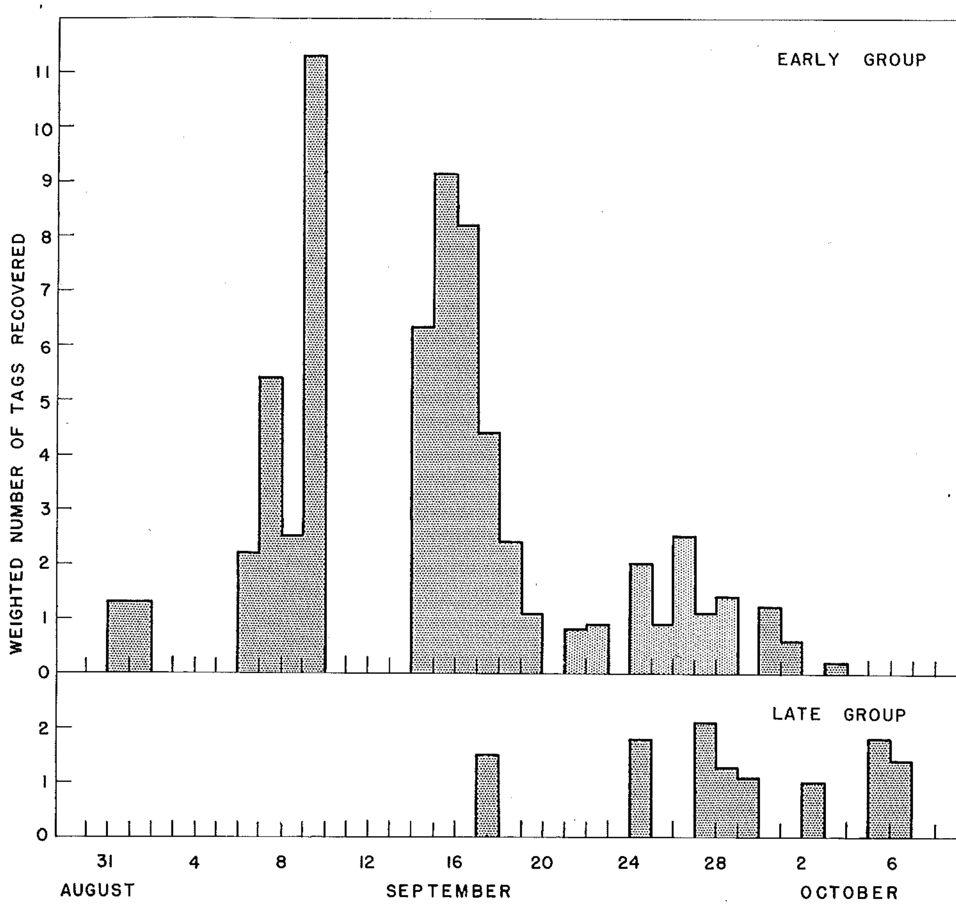

FIGURE 3—Times of passage in 1957 of early and late groups of minor races of pink salmon through the Fraser River gill net fishery.

early run had escaped the fishery by September 23 and an almost equal portion, eighty-four per cent, of late migrating fish was yet to escape. Apparently this date was most suitable for arbitrarily separating early and late segments of the escapement. Fish of the late races were still abundant during the first week of October. The bulk of the Harrison fish passed through between September 26 and October 6. The Chilliwack-Vedder race appeared to be later, with an apparent peak of escapement during the first week of October.

Small numbers of pink salmon migrate to numerous other streams in the Fraser River system. Tags recovered from individual streams were too few to use to determine times of passage; however, on the basis of differences in peak spawning (International Pacific Salmon Fisheries Commission, 1957), these races were classified into early and late groups as in the case of the

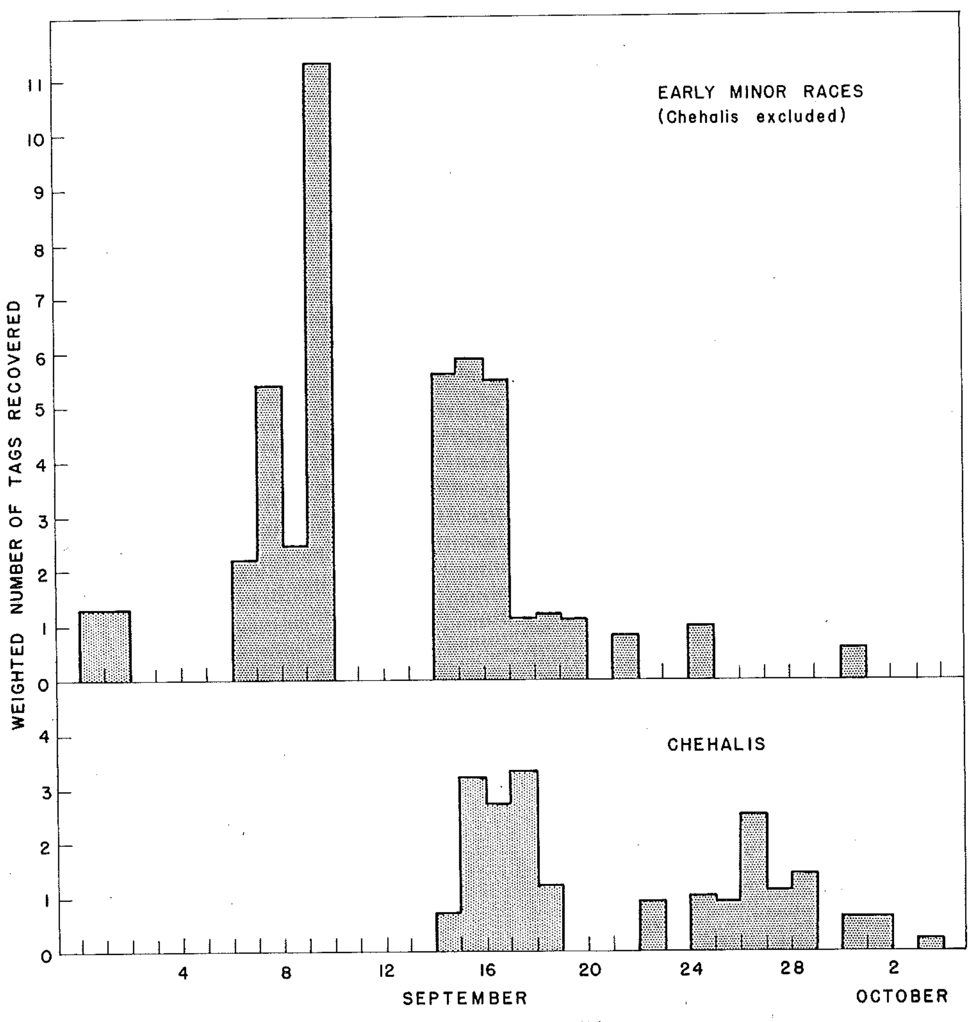

FIGURE 4—Times of passage of the Chehalis race and other minor early races in 1957 through the Fraser River gill net fishery.

major races. Streams belonging to the early group from which tags were recovered were: Chehalis River, Jones Creek, Lorenzetti Creek, Silver Creek, Coquihalla River, Anderson Creek, Nicola River, Bonaparte River, Deadman Creek and Portage Creek. Recoveries were also made from the following late run streams: Whonnock Creek, Stave River and Weaver Creek. These early and late recoveries are shown in FIGURE 3, plotted according to date of tagging.

Recoveries from small late run populations were too few to indicate a peak or peaks of passage but it will be noted that all recoveries were made after September 16. The peak of passage of the early group appeared to be earlier than the peaks of passage of the major early races (FIGURE 2). This was particularly notable when recoveries from the Chehalis race were removed from the totals. Times of passage of Chehalis and remaining minor races are shown in FIGURE 4.

It can be seen that the peak of passage of these minor races (excluding the Chehalis) occurred on or shortly after September 9 whereas the major early races (FIGURE 2) peaked during the period September 14 to 17 inclusive. Although the Chehalis race was classified as early, it will be noted that late tags were recovered. Additional information in the future may show that the timing of this race is intermediate to early and late groups.

Effects of the River Fishery on the Timing of the Escapement

For reasons given by Royal (1953), which will be discussed in a later section, it was considered desirable to obtain the major part of the escapement from the peak of each racial migration. It has been shown that the run was composed of early and late segments, each of which was made up of races which had similar timing. It is evident in this situation that by obtaining escapement from the peak of the early segment and from the peak of the late segment this requirement would be fulfilled for most if not all the individual races. However, the effects of the intervening river fishery could have modified the escapement migration so that the peak escapement was not composed of the same group of fish as the peak of the run as it entered the river.

The daily number of fish escaping the fishery, shown in TABLE 3, was obtained by apportioning the total escapement on a daily basis. This total escapement was calculated by a method discussed in a following section. The apportionment was accomplished by using total tag recoveries arranged by date of tagging. To be used for this purpose these recovery data required adjustment. The first adjustment, as previously discussed, was to account for variations in fishing effort and availability at the tagging sites. Adjusted values are shown in TABLE 1. Since individual racial abundance varied, it would be expected that most tags would be recovered from the most abundant races; however rates of tag recovery varied greatly from stream to stream. (The method for determining these rates of recovery will be discussed in a later section.) If the rate of recovery pertaining to an abundant run was low, too few tags would be recovered in proportion to the abundance of the run.

To make all recoveries proportional to racial abundance totals shown in TABLE 1 for each major race and the miscellaneous races combined were divided by the pertinent rates of recovery. Daily values were summed to obtain the daily total weighted number of tags. In turn, these daily totals were summed to obtain a season weighted total. Each daily total was then expressed as a percentage of the season total. The total escapement to the Fraser River system was then apportioned on the basis of these daily percentage recoveries.

Catch and escapement data presented in TABLE 3 and FIGURE 5 indicate that most of the catch made in the Lower Fraser came considerably earlier than the peak of escapement. Peak catches were made on September 3 and 10. Largest catches were made during the period September 2 to September 12 inclusive, whereas peak escapement of the early segment occurred during the

TABLE 3—Calculated total daily escapements past the tagging sites and daily catches of pink salmon in the Fraser River fishery.

Date	Catch	Escapement	Date	Catch	Escapement
Aug. 31		488	Sept. 20		7,315
Sept. 1		23,651	21		38,525
2	82,291		22		23,651
3	99,119		23		51,447
4	74,290		24		63,639
5			25		64,614
6		26,577	26		107,915
7		95,824	27		81,682
8		77,293	28		73,636
9		120,106	29		38,525
10	95,661		30		31,454
11	84,154		Oct. 1		39,500
12			2		97,250
13		25,602	3		116,693
14		172,285	4		18,775
15		227,390	5		48,034
16		294,930	6		71,929
17	68,804	272,742	7		52,666
18	30,893	64,370	8		3,170
19		1,707	9		4,877
			Total	535,212	2,438,262

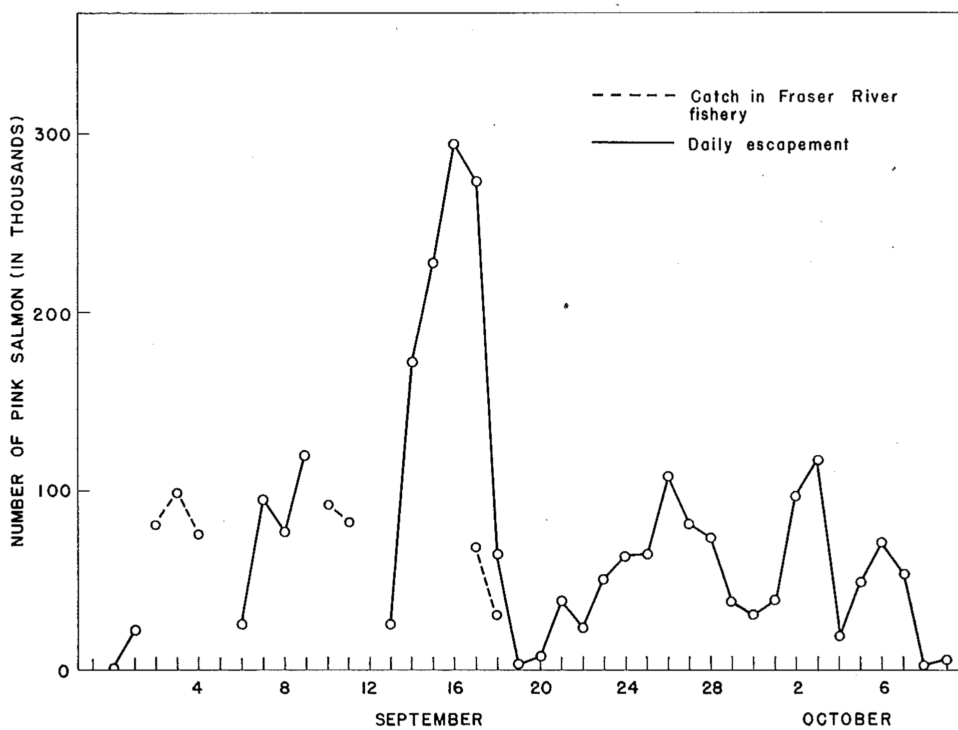

FIGURE 5—Daily catches and daily escapements in 1957 from the Fraser River gill net fishery.

period September 14 to 17 inclusive and the late segment in late September and early October. It was possible then that the effects of the fishery could have modified the shape of the escapement curve and could perhaps have caused the peak escapement to occur relatively later than the peak of abundance of fish entering the river. However, calculated escapements during the peak were so much larger than the catches which preceded and followed that it is logical to conclude that these relatively minor catches could not have greatly affected the timing or size of the peak. It can be concluded, therefore, that the peak of the escapement represented the peak of abundance of the early segment entering the river. Since fishing was terminated before pink salmon belonging to the late group were abundant in the escapement, it can also be concluded that the peak of the late escapement represented the peak of the late segment entering the river. Data pertaining to the effects of other Convention waters fisheries on the timing and size of the peak were not available.

Timing of the Run in Convention Waters Fisheries Other than the Fraser

Information was not obtained which could be used to determine the times of passage of the individual races through other Convention waters fisheries (FIGURE 6); however daily catches made in these areas, when plotted (FIGURE 7), showed a peak of abundance in each area. In this section, data are examined which indicate, in terms of early and late groups of races, the composition of these peaks of abundance.

Incidental to tagging of other species, the Fisheries Research Board of Canada and the Washington State Department of Fisheries tagged pink salmon during the summer of 1957 at sites located near the entrance to the Strait of Juan de Fuca (FIGURE 6). The results of this incidental tagging program were made available to the International Pacific Salmon Fisheries Commission. Recoveries on the spawning grounds of the Fraser River system were relatively numerous because of the intensive search for all tags conducted by the International Pacific Salmon Fisheries Commission. Recoveries of these Juan de Fuca tags made on the spawning grounds of the Fraser River system are presented in FIGURE 8 plotted according to date of tagging.

It will be noted that tag recoveries in early run streams were few and scattered for reasons not yet explained by the tagging investigators; however 50 per cent of early run recoveries were made from fish tagged prior to August 31 whereas only 8.3 per cent of recoveries from late spawning races were made from fish tagged prior to this date. Since 47 per cent of the 1941 pink salmon captured and tagged were tagged prior to August 31 it might be expected that more late run fish would have been captured and tagged prior to this date had they been present in the Juan de Fuca fishing area. From this it can be concluded that fish belonging to the early group were present

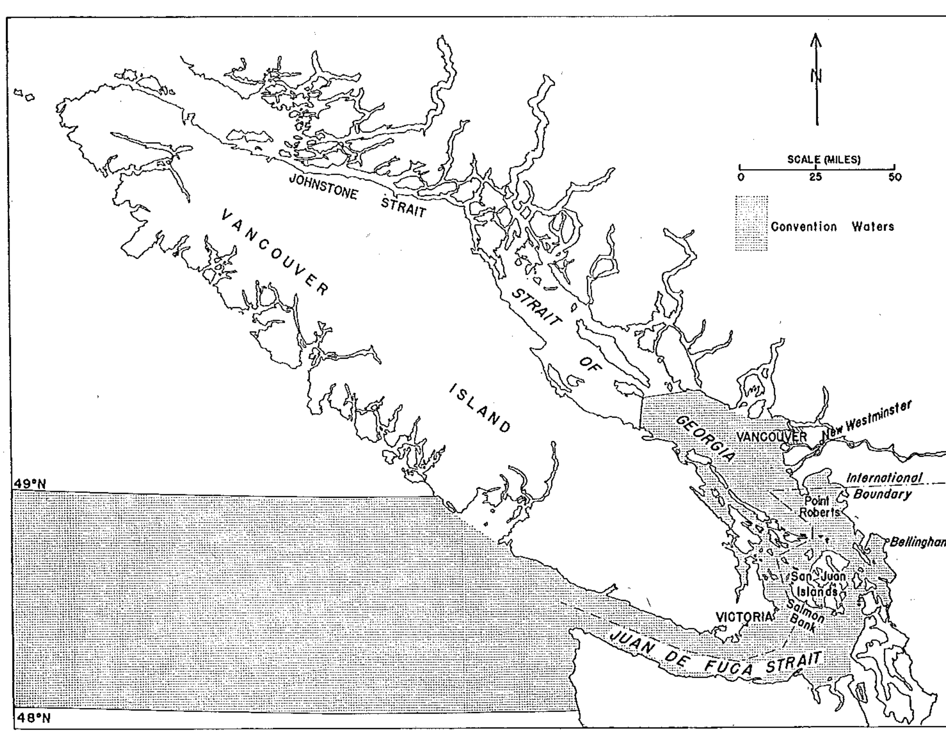

FIGURE 6—Extent of Convention waters.

in the Strait of Juan de Fuca before fish of the late group and that the bulk of catches made before August 31 were composed of fish belonging to the early migrating races. Since the largest part of the total catch was made in the area prior to this date it can be concluded that most of the catch was composed of fish of the early group.

These tagging and recovery data also suggest that chronological order of migration was maintained. In general the fish were recovered on the spawning grounds in the sequence in which they were tagged at the Strait of Juan de Fuca.

Since few late group fish were present in the Strait of Juan de Fuca fishing area prior to September 1, it was concluded that any peak catches made in the area prior to this date would be composed mainly of fish belonging to the early migrating races of the Fraser River system. Thus as the fish progress from the most distant fishery to those located near the native streams

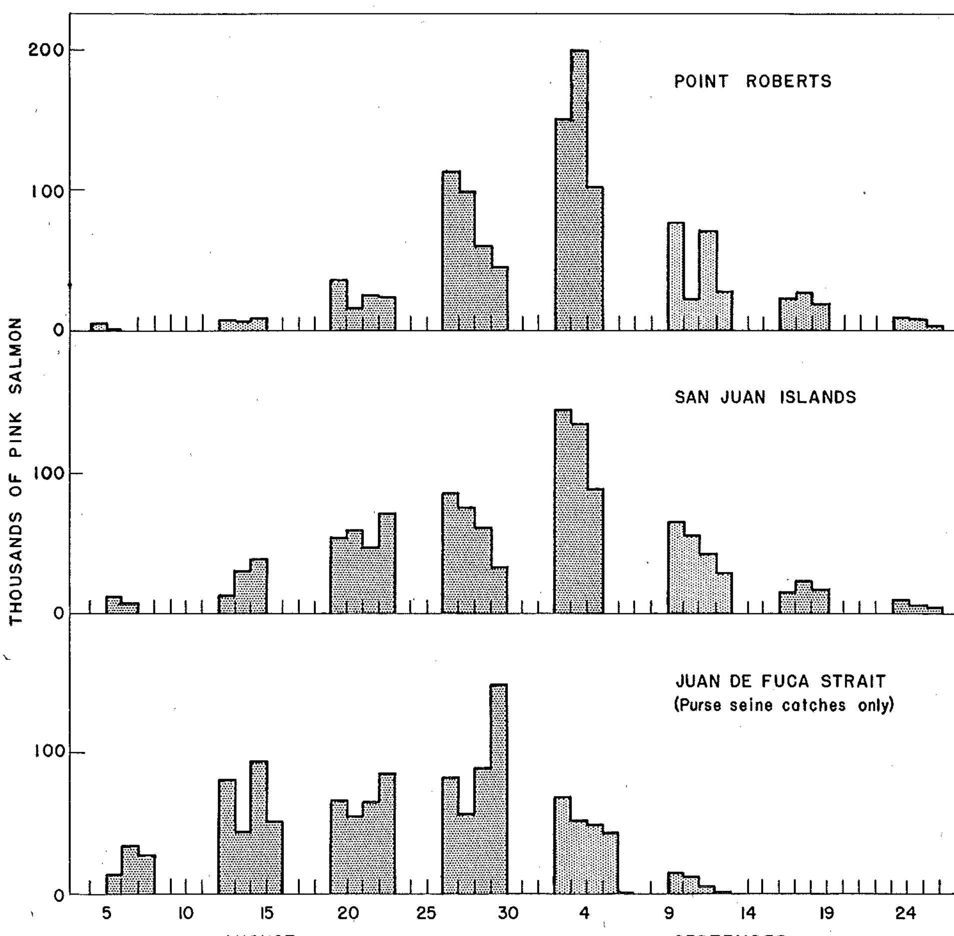

FIGURE 7—Daily catches of pink salmon in 1957 in the Point Roberts, San Juan Islands, and Strait of Juan de Fuca areas.

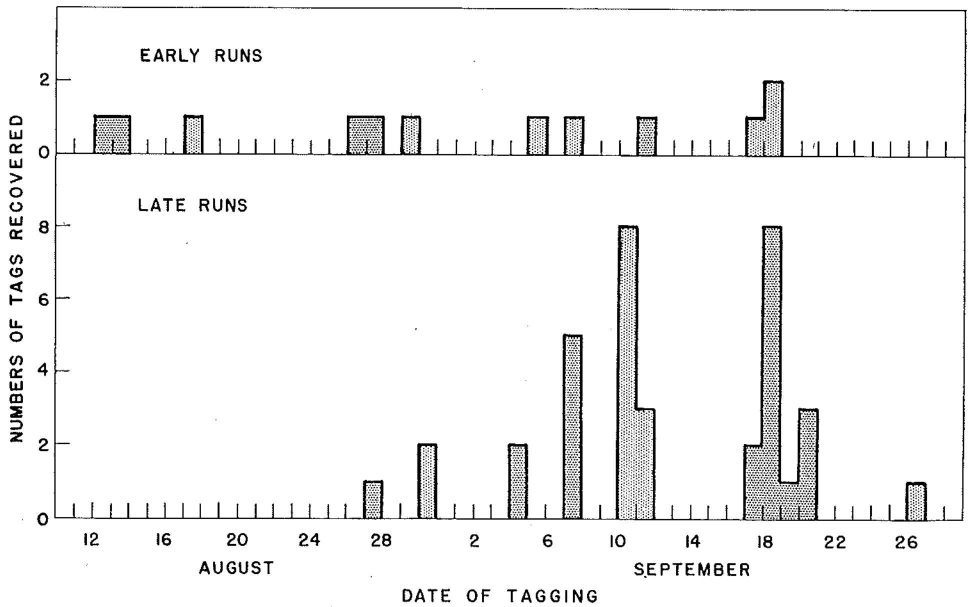

FIGURE 8—Stream recoveries of tags applied in the Strait of Juan de Fuca in 1957 (streams classified as early or late and tags arranged by date of tagging.

peaks of abundance of catches should progress accordingly. It is reasonable to conclude that the peak of abundance of the late run in the San Juan Islands fishery and the Point Roberts fishery must have occurred after the first week of September since early group fish were abundant in the Straits fishery until the end of August and it would take approximately a week for these fish to reach the inshore areas (see subsequent discussions). If so, peak catches during or before the first week of September in all fishing areas must have been composed largely of early run fish.

From the catch data presented in FIGURE 7, providing catches were representative of abundance, the peak of the early run was present in the Strait of Juan de Fuca fishery about August 29, in the San Juan Islands fishery about September 2 and at Point Roberts about September 3. It can also be concluded that catches of pink salmon made in Convention waters fisheries were largely composed of fish belonging to early migrating races of Fraser River pink salmon. These conclusions are subject to an important error. The inclusion of non-Fraser fish in the catches may have affected the shape of the curves and therefore the interpretation of the data. Until quantitative data on the racial composition of catches are available this source of error cannot be eliminated.

INTENSITY OF THE FRASER RIVER FISHERY

Knowledge of the effect of a fishery makes it possible to formulate suitable management regulations. For example, the percentage of available fish taken by a fishery can be used to design necessary regulations.

The percentage of fish taken by each Convention waters fishery other than the Fraser could not be determined because non-Fraser fish were present in the catches in unknown quantities. All that could be concluded, subject to the assumptions made in the previous section, was that the bulk of the catch was made from the early races of Fraser River pink salmon. More data were available pertaining to fishing mortalities which occurred in the Fraser River commercial fishery.

By summing catches and the appropriate escapements, estimates were made of fishing mortalities in the Fraser River commercial fishing areas (District I) as applied to the total run and to the early and late segments. The total Fraser River catch was 918,311 pink salmon. The estimated escapement to all streams of the Fraser system for the same period was 2,438,262; therefore the total run as it entered the Fraser River commercial fisheries was 3,356,573 and the fishing mortality rate was 27.4 per cent.

Mortalities affecting both early and late segments of the run during this period were estimated by determining the total run and the number of early and late fish composing this total run which had been taken in the fisheries up to the time fishing ceased on September 20. As shown in TABLE 3, daily escapements were calculated from tag recoveries on the spawning grounds. To obtain needed additional information, each spawning ground was classified as early or late. On this basis daily escapements were assigned. It was found that 5.9 per cent of the escapement up to and including September 20 was composed of late run fish. It was then assumed that 5.9 per cent of the catch made up to and including this date was also fish belonging to the late races. This catch was added to the total late run escapement. Incidental catches of pink salmon were made in October when the fishing areas were reopened. These catches were assumed to be composed entirely of fish belonging to late races and therefore were also added to the total late run escapement. The fishing mortality rate affecting this estimate of the total late run was obtained from these data. Fishing mortality affecting the early races was also derived in a similar manner from catch and escapement data (TABLE 4).

TABLE 4—Extent of fishing mortalities on early and late segments of the 1957 pink salmon run.

Run	Catch	Escapement	Total Run	Fishing Mortality
Early	855,445	1,624,964	2,480,409	34.5
Late	62,866	813,298	876,164	7.2

The most serious source of error is the assumption that the percentages of early and late run fish in the escapement are the same in the catches. Some of the catch was made off the mouth of the river on delaying fish, a proportion of which undoubtedly belonged to late races. It is possible that this proportion was higher than in the escapements up to the time fishing ceased on September 20. If this occurred, the estimated mortality on late run fish was somewhat low. Even so it can be concluded the fishing mortality on the late races was much lower than on the early runs.

RATES OF MIGRATION AND PERIODS OF DELAY

The rate of progress of groups of pink salmon through fishing areas and to spawning grounds is of importance in management. Slowly moving or delaying fish may be subject to fishing in an area for a longer time than more rapidly progressing fish and therefore may be subject to a higher fishing mortality. Conversely fish continually on the move may pass through a fishing area more rapidly and thus are subjected to a lower fishing mortality. In fresh water above the fishery, changes in migration rate may result from delay below obstructions. It is obviously important to separate the effect of these physical obstructions from natural delays.

Catch data collected in 1957 were used to estimate the rate of movement between individual Convention water fishing areas other than the Fraser areas. From the mouth of the river to the upper limit of commercial fishing and from this boundary to the spawning grounds, data regarding rates of migration were available from tagging and enumeration programs.

Migration Through Commercial Fishing Areas of Convention Waters Other than the Fraser River

Information regarding migration rates of pink salmon through fishing areas up to the mouth of the Fraser has been presented by Pritchard and DeLacy (1944) and DeLacy and Neave (1948). These authors conclude, from the results of tagging experiments, that the migration rate of pink salmon from Sooke to Salmon Bank and thence to Point Roberts was relatively uniform but that fish delayed for a considerable period off the mouth of the Fraser River.

In the following section differences in the date of occurrence of peaks of abundance of pink salmon (FIGURE 9) have been used to estimate the rate of progress of fish of the early group from the most distant fishery (Strait of Juan de Fuca) to the upper limit of the commercial fishery in the Fraser. Daily catches of pink salmon by purse seines are shown for the Strait of Juan de Fuca area. Catches by all gears are shown for the San Juan Islands and Point Roberts areas. Abundance at the upper limit of the commercial fishery is indicated by estimates of total daily escapement. These data indicate that it required 18 days for the fish to travel from the fishery in the Strait of Juan de Fuca to the upper limit of the Fraser River gill net fishery. Other times were 3 days from the Strait of Juan de Fuca area to the San Juan Islands fishery and one day from the San Juan Islands area to the Point Roberts fishery.

In terms of migration speed, the rate from the Strait of Juan de Fuca to the San Juan Islands area was approximately 27.2 miles per day (81.7 miles in 3 days). The indicated rate from the San Juan Islands area to Point Roberts was 62 miles per day. From this area to the upper limit of the Fraser River fishery, the indicated rate was only 4.8 miles per day. Independent estimates presented in a later section have given migration times of two days from the mouth of the river to the tagging sites. If it took thirteen days for fish to

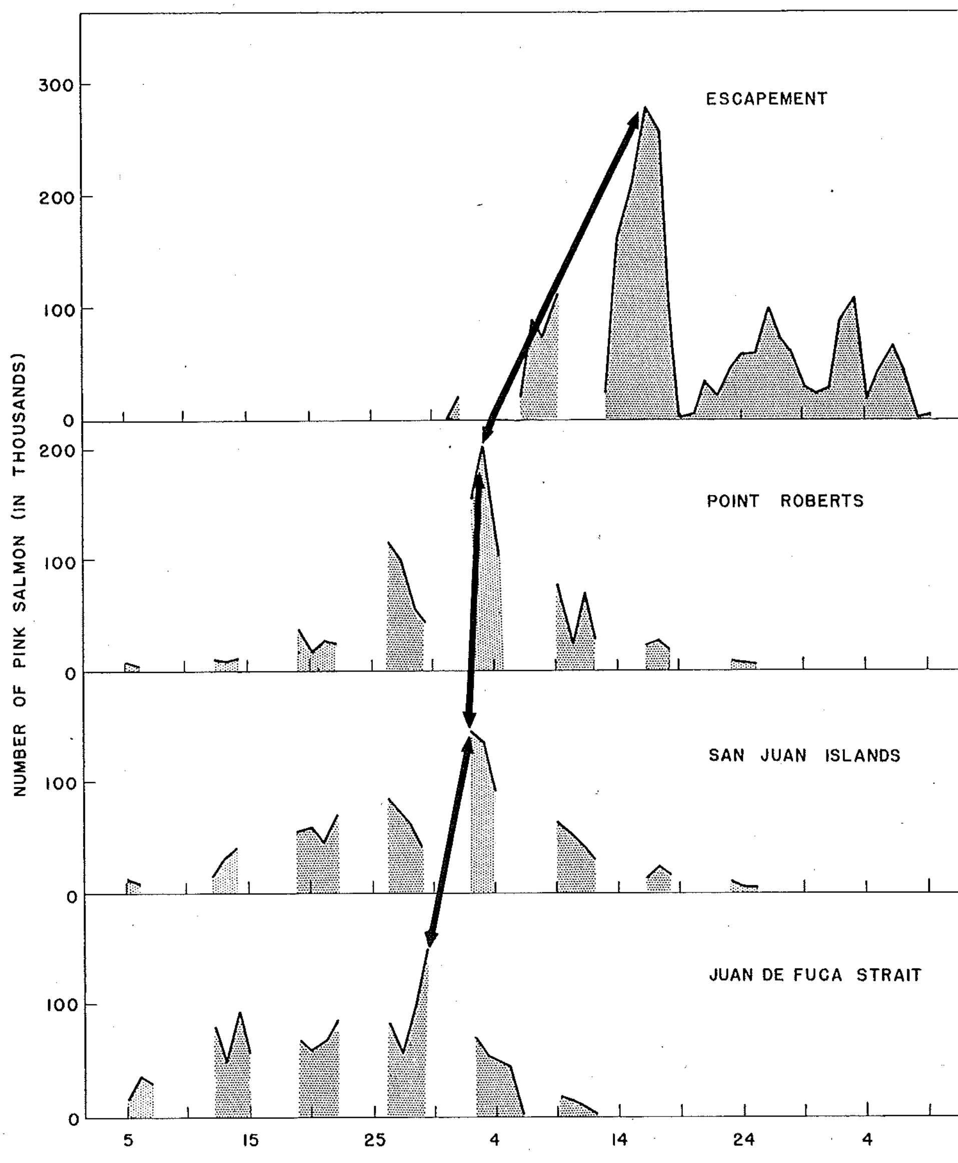

FIGURE 9—Daily seine catches of pink salmon in the Strait of Juan de Fuca, total daily catches of pink salmon in the San Juan Islands and Point Roberts areas and estimated daily escapements from the Fraser River gill net fishery in 1957 (arrows indicate peaks of abundance).

travel from Point Roberts to the Glen Valley area and two of these days were spent migrating from the mouth to the Glen Valley and Silverdale tagging sites, the remaining eleven days must have been spent between Point Roberts and the mouth of the river. Assuming that the peak catch at Point Roberts was representative of migrating fish rather than both migrating and delaying fish, it can be concluded that the delay period between Point Roberts and the mouth of the Fraser during the peak of early run in 1957 was of approximately eleven days duration.

These estimates of migration rate based on catch statistics could have been affected by a number of errors. Verhoeven and Davidoff (MS.) have considered factors affecting the apparent migration rate of tagged sockeye. Some of these errors apply to rates of migration of pink salmon derived from catch data. For instance, catches were reported from a general area whereas distance measurements were made between specific points. If peak catches were predominantly from either extremes of both general fishing areas and measurements were made between central points in each area, rates of migration calculated from these data might be inaccurate.

Another and perhaps more pertinent source of error could have affected the estimate of the period of delay off the mouth of the Fraser. Periodically, delaying pink salmon temporarily move back into the Point Roberts fishing area. Numbers of these "blowbacks" are caught and their catches are added to fish caught while migrating through the area for the first time. A situation can occur in which the true peak of migration through the area can be obscured by these additional catches and an apparent false peak established. The false peak could occur either before or after the true peak.

A source of error affecting estimates of migration rates, particularly over short distances, is the effect of closed seasons. It is possible for the peak of the migration to pass through one fishing area during a closure but be fished in subsequent areas. This results in a false peak in one area being compared to true peaks in succeeding areas.

These estimates of migration rates between fishing areas although not as yet precise are accurate enough to serve as useful aids in management. For example, it is probable that the estimated time taken for fish to travel from San Juan Islands to Point Roberts was too brief; however this estimate was very likely correct within one or two days. The same degree of accuracy applied to the other estimates.

Migration Through the Fishery of the Fraser River

If, after entering the river, fish of both segments of the run delayed while still in the fishery, overfishing with possible adverse effects on both segments might occur. On the other hand if one group of races delayed while the other group did not, or delayed to a lesser degree, an unbalanced and undesirable type of exploitation might take place. For these reasons data were analysed pertaining to rates of migration of both segments of the run during passage from the mouth of the river to the upper limit of the fishery.

RELATIONSHIP OF COMMERCIAL CATCHES TO CATCHES AT THE TAGGING SITES

Previously, evidence was presented indicating that fishing in the river was sufficiently intense to drastically reduce the escapement. Since the tagging sites were located near the upper limit of the commercial fishery it would be expected (presuming that no extended delay occurred) that the effects of the fishery located downstream would be reflected in catches at the tagging sites shortly after the commencement of a closed period. Similarly, it might be expected that catches at the tagging sites would remain high for a period after the commencement of fishing and show a rapid decline as escapement below the tagging site was curtailed by the fishery. Daily deviations from the average catch per haul at the tagging site are presented in FIGURE 10. It will be noted that although commercial fishing ceased on September 11 (actually 7:00 a.m. September 12) significant catches at the tagging sites were not made until the morning of September 14. The evidence suggests that it took about 48 hours for the wave of escapement to reach the tagging sites at Glen Valley and Silverdale bars. The starting point of this "front" of escaping fish was measured from the navigation light at the mouth of the river. The light was selected as the starting point because the fishery is so intense that the number of fish entering the river is greatly depleted soon after they pass this point on their upstream migration. Accordingly, a large proportion of the fish entering the river on the last day of fishing were caught soon after their entry. Upon cessation of fishing, these fish that would have been caught near the mouth formed a "front" of escaping fish which reached the tagging sites forty-eight hours later. Since it took two days for the fish

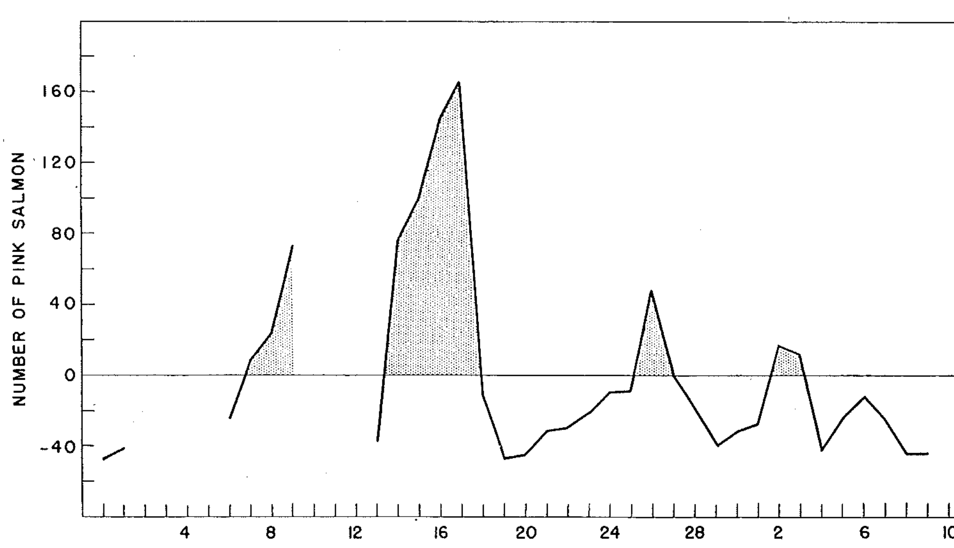

FIGURE 10—Daily deviations from the season average catch of pink salmon per net haul at the Glen Valley and Silverdale tagging sites.

to travel the forty-six miles between the navigation light and the tagging sites, the migration rate was approximately twenty-three miles per day.

Fishing started again below Pattullo Bridge at 8:00 a.m. September 17. The Above Bridge area remained closed for the rest of the pink salmon season. Catches per haul at the tagging sites were good during September 17 but were reduced on September 18 (FIGURE 10) suggesting that the effects of the Below Bridge fishery were partially operative at the tagging sites only twenty-four hours later. On the nineteenth the effects of the Below Bridge fishery became pronounced. Catch per haul was greatly reduced (FIGURE 10).

These occurrences can be explained in the following manner: Fishing pressure in the river below Pattullo Bridge reduced the number of fish reaching the tagging sites on the eighteenth but enough fish were near the upper limit of the fishery (Pattullo Bridge) and in the river above this point to maintain catches at a fairly high level. By the nineteenth all the fish which had entered the river during the previous closed period had either escaped or been caught. Catches at the tagging sites on September 19 were therefore representative of the very limited escapement from the Below Bridge fishery. These data also suggest a migration time of approximately forty-eight hours and show that no significant delay occurred in the fishing area.

Fishing in the river was stopped again at 7:00 a.m. on September 19 and remained closed for the rest of the pink salmon run. Catches at the tagging site at Glen Valley bar were low until September 21, when the daily catch increased to 177 from 70 on the previous day (TABLE 1). Based on the same assumptions as previously stated this would give a migration time from the mouth of the river to the tagging site of two days (from 7:00 a.m. September 19 to 7:00 a.m. September 21) and a rate of migration of approximately 23 miles per day as for the previous weekend.

These evidences from catch data regarding rates of movement are subject to errors. For instance, it is possible that the variations in catch at the tagging sites which have been used as evidence were entirely the result of variations in the size of the run and not caused by the imposition and removal of fishing mortalities. Stated rates of migration were certainly inaccurate to some degree because fishing was not conducted at the tagging sites on a twenty-four hour basis. For these reasons additional data were analysed regarding the progress of pink salmon through the Fraser River commercial fishery in 1957.

INCIDENCE OF NET-MARKED FISH AT THE TAGGING SITES

Salmon that escape gill nets are almost invariably marked about the head and back by the net twine. Talbot (1950) used the relative abundance of "net marked" sockeye on different days of the week at Hell's Gate to detect the presence of blockade conditions, and, incidentally, to estimate migration time from the mouth of the Fraser to Hell's Gate. Since it was expected that pink salmon would be similarly marked by gill nets, it was decided to record the presence of net marked individuals in catches made at Glen Valley and at

Silverdale. These "net mark" data were analysed and variations in relative abundance (FIGURE 11) were related to fishing regulations.

Four distinct peaks were apparent, indicating that net marks were particularly abundant at these times. The first and smallest peak occurred on September 6, forty-eight hours after the beginning of a closure. The next and second largest peak of abundance was on September 13, again forty-eight hours after the beginning of a closure. On September 17 fishing was reopened in the Below Bridge area. This fishing period ended at 7:00 a.m. September 19. It will be noted that net marks were abundant in catches at the Glen Valley tagging site on the nineteenth and twentieth of September. The fourth peak of net mark abundance occurred on September 23. This last peak of net mark abundance had no apparent relationship to catches in the river fishery but, perhaps, was related to catches made near the mouth of the river in the Strait of Georgia. The season ended in this area at 7:00 a.m. on September 21. It will be noted that three further peaks of net mark abundance occurred at the tagging sites on September 25, 27 and 29, after all the fisheries in Canadian Convention waters had terminated. It is probable that some fish were net-marked as a result of the gill net fleet operating in United States Convention waters. These fish would delay off the mouth and some would probably arrive at the tagging sites after the river and Georgia Strait fisheries were terminated. Similarly, some of these late migrating net-marked fish could have been marked as a result of the Strait or "Gulf" fishery before it was terminated. If the marking occurred shortly after their arrival in this delay area many would not migrate until after both the Below Bridge and Gulf areas were closed for the remainder of the season.

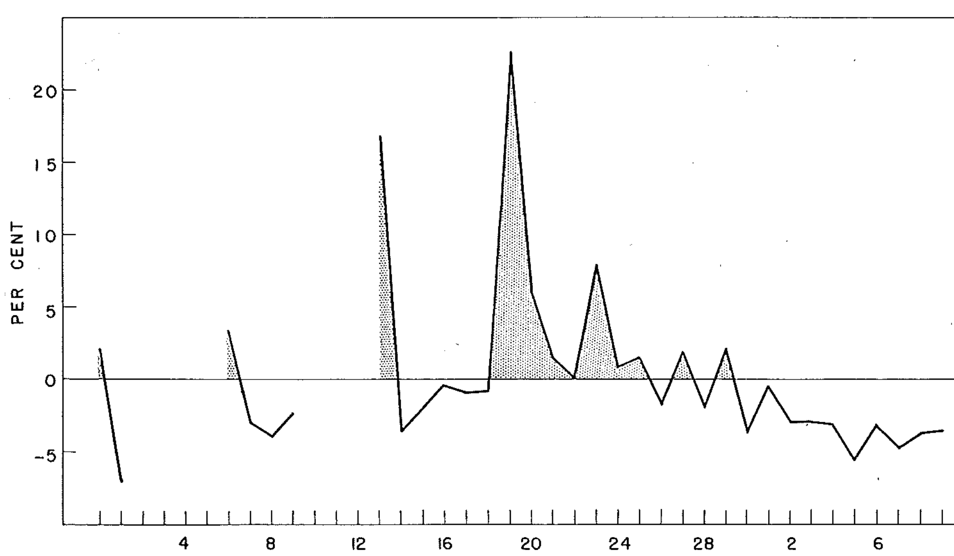

FIGURE 11—Daily deviations from the average percentage of net-marked pink salmon in the season catches at the Glen Valley and Silverdale tagging sites.

In the following discussions it was assumed that the appearance of a high proportion of net-marked fish in the catches at the tagging sites indicated escapement from the fishery and that the transition from a high proportion of net marks to a low proportion, indicated the first results of a closed period.

On September 6 the effects of the fishing period September 2 to 4 inclusive were still operative. This was not the case on September 7 when the proportion of net-marked pink salmon dropped appreciably. The data suggest that it took forty-eight hours for the first edge of the block of escaping fish of the closed period commencing at 7:00 a.m. on September 5 to reach the tagging sites. This migration time would give an estimated migration rate of 23 miles per day. The same conclusions can be drawn for the next fishing period. Catches on September 13 at the tagging sites were still affected by the fishing period ending at 7:00 a.m. September 12. It will be noted that catch data for this period presented in the previous section gave the same result.

Fishing in the Below Bridge area started again at 7:00 a.m. September 17 and continued until 7:00 a.m. September 19. The proportion of net-marked fish increased greatly in the catch of September 19 at the tagging site and was high again on September 20. It will be noted that this occurrence agrees with the catch per haul data presented in the previous section. The very high relative abundance of net marks and the low catch per haul on September 19 both indicate that the migration time from the mouth of the river to the tagging site was approximately forty-eight hours.

CHANGES IN THE SEX RATIO AT THE TAGGING SITES

Peterson (1954) has shown for sockeye that the gill nets can be selective for size, sex and age. During operations at the tagging site it was noted that the sex ratio of pink salmon catches sometimes varied considerably. It was assumed that gill nets tended to select the males because they were larger and had greatly developed humps, snouts and teeth. These characteristics made them more vulnerable than the smaller, "streamlined" females. This assumption was tested by comparing the sex ratio of net-marked fish to the sex ratio of unmarked fish captured during tagging operations.

For the whole tagging period, the proportion of net-marked fish was 23.6 per cent males and 76.4 per cent females. Comparable percentages for the unmarked catches were 53.6 per cent males and only 46.4 per cent females. From this it can be concluded that the Fraser River gill net fishery tended to be selective for males and that the observed major changes in the proportion of the sexes were caused by the fishery.

It would be expected, then, that during and shortly after a fishing period the proportion of females in the catch at the tagging sites would be high but that the proportion of males would increase rapidly when the closed period escapement reached the tagging sites. Conversely it might be expected that, after the fishing week commenced, the sex ratio would remain stable for a short time and then, as the effects of the fishery became operative, the proportion of females would increase abruptly.

Changes in the proportion of female pink salmon in the daily catches at the tagging sites are shown in FIGURE 12. Two major peaks of relative abundance of females occurred during the fishing operations. One peak occurred on September 13, 48 hours after the beginning of a closed period and the other on September 19, 48 hours after the end of a closed period. Any effect of the fishery on the sex ratio prior to September 13 was probably obscured by the preponderance of males in the early portion of the run (Milovidova-Dubrovskaya, 1937). After the peak of the early run, until the end of the fishery it is probable that variations in the sex ratio were caused by differing proportions of early and late run fish in the daily catches. After the peak of the early run (September 14-17 inclusive) most early run fish would be females while a large proportion of late run fish might be males. During the peak of the early run it would be expected that the sex ratio would be relatively stable because of the large numbers of fish involved and the similar timing of the races composing this segment of the escapement. If this assumption is correct then it seems probable that the relative abundance of females on September 13 and 19 was caused by the removal of males by the fishery forty-eight hours previously. If this conclusion is correct then the migration time during the weekend of September 13 to 18 was the same as that arrived at using catch and net mark data.

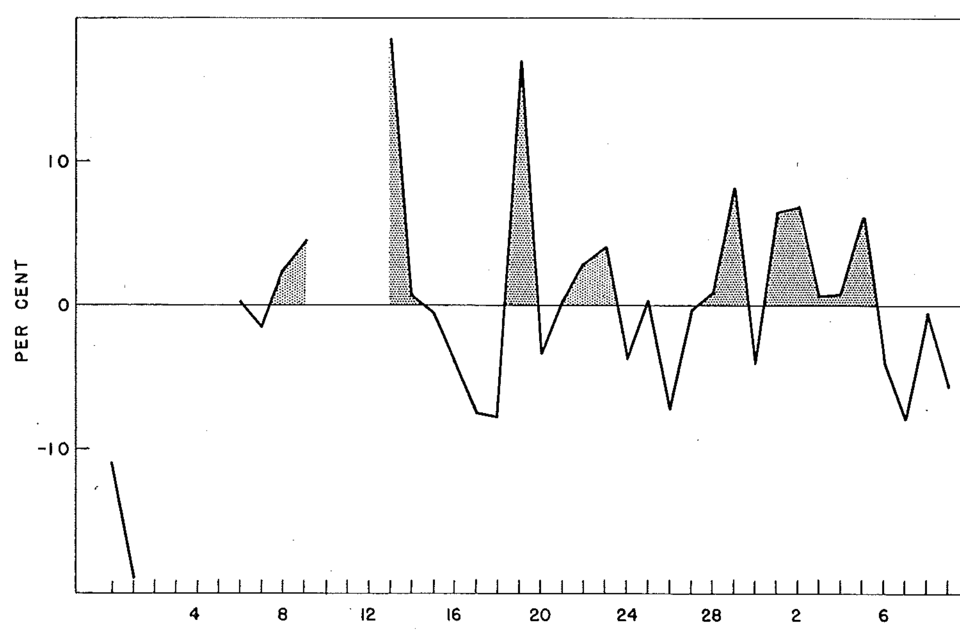

FIGURE 12—Daily deviations from the average percentage of female pink salmon in the season catches at the Glen Valley and Silverdale tagging sites.

RECAPTURE AT THE SILVERDALE SITE OF FISH TAGGED AT GLEN VALLEY BAR

During the peak of the run, tagging was conducted simultaneously at both the Glen Valley and Silverdale sites. The latter site was located five miles upstream from Glen Valley. If fish were delaying in the area or were moving randomly, time between tagging and recovery for fish tagged at one site and recovered at the other would be considerable. Further, it might be expected that fish tagged at both sites would be recaptured at both sites. Conversely, if fish were moving directly and rapidly upstream, time between tagging and recapture would be relatively brief and the majority of recaptures would be at Silverdale of fish tagged at Glen Valley.

Assuming that untagged fish behaved as tagged fish, data (Table 5) show that the fish were moving directly upstream. No Silverdale tags were recovered at Glen Valley as would have happened had milling or random movement occurred.

Table 5—Tags put on at Glen Valley and Silverdale bars and the occurrence of Glen Valley tags at Silverdale and vice versa.

DATE	NUMBER TAGGED AT GLEN VALLEY	NUMBER TAGGED AT SILVERDALE	RECOVERIES	
			Glen Valley Tags at Silverdale	Silverdale Tags at Glen Valley
Sept. 13	112	140	0	0
14	551	726	12	0
15	768	746	4	0
16	739	821	12	0
17	725	795	8	0
Totals	2895	3228	36	0

As shown in Figure 13 fish did not delay for any significant time between the two sites. Of a total of thirty-six Glen Valley tags recovered at the Silverdale site, thirty-three were recovered on the date of tagging.

During operations at both tagging sites the time was recorded at which each seine haul was started. From this information the time of recapture at Silverdale was accurately determined and, based on the number of fish in the haul, the time of tagging of individual fish at Glen Valley was estimated. The estimated time out, in hours, of the thirty-three fish recaptured on the date of tagging is shown in Figure 14. The average time out for these fish was 4.1 hours. The rate of travel between the two sites was 1.2 miles per hour. This rate of migration cannot be compared with the previous figure of 23 miles per day because it is not known whether the hourly rate was maintained for a twenty-four hour period. It can be concluded, however, that movement during the peak of the run up the river past the tagging sites was rapid and direct.

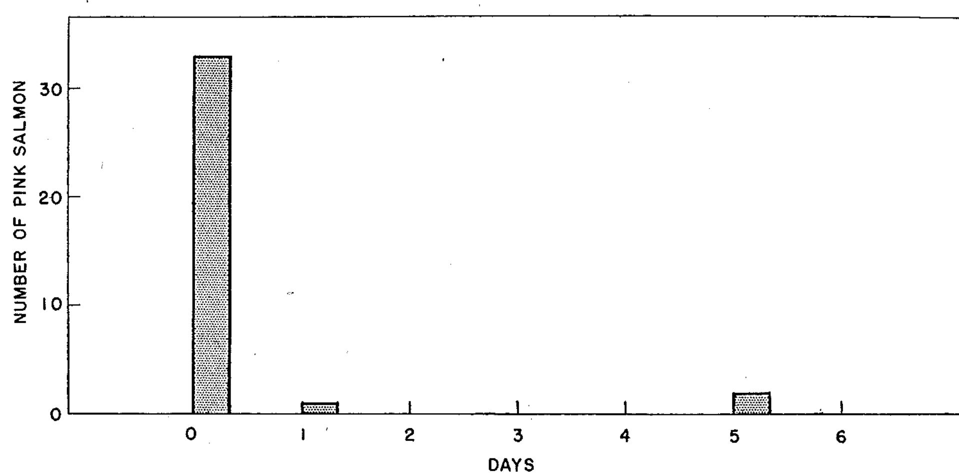

FIGURE 13—Number of days between tagging at Glen Valley and recovery of the tagged individuals at Silverdale.

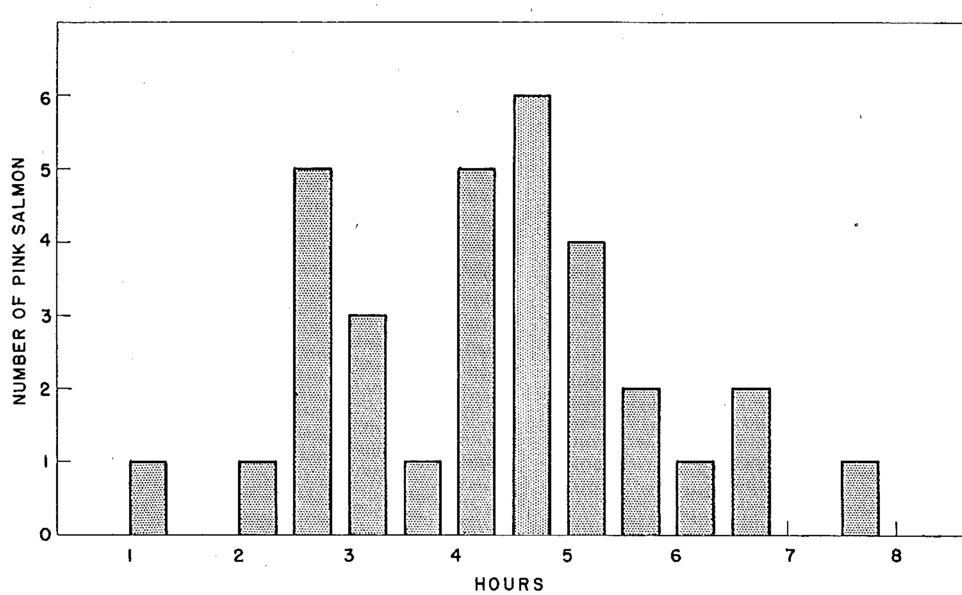

FIGURE 14—Number of hours between tagging at Glen Valley bar and recovery of tagged individuals at Silverdale bar for fish out less than one full day.

RECAPTURE OF PINK SALMON TAGGED AT GLEN VALLEY AND SILVERDALE IN THE FRASER RIVER COMMERCIAL FISHERY

It might be expected, if the fish were moving rapidly and directly upstream (as indicated previously) that most recoveries of tags from the commercial fishery would be made upstream from the tagging site. Fishing in the Above Bridge area ended on the morning of September 12 for the duration of the pink salmon run; therefore only the early part of the run was fished in the tagging area.

A total of forty-one recoveries were made from tagging conducted up to September 10 (TABLE 6). During this period, 1,710 pink salmon were tagged. Thirty-eight recoveries were made in the Above Bridge area. Of these, thirty-five were taken from fish captured at or above the tagging site. Only six of the forty-one recoveries were reported from the intense fishery located downstream from the tagging sites. It seems probable that these were made from fish injured during the tagging operation rather than from fish exhibiting retrograde migration. In any tagging operation, regardless of all precautions, some fish are injured.

Since twenty of the recoveries were made in the area of tagging it might be concluded that the fish delayed for some time in the tagging area; however this conclusion was not necessarily valid because 19 of the 20 recaptures came from fish tagged on September 9 just prior to the reopening of fishing. If delay in the tagging area had been significant more recoveries would have been made of fish tagged prior to September 9. Assuming that fish tagged on September 9 migrated at a similar rate to those tagged during the period September 14 to 17 inclusive (FIGURE 14) a considerable number must have escaped prior to the reopening of the fishery. If so, the apparent high rate of recovery in the tagging area may have been caused by a relatively small residue of delaying tagged fish and may not necessarily represent the normal migration.

It can be concluded that recoveries from the commercial fishery show that movement during the early part of the run was upstream and relatively rapid. In general, these data support the conclusions based on the analysis of information obtained from the recovery of Glen Valley tags at Silverdale during the period September 14 to 17 inclusive.

TABLE 6—Commercial recoveries of pink salmon tagged at Glen Valley prior to September 10, 1957.

DATE OF TAGGING	NUMBER TAGGED	NUMBER OF RECOVERIES				
		Above Bridge				
		Mission	Glen Valley	Below Glen Valley	Below Bridge	Total
Aug. 31	41	0	0	0	0	
Sept. 1	63	0	0	0	1	1
6	195	0	0	0	0	
7	416	0	0	0	1	1
8	447	0	1	0	0	1
9	548	15	19	3	1	38
Totals	1710	15	20	3	3	41

RATE OF RECOVERY OF PREVIOUSLY TAGGED FISH AT THE TAGGING SITES

It might be expected that, if fish tended to delay or mill in the tagging area as the season progressed, the rate of recovery of previously tagged fish would increase. This did not occur (FIGURE 15). On the contrary the rate of recapture declined, suggesting that the fish became less available for recapture with the passage of time. From these data it can be concluded that there was no tendency for late run Fraser pink salmon to delay in the tagging area. In fact it is indicated that they cleared the area more rapidly than the early run fish.

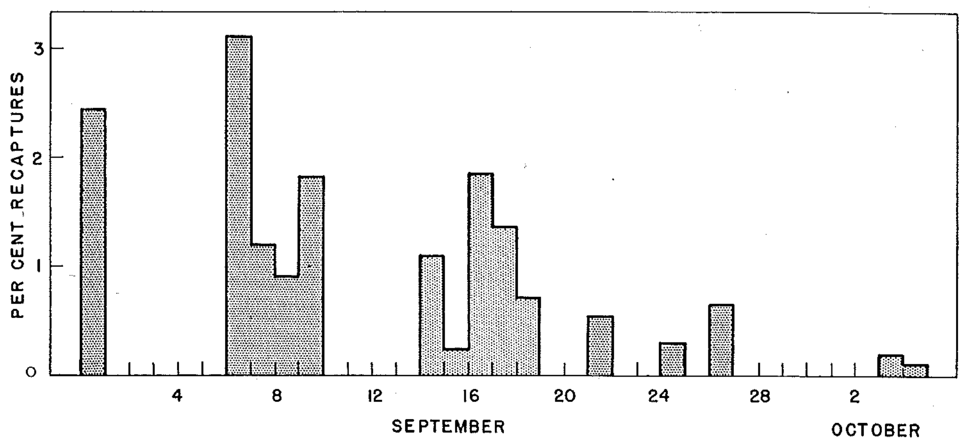

FIGURE 15—The daily percentage of the fish tagged at Glen Valley and Silverdale which were recaptured at the point of release.

If fish were moving fairly rapidly through the tagging area it might be expected that the time out for fish tagged and recovered at the same site would be relatively brief. Conversely if fish were delaying or milling in the area the time out for tags recaptured at the tagging site would be highly variable.

It was found that, of the ninety-eight tagged fish recovered at the point of tagging, ninety-four were recovered on the date of tagging. Only four were recovered during the day following the date of tagging.

More evidence regarding delay in the tagging area was obtained by plotting the recaptures according to the number of hauls which were made between tagging the fish and recapture of the same fish. For example, if a fish was recaptured in the haul following the one in which the fish was first caught, the intervening number of hauls would be zero and a relatively short time out would be indicated.

The number of fish recaptured on the date of tagging are shown in FIGURE 16 plotted according to the number of hauls made between tagging and recapture. Most of the recaptures were of fish captured for tagging in the preceding haul. Of the 94 recaptures 74 were made from the immediately preceding haul. If fish were delaying in the tagging area for most of the day, delaying tagged fish would accumulate in the area and the number of hauls between capture and recapture would increase. Since the percentage of recaptures during the season was low and most of these were recaptures of fish tagged in the haul immediately preceding, it can again be concluded that fish did not delay in the tagging area for any significant period.

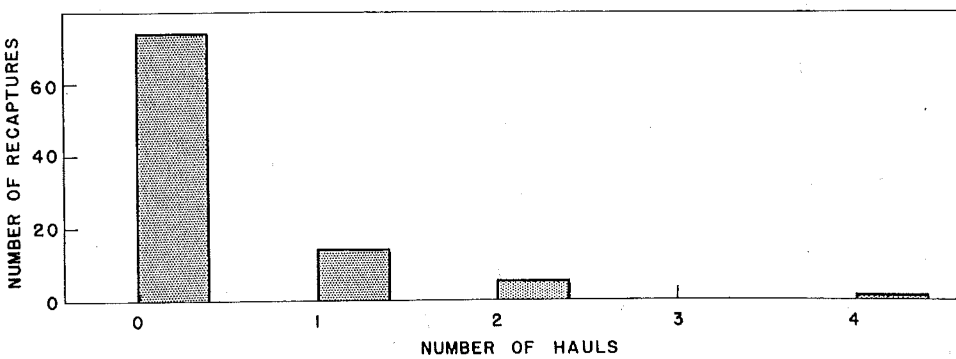

FIGURE 16—The number of pink salmon recaptured on the date of tagging at the same site according to the number of seine hauls intervening between capture and recapture.

Migration From the Fraser River Fishery to the Individual Spawning Grounds

Variable racial migration rates, occurring between the upper limit of the fishery and the spawning areas, could result from differences in the behavior of races of pink salmon or from delay at some point caused by an obstruction. Migration times and rates of migration were estimated for four of the five major races from information obtained by the recapture of tagged fish en route to spawning grounds, from counts of fish made at stations along the migration route and finally from visual observations along the migration routes. The spawning grounds of the fifth major race, the Fraser race, were located near the tagging sites on the main migration route. It was not possible to obtain direct evidence pertaining to migration time for this race but indirect evidence from the time of spawning and dying will be presented in a later section.

THOMPSON RIVER

Counting stations were situated on the banks of the Thompson River approximately six miles downstream from Spences Bridge. This bridge marked the approximate downstream limit of pink salmon spawning in the Thompson River. Throughout the run, during daylight, the total number of pink salmon and number of tagged individuals passing the stations hourly were determined. In the clear water white tags were easily seen against the dark background provided by the fish. Since most of the migration was along the left bank (118,179 out of 126,391), only data collected at this site are presented.

In a previous section, the peak of the Thompson River race was shown to have been present at the tagging sites during the period September 14 to 17 inclusive (FIGURE 2). The time difference between this peak and the peak counts at the counting site should represent the time taken for the peak of the run to travel between the two points. If tagging was roughly proportional to abundance and if the tagging procedure did not affect the migration rate of tagged fish, the peaks of passage at the Thompson River counting site of tagged and untagged fish should coincide.

As shown by Andrew and Geen (1958) the migration curves of tagged and total counts of pink salmon at the Thompson counting site were significantly different. These authors state that the difference was caused by a relatively high proportion of tagged fish counted in relation to the total count during the peak of the run. In turn, this high proportion of tagged fish probably resulted from the increased tagging effort which was applied during the peak at Glen Valley and Silverdale. In other words, during the peak of the run, the increased abundance at the tagging site was overcompensated by the additional tagging effort.

It will be noted (FIGURE 17) that the peak count of tagged fish came one day after the peak untagged count at the Thompson site. This difference may have resulted from delay of tagged fish or from a slightly slower migration rate for tagged fish. On the other hand, the difference may have resulted from chance occurrence at the tagging site. Large numbers of pink salmon bound for several streams were passing the tagging sites on September 16 (TABLE 3

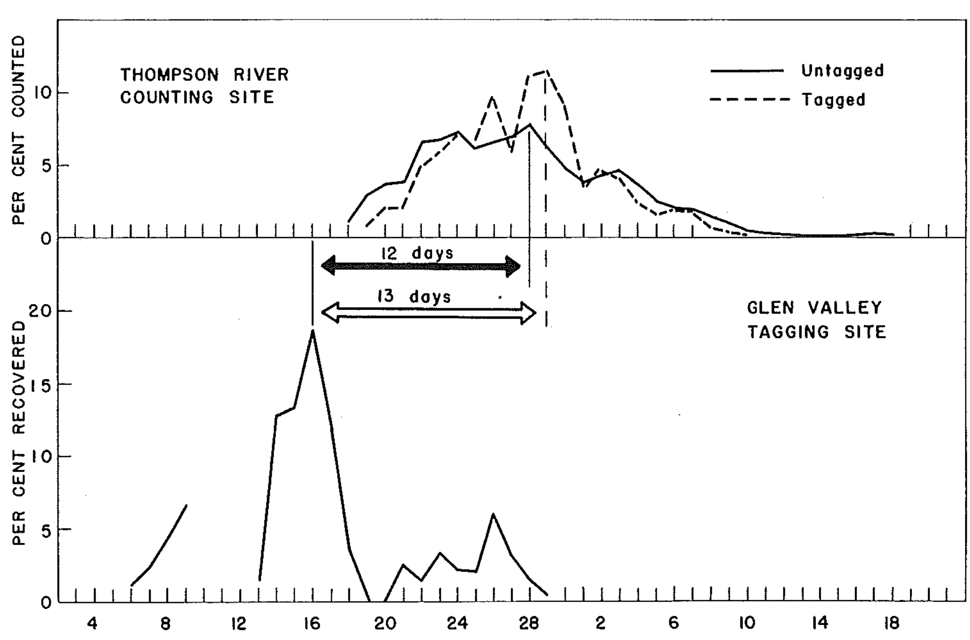

FIGURE 17—Relationship between peak of passage of the Thompson River race at the Glen Valley site and at the Thompson River counting station.

and FIGURE 5) and the number actually caught and tagged formed a very small percentage of the total present on this date (TABLE 1 and TABLE 3). It is quite possible that relatively too few Thompson fish were caught and tagged. If tagged fish actually did not behave as untagged fish it would be expected that the whole curve of abundance of tagged fish observed at the counting site would be shifted to the right of the untagged abundance curve. Except for the peak of the run the tagged fish curve followed the untagged curve closely, which does not suggest that tagged fish migrated at a slower rate.

It can be concluded that the peak counts of tagged fish at the Thompson River counting site adequately represented the peak of passage of the run. Similarly it can be concluded that the peak of passage at the tagging sites, as indicated by tags recovered from the Thompson River, represented the peak of abundance of the Thompson River run. The migration time between the two points using the peak counts of tagged fish was 13 days and for the peak counts of untagged fish it was 12 days (FIGURE 17). These data gave daily migration rates, for the one hundred and thirty-eight intervening miles, of 10.6 miles per day for tagged fish and 11.5 miles per day for total counts. As pointed out, this difference between tagged and untagged fish may be more apparent than real.

These estimates of migration rate from Glen Valley to the Thompson counting station were much lower than those which applied during the passage of the fish from the mouth of the river to Glen Valley (approximately 11.0 miles per day as compared with 23 miles per day). A further comparison of the two curves shown in FIGURE 17 tends to support the conclusion that a lower rate applied upstream from Glen Valley.

It will be noted (FIGURE 17) that the peak of the Thompson migration curve at Glen Valley occurred during a four day period (September 14 to 17 inclusive) whereas the peak counts of untagged fish at the Thompson station occurred during a period of approximately seven days (September 22 to 28 inclusive). A comparison of the coefficients of variation (C) for the two curves confirmed these observations. The value of C for the curve of migration past Glen Valley was 0.89 (88.7%) and for the migration curve measured at the Thompson counting station C was 3.1 (306.8%), indicating that the distribution at the Thompson station was considerably flatter. This spreading of the migration curve probably occurred as a result of a reduced rate of migration between the two locations. For instance, if the rate past Glen Valley was reduced to one-half by the time the fish arrived at the Thompson counting station the time taken for a given number of fish to pass would have been doubled. Similarly, during any comparable twenty-four hour period, only half as many fish would pass the Thompson counting station. Killick (1955) found that races of sockeye tended to maintain a constant freshwater migration rate; however occasionally changes in rate did occur. In 1954 it was estimated that eighty per cent of the Adams racial escapement passed through the Fraser River fishing areas during a three day period. This estimate indicated a very steep peak to the migration curve at this time.

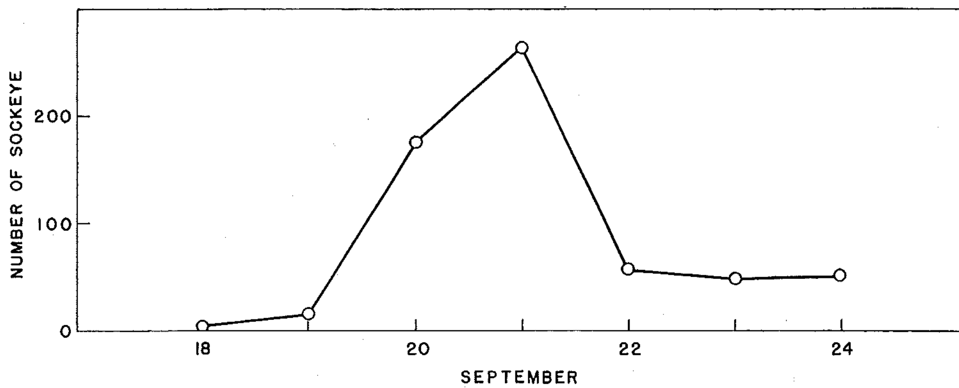

FIGURE 18—Daily catch per drift of sockeye made during test fishing operations conducted in the Above Bridge area in 1954.

This steep peak was also indicated by the test fishing data (FIGURE 18) collected during the closed period when the bulk of the Adams escapement passed through the Fraser River fishing areas. Arrival of the escapement on the spawning grounds was spread out over a much longer period of time (FIGURE 19). It can also be seen that no distinct peak of arrival occurred. It might be concluded that a general reduction in migration rate resulted in the dispersion of the peak which had been present in the fishing area.

In the case of the 1954 Adams sockeye run, it is probable that the reduction in migration rate was, in part, caused by the size of the run and the shape of the migration curve upon arrival at the lower margin of the turbulent Fraser Canyon. Large numbers of fish arrived at the Canyon during a short period of time. Assuming that a fixed number of fish could pass through the Fraser and Thompson Canyons in a given time, any number in excess of this

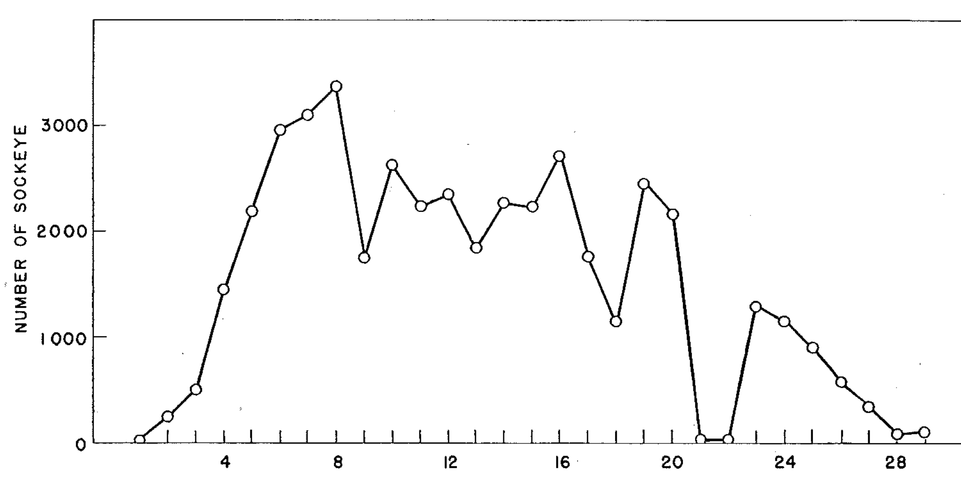

FIGURE 19—Daily counts of sockeye passing under a section of the Adams River bridge in 1954 during the period 10:00 a.m. to 11:00 a.m.

maximum would be delayed. This delay might only amount to a few hours or even minutes in a particular area but a large number of such delays could result in a considerable reduction in migration rate with a resultant spreading-out of the migration curve.

In the case of pink salmon it is also probable that the reduction in migration occurred in the turbulent Fraser and Thompson Canyons. Some evidence is available which suggests that most of the reduction occurred in the Fraser Canyon above Hope.

Fish-wheel catches compared with commercial catches suggested a migration time, in 1955, of five days from the mouth of the Fraser to the fish-wheel located near Hope (Department of Fisheries, Canada, 1957). The migration rate calculated from this information was 21 miles per day, very similar to the rate of 23 miles per day from the mouth to the tagging sites calculated from data collected in 1957. These data indicated that the migration rate was not reduced between the tagging site and the beginning of the Fraser Canyon. The migration time from the mouth of the Fraser to Hell's Gate in 1953 was estimated to be nine days (Department of Fisheries, Canada, 1957). If the migrations were comparable in 1953 and 1955, the time between Hope and Hell's Gate was four days (the difference between the time to Hope and the time to Hell's Gate). The rate of migration was only 8 miles per day between these two points which suggests a major reduction in migration rate in the area.

One possible explanation for this reduction in migration rate might be that pink salmon were blocked in the Fraser Canyon below Hell's Gate. This did not occur in 1957 because no concentrations of blocked fish were observed anywhere along the migration route and fish reached the spawning grounds in good physical condition. The most likely cause for the reduced migration rate was a change in migration behavior brought about by high water velocities in the canyon region. Below the canyon migration during

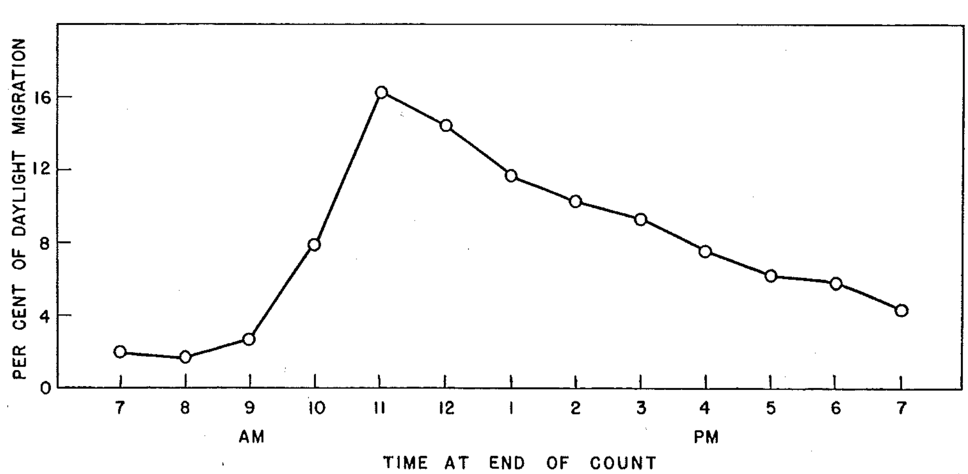

FIGURE 20—Average hourly percentage of Thompson River pink salmon migrating past the left bank counting station.

darkness may have been quite heavy. Almost thirty-nine per cent of the catch made by the fish-wheel in 1955 was made during the period 5:00 p.m. to 8:00 a.m. whereas few pink salmon in 1957 moved at night past the Thompson River counting site. On three occasions during the migration, photographic and visual counts made during the night showed that numbers of pink salmon passing the site were slightly less than nine per cent of the daylight total. The pattern of daylight migration is shown in FIGURE 20. If fish tended to rest in eddies during the hours of darkness the slow migration rate in the canyon would be accounted for.

Apparently the migration rate tended to increase again once the fish had travelled through the most difficult sections of the river. Migration time to Hell's Gate in 1953 was nine days. Time to the Thompson counting station in 1957 was approximately 12 days. Assuming the two migrations were comparable, time between Hell's Gate and the Thompson River counting site was three days and the migration rate was approximately 16.5 miles per day.

It can be concluded that migration rate above the commercial fishery was variable. It is probable that the reduction in rate was caused by fast and turbulent water. Pink salmon migrating to the Thompson River were not obstructed during their migration from the fishery to the spawning grounds in 1957.

SETON CREEK

The arrival curve at Seton Creek of tagged pink salmon and the curve constructed from total counts were similar as shown by Andrew and Geen (1958), indicating that tagged and untagged pink salmon migrated at approximately the same rate. The peak of both tagged counts and total counts

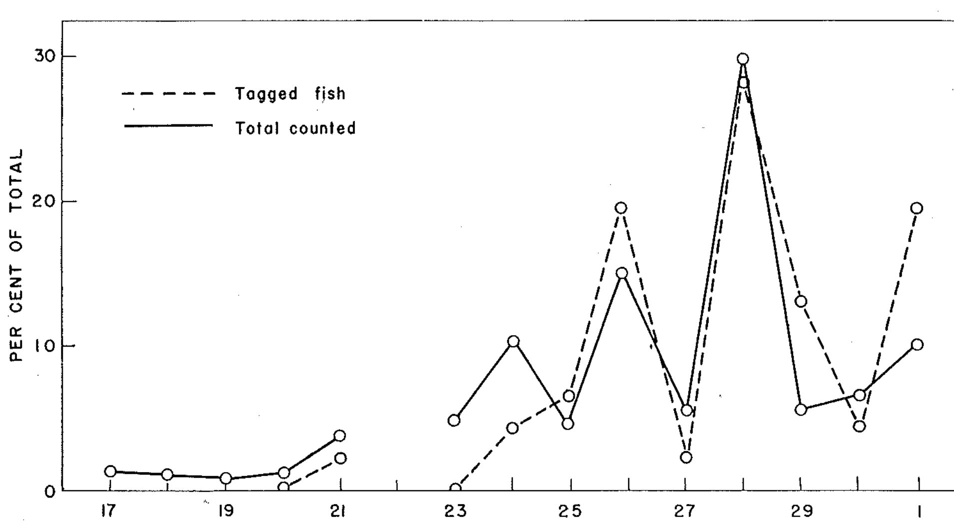

FIGURE 21—The percentage of tagged and total pink salmon counted at the Seton Creek counting site each day.

occurred on September 28 (FIGURE 21). The peak of abundance of Seton fish at the tagging sites occurred on September 16 (FIGURE 2). The time interval between these peaks which should represent the migration time between the two points, was twelve days. The calculated migration rate for the one hundred and sixty-one miles was 13.4 miles per day.

Direct evidence was available regarding the migration time from the tagging sites to Seton Creek powerhouse located on the Fraser 4500 feet downstream from the mouth of Seton Creek. Of fish captured from the tailrace of the plant, eighteen bore tags put on at Silverdale and Glen Valley bars. The average time taken for these tagged fish to travel from the tagging sites to the tailrace was 14.7 days. (The standard error of this mean was 0.4 days.) The rate of migration for the one hundred and sixty miles was estimated to fall between 10.4 and 11.7 miles per day. The difference in rates obtained by the two methods might be the result of delay incurred in the tailrace by tagged fish captured in that area (Andrew and Geen, 1958). If so, the rate of migration to Seton Creek was higher than the rate to the Thompson River. This higher rate may have resulted from the greater distance between Seton Creek and the canyon area. As previously indicated the rate increased between Hell's Gate and the Thompson station. It might be expected that the greater distance of comparatively easy route between Hell's Gate and Seton Creek might allow for a greater increase.

It can be concluded that the same conditions applied to the Seton Creek race as applied to the Thompson race. There was no evidence suggesting any protracted period of delay en route from the tagging area.

HARRISON RIVER

Large schools of pink salmon were observed milling in the mouth of the Harrison River and in the clear "tongue" of Harrison water which could be readily distinguished for some distance in the Fraser below the mouth of the Harrison. Pink salmon were first observed on September 25 and were still present in reduced numbers on October 18. These observations suggested that pink salmon bound for the Harrison River spawning grounds delayed in the mouth for some time before moving upstream.

Fish were captured for tagging at a site in the Harrison Rapids just downstream from the spawning grounds. During this tagging operation a total of forty-five fish bearing Glen Valley and Silverdale tags were recaptured. The average number of days between tagging and recapture was 10.8 $\pm$ 0.7 days. The distance from the tagging sites to the mouth of the Harrison River is approximately thirty miles. Assuming an average rate of travel of 23 miles per day it would take the fish less than two days to reach the mouth of the Harrison. This estimated travel time would allow an average delay period in the mouth of the river of about nine days.

Further evidence regarding the location of the delay area and the duration of delay was available from other tagging. Fish were tagged at the mouth of the Harrison River during the period October 1 to 6. Three of these tags were recovered 4.3 miles upstream at the Harrison Rapids tagging site. The average number of days out for these three tagged fish was 8.3 days. These additional data supported the conclusion drawn from the recovery of Glen Valley and Silverdale tags at the rapids and also confirmed the observed location of the delay area.

It is evident that fish destined for the Harrison River spawning grounds behaved differently from those destined for Seton Creek and the Thompson River. Pink salmon of the Harrison race delayed near the mouth of the Harrison for a considerable period, whereas fish of the other two races migrated directly to their respective spawning grounds.

CHILLIWACK-VEDDER RIVER

Pink salmon were captured for tagging at a site located seven miles above the mouth of the Vedder River. During this operation twenty-two Glen Valley and Silverdale tags were recaptured. The average number of days between tagging and recapture was 12.2 ± 1.3 days and the range was from 3 to 28 days. Since the fish were migrating upstream at the time they were recaptured it can be concluded that the delay took place between the tagging and recapture sites.

Evidence regarding the area of delay and the length of the delay periods were provided by another tagging program which was conducted at the mouth of the Vedder Canal from October 3 to October 8 inclusive. During this operation five fish which had been tagged at the Glen Valley site were recaptured. The average number of days out was 2.80 ± 0.4. River distance from the Glen Valley site to the mouth of the Vedder was nineteen miles. Steadily migrating fish would cover this distance in approximately one day; therefore it can be concluded that pink salmon delayed in the mouth of the Vedder or in the Fraser for a period of approximately two days before recapture.

A total of twelve fish which were tagged at the mouth of the Vedder were recaptured later at the upper tagging site. The average number of days between tagging and recapture was 7.50 ± 0.1. These data indicate that most of the delay took place in the lower part of the Vedder system rather than in the Fraser River.

It can be concluded that the migration behavior of the Chilliwack-Vedder race was similar to the Harrison race. Fish delayed in the lower part of the stream for considerable time before moving upstream to the spawning ground.

CHRONOLOGICAL ORDER DURING MIGRATION

Royal (1953) expressed the concept that the central portion of the steeply domed migration curve for a given race of sockeye included those individuals which were properly related to the normal environmental cycle controlling reproduction. Conversely, the tails of the curve consisted of "abnormalities" not properly timed. This concept is still being tested although a great deal of supporting evidence has been accumulated.

In the absence of contradictory evidence, it was decided that this concept applied to races of pink salmon. Data will have to be collected for a number of years and analysed before this assumption can be tested.

The primary implication of the concept from a management standpoint is, providing chronological order is maintained between escapement and spawning, that it is necessary for the purpose of obtaining maximum freshwater survival of progeny to allow escapement from the peak of each racial migration curve. Killick (1955) showed that the main races of Fraser River sockeye maintained chronological order throughout migration and spawning. In the following section data have been presented pertaining to the maintenance of chronological order among races of Fraser River pink salmon. Unfortunately, data were not available which could be used to determine if the original chronological order in the escapement was maintained during spawning; however data from several tagging and recovery programs conducted in 1957 were available regarding the chronological order between points along the migration routes and the time of recovery of tags from dead fish examined on the spawning grounds.

If fish tagged first were recaptured first and fish tagged late were recaptured last it could be concluded that chronological order had been maintained between two points. It would be expected that changes in migration rate with time, which would produce mixing, would be indicated by the regression coefficient of date of recovery on date of tagging. The order of magnitude of the correlation and regression coefficients would indicate the degree of mixing which occurred (Schaefer, 1951). In the following sections, data were analysed by the same method used by Schaefer. A regression coefficient of 1.0 indicated that a uniform migration rate occurred and therefore, no mixing or loss of chronology was apparent throughout the particular experiment. A regression coefficient of more than 1.0 indicated that the later fish migrated more slowly than the earlier fish and conversely a regression coefficient of less than 1.0 indicated an increase in migration rate with the passage of time. A correlation coefficient of 1.0 would indicate no mixing and a correlation coefficient of zero would indicate complete mixing.

In subsequent discussions the term "migration" is used as defined by Schaefer (1951). According to this author "migration includes all the changes of location in space and time of the fish between passage of the tagging point and arrival at the place where samples are drawn for tag ratios". In the analyses conducted below, the end point of migration is the time and place of examination of fish.

Dates of recovery on the various spawning grounds were correlated to dates of tagging at the Glen Valley and Silverdale fishing sites. Results obtained from analyses of these data showed the amount of mixing which occurred between the time the fish left the fishery to the time they were examined as dead fish on the spawning grounds. Other analyses were conducted to determine chronological order between the fishery and arrival on the spawning grounds and between arrival and death.

Fishery to Death

Adequate numbers of tags which were put on at the Glen Valley and Silverdale sites during the period August 31 to October 9 were recovered from dead fish examined from the spawning grounds of the three major early migrating races and the two late migrating races. Average number of days out (*d*) between tagging and recovery are shown in TABLE 7. Also shown are "*n*" the number of tags recovered, "*r*" the product moment correlation coefficient and "*b*" the coefficient of mean square linear regression of date of recovery on date of tagging.

Fish of the early races tended to have a shorter freshwater life span than fish of the late races. The average life span for fish of the three early races was 28 days as compared with 36.4 days for individuals of the late races. In all cases the regression coefficients (*b*) were less than 1.0, indicating that the later migrating fish of each race examined tended to migrate more rapidly, or have a shorter life span or a combination of the two. In all cases the correlation coefficients (*r*) and the regression coefficients (*b*) indicated chronological order was maintained but that some mixing of fish occurred. Fish of the Chilliwack-Vedder and Thompson races apparently mixed to a greater extent than other races while the Harrison and Seton races maintained their order of migration to a high degree.

In many cases tags may have been recovered from fish which had died a number of days previous to examination. In these cases, indicated life spans would be too long and mixing would be shown to a greater degree than that which actually occurred. In other words, correlation coefficients would be too low. It is important to note that correlation coefficients were lowest for the Fraser, Thompson and Chilliwack-Vedder races where conditions for the recovery of tags were poorest. Spawning grounds were extensive and particular areas could only be visited at irregular intervals, thus allowing accumu-

TABLE 7—Average duration of migration of tagged fish, and correlation and regression coefficients of date of recovery on the spawning grounds on date of tagging of pink salmon tagged at the Glen Valley and Silverdale sites. Also presented are tagging and recovery periods spanned by the recovered tags.

Recovery Area	Tagging Period (Days)	Recovery Period (Days)	*d*	*n*	*b*	*r*
Early Races						
Seton Creek	25	33	28.2	220	0.82	0.65
Fraser River	39	36	27.3	436	0.62	0.55
Thompson River	24	33	28.5	203	0.51	0.49
Late Races						
Harrison River	33	39	32.4	393	0.82	0.63
Chilliwack-Vedder River	26	39	40.4	204	0.65	0.48

lation of dead fish between visits. Correlation coefficients were highest for the two races inhabiting the most compact spawning areas, the Harrison River and Seton Creek. Dead recoveries were made at frequent intervals and accumulations of dead fish were kept to a minimum.

It is also of importance to note that regression coefficients were highest for the Harrison and Seton races. This indicates that the freshwater life spans of individuals of these races tended to remain the same throughout the run and also indicated that less mixing occurred. There was apparently only a slight tendency for later migrating fish to live a shorter time between tagging and recovery. Regression coefficients for fish of other races showed that there was apparently a pronounced reduction in life span as the run progressed. Again this tendency may have been exaggerated by conditions affecting examination of dead fish at particular spawning grounds. On the more difficult streams, such as the Fraser, Thompson and Chilliwack-Vedder considerable experience in organizing field parties and knowledge of the streams were required before the dead recovery became efficient. It is possible that efficiency increased with experience and the recovery of the available dead fish became more complete towards the end of the runs. This would result in an apparent progressive reduction in days out between time of tagging and time of recovery.

Although the above mentioned sources of error may apply to the data analysed, it is apparent that all races of pink salmon maintained, to a considerable degree, chronological order of migration between the tagging area and the time of death on the individual spawning grounds.

Fishery to Arrival at the Spawning Grounds

Although it was shown that chronological order was reasonably well maintained over the whole period of adult freshwater life, it was possible that "mixing" or loss of chronology could have occurred at some intervening stage in the freshwater life span. Since chronology was maintained between tagging and death any intervening mixing would have to be followed by at least partial rearrangement of timing to regain chronology. One phase of life during which loss of chronology could have occurred was during movement of the fish from the fishery to the spawning areas.

Fish which had been tagged at the Glen Valley and Silverdale fishing sites were recaptured and examined for tags at several points located near these spawning grounds. The recapture sites were at the downstream margin of Harrison River rapids, at the B.C. Electric bridge seven miles upstream from the mouth of Chilliwack-Vedder River and at the tailrace of Seton Creek powerhouse. The regression coefficients of date of recovery at these sites on date of tagging and the correlation coefficients are presented in TABLE 8 together with the number of tags recovered (n) and the average number of days between tagging and recapture (d).

From data presented previously it was concluded that migration from the upper limit of the fishery to Seton Creek was relatively direct. Delay did not occur in any location en route for any considerable period. On the basis of evidence presented in TABLE 8 it can be concluded that during this movement fish maintained their order of passage with very little mixing. Since overall chronology was maintained by this race, it is probable that order of migration was maintained throughout all stages of freshwater life.

TABLE 8—Average duration of migration of tagged fish and correlation and regression coefficients of date of recovery on date of tagging of pink salmon tagged at the Glen Valley and Silverdale sites. Also presented are tagging and recovery periods spanned by the recovered tags.

Recovery Area	Tagging Period (Days)	Recovery Period (Days)	*d*	*n*	*b*	*r*
Early Races						
Seton Tailrace	15	12	14.2	18	0.831	0.930
Late Races						
Harrison Rapids	23	15	10.9	45	0.255	0.295
Vedder B.C.E. Co. Bridge	22	9	11.5	21	0.005	0.009

Correlation coefficients and regression coefficients are not comparable to those presented in TABLE 7. For the Harrison and Chilliwack-Vedder races recovery periods shown in TABLE 8 are shorter than those shown for the same two races in TABLE 7. It is therefore possible for correlation and regression coefficients to be proportionately lower. This type of error did not, however, account for the differences in r and b values shown for these races in the two tables. Results presented in TABLE 8 indicate that between tagging and recapture mixing was almost complete for Chilliwack-Vedder fish and was considerable for fish of the Harrison race. It seems probable that this temporary mixing occurred primarily in the delay areas located near the mouths of the two streams.

Arrival at the Spawning Grounds to Death

Since fish of the two late runs apparently lost their order of migration to a large degree while en route to the spawning grounds in spite of the fact that chronology was maintained over the whole life span, it follows that chronology must have been regained to a large extent during the period between arrival on the grounds and death. If so, it would be expected that order of arrival would not be well correlated with order of death.

Pink salmon of the Harrison and Chilliwack-Vedder races were captured and tagged immediately below their respective spawning grounds during their migration to these grounds. Dead fish were examined and tags were recovered. The regression coefficients of date of recovery on date of tagging and the correlation coefficients together with number of tags recovered (n) and the average number of days between tagging and recapture (d) are presented in TABLE 9.

The low regression and correlation coefficients obtained from this analysis suggested that the hypothesis was correct, that considerable rearrangement of chronological order occurred in this area. It therefore follows that the initial order of migration must have been regained to a large degree during the period between arrival and death.

TABLE 9—Average duration of migration of tagged fish and correlation and regression coefficients of date of recovery on date of tagging of pink salmon tagged near the B.C. Electric Company Bridge over the Vedder and at the Harrison River Rapids fishing site. Also presented are tagging and recovery periods spanned by the recovered tags.

Recovery Area	Tagging Period (Days)	Recovery Period (Days)	*d*	*n*	*b*	*r*
Harrison River	15	33	21.0	1603	0.57	0.34
Chilliwack-Vedder River	18	41	28.1	328	0.51	0.25

Comparison of Life Spans

In summation it may be stated that the portions of the total life span spent en route to the spawning areas and on the spawning grounds was approximately the same for all early migrating races but was considerably longer for the two late races (Harrison and Chilliwack-Vedder) (TABLE 10). Those races which migrated furthest (Seton and Thompson races) spent the least time on the spawning grounds and the most time actively migrating. The Harrison and Chilliwack-Vedder races spent the majority of their life spans either in delay areas or on the spawning grounds while fish of the Fraser River race spent a considerable time actually on the spawning ground. Loss of chronology during migration from delay areas to the spawning grounds was not necessarily associated with maturity. Apparently fish arrived on the spawning grounds after delaying, in various stages of maturity. This

TABLE 10—Average duration of freshwater life of adult pink salmon; time spent en route from the fishery to the spawning areas and time spent on the spawning grounds prior to death.

RACE	DAYS FROM FISHERY TO DEATH	FROM FISHERY TO ARRIVAL		FROM ARRIVAL TO DEATH	
		Days	Per Cent of Total	Days	Per Cent of Total
Seton Creek	28.2	14.2	50.4	14.0	49.6
Fraser River	27.3	2.0[1]	7.3	25.3	92.7
Thompson River	28.5	12.0	42.1	16.5	57.9
Harrison River	32.4	10.9	33.6	21.5	66.4
Chilliwack-Vedder River	40.4	11.5	28.5	28.9	71.5

[1]Estimated from migration rate data.

resulted, between races, in different proportions of the life span being spent on the spawning grounds. For instance, fish belonging to races with long migration routes may have arrived at the spawning areas in a mature state without delaying en route and may have spawned soon after arrival. Fish of these races would probably maintain the chronology exhibited in the escapement throughout the remainder of their lives. Conversely, a race such as the Harrison, with a short migration route, probably spent the apparently excess portion of the life span in the delay area and again delaying on the spawning grounds. From presently available data it cannot be determined whether or not chronology was regained during spawning or after spawning, however it seems probable that this rearrangement took place during the period of spawning. Killick (1955) showed that, after spawning, sockeye tended to lose chronology. Since it has been shown that pink salmon maintained chronology to a considerable degree to death, it is possible that much less mixing could have been demonstrated had spawning time data been available.

ENUMERATION OF THE ESCAPEMENT

Management of the Fraser River pink salmon fisheries is dependent upon knowledge of the size of the total run. A part of this information can be supplied by enumerating individuals on the spawning grounds. Knowledge of the size of the total escapement allows the effectiveness of fishery regulations to be judged and is a first step necessary for predicting the size of the resulting run. Other factors may control the ultimate size of returning runs but without adequate escapements, maximum productivity cannot be obtained. Knowledge of the size of individual racial escapements is even more valuable. In conjunction with knowledge regarding times of passage of individual races, size of racial escapements can be used to design fishery regulations to be applied at particular times and in particular fishing areas during the season. Rehabilitation programs depend on accurate knowledge of racial escapement. Without spawning ground estimates the efficiency of these programs cannot be judged.

Populations of spawning pink salmon were enumerated in 1957 by several methods. The tagging and recovery method was most frequently used when dealing with large populations. This method was employed to estimate the total escapement to the Fraser River system. Tagging programs were also used to enumerate a number of racial escapements. Other methods were applied in special circumstances. The size of small runs was most frequently estimated by the visual count-index method. One major racial escapement was estimated by the use of the ratio of jack sockeye to pink salmon. Finally the number of fish spawning in the main Fraser was enumerated by a subtraction method.

In this section the tagging method is discussed as it has been employed to enumerate sockeye populations and as it applies to the enumeration of pink salmon populations. Other methods of enumeration which were used are described. The enumeration of the total escapement and of major racial escapements are treated separately.

Enumeration by the Tagging Method

Howard (1948) and Schaefer (1951) have discussed in detail the sources of error which can affect estimates of sockeye populations based on data provided by tagging and sampling programs. From these studies practical methods for enumerating sockeye populations have been developed by the Commission. These methods and their application to the 1957 pink salmon studies are presented.

Using the notation of Chapman (1948), an estimate of the abundance of a spawning population of sockeye can be obtained by

$$N = \frac{n\,t}{s}$$

where: N is the total number in the population;
t is the number of tagged or marked fish;
n is the number subsequently sampled;
s is the number of tagged fish in the sample.

If no loss of either tagged or untagged fish occurs prior to spawning the estimate of N applies to the spawning population; however if both tagged and untagged are reduced at an equal rate by the action of some factor or factors prior to spawning the estimate for N applies not to the spawning population but to the population as it existed in the tagging area and at the time of tagging.

Loss of tagged and untagged individuals in equal proportions could be brought about by delay below an obstruction (Thompson, 1945), effects of overcrowding combined with unfavorable environmental conditions in the stream or perhaps by predation (Shuman, 1950).

In practice, most enumeration programs undertaken by the Commission have been designed to avoid errors of this type. Tagging operations are almost invariably conducted immediately downstream from spawning grounds. This procedure virtually eliminates the possibility of fish dying prior to their arrival. All mortalities occur on the spawning grounds and any mortality occurring prior to spawning can be evaluated on the basis of the number of unspawned carcasses which are discovered.

When fish must be tagged at a point distant from the sampling areas, it is still unlikely, in most cases that a significant loss of tagged and untagged fish would occur prior to spawning. Although Davidson (1933) and Dvinin (1952) have reported the occurrence of significant natural mortalities affecting adult pink salmon in Alaskan and Asiatic streams, in the lower Fraser system no mass natural mortalities of salmon have ever been recorded. Obstructions to migration in the Hell's Gate region of the river caused serious mortalities to sockeye in some years (Thompson, 1945); however Talbot (1950) showed that the construction of fishways eliminated the delay and the resultant mortality.

Shuman (1950) and Mossman (1958) have indicated that predation by bears and birds may have serious effects on Alaskan salmon populations, however these authors showed that these predators operated primarily in the shallow spawning streams during spawning. In addition, bears are scarce in most areas of the Fraser and birds attack either carcasses or spawned, dying fish. It is, therefore, probable that the effects of predation on runs of salmon en route to spawning grounds are negligible.

Erroneous estimates of N can be made through the action of factors which reduce the number of tags or tagged individuals between tagging and arrival on the spawning grounds but do not affect untagged members of the population. Excessive estimates of N result from these losses of tags. Tags could be lost between tagging and arrival on the spawning grounds in two important ways. Tags could actually be lost from fish; however Petersen type tags leave characteristic scars which can be readily identified. Studies made on many sockeye populations for a number of years have indicated that few tags are lost from fish prior to death. The other important way in which the tagged to untagged ratio can be changed between the point of tagging and arrival, is through a mortality affecting only tagged individuals. Mortalities of this type are believed to be caused primarily by the tagging procedure.

Observations made for many years have indicated that mortality in fresh water as a result of the tagging procedures are small. In 1946 sockeye of the Adams River race were captured and tagged at Pritchard on the South Thompson, nineteen miles downstream from the mouth of the Adams River. The population estimate determined from this tagging program was 2,441,000 fish. The estimate from tagging at the mouth of the Adams was 2,352,000 (International Pacific Salmon Fisheries Commission, 1957), a difference of only 89,000 fish.

Although, under normal conditions, losses prior to arrival on the spawning grounds are apparently small they can, in some instances, be important. An intense and selective Indian fishery can affect estimates. Tagging mortalities might be important if immature fish are tagged (see later discussions). Unusual water conditions may prevent the migration and mortalities resulting from delay may be significant. These possibilities must be borne in mind when specific enumeration programs are designed.

Schaefer (1951) has stated: " . . . that either sampling for tagging must be uniform, or the subsequent sampling for tag-ratio must be such as to yield a representative sample of the whole population." Experience has shown that in most cases it is neither practical nor necessary to attempt to tag individual sockeye populations uniformly. In practice, it has been found that examination of carcasses to obtain tag ratios should be conducted throughout the period of dying and that the percentage examined should be uniform, both by area and by time. A simplified, hypothetical demonstration of the method is presented in TABLE 11. Although only a part of one segment of the run was tagged, a complete and uniform recovery effort yielded an accurate estimate of N regardless of variations in the tag ratio by time.

The situation represented by data shown in TABLE 11 is greatly simplified. Chronological order is not always fully maintained and mixing by time of both tagged and untagged does occur to some degree. This mixing, however, does not result in erroneous estimates of N if recovery effort is uniform and complete. In fact mixing is often advantageous as will be shown in the next paragraph.

Sampling of carcasses can be conducted throughout the whole period of dying but to obtain a uniform rate of examination by time and by area offers theoretical difficulties. In certain sections of the stream, carcasses may be more available than in other sections. If these differences in availability are coupled with differences in tag ratio, erroneous estimates of N are likely to be made if unadjusted data are used in the calculation. In practice, problems of this nature, can be solved. Tagged fish tend to distribute randomly, when alive, both by area and by time. Again after spawning, mixing by time is indicated (Killick, 1955) and finally after death further mixing by area occurs. All this mixing tends to establish a uniform tag ratio from area to area and between segments of the run. This mixing reduces errors which could result from differences in tag ratios combined with different rates of examination. Most spawning grounds are reasonably compact and uniform thus minimizing area differences which might cause differences in the percentage of fish examined.

In general, it can be concluded that the nature of most spawning grounds and the behavior of sockeye salmon tend to minimize or even eliminate errors which might result from differences in tag ratios coupled with differences in the availability of carcasses for examination. In certain instances errors which might result from differences in availability cannot be assumed to be negligible. These instances and methods for avoiding errors are discussed below.

It has been demonstrated (Peterson, 1954) that the availability of dead male and female sockeye differ. Females tend to remain close to their redds after spawning and come to the adjacent shore area after death. Males wander and may be carried out of the recovery area. The difference in availability resulting from the different behavior does not affect estimates of the population; however male and female tag ratios are usually different. Frequently

TABLE 11—Demonstration of the accuracy of a population estimate based on tags applied to only one segment of the run but uniform recovery effort applied to all segments.

TAGGING PERIOD			EXAMINATION PERIOD			
Segment of Run	Actual Number of Fish (N)	Number Tagged (t)	Segment of Run	Per Cent of Actual Number Examined	Number of Carcasses Examined (n)	Tags Recovered (s)
1	1000	0	1	25	250	0
2	2000	200	2	25	500	50
3	1000	0	3	25	250	0
Total	4000	200			1000	50

Calculated population is 4000

fish are captured for tagging with nets. Males tend to be selected and this results in proportionally more males than females being tagged. Under these conditions the use of combined male and female data may result in erroneous population estimates. Since males are less readily recovered, it can happen that too few are recovered in proportion to the number which are theoretically available. This applies to both tagged and untagged fish. Conversely it can happen that fewer females are tagged therefore fewer are available for recovery; however a larger proportion of both tagged and untagged female fish are recovered. A dilution of the combined tag ratio results from the proportionately heavy recovery of untagged females. In TABLE 12, a hypothetical example of the above situation is presented.

TABLE 12—Demonstration of the effect of combining male and female tagging and recovery data on the population estimate when rates of tagging and recovery differ for the sexes.

Sex	Number Tagged (t)	Number Examined (n)	Number Tagged Individuals Examined (s)	$\hat{N}$
Male	1,000	10,000	100	100,000
Female	750	20,000	150	100,000
Total	1,750	30,000	250	200,000

Combined male and female data estimate of N is 210,000

The data in TABLE 12, although hypothetical, are not unrealistic. The sex ratio (♂ : ♀) of fish tagged was 1.00 : 0.75 but on the spawning grounds an assumed difference in availability reversed the situation so that the sex ratio of tagged fish (♂ : ♀) was 0.67 : 1.00. In other words it was assumed that only ten per cent of the male fish were recovered whereas twenty per cent of the female fish were examined. It will be noted that the sum of N♂ and N♀ was 10,000 fish less than the estimate made from combined data.

When differences in availability occur between two groups and when it is possible to isolate the sampling data for the two groups, it is desirable in order to obtain the best estimate of N, to calculate the population of each group separately. These group populations can be added to obtain the total population estimate. It therefore follows, that provided enough males and females are tagged and recovered, it is desirable to calculate male and female populations separately and then add to get the total escapement estimate.

Calculation of separate male and female populations also provides data which can be used to obtain the best estimate of the spawning ground sex ratio (Peterson, 1954). A knowledge of this sex ratio is important in management and is therefore an additional reason for calculating male and female populations separately.

Killick (1955) has stated that 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. This type of behavior provides further opportunities for male and female tag ratios to differ and, therefore, gives an additional reason for calculating separate male and female populations.

To tag the required number of both males and females, effort should be intense during the period of the peak of migration to the spawning grounds. This procedure will insure that sufficient numbers of both males and females are tagged to provide for reliable estimates of N♂ and N♀. If effort is concentrated either at the beginning or at the end of the migration too few of one sex may be tagged. This can give an unreliable estimate of either N♂ or N♀. Combined data under these circumstances will also result in an erroneous estimate, but may provide a smaller confidence interval.

It can be concluded that differences in availability of sexes coupled with different tag ratios may result in erroneous estimates of N. Possible errors can be avoided by calculating populations of males and females separately. Addition of the two estimates gives the best estimate of the total population.

Differences in availability coupled with varying tag ratios can affect the estimate of total escapements to a river system if the estimate is based on data obtained from tagging at a single site. The population to be enumerated probably consists of a number of distinct races each of which spawns in a particular stream. Since fish of different races do not mix during spawning (or after death) to any appreciable degree, any differences in racial tag ratios at the tagging sites will also be apparent during sampling on the racial spawning grounds. Characteristics of streams and local climates vary. Both these factors affect the percentage of fish which can be examined. Timing of races usually varies, therefore the racial composition of catches at the tagging site must also vary. If tagging effort is not uniform and if sampling is not random, racial differences between tag ratios are likely to occur. The ratio differences, when coupled with differences between spawning ground availability, are likely to result in erroneous estimates of the total escapement. Errors of this kind are usually accentuated by differences in racial abundance.

Errors can be minimized by efficient experimental design. Sufficient tags should be applied to insure that the predicted amount of recovery data will provide reliable estimates of N. At the tagging sites, tags should be applied so that the tagged to untagged ratio is the same for each race. The only practical approach to this problem is to attempt to tag in proportion to abundance throughout the total run. If the fish are randomly mixed at the tagging site regardless of race this procedure will result in similar tagged to untagged ratios for all races. If attempts to tag in proportion to abundance do not result in similar tagged to untagged ratios for all races, recovery data must be adjusted. If adjustments are not made, the estimate of the total population will be erroneous (see Table 12).

Enumeration of sockeye populations by Commission personnel has shown that as many as ten per cent of tags available for recovery may be overlooked during the first examination of carcasses. Since all carcasses are counted, those which carry overlooked tags dilute the actual tagged to untagged ratio and cause an excessively high estimate of N to be made. It has been standard procedure for a number of years to re-examine an adequate sample of carcasses to determine the percentage of overlooked tags. Totals have been corrected by these percentages.

During the 1957 pink salmon studies it was found that sockeye tagging enumeration methods could be used virtually unchanged to enumerate pink salmon populations. For instance, female pink salmon were generally much more available as carcasses than were males. Males were more vulnerable to capture at the tagging sites. These differences required that separate male and female populations should be calculated. As previously described the total escapement was composed of races. Within each race males were apparently more abundant during the first part of the migration and females at the end. Migration and spawning behavior were similar for the two species. Unless otherwise stated methods and assumptions were identical to those discussed in relation to sockeye populations in previous paragraphs.

Total Escapement

Although the presence of a race of pink salmon spawning in the main stem of the Fraser River between the mouth of the Chilliwack-Vedder River and Jones Creek was suspected, no direct method could be devised for enumerating this run. Velocity conditions in this section of the Fraser made it impossible to tag; thus, if this race proved to be abundant a large error would be inherent in any estimate of total escapement based on the summation of individual racial estimates. For this reason it was believed necessary to enumerate the total pink salmon escapement. Another reason for making a total estimate was the possibility that attempts to enumerate fish on some spawning ground would be unsatisfactory because periodic floods might remove most of the carcasses from the stream. In this event, some estimate of the total escapement would be extremely valuable for management purposes.

The most suitable means for obtaining a total escapement estimate appeared to be the tagging and recovery method. Tags were placed on pink salmon captured at the Glen Valley and Silverdale sites throughout the upstream migration roughly in proportion to their daily abundance. Dead fish were examined on all spawning grounds throughout the period of dying. These tagging and recovery data were used to estimate the escapement (Chapman, 1948).

In the following sections treatment of these data are presented. Errors which might affect the data were considered. It was convenient to group these errors into two categories. The first type of error was that which affected either the tag ratio prior to arrival on the spawning grounds or the actual number of both tagged and untagged which reached the spawning areas. The second type of error resulted from the action of factors which affected the number of tags recovered on the spawning grounds. Corrections for the appropriate errors were considered under these two classifications.

TAGS AVAILABLE FOR RECOVERY

During operations at the tagging sites almost thirteen thousand pink salmon were tagged. It was assumed that the great majority of these would reach the spawning grounds. It was also assumed that some would be captured by commercial fishermen, by Indians and a certain number might die en route. TABLE 13 shows the number of fish tagged at the sites and the numbers of recovered tagged fish that could actually be assigned to the above mentioned sources.

TABLE 13—Number of pink salmon tagged at the Glen Valley and Silverdale sites and the number recaptured en route to the spawning grounds.

No. Fish Tagged	Source of Recovery	No. Tags Recovered
12,910	Commercial Fishery	60
	Indian Fishery	52

Recovered tags shown in TABLE 13 were those actually returned from the sources shown. Undoubtedly more tags were recovered but not reported. In the case of the Indian fishery this source of error was not important because the total catch made upstream from the tagging site was known from information supplied by the Department of Fisheries of Canada. The total escapement could be corrected by subtracting this Indian catch. In the commercial fishery the problem was more difficult because most tagged fish escaped the fishery and it was not possible to determine the percentage actually available for recovery or the segment of the catch which contained tagged individuals.

Although, as previously discussed, it was considered unlikely that natural mortalities affecting fish en route to the spawning grounds would be significant, the possibility was considered and the data were examined. The available evidence suggested that errors resulting through tagging mortality, natural mortality and unreported tags were of minor importance.

During operations at the tagging sites fish were handled carefully and only fish in apparently good condition were tagged. If pink salmon had reacted adversely to tagging it might be expected that during the commercial fishing seasons, weakened tagged fish would have been recaptured downstream from the tagging sites by commercial fishermen and that time between tagging and recovery would be considerable. Data were presented previously (TABLE 6) which showed that during the period when the Above and Below Bridge fishing areas were both open, tags were recovered primarily in the Above Bridge area. Only three of forty-one recoveries were made downstream from Pattullo Bridge. Of the thirty-eight upstream recoveries, thirty-five were made either at or above the tagging site. Most recoveries were made on September 10 from fish tagged on September 9. These results showed that there was very little retrograde movement of tagged pink salmon. This conclusion was substantiated by information obtained by comparing recaptures of Glen Valley tags at Silverdale and vice versa (TABLE 5). No fish captured and tagged at Silverdale were recaptured downstream at the Glen Valley site whereas thirty-six Glen Valley tags were recaptured upstream at the Silverdale location.

It might be expected that fish tagged from large catches might have a significant mortality caused by repeated handling, by fighting the net during holding and finally, as a result of the tagging process. Fish tagged from smaller catches might be expected to be in better condition at release because they were held for a shorter period of time and were handled less often. If these assumptions were correct, one would expect that the rate of recovery of tags from fish tagged from large catches would be lower than from smaller releases. Catches made at Glen Valley and Silverdale on September 15 are presented in TABLE 14. Recoveries by haul from the Seton, Thompson and Fraser races are also shown.

TABLE 14—Number and percentage of tags recovered from each catch made at the Glen Valley and Silverdale sites on September 15, 1957.

SILVERDALE			GLEN VALLEY		
Number Tagged	Recoveries		Number Tagged	Recoveries	
	Number	Per Cent		Number	Per Cent
368	36	9.78	377	37	9.81
102	10	9.80	104	10	9.62
169	16	9.47	157	10	6.37
17	1	5.88	66	5	7.58
85	7	8.24	64	6	9.38

On the basis of these data the hypothesis must be rejected. There was no indication that percentage recoveries were higher from smaller releases. On the contrary, highest recovery rates were attained from the largest releases.

It has been suggested that mortalities may result from the presence of lethal amounts of lactic acid in the blood of chinook and coho salmon released after tagging (Parker and Black, 1959). Parker, Black and Larkin (MS.) have shown that a significant number of coho caught at sea died after capture and tagging. This mortality was associated with an accumulation of lactic acid in the blood due to excessive exercise. These authors also showed that non-feeding coho captured in fresh water en route to spawning grounds were not adversely affected when subjected to the same procedure. No mortality was evident nor did lactic acid accumulate to what was considered to be the lethal range. The authors associated the lack of mortality with the cessation of feeding, a behavior common to all species of Pacific salmon during adult migration in fresh water. It is probable, therefore, that tagging and handling mortalities affecting pink salmon tagged in fresh water during the 1957 studies were also negligible. Similarly, the lack of evidence suggesting any mortality caused by delay, disease or predation indicated that losses of both tagged and untagged fish were minor between the fishery and the spawning grounds.

Undoubtedly some tags were recovered by commercial fishermen but not reported. Efforts were made by Commission personnel to secure a good return of these tags. Since most of the tags were available for recovery in the Above Bridge area where the tagging was conducted and where fishermen were well acquainted with the project, it is believed that a high proportion of recovered tags were returned.

Although it seems that loss of tags must have been a minor source of error, some loss certainly occurred and any estimate based on uncorrected data would produce an excessive population estimate. For this reason the total number of tags applied was reduced by the number of tags returned from fish captured en route to the spawning grounds. The total tagged at Glen Valley and Silverdale was 12,910 and the number subtracted was 60 (the reported number taken by the commercial fishery). It was then assumed that five per cent of the remaining tagged fish were lost and unaccounted for prior to their arrival on the spawning grounds. This correction left 12,207 tagged fish which were assumed to be the number present on all the spawning grounds of the Fraser River system. On the basis of the sex ratio of the fish tagged at the two tagging sites it was calculated that of the total available on the spawning grounds, 6,538 were males and 5,669 were females.

TAGS RECOVERED

As discussed previously, it was necessary to apply corrections to the number of tags actually recovered from dead pink salmon. The first correction was the upward adjustment of the number of Glen Valley and Silverdale tags recovered to account for those which were overlooked on the dead fish originally examined. Numbers of dead fish originally examined, numbers of tags

TABLE 15—Number of dead pink salmon examined, number of tags recovered and the resulting ratio.

Area	Number Examined	Number of Tags Recovered	Ratio
Main Fraser River	79,924	421	1:189.8
Harrison River	125,493	401	1:313.0
Chehalis River	4,328	31	1:139.6
Chilliwack-Vedder River	40,291	203	1:198.5
Seton Creek	30,065	218	1:137.9
Thompson River	34,456	185	1:186.2
Misc. Streams	9,766	60	1:162.8
Totals	324,323	1,519	

recovered and the resulting ratio of total fish examined to numbers of tags collected are presented in TABLE 15.

A re-examination of previously inspected fish was made in the Harrison River. One tag was recovered from a total of 12,688 carcasses re-examined. Since a total of 125,493 fish were pitched from the Harrison, it was estimated that ten tags were overlooked during the dead recovery program (125,493 ÷ 12,688). These additional tags should be added to the total shown in TABLE 15 giving a new total of 411. Although no re-examination was made on the Seton Creek spawning grounds, conditions affecting recovery were believed to be similar. Both spawning areas were compact and large numbers of dead fish were present in small areas. For these reasons the total number of tags recovered from Seton Creek was adjusted to the same degree as was the Harrison total. This adjustment resulted in the addition of two tags, correcting the total shown in TABLE 15 to 220 tags.

A similar re-examination experiment was conducted on the Main Fraser spawning grounds. A total of 5,222 previously inspected fish were re-examined. No additional tags were found so no correction was made to the total shown in TABLE 15. It is believed that few tags were overlooked because dead fish were widely dispersed and each fish was thoroughly inspected. Although no other re-examinations were conducted, it was believed that fish on the remaining racial spawning grounds were also widely dispersed; therefore no adjustments were made to account for overlooked tags.

It will be noted (TABLE 15) that ratios obtained from Seton Creek and Harrison data differed considerably from those obtained from the remaining three major races. It is probable that these races were not tagged at the tagging site at the same rate as were the remaining races. Since it was known from individual enumeration programs that the availability of dead fish varied considerably between streams, it was possible that unadjusted data might result in an erroneous estimate of N.

If recovery rates were known for all streams, recoveries from each stream could be weighted to an average value. Treatment of resultant recovery data and the tagging information would provide an accurate estimate of the total escapement to the Fraser River system. All racial rates of recovery were known except for the rate applying to the race spawning in the main Fraser River. It was therefore necessary to obtain an estimate of this rate.

The total escapement to the Fraser system was calculated from the previously presented tagging information and unadjusted recovery data. By summing individual population estimates and subtracting the resulting total from the total estimate, a preliminary estimate of the abundance of the main Fraser race was obtained. From these data and the number of carcasses examined in the main Fraser, an approximate rate of recovery of 5.9 per cent was obtained. This estimate, in conjunction with the known rates, was used to calculate an average rate of recovery of 12.8 per cent. Recoveries from each stream were then recalculated assuming that a rate of 12.8 per cent applied. Unadjusted and adjusted recovery data are presented in TABLE 16.

TABLE 16—Adjusted and unadjusted number of Glen Valley and Silverdale tags recovered in 1957 from all the spawning grounds of the Fraser River system. Also shown are estimated rates of recovery which applied to the various spawning streams.

STREAM	UNADJUSTED DATA			ADJUSTED DATA			
	n	s	$\frac{100n}{N}$	n♂	n♀	s♂	s♀
Fraser	79,924	421	5.9[1]	53,071	120,364	436	478
Harrison	125,493	411	21.4	27,784	47,512	122	125
Chehalis	4,328	31	46.4	474	738	3	6
Chilliwack-Vedder	40,291	203	18.4	11,874	16,330	69	73
Seton	30,065	220	49.5	2,939	4,878	28	29
Thompson	34,456	185	12.8	11,316	23,140	97	88
Miscellaneous	9,766	60	58.7	913	1,236	7	6
Total	324,323	1,531		108,371	214,198	762	805

[1]Approximation.

The adjusted numbers of male and female carcasses examined in each stream (n♂ and n♀) were determined by apportioning the adjusted totals according to the sex ratio of the actual number examined in each stream. The adjusted numbers of male and female tagged individuals examined in each stream were also determined (s♂ and s♀) from the sex ratio of the actual tagged fish recovered.

Although more males were tagged than females (53.6% males) a slight majority of the dead tagged fish examined (51.4%) were females. It is possible then, that males may have been slightly more available for capture at the tagging sites and it was obvious that females were more available as dead fish. These results indicate that the greater availability of females as dead fish more than compensated for the excessive number of males tagged at Glen Valley and Silverdale. As shown (TABLE 12) differences between availability of the sexes at the tagging site and during recovery can lead to erroneous estimates of N. For this reason tagging and recovery data for the two sexes were separated as shown in TABLE 16 and separate male and female population estimates were made.

CALCULATION OF TOTAL ESCAPEMENT

Population estimates for both sexes are presented along with tagging and recovery data in TABLE 17. The 95 per cent confidence limits by the Poisson approximation (Chapman, 1948) are shown in TABLE 18.

To obtain the best estimate of the actual escapement it was necessary to subtract from the total (2,438,262) the Indian catch of 13,395 leaving a remainder of 2,424,867. This figure represents the best estimate of the escapement to the Fraser River and all tributaries for 1957. The composition of this escapement was 61.9 per cent females and 38.1 per cent males.

TABLE 17—Tagging and recovery data and estimates of total escapement to the Fraser River system calculated from these tagging data.

Sex	Number Tags Available (t)	Number Tags Recovered (s)	Number Fish Examined (n)	Population Estimate ($\hat{N}$)
Male	6,538	762	108,371	929,829
Female	5,669	805	214,198	1,508,433
Totals	12,207	1567	322,569	2,438,262

TABLE 18—Confidence limits (95 per cent) applied to estimates of the total number of males and females in the escapement.

Sex	Estimated Escapement	Lower Limit	Difference	Upper Limit	Difference
Male	929,829	861,717	68,112	994,274	64,445
Female	1,508,433	1,400,838	107,595	1,610,056	101,623
Total	2,438,262				

Individual Racial Escapements

Several methods were used to estimate escapements to particular spawning areas. As mentioned, enumeration was by the use of tagging and recovery data, the use of ratios, the visual count-index method and a subtraction method. Each of these methods is presented separately in this section.

ENUMERATION BY TAGGING

Most sources of error inherent in population estimates made from tagging data have been discussed previously. One important source, not discussed was applicable when enumerating individual races. An error could have resulted from the straying of unspawned tagged fish from one area to another. If it could have been assumed that an equal proportion of untagged fish also strayed then estimates could probably have been adjusted to correct for this straying. However, straying, if it occurred, might have been caused by the tagging process. Thus tagged fish would have strayed to a greater extent than untagged fish and it would have been difficult to make the necessary adjustments.

Fish captured at the mouths of the Harrison and Chilliwack-Vedder Rivers were tagged and released. Migrating fish were also tagged as they arrived on the Harrison, Chilliwack-Vedder and Seton Creek spawning grounds. Numbers and percentage of recoveries from the commercial fishery and from spawning streams other than the stream of release are shown for each release area in TABLE 19.

Most of the fish recaptured by the commercial fishermen were spawned out and either dead or dying at the time of recapture. Fish recaptured by the commercial fishery cannot, therefore, be counted as strays. Actually, of the recaptures shown in TABLE 19, only two can be definitely attributed to fish which had strayed. Both tags were recovered from dead fish on other spawning grounds.

On the basis of this information, it can be concluded that straying of unspawned pink salmon from one spawning stream to another was infrequent. Errors resulting from a loss of tagged fish to streams other than the one in which they were tagged were negligible.

Since there was no evidence suggesting a significant loss of live tagged fish or for that matter untagged fish during any of the studies, it was assumed that the number of fish tagged was the number available for recovery. Tags were removed from dead fish by sportsmen in some areas. The number of returned tags was subtracted from the number available for recovery.

Data from the Harrison and Seton Creek areas were adjusted on the basis of results obtained by the re-examination of carcasses. The total number of

TABLE 19—Number and percentage of tags recovered in the commercial fishery and on other spawning grounds from fish tagged and released adjacent to spawning areas.

AREA OF RELEASE	NUMBER RELEASED	RECOVERIES			
		Commercial		Other Spawning Grounds	
		No.	Per Cent	No.	Per Cent
Harrison Rapids	7731	3	0.04	2	0.03
Harrison Mouth	382	0	0	0	0
Vedder	1868	0	0	0	0
Vedder Mouth	885	1	0.11	0	0
Seton Creek	999	1	0.10	0	0

TABLE 20—Tagging and recovery data used to make escapement estimates.

AREA	TAGGED FISH AVAILABLE FOR RECOVERY (t)		DEAD FISH EXAMINED (n)		TAGS RECOVERED (s)	
	Male	Female	Male	Female	Male	Female
Harrison River	3,230	4,501	46,242	79,231	577	1,090
Chehalis River	315	230	1,694	2,634	127	118
Chilliwack-Vedder River	1,038	830	16,955	23,336	167	170
Seton Creek	363	636	11,333	18,732	195	301

tags recovered in both areas was corrected by the addition of 4.38 per cent of these totals. In each case the sex ratio of the added tags was determined from the sex ratio of the dead recovery.

Corrected tagging and corrected recovery data are shown in TABLE 20 and escapement estimates and confidence limits are shown in TABLE 21. Some of the escapement estimates include small populations spawning in tributary streams. These have been enumerated by other methods. For instance, the Harrison area population of 586,144 includes the Weaver Creek escapement which was estimated by another method at 346 fish. When this figure was subtracted the actual escapement to the Harrison River was assessed at 585,798.

Pink salmon were tagged at the mouth of the Harrison River and at the mouth of the Vedder River. These two sites were abandoned and tagging sites in both cases were moved upstream to the lower limit of the spawning grounds. The reasons for the changes were to reduce the possibility of fish straying to other areas and also to increase catches and, therefore, tag releases. Totals of 145 males and 237 females were tagged and released at the mouth of the Harrison River. Of carcasses examined, 27 males and 32 females carried these tags. At the mouth of the Vedder River, 407 males and 478 females were tagged and released. Totals of 78 and 97 tags were recovered from male

TABLE 21—Escapement estimates determined from results of tagging programs and confidence limits (95 per cent) on the estimated abundance of each sex.

Area	Sex	Estimated Escapement	Per Cent Composition	Upper Limit	Difference	Lower Limit	Difference
Harrison River	Male	258,971	44.2	279,578	20,607	237,199	21,772
	Female	327,173	55.8	346,030	18,857	307,014	20,159
	Total	586,144					
Chehalis River	Male	4,202	45.0	4,950	748	3,488	714
	Female	5,134	55.0	6,087	953	4,232	902
	Total	9,336					
Chiliwack-Vedder River	Male	105,385	48.1	121,601	16,216	89,587	15,798
	Female	113,935	51.9	131,288	17,353	97,000	16,935
	Total	219,320					
Seton Creek	Male	21,097	34.8	24,082	2,985	18,154	2,943
	Female	39,580	65.2	44,030	4,450	35,070	4,510
	Total	60,677					

and female carcasses. The total numbers of examined carcasses of both sexes for the Chilliwack-Vedder and Harrison areas is shown in TABLE 21. Population estimates and confidence limits based on results of these releases and recoveries are presented in TABLE 22.

TABLE 22—Estimated escapements to the Harrison and Chilliwack-Vedder areas and confidence limits (95 per cent) on these estimates based on the results of tagging programs conducted at the mouths of the Harrison River and Vedder Canal.

Area	Sex	Estimated Escapement	Upper Limit	Difference	Lower Limit	Difference
Harrison River	Male	248,337	354,017	105,680	166,214	82,123
	Female	586,806	812,538	225,732	405,655	181,151
	Total	835,143				
Chilliwack-Vedder River	Male	88,470	109,050	20,580	69,788	18,682
	Female	114,996	138,722	23,726	92,955	22,041
	Total	203,466				

It will be noted that the estimated Harrison escapement, determined from the limited operations at the mouth of the river, was much higher than the estimate obtained from the complete and intensive operations conducted at the rapids site. It will also be noted that most of the difference resulted from a high estimate of the female population. The estimate based on tagging at the mouth was 835,143 of which 248,337 were males and 586,806 were females. The estimates determined from the upstream program were 258,971 males and 327,173 females, giving a total estimate of 586,144. It is probable that the high estimate obtained from the downstream tagging program was caused by insufficient recoveries of tags which in turn resulted from insufficient numbers of tags applied. It is also important to note the wide confidence intervals which apply to these estimates as a result of insufficient data.

Chilliwack-Vedder escapements determined from downstream and upstream tagging agreed quite closely (TABLES 21 and 22). More tags were applied at the upstream site and more recoveries were made. This resulted in shorter confidence intervals, although those which applied to the downstream estimates were not excessive.

Comparisons of upstream and downstream estimates, indicated that in the future under similar conditions, tagging effort applied to the Chilliwack-Vedder race could be reduced. Results of the tagging at the mouth of the Harrison showed that this effort on the Chilliwack-Vedder should not be reduced, until, as suggested by Chapman (1948), a reasonable estimate of the upper limit of the population can be made. Care should be taken to tag during the peak of the run so that sufficient numbers of both sexes are available for recovery.

ENUMERATION BY SPECIES RATIO

Both pink salmon and jack sockeye were counted in the Thompson River as they migrated upstream. The counting site was located six miles downstream from Spences Bridge, the lower margin of the spawning ground. After passing the site, pink salmon travelled as far as the outlet of Kamloops Lake. Spawning occurred downstream from this point to Spences Bridge. All jack sockeye were en route to the South Thompson area. Most of them were destined for Adams River and Little River (International Pacific Salmon Fisheries Commission, 1957) and on their arrival in the Adams-Little River area, fish were captured and tagged. The population estimate of 304,151 (Adams River, Little River and the South Thompson populations) was obtained from tagging and recovery information. A special effort was made in 1957 to make this estimate particularly reliable. Confidence limits (95 per cent) are presented in TABLE 23.

TABLE 23—Estimated escapement of jack sockeye to the South Thompson district in 1957. Also presented are confidence limits (95 per cent) on the estimate. Early run estimates were excluded.

Estimated Escapement	Upper Limit	Difference	Lower Limit	Difference
304,151	325,165	21,014	282,118	22,033

The ratio of jack sockeye to pink salmon at the counting site was obtained by summing daily counts of both species and dividing the number of pink salmon observed by the number of jack sockeye seen (118,179 ÷ 133,569). The total escapement of jack sockeye to the South Thompson district (excluding the Seymour run which was an early escapement) was multiplied by the ratio to obtain an estimate of 269,106 pink salmon spawning in the Thompson River and tributaries. Limits were obtained by multiplying the ratio of jack sockeye to pink salmon by the upper and lower limits of the jack sockeye population (TABLE 23). This procedure resulted in a lower limit of 249,612 and an upper limit of 287,699.

It was not possible to calculate directly separate male and female populations and thus determine the percentage composition, by sex, of the escapement, however this apportionment was made by an indirect method. A total of 185 Glen Valley and Silverdale tags were recovered from fish examined from the Thompson race. As presented, it was calculated that 12.8 per cent of the total Thompson run was available as dead fish. Assuming that the same percentage of dead tagged fish were available, the total number of tagged individuals present was 1445. Since most of the Thompson race passed the Glen Valley and Silverdale areas prior to September 23 and 53.8 per cent of the total fish tagged to this date were males it was assumed that 53.8 per cent of the total theoretical number of tagged individuals present on the Thompson spawning grounds were also males. Apportionment on this basis gave totals of 778 males and 668 females. Using Thompson River recovery data presented in

TABLE 16 it was then possible to calculate separate male and female populations. It was found that males formed 34.1 per cent of the total and that females formed 65.9 per cent.

Errors which might have affected the accuracy of the population estimate were:

1. A significant mortality affecting jack sockeye en route between the counting site and the South Thompson district;
2. A significant error in estimating the jack escapement;
3. Differing behavior of the two species at the counting site.

A significant mortality affecting jack sockeye would cause the pink salmon escapement to be underestimated; however a loss of ten per cent of the estimated jack escapement (about 30,000 fish) would result in the pink salmon population being underestimated by only 26,000 fish. Since observations revealed that there was no significant loss of jacks between the counting site and the spawning grounds, errors resulting from a migration mortality were considered to be negligible.

As stated, particular effort was expended to obtain a reliable estimate of the jack sockeye escapement to the South Thompson district. Data presented in TABLE 23 indicate that the estimate was reliable.

It was known that pink salmon migrated earlier than sockeye therefore to obtain an accurate ratio of one species to the other, counting had to be conducted for the duration of both migrations. Daily counts of both species are shown in FIGURE 22. It can be concluded that counts were made throughout the complete migration periods of both species.

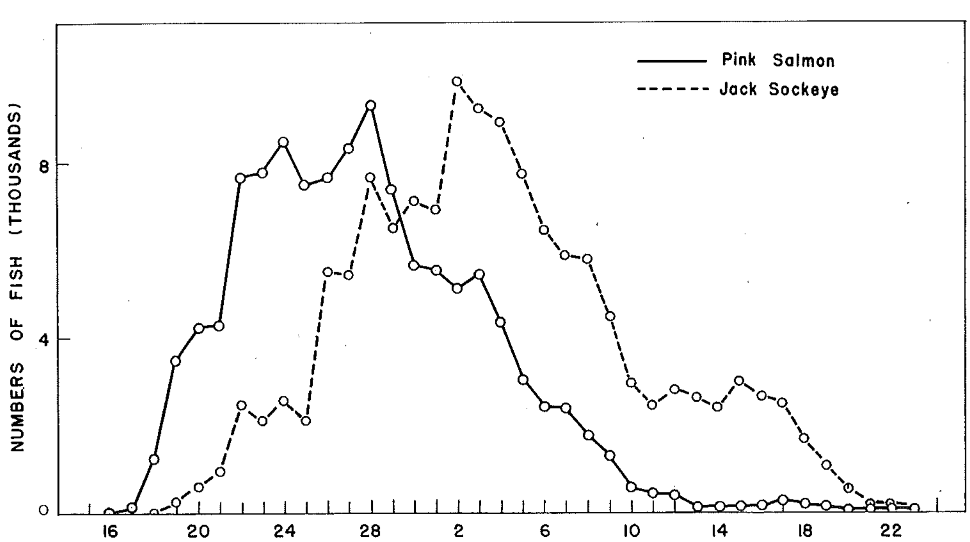

FIGURE 22—Daily counts of pink salmon and jack sockeye at the left bank site on the Thompson River.

Both jack sockeye and pink salmon were visible and distinguishable at the counting site. The Thompson River was clear and the bottom of the river could be seen in the counting area. Pinks and sockeye were separable on the basis of color and size differences. Pink salmon weighed almost twice as much as jack sockeye and were dark grey in color whereas the jack sockeye were red. There was no reason to suspect that one species was significantly easier to count at the site than the other.

If the ratio of pink salmon to jack sockeye varied in different localities, indicating that their migration behavior differed, the ratio established from data collected at the counting site could have been erroneous. For instance, if a higher proportion of jack sockeye migrated up the center of the river, the pink salmon estimate based on the counting site ratio would be too low.

The possibility of differences in migration behavior was tested by making counts of pinks and jack sockeye at a point on the left bank approximately one mile upstream from the regular site. If there was a tendency for one species to select different flow conditions than the other, it might be expected that the ratio of one species to the other at another counting site would be different. TABLE 24 presents the total counts of both species made at both sites for the same day. The results of the chi-square test show that the difference in ratios at the two sites could have arisen by chance. These results suggest that the migration behavior of the two species was similar.

TABLE 24—Chi-square test of differences between ratios of pink salmon to jack sockeye established from counts made at the regular Thompson River site and a site located further upstream. Counts were made at both sites on October 8.

Site	Total Fish Counted	Number of Pinks Counted	Expected No. of Pinks	No. of Jack Sockeye Counted	Expected No. of Jack Sockeye	Chi-Square
Upstream	3,992	1,005	977	2,987	3,015	1.062
Regular	7,568	1,823	1,851	5,745	5,717	0.561
Total	11,560	2,828		8,732		1.623

Chi-square = 1.623 $P < 0.20$

It has been estimated that most of the pink salmon migration took place during daylight (FIGURE 20). If more jack sockeye migrated at night than pink salmon, the population estimate of pink salmon would be too high. The average daily migration curves for both species are shown in FIGURE 23. It will be noted that the daily migration pattern for both species was very similar. There was no evidence indicating that the proportions of the two species might differ during migration at night.

It can be concluded that the various sources of error considered did not significantly affect the population estimate determined from the known abundance of jack sockeye and the ratio of pink salmon to jack sockeye at the Thompson River counting station.

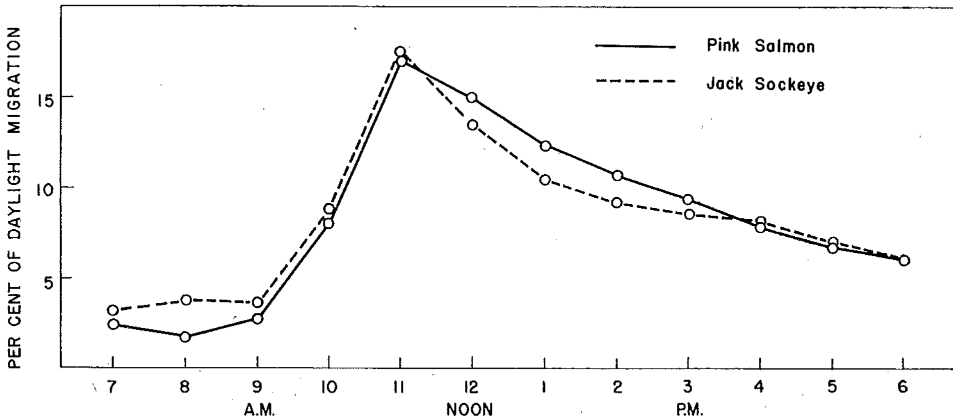

FIGURE 23—Average hourly migration of pink salmon and jack sockeye past the Thompson River counting station.

ENUMERATION BY THE INDEX METHOD

During the early part of a salmon spawning run, the population increases as a result of recruitment of fresh fish onto the spawning area. Later, recruitment declines and natural mortality affecting spawned fish reduces the number of live fish. When recruitment is less than the number of fish dying the population decreases. The live population continues to decrease until all fish are dead. In this situation of changing abundance, spot counts of either live or dead fish made at any time during the period of availability on the spawning grounds underestimate the total abundance of fish. More accurate estimates can be made by methods which are dependent upon sampling throughout the whole run. Estimates made from data supplied by tagging fish and the sampling of carcasses during the period of dying is one method which has been discussed in detail. Another method sometimes used, is to count all arrivals through a weir located downstream from the spawning grounds. The tagging method is best suited to the enumeration of large populations. Enumeration by weir counts is sometimes undesirable for several reasons. Fish tend to delay below weirs and this additional delay could produce undesirable results. Weirs are expensive to install and often difficult to maintain.

When numerous minor runs must be enumerated some economical method is required. The abundance of small sockeye populations has been assessed by multiplying counts of live and dead fish by a suitable index. The resultant product is used as an estimate of the abundance of spawners in the particular stream. The maximum visual count of live fish made during the period plus the accumulated number of dead fish examined up to and including the date of the maximum visual count is multiplied by the index.

In addition to variations in the number of fish present and available to be counted the index must account for those that are present but not seen by the observer. For a particular race of salmon, the validity of the index used depends on two important assumptions. The method assumes that the maximum visual count plus the accumulated dead represents a constant percentage of the run from year to year and that the number of fish present but not observed also forms a constant percentage of the total population. If the same index is used to enumerate different races it must also be assumed that conditions on the racial spawning grounds and the character of the racial migrations are similar.

Indices were first developed for runs of sockeye spawning in streams flowing into Middle River in the Stuart Lake district of the Fraser River system. Listed in TABLE 25 are population estimates derived from tagging experiments and weir counts. Also shown are maximum visual counts, the accumulated number of carcasses which were examined up to and including the date on which the maximum count was made and the index for each of the two runs. Indices were obtained by dividing the population estimate, determined from weir counts, by the maximum visual live count plus accumulated dead.

TABLE 25—Sockeye population estimates, maximum visual counts, accumulated dead fish totals and indices derived from these data.

YEAR	STREAM	POPULATION ESTIMATE		MAXIMUM VISUAL COUNT	ACCUMULATED DEAD	INDEX
		Weir Count	Tagging Program			
1946	Forfar Creek	1822	1789	780	163	1.93
1952	Forfar Creek	6301	6305	3594	119	1.70

Mean Index — 1.82

Often, tagging programs have been conducted in conjunction with visual counts. In TABLE 26, indices are presented which were obtained by dividing these population estimates by maximum visual counts plus accumulated dead.

TABLE 26—Population estimates derived from tagging programs and indices obtained by dividing these estimates by the maximum visual count of live fish plus the accumulated dead fish examined.

Year	Stream	Population Estimate	Index
1946	Forfar Creek	1,789	1.90
1950	Gluske Creek	11,007	1.57
1950	Forfar Creek	10,259	1.46
1950	Rossette Creek	6,260	1.59
1952	Forfar Creek	6,305	1.70
1953	Forfar Creek	18,054	1.71
1953	Kynoch Creek	16,676	1.42
1954	Forfar Creek	5,702	1.80
1954	Kynoch Creek	14,088	1.69

Mean Index — 1.65

It will be noted that the average index obtained from this series of experiments, was considerably lower than that obtained from data presented in TABLE 25. This difference probably occurred for a number of reasons. In several instances the populations were too large to be accurately enumerated by the live count method. Visual counts made at Kynoch Creek in 1953 were hampered by poor visibility. Periods of arrival and residence on the spawning grounds may have varied somewhat between years and between streams. If this occurred the percentage, formed by counts, of the total population would vary and would cause the index to vary accordingly. It is also possible that certain population estimates obtained from tagging programs may have been erroneous. In spite of these possibilities it is evident that small populations of sockeye spawning in small streams can be enumerated with a reasonable degree of accuracy by the visual-count index method. The index which should be used apparently lies between 1.4 and 1.9.

During the 1957 season, minor runs of pink salmon were enumerated by multiplying visual counts plus accumulated dead by an index derived from data obtained from enumeration of the Chehalis race. The population estimate of 9336 was determined from data supplied by a tagging program. During the arrival and spawning periods visual counts and enumerations of carcasses were made. The maximum visual count was 3540 on October 4, and the cumulative total number of carcasses examined to this date was 51. The index obtained by dividing the population estimate by the visual count plus the accumulated dead total was 2.6. Maximum visual counts made on other minor runs were multiplied by this index to obtain estimates of the number of spawning pink salmon.

The pink salmon index was larger than the ones derived for sockeye. One reason for this difference could be that pink salmon are less visible in turbulent water than sockeye therefore a lower percentage of those present are counted. Another cause of the difference could be that the maximum number present at any one time formed a smaller percentage of the total run. This latter situation could be associated with a lower rate of arrival onto the spawning grounds. One or a combination of both these causes could account for the larger pink salmon index. Further studies are required to determine the best index and factors affecting the index.

ENUMERATION BY THE SUBTRACTION METHOD

The escapement to the main Fraser was estimated by summing the escapements to all other streams and subtracting this sum from the estimated total escapement. A complete list of escapement estimates along with periods of peak spawning are shown in TABLE 27. From these data it will be noted that the estimated escapement to the main Fraser River spawning grounds was 1,263,651 or 52 per cent of the total escapement.

Each individual escapement estimate had upper and lower confidence limits and so had the total population estimate. If the sum of the upper limit values for individual estimates (both sexes combined) was subtracted from

TABLE 27—Summary of the pink salmon escapement to the Fraser River spawning areas, 1957.

District and Streams	Period of Peak Spawning	Estimated Number of Pink Salmon
EARLY RUNS		
LOWER FRASER		
Main Fraser	Sept. 20-30	1,263,651
HARRISON		
Chehalis River	Oct. 6-12	9,336
FRASER CANYON		
Coquihalla River	Sept. 24-26	4,433
Jones Creek	Sept. 29-Oct. 5	1,493
Lorenzetti Creek	Sept. 29-Oct. 4	6
Silver Creek	Sept. 26-30	549
Hunter Creek	Sept. 22-25	13
American Creek	Oct. 3	4
Spuzzum Creek	Oct. 3-18	1,076
Nahatlatch River	Oct. 5-10	208
Anderson Creek	Sept. 28-Oct. 3	824
Stein River	Oct. 7	185
Churn Creek	Oct. 10-12	8
SETON-ANDERSON		
Seton Creek	Oct. 1-10	58,810
Portage Creek	Oct. 8-10	1,867
THOMPSON		
Thompson River	Oct. 1-9	266,329
Nicola River	Sept. 26-30	1,560
Bonaparte River	Sept. 22-Oct. 1	653
Deadman River	Oct. 1	564
TOTAL		1,611,569
LATE RUNS		
LOWER FRASER		
Stave River	Oct. 25-28	6,500
Whonnock Creek	Oct. 22-25	549
Suicide Creek	Oct. 15	2
Silverdale Creek	Oct. 20-25	52
Kanaka Creek	Oct. 20-23	153
South Alouette River	Oct. 25-28	8
North Alouette River	Oct. 25	8
Silver Creek (Pitt Lake)	Oct. 25-30	239
Coquitlam River	Nov. 1	6
Upper Pitt River	—	0
Upper Sumas Creek	—	0
Legace Creek	—	0
Beaver Creek	—	0
HARRISON		
Harrison River	Oct. 19-25	585,798
Weaver Creek	Oct. 25-29	346
Squakum Creek	—	0
Silver Creek (Harrison Lake)	—	0
CHILLIWACK-VEDDER		
Chilliwack-Vedder River	Oct. 10-25	212,334
Sweltzer Creek	Oct. 18-25	6,874
Little Chilliwack Creek	Oct. 15	68
Brown Creek	Oct. 15	44
FRASER CANYON		
Kawkawa Creek	Oct. 20-25	317
Popkum Creek	—	0
Emory Creek	—	0
Yale Creek	—	0
TOTAL		813,298
GRAND TOTAL		2,424,867

the lower limit value obtained for the total population estimate (both sexes combined), the difference would represent a minimum estimate of the number of pink salmon spawning in the main Fraser River. Conversely, if the sum of lower limit values was subtracted from the upper limit value for the total escapement, the difference would represent a maximum estimate of the main Fraser spawning population.

In previous sections upper and lower 95 per cent limits were presented for the abundance estimates of the two sexes for populations spawning in a number of streams. Similarly, limits were placed upon the estimates of the total escapement of males and females. Of the major races, the Thompson was the only one on which limits were placed on an estimate of the escapement of both sexes combined. To obtain confidence limits for the combined male and female estimates for the remaining races and the total escapement estimate, populations were recalculated using combined male and female data. Confidence intervals for these estimates were determined but were applied to the estimates of N obtained by summing estimates of N♂ and N♀. Minor races were enumerated by the visual count-index method. Some of these minor runs were included in estimates obtained from tagging programs but others were not. It was not possible to calculate confidence limits for the latter, however escapement to these streams was estimated to be only 16,633 pink salmon. Absence of upper and lower limits on this small total would contribute very little error to the totals; therefore this sum, without the addition of limits, was included in TABLE 28.

TABLE 28—Escapement estimates, 95 per cent limits and maximum and minimum estimates of the number of pink salmon spawning in the main Fraser River.

Estimate	$\hat{N}$	Upper Limit of N	Lower Limit of N
Harrison River	586,144	616,960	556,975
Thompson River	269,106	287,699	249,612
Seton Creek	60,677	65,920	55,229
Chilliwack-Vedder River	219,320	242,987	195,186
Chehalis River	9,336	10,543	8,127
Separate Minor Runs[1]	16,633	16,633	16,633
Total	1,161,216	1,240,742	1,081,762
Total Escapement	2,424,867	2,545,093	2,295,041
Main Fraser River	1,263,651		
Greatest Main Fraser River	2,545,093 — 1,081,762 = 1,463,331		
Smallest Main Fraser River	2,295,041 — 1,240,742 = 1,054,299		

[1]Confidence intervals could not be calculated for separate minor estimates.

From data presented in TABLE 28 it can be concluded that the difference between the sum of individual estimates and the total escapement estimate was a reliable estimate of the number of pink salmon spawning in the main Fraser River. The contribution of experimental error to this difference was negligible. It is interesting to note that the accuracy of the subtraction method improves with increases in the difference between the two totals.

The sex ratio of the escapement of pink salmon to the main Fraser spawning grounds could not be determined by direct methods; however this information was derived indirectly. Presented in TABLE 29 are adjusted escapement data from the main Fraser spawning grounds.

TABLE 29—Adjusted escapement data to the main Fraser River spawning grounds.

Sex	Number of Carcasses	Number of Tags Recovered
Male	53,071	436
Female	120,364	478
Total	173,435	914

Using the estimated escapement to the main Fraser (1,263,651) and the totals shown in TABLE 29, the theoretical number of tags available for recovery was calculated. The sex ratio of this theoretical total of 6659 was not known; however, the sex ratio of fish tagged at Glen Valley and Silverdale was 53.8 per cent males to September 23 inclusive. Most of the Fraser run passed the tagging area prior to this date and the Fraser race formed the bulk of the fish tagged during this period before September 23, therefore it was assumed that 53.8 per cent of Fraser tags available for recovery were males. Apportionment of this theoretical total of 6659 tagged fish into 3583 males, 3076 females, allowed theoretical male and female populations to be calculated. Of the total it was estimated that 34.5 per cent were males and 65.5 per cent were females.

SUMMARY

Individual populations of pink salmon spawning in particular streams were defined as races.

Identification of races in the escapement, timing of the total escapement and the timing of individual racial escapements were determined from a tagging and recovery program. Weighted numbers of tags recovered on individual spawning grounds, when plotted according to date of tagging, represented the migration curve of each race. Among the five major races three were found to migrate earlier than the remaining two. Peaks of abundance of the three early races coincided during the period September 14 to 17 inclusive. Peaks of passage of late races were less well defined but occurred during the last week of September and the first week of October.

It was found that minor races of pink salmon spawning in numerous streams could also be classified as early and late runs.

Commercial catches by the Fraser River fishery were made early in the run. Daily total escapement was calculated and it was concluded that catches were unlikely to have significantly affected the peak of the escapement curve. From this it was also concluded that the escapement was representative of the run entering the river. Since late races were lightly fished the escapement curve was also representative of the migration curve of these races as they entered the Fraser River.

Results of tagging investigations indicated that peak catches made prior to the end of the first week of September in fishing areas other than the Fraser were composed predominantly of fish belonging to early migrating races.

Since the timing of the races and racial composition of catches from fishing areas other than the Fraser were unknown it was not possible to determine either the times of passage of races of Fraser River pink salmon or the fishing intensity applied to these races.

In the Fraser River fishing areas (District I) it was possible to calculate the total fishing mortality because both total catch and total escapement were known. The calculated fishing mortality was 27.4 per cent. Fishing mortalities affecting early and late segments of the run were also calculated from catch and escapement data. The mortality affecting late runs was assessed at 7.2 per cent and that affecting early runs at 34.5 per cent. Some of the catch was made on delaying fish off the mouth of the Fraser. It was therefore possible that the proportion of late run fish in the catch was higher than in the escapement at the time fishing ceased. In this event, the estimate of 7.2 per cent would be somewhat low. Even so it was concluded that fishing mortality affecting late races was much lower than that affecting early races.

The difference between peak daily catches in the fishing areas indicated, within useful limits, the time taken for fish to travel between these areas. From the peak daily catch at Point Roberts and the peak daily escapement at

the upper limit of the commercial fishery, it was estimated that pink salmon delayed off the mouth of the Fraser for approximately twelve days.

For early migrating races, daily changes in catch per haul, changes in daily percentage of net-marked individuals and changes in the sex ratio in catches made at the tagging sites, when evaluated in terms of the fishing regulations, all indicated a migration time from the mouth of the river to the tagging site of 48 hours or about 23 miles per day.

During the period when tagging was conducted at both the Silverdale and Glen Valley sites, some fish tagged at Glen Valley were recovered at the upstream Silverdale site but no Silverdale tags were recovered at Glen Valley. These results and the estimated time out for these upstream recoveries indicated that pink salmon moved rapidly and directly upstream. This conclusion was supported by recoveries of tags from the commercial fishery.

A decreasing rate of capture of previously tagged fish indicated that there was no tendency for late run fish to delay in the tagging area. In fact the data indicated that late run fish may have moved more rapidly than early migrating fish. Estimates of the time between release and recapture at the same site indicated that tagged fish did not delay for a significant period in the tagging area.

It was concluded that pink salmon did not delay for a significant period while en route between the mouth of the Fraser and the upper limit of the commercial fishery.

The time interval between the peak of the Thompson escapement at the tagging site and the peak of occurrence of tagged individuals at a counting site on the left bank of the Thompson below the spawning grounds indicated a migration rate of about eleven miles per day. This reduction in the rate of migration as compared with that exhibited in the lower Fraser was also indicated by a comparison of the migration curves measured at the two sites. An unusual but similar reduction affected the 1954 Adams River sockeye migration. In the case of pink salmon, reduced migration rate was associated with areas of difficult passage, particularly in the Fraser Canyon. There was evidence suggesting that migration rate may have increased again after the fish passed through the Fraser Canyon. There was no evidence suggesting a protracted delay en route.

Data collected pertaining to the Seton Creek race indicated a similar migration behavior but the actual migration rate was slightly higher, about 12 miles per day as compared with 11 for the Thompson race. Again there was no evidence indicating delay or blockage en route.

Fish of the two major late runs delayed for extended periods in the lower reaches of their native stream. Information obtained from recovered tags suggested that Harrison River pink salmon delayed for an average of about 9 days in the lower part of the Harrison River and in the Fraser River adjacent to the mouth of the Harrison. Similar data indicated that pink salmon of the Chilliwack-Vedder race delayed in the mouth of the Vedder River for an average of about eight days. The behavior of fish of these two races differed from that of fish belonging to the two earlier migrating races. The latter did not delay en route to the spawning areas.

Although information regarding maintenance of chronological order to spawning was not available, data were available indicating that chronology was maintained from escapement at upper limit of the fishery to death. Analysis of additional tagging data indicated that in some cases chronology was lost between the fishery and arrival. It was concluded that in these instances chronology was regained during residence on the spawning grounds. Since mixing was known to occur among sockeye between spawning and death it seemed probable that chronology was regained during the spawning period of pink salmon.

Knowledge of the number of fish reaching the spawning grounds was considered necessary for most efficient management. In 1957, the total escapement and escapements to individual streams were enumerated by several methods. The most important method involved tagging live fish and, after death, examining all available carcasses. The method used to calculate the estimate from these tagging data and various errors which might affect the estimate were considered. The tagging method was used to obtain an estimate of the total abundance of pink salmon in the Fraser River system and also to obtain estimates of the abundance of several important races.

One of the major races was enumerated by multiplying the ratio of pink salmon to jack sockeye by the escapement of jack sockeye. The product was an estimate of the escapement of pink salmon to the Thompson River system. Errors affecting this estimate were considered.

Numerous small populations of pink salmon were enumerated by multiplying the maximum live count by an index. This method was first applied to sockeye spawning populations in the Stuart River system. The pink salmon index was determined by dividing the estimated escapement to the Chehalis River, determined from tagging data, by the maximum number of live individuals counted on the spawning grounds. Maximum live counts made on other streams were multiplied by this index to obtain escapement estimates. This method depended on the assumption that each maximum live count represented the same fraction of each escapement.

The escapement to the main Fraser River was estimated by subtracting the sum of individual racial estimates from the total escapement estimate. The difference was the number of pink salmon which spawned in the Fraser River. Maximum and minimum estimates for this population were calculated.

LITERATURE CITED

Andrew, F. J. and G. H. Geen. 1958. Sockeye and pink salmon investigations at the Seton Creek hydroelectric installation. *Internat. Pacific Salmon Fish. Comm.,* Progress Report.

Chapman, D. G. 1948. Problems in enumeration of populations of spawning sockeye salmon, 2. A mathematical study of confidence limits of salmon populations calculated from sample tag ratios. *Internat. Pacific Salmon Fish. Comm.,* Bull. II.

Davidson, F. A. 1933. Temporary high carbon dioxide content in an Alaskan stream at sunset. *Ecol., 14 (2):* 238-240.

DeLacy, A. C. and F. Neave. 1948. Migration of pink salmon *(Oncorhynchus gorbuscha)* in southern British Columbia and Washington in 1945. *Bull. Fish. Res. Bd. Can., 74.*

Department of Fisheries, Canada. 1957. The spawning of pink salmon in the Fraser River system above Hope, 1955. MS.

Dvinin, P. A. 1952. The salmon of South Sakhalin. *Izvestiia Tikhookeanskovo N-I Instituta Rybnovo Khoziaistva i Okeanografii, 37:* 69-108.

Howard, G. V. 1948. Problems in enumeration of populations of spawning sockeye salmon, 1. A study of the tagging method in the enumeration of sockeye salmon populations. *Internat. Pacific Salmon Fish. Comm.,* Bull. II.

Internat. Pacific Salmon Fish. Comm. 1957. *Annual Report.*

Killick, S. R. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning and death. *Internat. Pacific Salmon Fish. Comm.,* Bull. VII.

Milovidova-Dubrovskaya, N. V. 1937. Material on biology and fishery of Primorsky (Maritime) gorbuscha (Pink Salmon). *Bull. U.S.S.R. Pacific Sci. Inst. Fish. and Ocean., 12:* 101-114.

Mossman, Archie S. 1958. Selective predation of glaucous winged gulls upon adult red salmon. *Ecol., 39 (3):* 482-494.

Parker, Robert R. and Edgar C. Black. 1959. Muscular fatigue and mortality in troll-caught chinook salmon *(Oncorhynchus tshawytscha). J. Fish. Res. Bd. Can., 16* (1) : 95-106.

Parker, Robert R., Edgar C. Black and P. A. Larkin. Fatigue and mortality in troll-caught Pacific salmon *Oncorhynchus,* MS.

Peterson, Alvin E. 1954. The selective action of gillnets on Fraser River sockeye salmon. *Internat. Pacific Salmon Fish. Comm.,* Bull. V.

Pritchard, A. L. 1939. Homing tendency and age at maturity of pink salmon *(Oncorhynchus gorbuscha)* in British Columbia. *J. Fish. Res. Bd. Can., 4* (4) : 233-251.

Pritchard, A. L. and A. C. DeLacy. 1944. Migration of pink salmon *(Oncorhynchus gorbuscha)* in southern British Columbia and Washington in 1943. *Bull. Fish. Res. Bd. Can.*, 66.

Royal, Loyd A. 1953. The effects of regulatory selectivity on the productivity of Fraser River sockeye. *Can. Fish. Cult.*, *14*: 1-12.

Schaefer, Milner B. 1951. A study of the spawning populations of sockeye salmon in the Harrison River system, with special reference to the problem of enumeration by means of marked members. *Internat. Pacific Salmon Fish. Comm.*, Bull. IV.

Shuman, Richard F. 1950. Bear depredations on red salmon spawning populations in the Karluk River system, 1947. *J. Wildlife Manag.*, *14* (1) : 1-9.

Talbot, G. B. 1950. A biological study of the effectiveness of the Hell's Gate fishways. *Internat. Pacific Salmon Fish. Comm.*, Bull. III.

Thompson, William F. 1945. Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. *Internat. Pacific Salmon Fish. Comm.*, Bull. I.

Verhoeven, L. A. and E. B. Davidoff. Marine tagging of Fraser River sockeye salmon. *Internat. Pacific Salmon Fish. Comm.*, MS.