

INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT

NO. 7

**MIGRATORY BEHAVIOR OF
ADULT FRASER RIVER SOCKEYE**

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NEW WESTMINSTER, B. C.
CANADA

1960

INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

Appointed under a Convention
Between Canada and the United States for the
Protection, Preservation and Extension of
the Sockeye Salmon Fisheries in
the Fraser River System

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ABSTRACT

Variable migratory behavior of adults of Fraser River sockeye races was analyzed to assist the design of regulations for the fishery. Unusually large diversions of sockeye through Johnstone Strait were associated with unusual oceanographic conditions and with sunspot maxima. Variable migration timing of the Adams River race and of other sockeye races is illustrated and possible relationships with abundance of sockeye and with moon phase are noted. Variations in the upriver migrations of Adams River sockeye is related to variable Fraser discharge in the summer. It is suggested that migration and spawning timing is a consequence of maturation, which is photoperiodically controlled, and that photoperiodism may be involved in variable timing.

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MIGRATORY BEHAVIOR OF ADULT FRASER RIVER SOCKEYE

INTRODUCTION

The International Pacific Salmon Fisheries Commission must, by the terms of Sockeye Salmon Fisheries Convention ratified in 1937 by the United States and Canada, restore and maintain the fishery for Fraser River sockeye (Oncorhynchus nerka) and must also divide the allowable catch equally, as nearly as practicable, between the fishermen of the two nations. Many individual sockeye runs are involved, each with its own special requirements for escapement. Extreme precision in regulatory control of catch is therefore needed to obtain both acceptable division of allowable catch and requisite volume and distribution of individual escapements.

In order to regulate such a fishery properly, management requires a thorough knowledge of the movements of salmon which can be largely drawn from a detailed study of commercial catches. Variation in routes of migration or times of occurrence, unless forecasted, may seriously impair the beneficial effect of fishery regulations prepared in advance of the season. Timely adjustments of the regulations during the course of fishing may help rectify the adverse effect of unexpected variations but this method lacks the desired precision.

The analyses in this paper are based on the urgent need of management for an understanding of variability in the routes and time of migration. This variability in the individual migrations has sufficient effect on catches and spawning escapement that regulations must be made compatible with the individual migration characteristics in any given year. The

analyses are largely exploratory and allow tentative conclusions which will require re-examination as more data become available. Although use has been made of historical and other subjective information, as much use as possible has been made of objective data. The results of the analyses are mainly qualitative but are a necessary step toward quantitative examination of variability in migration.

THE NATURE OF SOCKEYE RUNS

Fraser River Sockeye in General

The majority of Fraser River sockeye mature at four years of age, having spent from five to nine months in the gravel of their home stream, a year in a lake, and the remaining $2\frac{1}{2}$ years at sea. The marine life of Fraser River sockeye is spent in the Pacific Ocean presumably somewhere westerly or northwesterly of Vancouver Island (FIGURE 1). Returns of tags placed on sockeye in the Gulf of Alaska indicate that Fraser River sockeye are distributed as far west and north as Kodiak Island (Internat. North Pacific Fish. Comm., 1959). The migration from the feeding grounds in the ocean must begin in the spring or early summer to effect the coastal landfall which is usually made between late June and the latter part of August. After migration through the inshore fishery and up the river, the sockeye deposit their eggs and die shortly thereafter.

The four year life span gives rise to four relatively discrete lines of descent which are called cycles. A given year within a cycle is termed a cycle year. The term cycle has an historical origin and in the case of Fraser River sockeye has had two other meanings. It has denoted a single sockeye generation or brood year or, alternately, the fact that in the

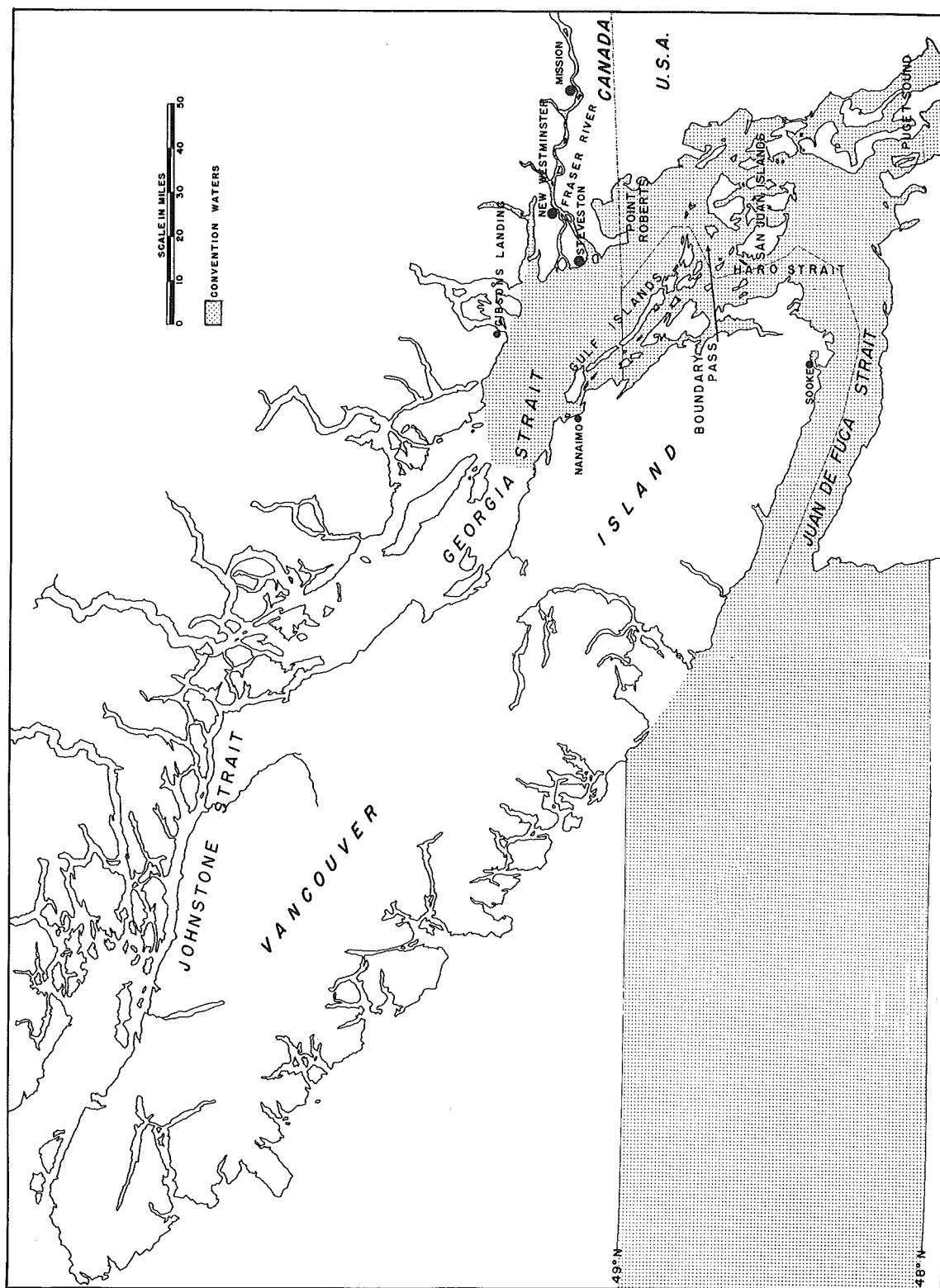


FIGURE 1 -- Coastal area adjacent to Fraser River mouth, including Vancouver Island.

early years one very large annual run to the Fraser occurred every fourth year with three smaller runs intervening (Thompson, 1945). In making comparisons between annual runs, the greatest similarities will be found within a cycle because of the direct connection between parents and offspring.

The individual runs or races¹ which constitute a total annual run, pass in a succession through the fishery. Each race has its characteristic timing, and spawns in a particular home stream tributary of the Fraser River. The racial runs overlap in the fishery and show no easily visible differences between individual sockeye. A method has been devised for determining the proportions of the racial elements in a given group of sockeye, e.g. a commercial catch, from variations in the section of the scales laid down in fresh water (Clutter and Whitesel, 1957). This allows the passage of a single race through the fishery to be ascertained with considerable accuracy when adequate scale samples are available.

The typical time-abundance curve of a racial run of Fraser River sockeye at a given point on its migration path is a bell-shaped curve with a rather sharp peak and with long tails extending to either side. The shape of the curve resembles but may differ significantly from the mathematical normal distribution. The curve is usually symmetrical with a base covering more than a month. Approximately two-thirds of the racial migration appear within the peak period of a week to twelve days (cf. Royal, 1953). Attributes of the time-abundance curve which can vary

¹The term "run", taken from the fishing industry, is often used synonymously with "race", as by Royal (1953). "Individual run" or "racial run" is used to indicate the fish of a single race appearing in a given year.

from year to year are: time of peak abundance, sharpness of the peak (dispersion), the occurrence of two peaks (bimodality), and in symmetry of the run (skewness).

The time of occurrence of a race of Fraser River sockeye can be designated by the peak or modal date at a given point on its migration path. The peaks of individual races in the marine fishing areas regulated by the International Pacific Salmon Fisheries Commission occur in succession from the first few days in July to the end of August or the beginning of September. Peaks in the gill net fishery within the Fraser River proper are later by the amount of time required for each sockeye race to begin river migration after arrival at the river mouth.

Sockeye migrating through the fishing areas are observed quantitatively through catches made by the commercial fishery. Catches may vary with changes in amount and distribution of fishing gear and with fishing conditions, as well as with variations in abundance of fish. Because catches are interpreted as demonstrating the distribution of sockeye within racial and annual runs, some consideration must be given to the characteristics of the fishery.

However, the distribution of catches by date in any sockeye season is determined largely by the relative abundance of the different races. As a consequence of variations of racial abundance the bulk of sockeye catches in some years have been in the month of July, in others in early August, and in still others in late August and September. When one race is far more abundant than all others in the season, the catches will approximate the time-abundance curve of the single race.

Most Fraser River sockeye races follow a consistent sequence of numerical abundance in each set of four consecutive generations or cycle years, a phenomenon termed quadrennial dominance. This phenomenon has been given preliminary treatment by Ricker (1950). Royal (1953) has discussed it in relation to management principles. Quadrennial dominance may be briefly described as the four-year succession of adult racial sockeye populations in which one cycle (dominant cycle) consistently exceeds the three other cyclic runs in numerical size.

Apart from changes in fishing gear and fishing conditions, there are two sources of variation in the distribution with time of daily sockeye catches between two different fishing seasons. The first is the result of variations in size of individual racial runs between years and from cycle to cycle. The second source is the deviation of migration time from year to year for the same race. The latter variation appears to be the result of changes of the physical environment which influence sockeye on their migrations. A study of these variations and of the associated environment may thus lead to predictions of sockeye behavior.

Adams River Sockeye

Most important of the individual Fraser River sockeye races at the present time is the Adams River run. It has provided approximately half the commercial catch over the past three decades. Every fourth year it has a very large run which presents a major problem for regulation in the fishery. In these years, the run ordinarily provides in excess of 75% of the total catch of Fraser sockeye. Variations in the characteristics

of migration of this large run have been large and easily measured, making it also an important source of information concerning sockeye behavior.

The Adams River race differs in several respects from the other important sockeye races which spawn in that part of the Fraser watershed lying above Hell's Gate. It is the latest of the upriver races of sockeye to migrate and spawn. Its migration rate appears to be slower at least during the upriver migration. The time of passage from the fishery to the spawning grounds is further lengthened by a delay off the mouth of the Fraser River. The run is also highly variable in time of occurrence in different years. Large variations occur in symmetry and spread of the time-abundance curves, and in date of peak migration. This range of variability makes the design of fishing regulations for the dominant Adams River run a difficult task.

The dominant run to the Adams River is unmistakable in the fishery and during its spawning migration in the river because of its late timing and large size. Evidence of the large runs of the dominant cycle may be found as early as 1861 in the journals of the Hudson's Bay Company men stationed on the migration path in the Kamloops area. As early as 1893, these dominant runs were identifiable in commercial gill net catches as reported in newspaper articles relating the progress of fishing on the Fraser River. The large runs occurred in the same cycle years (1901, 1905, 1909, 1913) as the dominant runs of most other Fraser sockeye races. Thompson (1945) reveals how the Hell's Gate obstruction, which decimated many other sockeye runs, and other adverse conditions caused the dominant

run to fall to a low level of abundance. When conditions improved, a new dominant cycle was formed on the 1922, 1926, 1930 cycle. A very large run occurred in 1930, beginning the sequence of large dominant runs which has been maintained to the present.

The relative size of the total adult Adams River run in its four cycles is approximately as follows:

Cycle	Total No. of Sockeye	Name of Cycle
1954-1958	10,000,000	Dominant
1955-1959	500,000	Sub-dominant
1956-1960	25,000	Off-year
1957-1961	10,000	Off-year

The dominant cycle year, since 1930, has varied from approximately 2.75 million in 1950 to 16 million in 1958. The sub-dominant run is sometimes difficult to separate from other races but its variations do not appear to have been as extreme. This annual succession of numerical size is a most convincing demonstration of the reality and stability of dominance among Fraser River sockeye runs.

ROUTES OF MIGRATION IN SALT WATER

Evidence from the Offshore Troll Fishery

Incidental catches of Fraser River sockeye by salmon troll gear off the seaward coast of Vancouver Island each year indicate the approach of returning fish which shortly appear in the inshore fisheries. FIGURE 2 shows the relationship of the total catch of sockeye by troll gear in Areas 12, 21, and 23 through 27 (Statistical Areas of the Canada Department

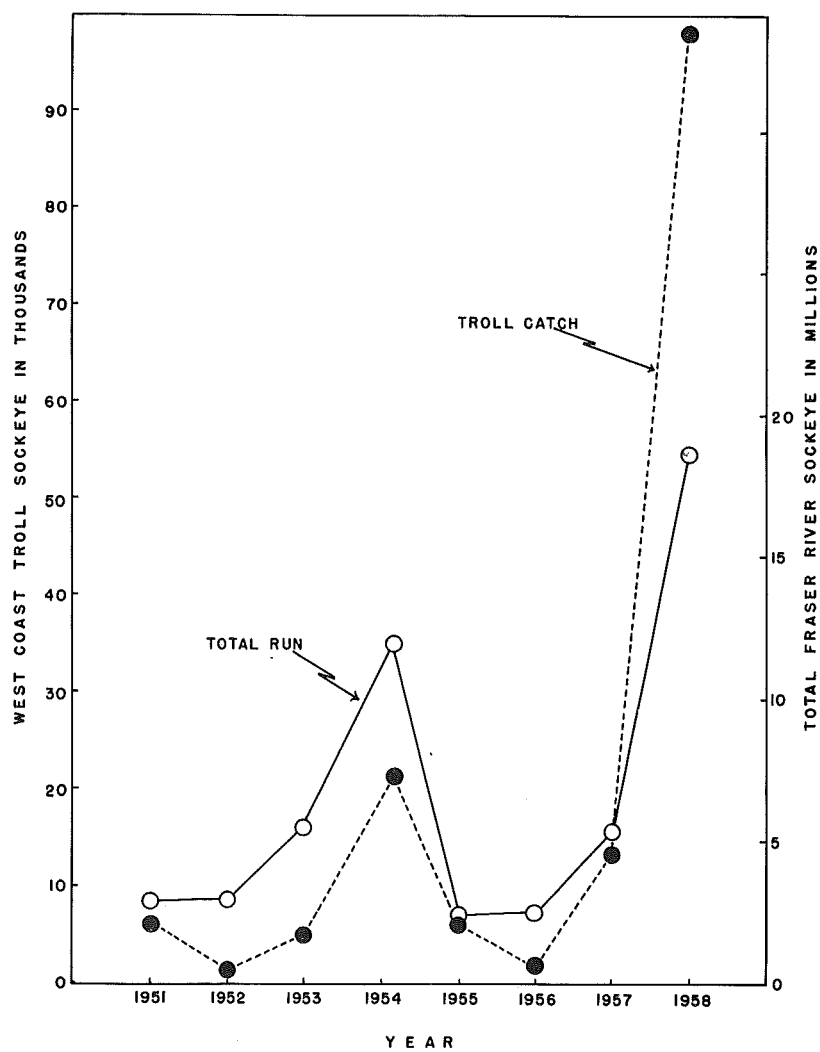


FIGURE 2 - Relationship between the total troll sockeye catch along the West Coast of Vancouver Island and the total size of the Fraser River sockeye run for the years 1951-1958.

of Fisheries) to the total numbers of sockeye in the annual runs to the Fraser River from 1951 through 1958. The occurrence of small troll catches in years of small runs and large troll catches in years of large runs is evidence that Fraser sockeye predominate in the troll fishery off Vancouver Island. Examination of scales taken from troll caught sockeye, using the methods illustrated by Clutter and Whitesel (1956), confirms this conclusion.

The troll catches of sockeye are an indication of the coastal area in which Fraser River sockeye make their landfall. The variability of the landfall is illustrated by the extreme difference between troll catches in the years 1954 and 1958 when the Adams River race predominated. FIGURE 3 shows the troll catch by statistical areas off the west coast of Vancouver Island by months for the two fishing seasons. Total catch by area alone indicates that the 1958 landfall was made far north of the 1954 landfall which is fairly representative of most years. An examination of troll fishing effort revealed that the wide differences in catch between years in the various areas were not due to changes in amount or distribution of troll gear. In 1958, Fraser River sockeye appeared to approach the coast much farther north than usual.

Migration Through Johnstone Strait

In addition to the more northerly appearance of Fraser River sockeye along the outer coast in 1958 an unusually large proportion of the run entered Georgia Strait via Johnstone Strait as opposed to Juan de Fuca Strait (FIGURE 1). That this phenomenon has been observed in other years is indicated by reports concerning the sockeye fishery published in the British Columbian newspaper, New Westminster, B.C., and in the Pacific

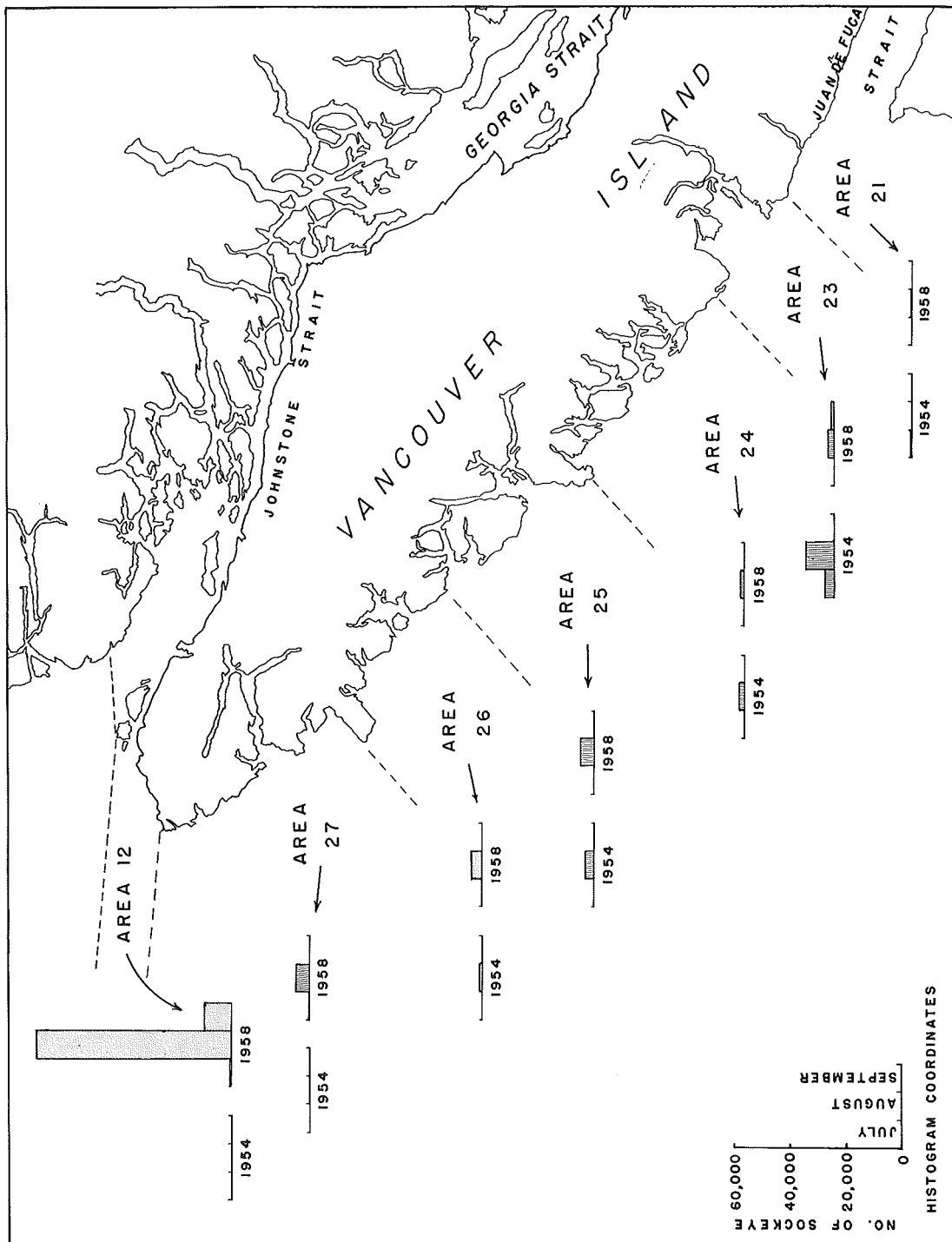


FIGURE 3 - Troll catches of sockeye by month and area off West Coast of Vancouver Island in 1954 and 1958.

Fishermen magazine. Abnormally heavy migration of Fraser River sockeye through Johnstone Strait was reported both in 1926 and in 1936.

Catch data from the Johnstone Strait purse seine and gill net fishery are available in some form since 1926 and may be used to indicate the variation in the migration of Fraser River sockeye through this passage. An incomplete record of catches for the Johnstone Strait area have been compiled for the years from 1945 to 1951, when the Canada Department of Fisheries commenced publishing complete catch records. For the period prior to 1945, estimates of the catch from this fishery have been made using the records of a single cannery which packed approximately one-quarter of the total sockeye catch in Johnstone Strait.

Two methods have been used for indexing the proportion of migration through Johnstone Strait using these data. The first index is the percentage of the total Fraser River sockeye run, including both catch and escapement, caught in Johnstone Strait for the years in which Fraser River sockeye escapements have been enumerated. The catch in Johnstone Strait prior to July 16 of each year was excluded to eliminate as nearly as possible the non-Fraser River sockeye which sometimes predominate in the catch prior to that date. The second index is the simple ratio of catch in Johnstone Strait to the catch in the waters defined by the Sockeye Salmon Fisheries Convention, namely, southern Georgia Strait, outer Puget Sound and Juan de Fuca Strait (FIGURE 1). The two indices are compared in FIGURE 4, and are found to be quite similar in trend with the exception of the year 1947. The sockeye run of 1947 was a small

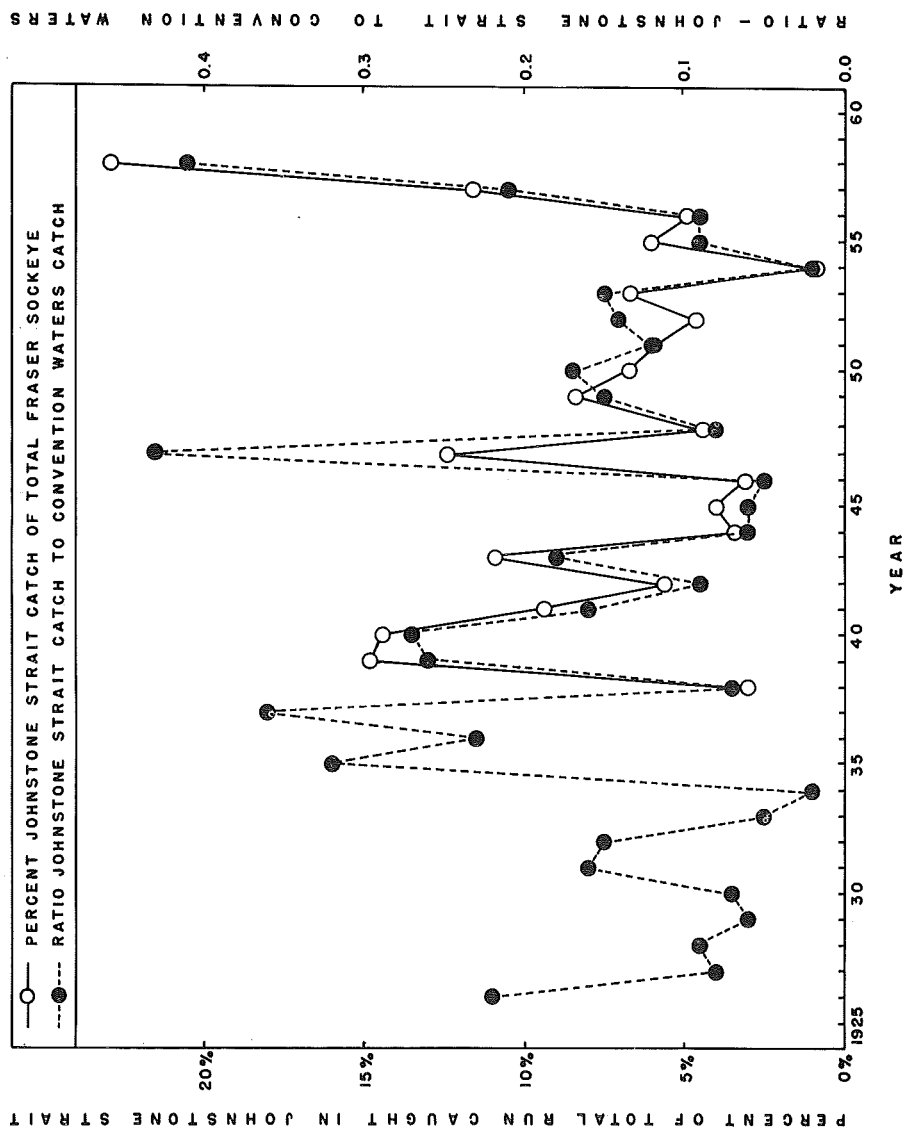


FIGURE 4 - Two indices of proportion of Fraser River sockeye migrating through Johnstone Strait.

one and only a greatly restricted catch was allowed in Convention waters (Internat. Pacific Salmon Fish. Comm., 1948). The difference between the indices in that year resulted from the large proportion of the run which was allowed to escape to the spawning grounds as a result of the restrictions on fishing.

The indices of Fraser River sockeye migration through Johnstone Strait, shown in FIGURE 4, confirms the reports of heavy migration through the northern passage in 1926 and 1958. However, the index for 1936, also reported as having a heavy migration through Johnstone Strait, is lower than several adjacent years. Large index values are found for several years in the period 1935 to 1947. The relatively good catches in Johnstone Strait in 1935, 1937, 1939, 1940 and 1943, in the absence of any further evidence of heavy Johnstone Strait migration, is presumed to be mainly the result of an intense fishery in the Strait in those years. Catches in 1947 will be considered in detail in a later paragraph. The percentage of total available sockeye caught by the fishery in Johnstone Strait will vary with the fishing effort expended, i.e., the amount of gear operating modified by the amount of fishing time allowed. The size of the fishing fleet will be strongly influenced by relative fishing success elsewhere. Weather and tides may also modify the success of fishing. In any event, the proportion of the run migrating through Johnstone Strait indicated in FIGURE 4 will be less than the true proportion because of the escapement past this fishery. MacKay, et al. (1944) present the results of sockeye tagging in Johnstone Strait in 1940 and 1941 in which more than half of

the total tag recoveries were made in Convention waters, suggesting considerable escapement in these two years at least. The indices in FIGURE 4 are thus a minimum measure of migration of Fraser River sockeye through Johnstone Strait and a second source of information is therefore examined.

A further source of information concerning the migration of Fraser River sockeye through Johnstone Strait extends back to the turn of the century. This is the relative size of catches made by the United States and the Canadian fishing fleets, in the area which later became Convention waters, and prior to the time (1946) that the International Pacific Salmon Fisheries Commission began regulating the fishery to give equal catches to both countries. Migration through Johnstone Strait would yield a recruitment of sockeye to the Canadian gill net fishery in the Fraser River while providing at most a small proportion of extra fish for the United States fishery in the Point Roberts area. Thus in years of large migration through Johnstone Strait the Canadian catch in Convention waters would be larger relative to the American catch, providing that changes in regulations and fishing effort were not of sufficient magnitude to mask the effect. FIGURE 5 shows the Canadian percentage of the total catch made in the area now designated as Convention waters, from 1899 to 1945. Prior to 1899 the United States fishery had a small capacity and the Canadian percentage of the total catch was very large in every year.

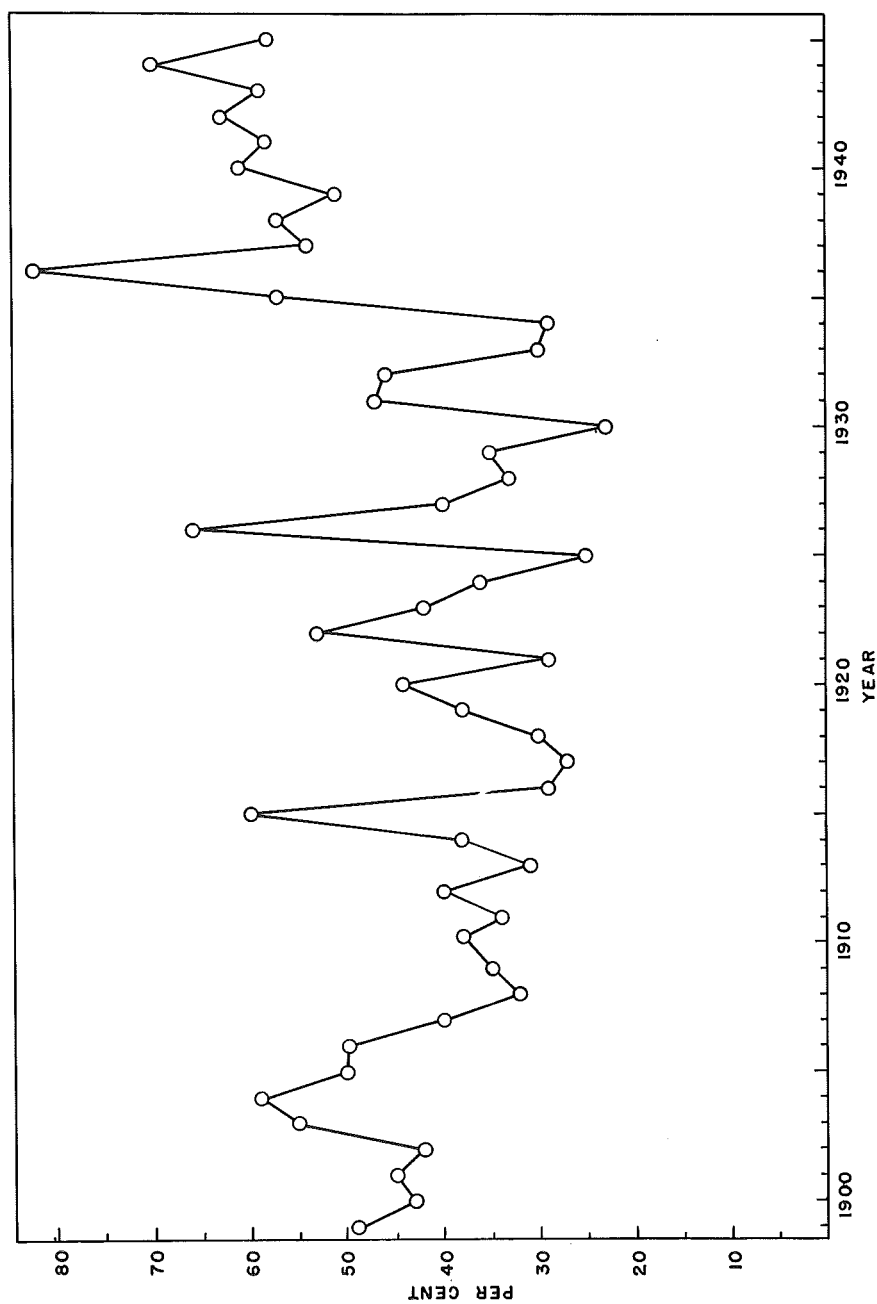


FIGURE 5 - Canadian percentage of the total catch of Fraser River sockeye in Convention waters, 1899 to 1945.

Certain years of possible large Johnstone Strait migration can be noted in FIGURE 5. In agreement with contemporary newspaper reports, there was a high Canadian percentage of catch in 1926 and 1936. In addition, 1903 and 1904, 1915 and possibly 1922 may be included in the same category. However, the year 1922 and the adjacent years with relatively large Canadian percentages occurred during an economic depression when United States fishing effort was curtailed (see Thompson, 1945, Figure 16). Such a curtailment in the United States fishing effort would result in a similar large increase in the Canadian catch which would not be the result of increased migration through Johnstone Strait. Likewise, the sudden rise in the Canadian proportion of the catch beginning with 1935 is the result of the elimination of traps from United States waters after the 1934 fishing season.

In 1947, a very large Canadian percentage of the sockeye catch indicated heavy Johnstone Strait migration, despite regulations designed to achieve division in the catch. The 1947 regulations were designed to provide for a heavy escapement of sockeye but allow exploitation of the pink salmon run which occurred late in the season. Nevertheless, division of sockeye catch should have been fairly equitable. This may be demonstrated by comparing sockeye catches in 1947 with catches in the two previous cycle years, 1939 and 1943. This is accomplished by totaling those catches in the two earlier cycle years made only on the days on which fishing was allowed in 1947. On the basis of the 1947 regulations, Canada would have taken 38 per cent of the sockeye in 1939,

and 63 per cent in 1943. The higher percentage calculated for 1943 is the result of a very small United States fishing fleet occurring under war-time conditions. Since the United States fleet in 1947 was about the same size as in 1939 during the latter part of the sockeye season, the Canadian percentage of the catch of sockeye in 1947 should have been near 38 per cent. The actual Canadian proportion of the catch in 1947 was 80 per cent, a figure too extreme to be accounted for by any hypothesis except the occurrence of a very heavy diversion of Fraser River sockeye via Johnstone Strait.

Inferences relating to path of migration, as drawn from the data of FIGURE 5, can be justified by considering the nature of the fisheries involved. The intensity of the United States fishery varies with the amount of gear as indicated in the previous paragraph. This fishery has operated with high intensity since its rapid growth before the turn of the century. A seven day fishing week was allowed until 1905 when a $5\frac{1}{2}$ day fishing week (i.e., a 36 hour weekend closure) was initiated (Rounsefell and Kelez, 1938). Thus changes in United States fishing intensity have been gradual with the exception of the sudden elimination of all traps in 1935. The Canadian fishery up to 1945 consisted principally of gill nets fishing in the Fraser River and vicinity. These gill nets allow an escapement related to the length of the weekend closure since very little escapement occurs while fishing is in progress (Royal, 1953). Thus the Canadian fishing intensity was almost independent of the number of gill nets and changes in amount of gear merely increased

or decreased the catch per fisherman for a given level of sockeye abundance. Examination of the historical record reveals that changes in regulations for the gill net fishery during the sockeye season for the years in question were few and unimportant. The data in FIGURE 5, except where modified above, can therefore be accepted as indicating the years in which an unusual proportion of Fraser River sockeye migrated through Johnstone Strait.

Within each yearly migration through Johnstone Strait there may be seasonal changes or racial differences. However in the few years in which seasonal information can be compared, there does not appear to be a seasonal trend in proportion which could not be explained by changes in fishing intensity. Whatever controls the migration through Johnstone Strait, it appears to operate at a fairly constant rate throughout the sockeye season (July and August).

Route of Migration and Environmental Periodicity

The years of probable unusual migration through Johnstone Strait, viz., 1903-1904, 1915, 1926, 1936, 1947 and 1958 suggest a ten or eleven year cycle of occurrence which is similar in periodicity to the cycle of solar activity. In FIGURE 6 the annual means of sunspot numbers are compared with years of unusually heavy migration through Johnstone Strait. The sunspot numbers are annual means of daily values known as Wolf Sunspot Numbers compiled by the Federal Observatory, Zurich, Switzerland (Kuiper, 1953, and Sky and Telescope, 1953-1959). There is a close correspondence of years of unusually high proportion of migration

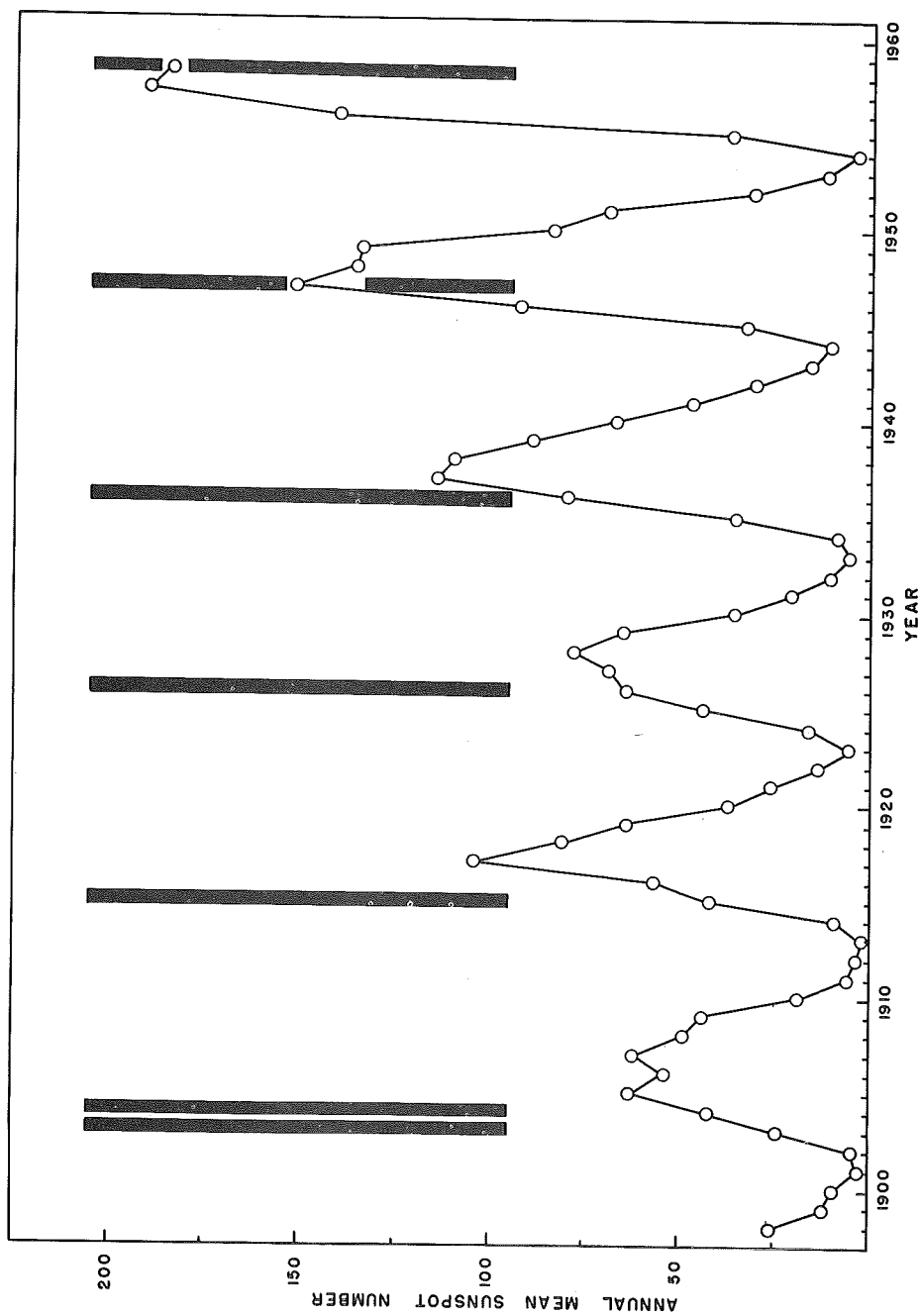


FIGURE 6 - Years during which an unusually large proportion of Fraser River sockeye migrated through Johnstone Strait compared with the cycle of solar activity as indicated by annual means of sunspot numbers. Bars indicate years of heavy migration through Johnstone Strait.

through Johnstone Strait to the solar activity maxima of which the sunspot maxima are an index. Heavy migration in the Strait tended to occur just prior to sunspot maxima. By this criterion, the 1958 maximum of migration occurred a year or two late. The relationship suggests that unusually heavy migration through Johnstone Strait will occur no more than one or two years out of each ten or eleven, and that an approximate forecast of the event can be made. It is evident that sunspots, or the solar activity they indicate, cannot directly affect sockeye. Any connection between the two will most certainly be quite indirect.

The cause of periodic variation of migration through Johnstone Strait appears to be related to periodic changes in oceanographic conditions in the Northeast Pacific Ocean. The heavy sockeye migration through Johnstone Strait in 1958 was concurrent with what appeared to be an unusual intrusion of warm water into the Gulf of Alaska from the south along the British Columbia coast. The eastward-moving surface currents west of the British Columbia coast turned northward and were intensified as shown by geopotential topography, and the center of the Alaska Gyral was displaced westward (Tully, et al., 1960). The gradual growth of this anomalous situation was detected in 1957 at which time an increase in the migration of sockeye through Johnstone Strait was noted (FIGURE 4).

Tully, et al., (1960) mention that the conditions noted in the Northeast Pacific Ocean in 1957-1958 have probably occurred before. They state that a previous oceanographic survey off the outer coast of Vancouver Island suggested that conditions in 1936 were similar to

those in 1958. There is also evidence that ocean temperatures were high in this area in 1947. During the period of Albacore fishing by Canadian fishermen off the coast of Washington and British Columbia from 1946 to 1951, many observations of sea surface temperatures were made by fishermen and by patrol vessels of the Canada Department of Fisheries (Fisheries Research Board of Canada, 1948, 1949, 1950, 1951; Doe, 1951). Maximum surface water temperatures westward of Juan de Fuca Strait in 1947 were as high as 70°F. whereas in the other years maximum surface temperatures never exceed 65°F. Bathythermograph data for this area reported by Robinson (1957, Figures 58 and 59), indicate extremely warm temperatures in the spring of 1947 from the surface to at least 100 feet in depth. The 1947 ocean temperature structure appears to have been similar to that of 1958 when the spring and early summer sea temperatures from the surface to a considerable depth were much above average. Since 1936, 1947 and 1958 are closely associated with sunspot maxima, it is tentatively concluded that oceanographic conditions similar to those of 1958, though perhaps not as extreme, will continue to occur near each sunspot maximum.

A partial explanation has been provided for the inferred relationship between solar activity (type and/or amount of solar radiation) and oceanographic conditions. Lawrence (1958) suggests that solar activity, as indexed by the sunspot cycle, strongly affects meteorological conditions in at least certain areas of the world. Lawrence found periodicities, correlated with the sunspot cycle, in the withdrawal of

glaciers in Southeastern Alaska and other areas. He suggests that periodic variations in atmospheric pressure patterns, in response to changing solar activity, control the balance between precipitation of snow and runoff for the glaciers.

Winds over the ocean are the "result" of atmospheric pressure patterns (the two have a dynamic relationship, i.e., they are interdependent). The major currents in the ocean are powered to a great extent by wind stress with modification by momentum and by the density distribution in the water as a result of heating and cooling, evaporation, precipitation and land runoff (Sverdrup, et al., 1942, pp. 395-398). Sverdrup, et al., state (p. 398):

"Since the larger features of the distribution of density (i.e., temperature plus salinity) remain unaltered from year to year, it follows that the currents represent a necessary link in the delicate mechanism that maintains a steady state. Superimposed upon the average steady state are numerous disturbances, some of which are related to the change of season and are repeated in more or less similar manner year after year, and some of which are related to the irregular atmospheric disturbances and are unpredictable."

Thus solar activity appears to influence sockeye migration paths by causing changes in meteorological conditions, such as winds and insolation. These in turn produce disturbances in the currents of the ocean and in the associated physical variables. Sockeye, immersed in this changeable medium, are presumed to be affected through an unknown mechanism.

Although a study of solar activity appears to allow a qualitative prediction of the proportion of migration through Johnstone Strait, a more accurate method is desired. Use could possibly be made of

meteorological information but undoubtedly the most promising approach is a study of oceanographic conditions in the areas of marine residence and migration of sockeye. The physical variables in the ocean appear to be the factors most directly connected with variable migration route. These factors are therefore the most likely to yield correlations which will allow accurate numerical predictions of the routes of sockeye migration to the Fraser River. Because variable migration of sockeye through Johnstone Strait so markedly affects both division of catch in Convention waters and the percentage of the total run escaping to the spawning grounds, there is urgent need of oceanographic information related to this important variation in behavior.

TIMING OF SALTWATER MIGRATION

The time of occurrence of a given race of sockeye in any season at a given point on the migration path can be described in several ways. Since sockeye of the same race appear to migrate at a consistent rate (Killick, 1955), the times of occurrence in the various fishing areas along the migration path are related to one another by the migration rate. It has been the practice of the Commission to measure the time of occurrence of a racial sockeye run in salt water at the San Juan Islands area of United States Convention waters, where a consistent and effective fishery has been operating since the turn of the century. The time of occurrence can be shown by curves of daily racial catches, but because these curves tend to be symmetrical, the timing of migration in the area can be indicated simply by the date of

the maximum daily catch ("peak of the run"). The dates between which the catch exceeded a specified value might also be used.

Variation in Timing of Saltwater Migration

The clearest picture of the variation in migration timing of a racial run is provided by the dominant Adams River sockeye run. Peak dates of occurrence were determined for this run in the San Juan Islands for the last nine cycle years, and are as follows:

1926 - August 7-10	1938 - August 24	1950 - August 21
1930 - August 28-31	1942 - August 24	1954 - August 29
1934 - August 18	1946 - August 28	1958 - September 2

The dates were not all derived by the same method. In 1942 through 1954, the date of peak catch in the San Juan Islands was used. In 1938 and 1958, the catches were not strictly symmetrical and therefore the peak date was taken as the center of a sixteen day catch period which gave the minimum standard deviation in days. Catch on days closed to fishing was provided by interpolation. In 1942 through 1954, this method gives the same date as the peak catch. In 1926, 1930 and 1934, traps took an important part of the United States catch, and of necessity the timing was estimated mainly on the basis of trap catches. Purse seine catches could not be used because, prior to 1935, catches in the San Juan Islands were not recorded separately from those made at Point Roberts where Adams River sockeye are sometimes taken in large numbers after saltwater migration has ended. Catches by the Canadian traps in the vicinity of Sooke on Southern Vancouver Island were also used as verification of the time of occurrence in United States traps. This is

possible because the Sooke traps reflected the timing of the run within two or three days prior to 1947 when an effective purse seine fishery developed in the same general area.

Abundance and Time of Migration

The large variations both in size of the Adams River run and in its time of migration allow a comparison to be made between these factors in the dominant cycle years. Such a comparison is made advisedly, since to observers familiar with Fraser River sockeye there is clearly more than one cause of variation in migration time. Large variations in migration time can be shown for racial runs of similar size. An example of this variation is found in the cyclical sockeye runs of 1953 and 1957. In 1953, the largest catches of the season in United States Convention waters were between July 21 and 30 while in 1957 largest catches were between August 5 and 14 (Internat. Pacific Salmon Fish. Comm., 1958, TABLE III). In these two years, the sockeye runs were of approximately the same size and racial composition, and the fishing fleet sizes followed parallel trends through the two seasons. The difference in timing of about two weeks is an illustration of variability of time of migration obviously not due to differences of abundance nor to a drastic change in racial composition.

In the nine recent cycle years of the dominant Adams River sockeye race, it was noted that the smallest run, that of 1926, was the earliest and the largest run, that of 1958, was the latest. A comparison was made between size of run, as indicated by the total sockeye catch of the

year, and the time of migration listed on page 25. This comparison, illustrated in FIGURE 7, suggests that among other factors, abundance of sockeye may affect timing. The data in FIGURE 7 must be justified since catch is not always a good index of abundance, and because uncertainty exists concerning the exact migration time of two of the runs. However, the fishery has taken at least two-thirds of the total run in all the nine cycle years excepting 1950 and possibly 1930. In these two years the fishery took no less than half the run. Total catch is therefore a reasonable index of abundance for the cycle with such a wide variation in total size. Since potential sockeye production in this cycle, excluding Adams River fish, is small, total catch is a usable index of the size of the Adams River run.

The uncertainty of time of migration to the extent of four days in 1926 and 1930 has two causes. First, trap catches were often left in the traps for two or more days but recorded as a single day's catch, therefore time of migration in these years could not be estimated to the nearest day. Second, the apparent timing of one race may be distorted by the inclusion of sockeye of other races in the catches. However, the Adams River runs of 1926 and especially 1930 were far larger than any other racial runs accompanying them (Thompson, 1945), hence they were used for comparison.

The correlation in FIGURE 7 is not highly significant when dates for 1926 and 1930 are chosen which produce the lowest possible correlation coefficient. The coefficient is -0.72 ($p = .03$) if August 7 is used for 1926 and August 31 is taken for 1930. However, there is

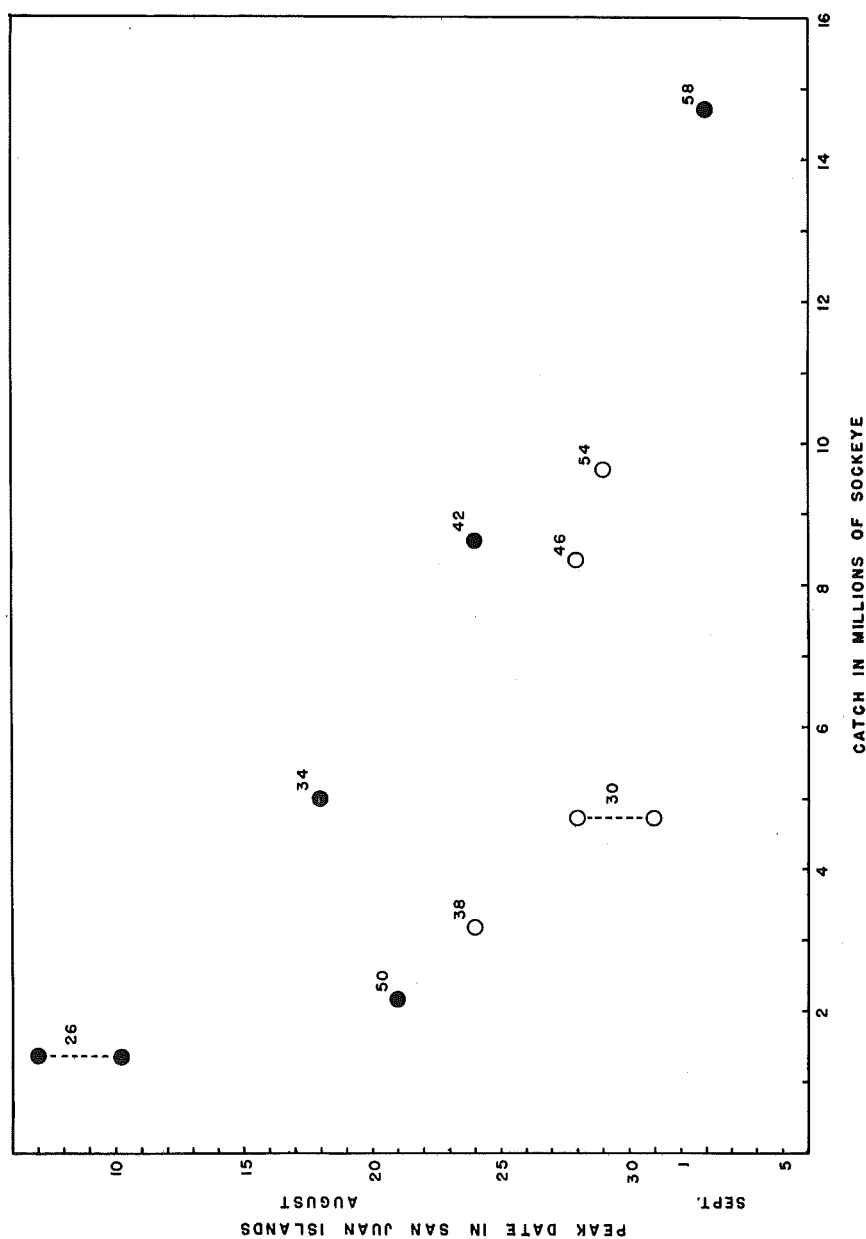


FIGURE 7 - Relationship between time of migration of dominant Adams River run and total catch in the cycle year. Dates are day of peak in the San Juan Islands fishery and catch is total for Convention waters plus estimated Johnstone Strait catch of Fraser River sockeye. Alternate generations shown by open and solid circles.

more information to confirm the relationship of run size and timing. The sub-dominant Adams River runs which can be identified in the statistics of catch have been small (less than a million sockeye) and have in all cases been early, i.e., before August 25 at their peak in the San Juan Islands.

There is also evidence in the case of pink salmon that the more abundant runs migrate later. Davidson and Vaughan (1941) showed such a phenomenon in the pink salmon of Southeastern Alaska. As in Fraser River sockeye, the relationship showed exceptions and a high degree of variability. Because large variations occur in migration time of racial sockeye runs of similar size, it is obvious that there are other factors influencing the time of migration in salt water, in addition to population size.

Time of Migration in Successive Generations

An additional characteristic of variation in time of migration appears in FIGURE 7. The alternate cycle years of the dominant Adams River run during the years 1926 to 1958 are denoted by open and solid circles. The alternate generations represented by the solid circles are earlier in time of migration than the intervening cycle years of the open circles, with 1950 appearing as an exception. This relationship would not be quite as consistent if the abundance effect on timing had not been considered.

The alternation of sockeye migration time in successive cycle years of a cycle is not confined to the dominant Adams River cycle. This alternation has been observed in certain races occurring in two of

the three other sockeye cycles. The effect of abundance on time of migration has not been evident in these other cycles, possibly because the variation in abundance has been less than has occurred in the dominant Adams River cycle. The alternate migration time in successive generations is most obvious in recent cycle years of the 1952-1956 cycle in which the Chilko sockeye race has predominated. This phenomenon is evident in seasonal catch curves for the principal fishing period in the United States fishery in Convention waters inside of Juan de Fuca Strait. Catch curves for the seven most recent cycle years of the 1956 sockeye cycle are shown in FIGURE 8. These smooth curves were fitted by inspection to graphs of daily catch. The resultant curves were then converted from numbers of fish to daily percentages of the total represented by the curve. A consistent alternation of migration time is found in FIGURE 8 when the timing of the Chilko run, which produced the maximum catches in the major single or double mode, is considered apart from other catches. The cycle years 1932, 1940, 1948 and 1956 are clearly later than the cycle years 1936, 1944 and 1952.

Sockeye in the 1953-1957 cycle have not been as consistent in racial composition as the 1952-1956 cycle but nevertheless show the same alternation of timing. For the cycle years from 1937 to 1949, the Chilko sockeye race formed the major share of the sockeye in these runs. Beginning in 1949, as a result of Hell's Gate fishways and partial protection of the important upriver races by restrictions on fishing, the Chilko race became overshadowed by the other sockeye races. However,

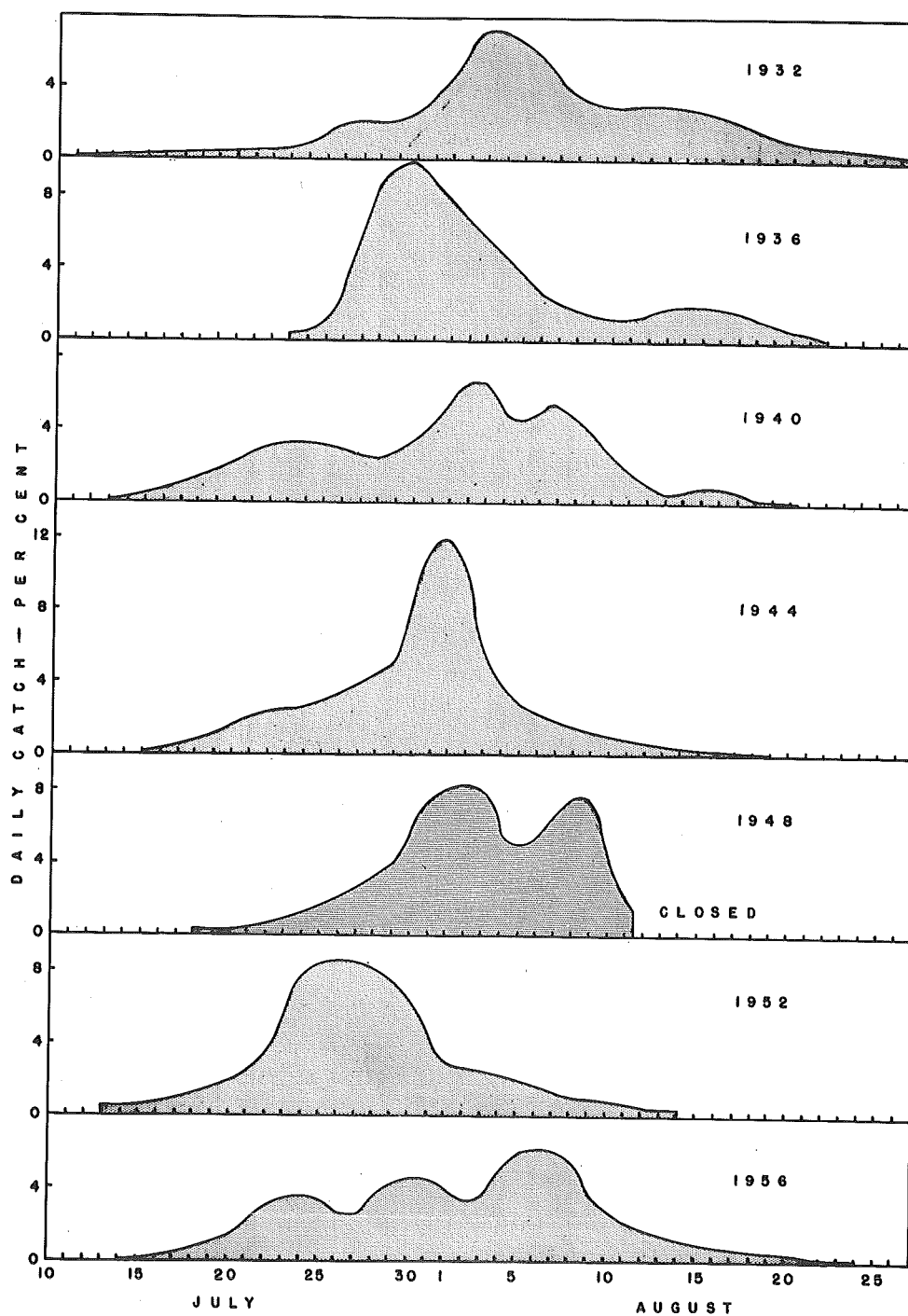


FIGURE 8 - Distribution of daily sockeye catches in the United States fishery of Convention waters for seven cycle years of the 1932-1956 cycle.

these important upriver sockeye races migrate at about the same time as the Chilko race and are seen to follow the same alternation of migration time in successive generations. This phenomenon is demonstrated by empirical catch curves determined for the principal fishing period in United States Convention waters and shown in FIGURE 9. These curves were derived in the same manner as those in FIGURE 8. Five of the six years in FIGURE 9 show the alternating time of occurrence. The years 1941, 1949 and 1957 were late while 1945 and 1953 were early. The exception, 1937, which was late in migration time when an early run would have been expected, was probably affected by another factor which will be considered in a later section. It is to be noted that the last mode in the 1937 run evidently consists of sockeye largely from races other than Chilko.

Alternating time of migration in the 1957 cycle cannot be demonstrated for the cycle years of 1917 through 1933. Neither the Chilko race nor any of the similar upriver races which migrate about the same time were abundant enough to be identified with certainty in the commercial catches. The low abundance has been attributed to the adverse effects of the Hell's Gate obstructions (Thompson, 1945). The obstructions varied within each yearly migration and thus had variable effects on the several upriver races. Before the beginning of the Hell's Gate obstructions, the large upriver races would have had rather consistent abundance in this cycle. Thus evidence of alternation of timing in successive generations might be expected in these runs.

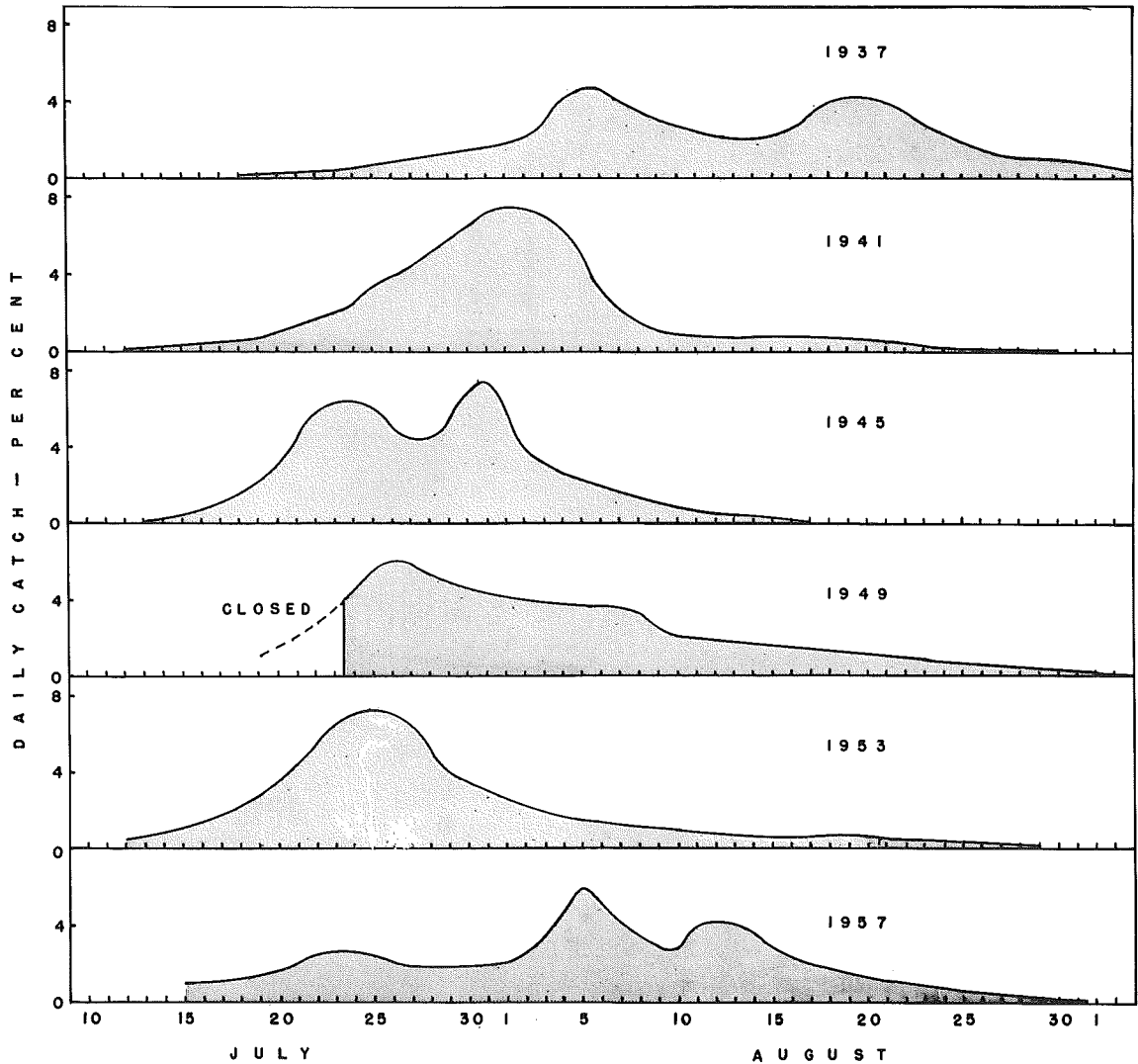


FIGURE 9 - Distribution of daily sockeye catches in the United States fishery of Convention waters for six cycle years of the 1937-1957 cycle.

Empirical curves of daily trap catches of sockeye during the principal fishing period in the United States fishery in the large dominant runs of 1897 through 1913 are shown in FIGURE 10. Again, there appears to be an alternation of time of occurrence in these successive cycle years when racial composition was presumably rather constant. The large historical runs of the 1897-1913 cycle were probably of the order of 30 to 50 million sockeye in total numerical size. Years prior to 1897 could not be compared because no records are available for the United States fishery.

The alternation of migration timing of successive generations of sockeye has been demonstrated on three of the four cycles in the Fraser River populations during periods when racial composition has been fairly uniform or when one race has dominated the catch. Such alternation has not been observed in the 1911-1959 cycle, possibly because this cycle is composed in most years of a large number of relatively small racial runs which individually provide a rather small percentage of a relatively poor catch. The identification of races by means of scale characteristics over a usable period of time may uncover evidence of alternation of timing for individual races in this cycle also.

The alternation of time of migration in successive generations has been related to the phases of the moon in the same years (Internat. Pacific Salmon Fish. Comm., 1958, page 17). The possibility of the moon acting through the tides seems unlikely because the tides are very nearly the same each fourth year. The moon, however, is of almost opposite phase at the same time exactly four years later and a connection is quite

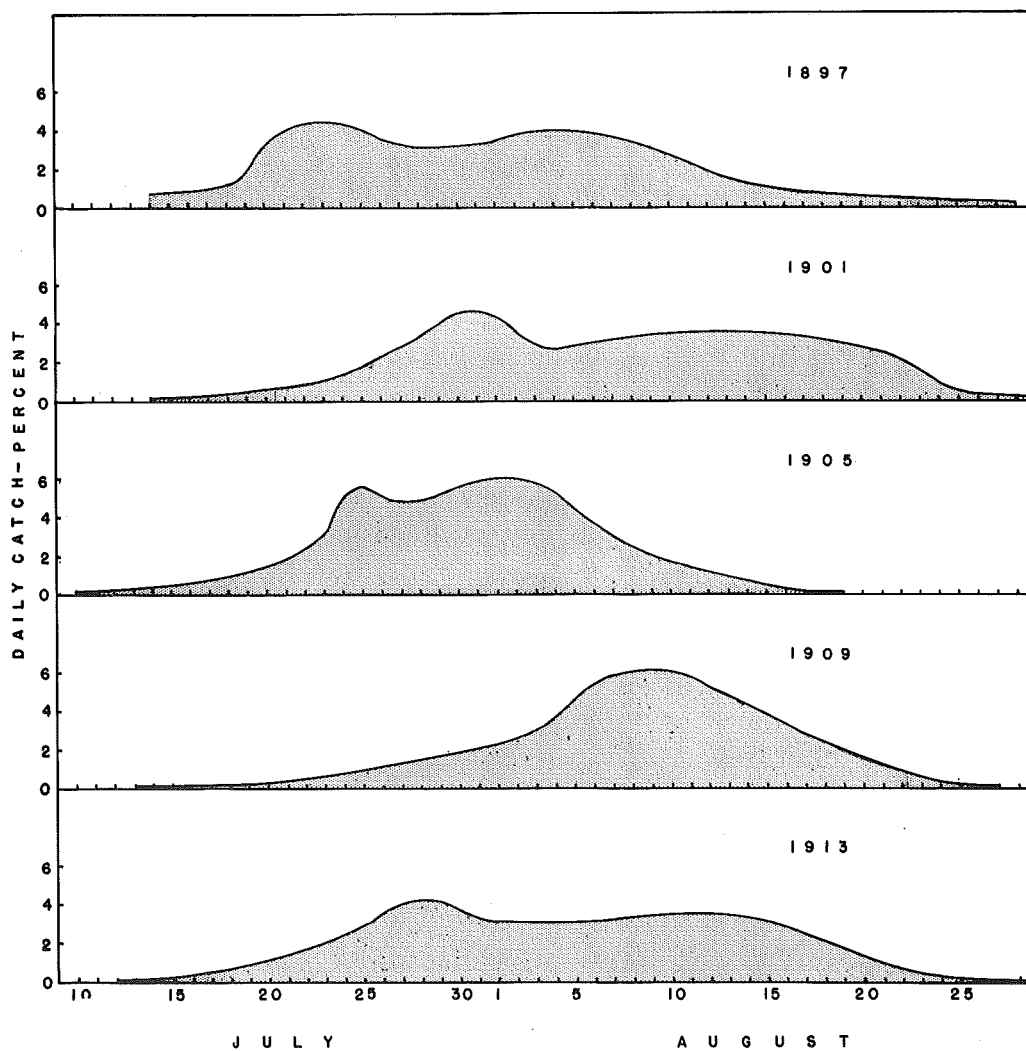


FIGURE 10 - Distribution of daily sockeye catches in the United States fishery of Convention waters for five cycle years of the 1897-1913 cycle.

reasonable. In fact the alternating moon phase is the only known factor which operates on an eight year cycle. FIGURE 11 shows the pattern of moon phases in mid-summer in the years of the 1913-1957 sockeye cycle from 1889 onward. The moon phase is approximately reversed each fourth year and the phase is almost the same each eighth year. The same relation would hold at any time in the year. Assuming a direct action on sockeye, the moon's phases might act at any time during maturation or migration. The phases of the moon in any given sockeye cycle gradually shift, as the alternate cycle years pass, until in a period of about 72 years (nine alternate sockeye generations) the new moon, for instance, replaces the full moon at the same date in the alternate cycle years. If the new moon at a given time causes earliness and the full moon causes lateness, the relationship of timing in successive generations would be reversed in approximately 72 years. Because the 1913-1957 cycle of sockeye runs was not **reversed** in alternation of timing in the 1893-1913 period compared with 1941-1957 (FIGURES 9 and 10), it is concluded that the simple relationship is not followed. If the moon's phases affect time of sockeye migration, the mechanism must be more complex. However, the possibility of the moon's phases being involved in the timing of successive generations is not eliminated.

The phenomenon of alternation of migration time in successive cycle years has been observed frequently enough to warrant consideration when regulations are being formulated preceding a fishing season. However, variation within each group of alternate generations has been

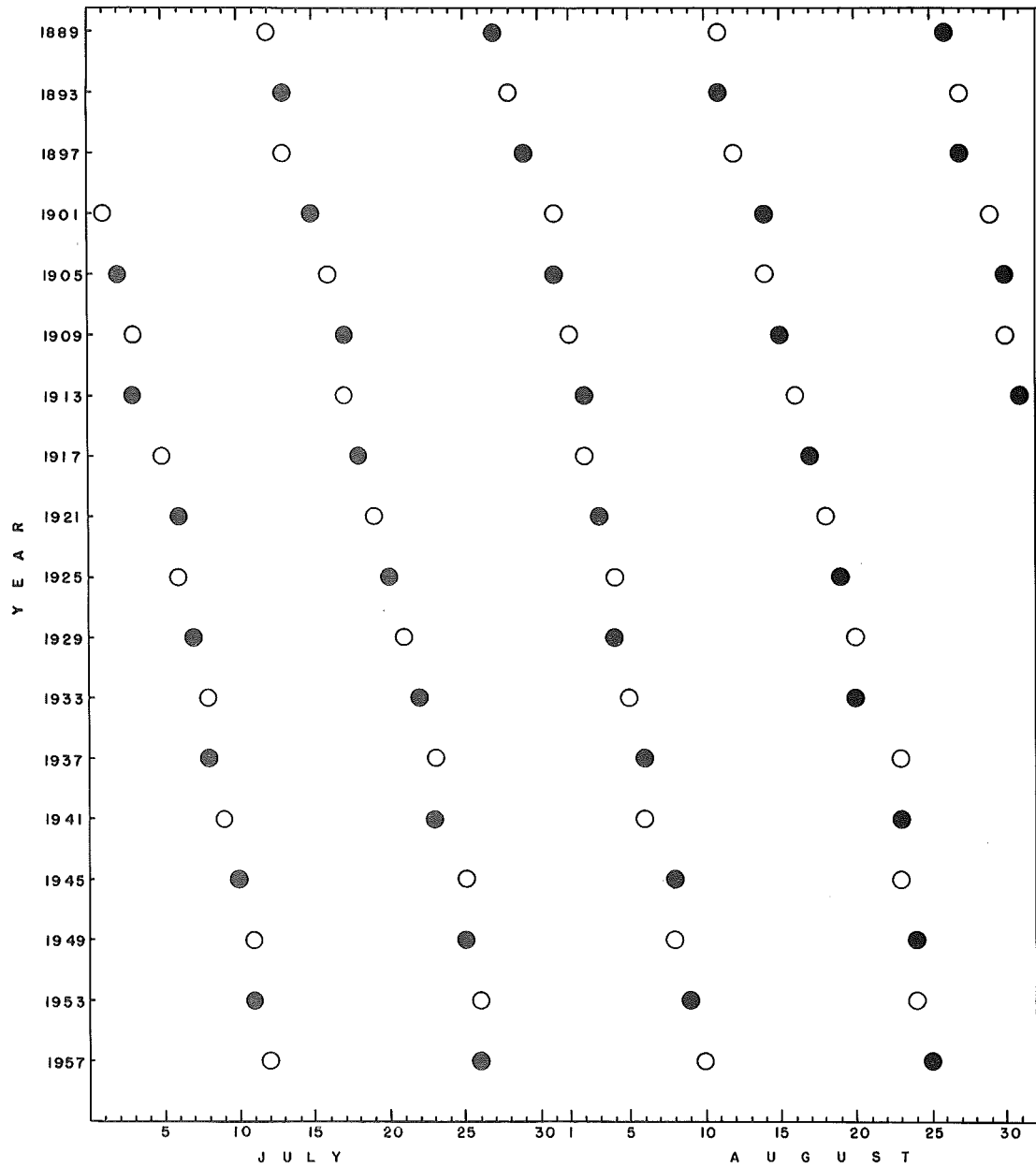


FIGURE 11 - Dates of new moon (solid circles) and full moon (open circles) in July and August in 18 cycle years of the 1889-1957 sockeye cycle.

considerable. Besides the obvious exceptions such as the 1937 sockeye season, there are smaller variations which are still of importance in regulating the fishery. Other factors appear to modify the time of migration, one example being the suggested relationship of timing to abundance. Another possible factor is to be discussed later.

Dispersion of Saltwater Migration

A complete description of timing of a racial sockeye run must include, in addition to the peak date at a specific location, some measure of the spread or dispersion of the run in time. Dispersion can be shown by a standard deviation or a duration above a specified minimum level of abundance.

The relative isolation of catches of Adams River sockeye in the dominant cycle allows a standard deviation to be calculated for comparative purposes. The calculated values for the cycle years when catch statistics were accurately assigned by area are as follows:

1938 - 2.4 days	1950 - 3.1 days
1942 - 3.0 days	1954 - 2.9 days
1946 - 3.0 days	1958 - 4.4 days

Mean standard deviation - 3.1 days.

The standard deviations were calculated from daily United States catches made in the San Juan Islands. In 1934 and previous years, catches by traps prevented comparison with later years. A sixteen day period was employed to minimize the inclusion of catches from earlier sockeye races. Catches on days closed to fishing were estimated by interpolation. The sixteen day period was chosen which gave a minimum

standard deviation. If all catches of Adams River sockeye beyond the sixteen day period had been used in calculating the standard deviations, the values would have been larger.

It is judged that there is no significant difference between the standard deviations listed above if that of 1958 is excluded.

Considering the large variations which occur in daily catches as a result of fluctuations in the amount and kind of gear fishing, in the effect of weather on fishing and possible changes of fish movements with weather and tides, it is perhaps remarkable that the standard deviations are so uniform. FIGURE 12 compares the catch curves in the San Juan Islands area for the six cycle years under consideration. Greater dispersion is indicated in 1958. Catches of Adams River sockeye in the San Juan Islands fishery in 1958 were affected by a very efficient fishery in Juan de Fuca Strait, because the San Juan Islands fishery operates on the escapement from the fishery in Juan de Fuca Strait. Although the catch curve of Adams River sockeye in 1958, shown in FIGURE 12, may not have been exactly representative of the unfished run, the catch curves in both Johnstone Strait and Juan de Fuca Strait in 1958 showed similar large dispersions. It is therefore unlikely that the large 1958 standard deviation was an artifact of the fishery.

Apparent variations in dispersion have occurred in other sockeye runs. During the years when the Chilko run predominated in the catch in the 1932-1956 cycle, the later alternate runs have tended to be of longer duration than the earlier alternate generations (FIGURE 8). In

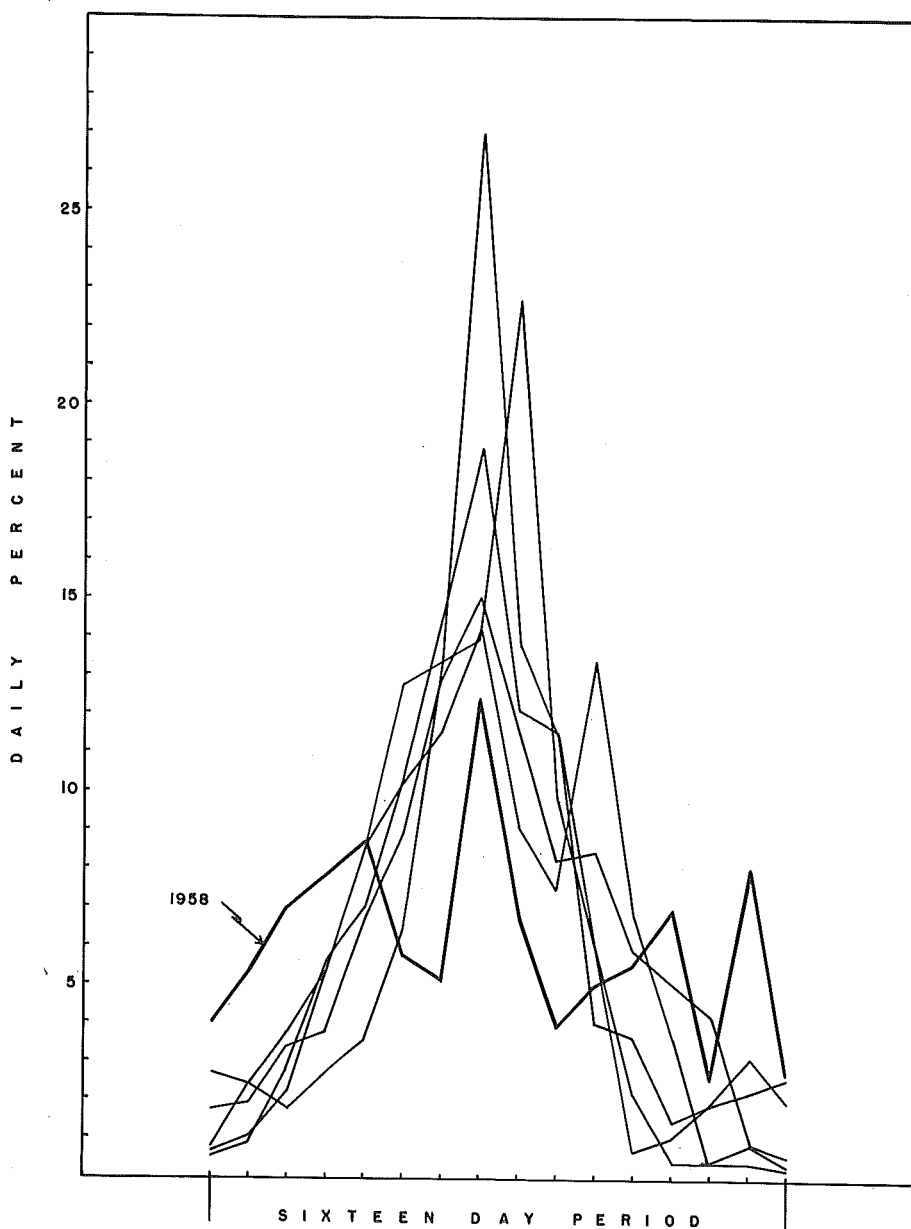


FIGURE 12 - Curves of daily percentage catch at San Juan Islands for dominant Adams River runs of 1938-1958. Catches during a 16 day period giving lowest standard deviation used; days of no fishing interpolated.

all the years except possibly 1932 catches made from the later alternate runs have had two peaks which could not be explained by changes in fishing effort. There does not appear to be any such consistent pattern of alternating dispersion in the 1913-1957 cycle although it is suggested in the last four cycle years of FIGURE 9. The data on dispersion of the dominant Adams River run shows no similar pattern. The alternation of dispersion within cyclic runs may be confined to the Chilko race or possibly also to certain other less important races migrating about the same time.

MIGRATION OF ADAMS RIVER SOCKEYE INTO THE FRASER RIVER

MacKay, et al. (1943 and 1944) showed in the results of marine tagging experiments that some sockeye delay off the mouth of the Fraser River between arrival at the river mouth and entry into the river. The longest delay occurred late in the sockeye season and differences between years suggested that changes in racial composition was the cause. More recent analysis of catch curves and identification of racial catches by means of sockeye scale studies (Henry, 1960) has extended the knowledge of this behavior. Immediate river entry (no delay) is characteristic of sockeye races which normally have their peak of arrival at the river mouth in July or the first few days in August. Races which arrive at the river mouth after early August delay for varying periods, later races generally having the longer delays. Duration of delay can vary from a few days for the earliest of the delaying races to several weeks for the very late races, notably the

Adams River race. At least one race appears to delay in some years and not in others.

Delay in the Adams River Race

The delay period of Adams River sockeye of the dominant run is spent in slow wandering movements in southern Georgia Strait apparently within the area where Fraser River discharge is present in the form of a distinct brackish layer at the surface. These sockeye do not approach the Fraser River mouth closely when they arrive off the Fraser Delta. At first they keep to the deeper, clearer waters beyond the edge of the tidal flats. The wide distribution at this time is shown by catches made by gill nets as far north of the delta as Gibsons Landing, as far west and south as the Gulf Islands which stretch from Gabriola Island near Nanaimo to Saturna Island at Boundary Pass, and as far east as the Point Roberts area.

As the time of river entry approaches, the sockeye begin to congregate close to the mouth of the Fraser and to move in on the tidal flats and later into the entrances of the river channels with the flood tide, retreating with the ebb. Catches by gill nets near the river mouth gradually rise with the increased availability. In the last day or two before upstream migration has begun, schools of sockeye have been noted as far upstream as two miles above Steveston, which lies at the river mouth. Once upstream migration begins, numbers of sockeye rise rapidly to a peak. Gill nets can then remove almost all the fish that enter the river during the time fishing is permitted.

In the recent years of the dominant Adams River run, there has been a closure in the river fishery covering most of the heavy upriver migration. Thus it has not been possible to determine the time of peak river migration, except in the last three cycle years when careful observations and test fishing have been used to estimate daily escapements. The date on which heavy upstream migration began was therefore used as an index of the timing of upstream migration. The beginning of the upstream migration of this run was always an item of interest in the years when the run was large. It is a rather sudden movement; in the course of no more than three or four days, a river apparently devoid of fish becomes alive with finning, jumping sockeye. The event has been often noted in the newspapers and in Canada Department of Fisheries reports. When fishing was allowed at the time of river entry, catches in the river showed a sudden increase. In the years when dipnetting was carried out by the Commission at Hell's Gate (1938-1942-1946-1950), a sudden increase in abundance was noted there seven or eight days after the upstream migration began.

The dates of first river entry, for the last eight cycle years of the dominant Adams River run, compiled from all available evidence, are as follows:

1930 - September 22	1946 - September 15
1934 - September 13	1950 - September 13
1938 - September 13	1954 - September 17
1942 - September 13	1958 - September 28

The relationship of time of migration into the Fraser River to the time of peak migration in the San Juan Islands is shown in FIGURE 13. Later runs in salt water are associated with later river entry, and early runs with early entry. The relationship may not be linear. A limiting date is suggested in FIGURE 13 (September 13), before which the run does not enter the river. However, the sub-dominant Adams River sockeye run has apparently entered the river as early as September 10 or 11. The sub-dominant run is also earlier in its saltwater migration. Although the smallest dominant runs in FIGURE 13 were the earliest, their river entry has a degree of uncertainty because sockeye of other races might have formed a significant percentage of fish in the river at the time. For the larger runs, the error could not be more than a day or two.

The most obvious measure of the length of delay is the time required for the peak of a run to move from the saltwater fishing areas outside the zone of delay to the fishery in the river above the zone of delay, less the time required for direct migration between the two locations. In a run which maintained symmetry in its time-abundance curve, this measure of delay would be the same as the average delay time for the whole run.

The Adams River run, however, is usually quite asymmetrical in its river migration and the peak of upstream migration cannot be used to obtain average duration of delay. Although no accurate estimates may be given for average length of delay, an inspection of estimated migration curves in the Fraser River allow the range of delay to be stated. The

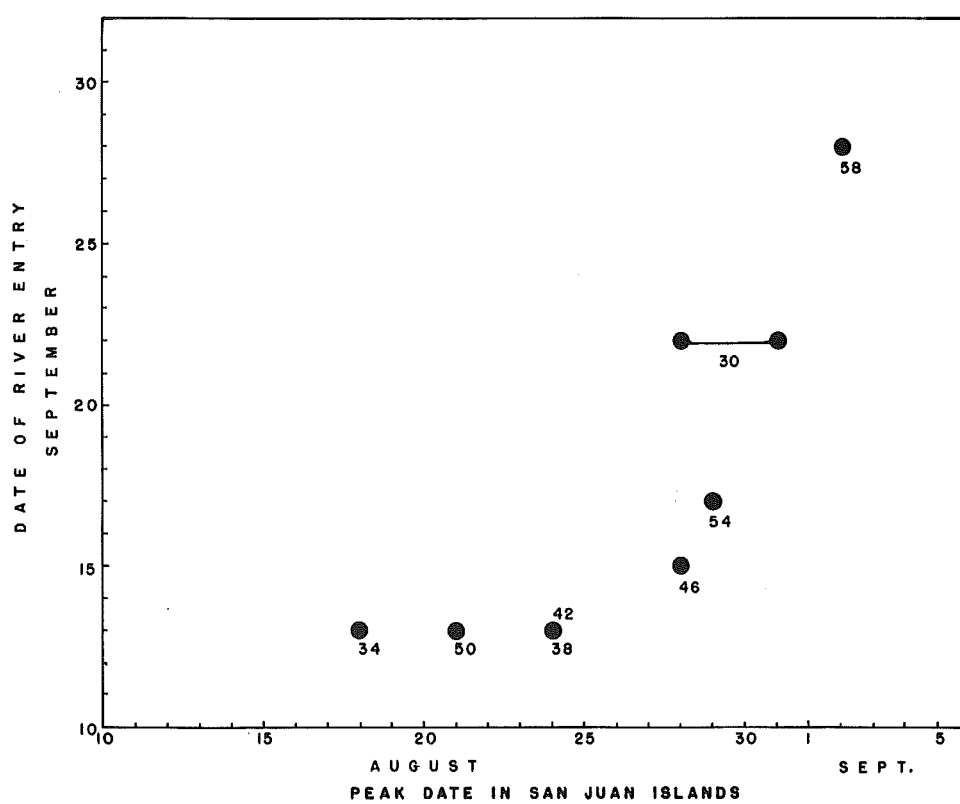


FIGURE 13 - Relationship of timing of Adams River run in saltwater migration to time of upriver migration for cycle years 1930-1958.

minimum delay for an individual sockeye appears to have been about two weeks assuming that chronological order is retained over the delay period. Maximum delay in the years of greatly extended river migrations appear to be as much as six weeks, also presuming retention of chronological order. Because of the skewed river migration, the average duration of delay must be closer to the minimum duration of delay.

Duration of Upstream Migration

The pattern of upstream migration of the Adams River run is of considerable importance to the fishing industry as well as to those who must ensure proper escapement to the spawning grounds. The long delay off the river mouth is accompanied by gradual changes in the maturing sockeye which make them less desirable to the canning industry. The problem becomes acute when the migration into the river is of long duration because the delay period of individual sockeye increases when the latter portion of the migration into the river is extended. Examples of the extremes of the migration pattern are found in 1942 and 1954, when the runs were approximately equal in size. The 1942 run was extended into October and catches by gill nets in that month exceeded 600,000 sockeye which had delayed off the river mouth for from four to six weeks. In 1954, the Adams River run migrated into the river so rapidly that less than 6000 sockeye were caught in the Fraser in October, and very few fish delayed longer than three weeks.

The end of migration of the Adams River run into the river has been determined for the last eight dominant cycle years to provide figures on duration of upstream migration. Dates of end of migration were estimated from all available information on commercial gill net catches, test fishing catches, and observations of sockeye breaking water in the river and off its mouth. Hell's Gate observations and dipnetting in years in which no blockades occurred provided confirming information. The passage of large numbers at Hell's Gate could be related to migration at the river mouth by the known migration speed. End of migration was not the passage of the last fish up the river but was rather the date on which the migration was judged to have fallen to a value no longer significant to the fishing industry or to escapement. The dates of beginning and end of the important part of the upstream migration of Adams River sockeye at the mouth of the Fraser and the consequent duration of migration for the last eight cycle years are given in TABLE 1.

TABLE 1 - Estimated dates of beginning and end of upstream migration of the last eight cycle years of the dominant Adams River run.

Cycle Year	Date of Beginning	Date of End	Duration in Days
1930	Sept. 22	Oct. 9	17
1934	Sept. 13	Sept. 26	13
1938	Sept. 13	Oct. 9	26
1942	Sept. 13	Oct. 7	24
1946	Sept. 15	Sept. 27	12
1950	Sept. 13	Sept. 20	7
1954	Sept. 17	Sept. 20	3
1958	Sept. 28	Oct. 22	24

In the interest of proper management, it was necessary to investigate the causes of the wide diversity of the upstream migration period. An attempt was made to relate the duration of migration to Fraser River temperatures or discharges in September but no significant relationship was found. Exploring further, the durations were compared with the annual discharge of the Fraser River on the chance that salinity in Georgia Strait was involved. A promising relationship was found in which high discharges were associated with short migration duration in the river and low discharges with long durations. This was investigated more fully by comparing duration of migration with Fraser discharge for individual months and groups of months.

The Fraser River discharge data employed were those obtained at the gauging station at Hope, B.C. (Canada, Water Resources Papers, 1935 to 1959). Some of the total discharge which reaches Georgia Strait is contributed by streams below Hope (e.g., the Harrison and Pitt Rivers) but the amount is a rather small proportion of the total annual discharge except under unusual circumstances. Many of the streams entering the Fraser below Hope have not been metered until very recently, hence, they could not be added to the discharge measured at Hope for comparison with the eight cycle years of the dominant Adams River run. However, there is a general correlation between discharge at Hope and the discharge entering below that point. The major streams entering the Fraser below Hope drain areas having snow fields and glaciers, which produce a spring freshet similar to the discharge pattern at Hope. Discharge at Hope is considered to be an acceptable index of total Fraser discharge on a

monthly basis during the spring and summer when most of the Fraser runoff occurs.

A series of correlation coefficients were calculated, each relating discharge during a certain period (one to seven months) to the duration of migration in the following autumn. These correlation coefficients are listed in TABLE 2. They suggest that the combined summer discharge for the months of June, July, August and possibly September is the factor which determines duration of upriver migration. The two highest values in TABLE 2 are -0.927 for the discharge of June, July and August and -0.930 for the discharge of June, July, August and September. These values are highly significant statistically. Because the Adams River run enters the Fraser in most years about the middle of September, the discharge of the latter half of September can have little effect on the pattern of migration. It is interesting to note that the discharge in the first half of September, the principal delay period, also had little relationship to river migration. A correlation coefficient was calculated for duration of migration related to Fraser discharge between June 1 and September 15, which yielded a value of -0.931. Since this is the highest numerical value of all the correlations obtained, this $3\frac{1}{2}$ month period appears to be the one most suitable for predicting the duration of river migration. FIGURE 14 shows the relationship of migration duration to discharge for this period.

TABLE 2 - Correlation coefficients for duration of river migration of 1930-1958 dominant Adams River runs related to Fraser River discharge for various periods. Coefficients are listed at center of discharge period from which they were derived.* Dashed and solid lines enclose values significant at 5% and 1% levels, respectively.

CENTER OF DISCHARGE PERIOD	DISCHARGE PERIOD						
	One Month	Two Months	Three Months	Four Months	Five Months	Six Months	Seven Months
April 15	+0.260		+0.101		-0.195		
May 1		+0.096		-0.204		-0.532	
15	-0.056		-0.236		-0.561		
June 1		-0.430		-0.610		-0.602	
15	-0.716		-0.762		-0.719		-0.643
July 1		-0.883		-0.811		-0.744	
15	(.05) (.01)	-0.907	-0.927		-0.855		-0.669 (.05)
Aug. 1		-0.919		-0.930		-0.782	
15		-0.828	-0.892		-0.864		-0.774
Sept. 1		-0.751		-0.800		-0.840	(.01)
15	-0.560		-0.559		-0.767		
Oct. 1		-0.319		-0.578			(.05)

* Example: the value of -0.927 near the center of the table is the coefficient for duration of river migration correlated with discharge for the period June 1 to August 31.

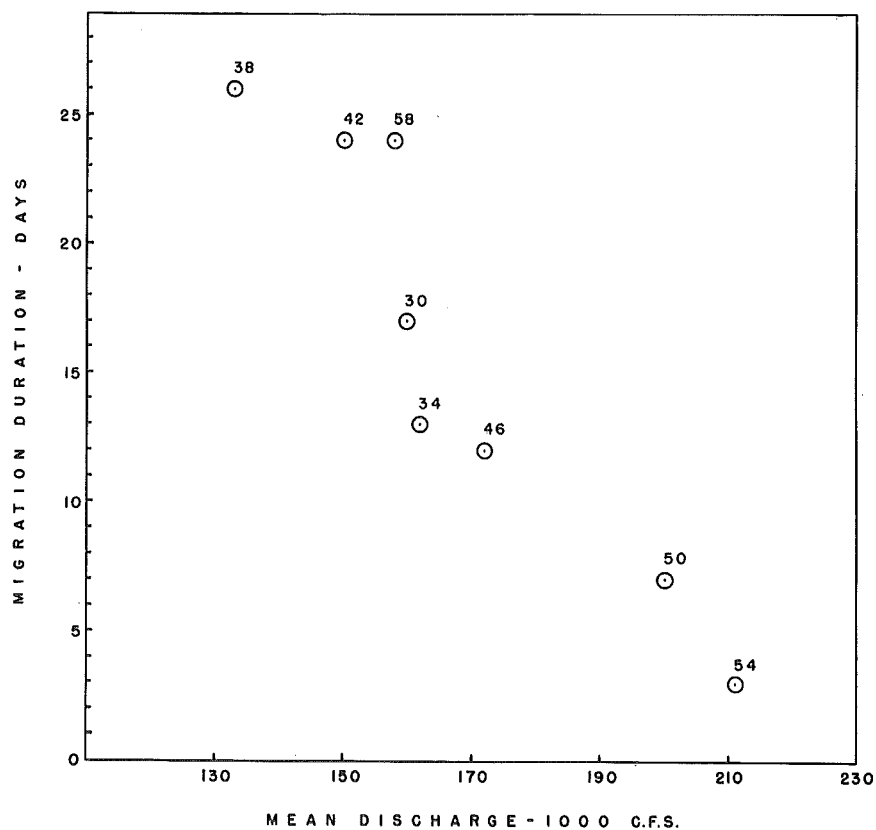


FIGURE 14 - Relationship of duration of upstream migration of dominant Adams River runs of 1930-1958 to Fraser River discharge from June 1 to September 15.

There are, however, several additional considerations necessary before a final conclusion is drawn. The very high numerical values of correlation coefficients, while statistically significant, must be interpreted with caution. Estimates of duration of river migration (TABLE 1) are somewhat empirical. Because different interpretations may be made of the date of ending of certain of the dominant Adams River runs, the estimates may be somewhat in error. The correlation coefficients in TABLE 2 are very sensitive to such errors. The durations of the 1938 and 1958 runs are the two most subject to error and may be shortened if certain facts are considered.

During the migration of the 1938 Adams River run into the Fraser, test gill net fishing by the Canada Department of Fisheries showed a bimodal migration with a period of low abundance from approximately September 23 to 27. Dipnetting for sockeye at Hell's Gate showed the same phenomenon. A second mode or wave of migrating sockeye appeared in the fishery approximately between September 28 and October 9. This wave did not appear in strength at Hell's Gate probably because the gill net fishery removed almost all of it. If the second wave of migration is ignored and a duration of migration of 10 days is assumed (September 13 to 23), then the numerical size of the correlation coefficients in TABLE 2 is reduced considerably.

The numerical values of the correlation coefficients in TABLE 2 can be raised somewhat if the duration of the 1958 migration of Adams River sockeye in the Fraser is decreased. It may be hypothesized that

the duration of river migration in 1958 is the sum of two factors. First is the effect of Fraser River discharge which is correlated inversely with duration of migration in the river. Second is the much increased dispersion noted in the 1958 migration in salt water which might have remained an essential part of the migratory behavior after delay. In comparing the duration of river migration with river discharge, it would then be necessary to remove that part of the 1958 duration which was attributed to an abnormally large dispersion in salt water. Reduction of duration of river migration over a considerable range was found to increase the closeness of correlation in TABLE 2. However, it did not appreciably alter the relationships within the table.

The interpretation of dispersion in 1958 cannot be accepted as valid merely because it increases the closeness of the relationship between river discharge and duration of river migration. An hypothesis such as this, which is formed by somewhat intuitive methods and cannot be verified by experimentation, must be tested by prediction. Only when circumstances similar to those of 1958 recur can a sufficient test of this hypothesis be made.

Fishing regulations during the upriver migration of the dominant Adams River run are quite different from those applied to the other important sockeye races. Because few sockeye of other races migrate at the same time, an extended closure is used to obtain escapement from the peak of the run. The length of the extended closure can be predicted

from the correlation between duration of upstream migration and summer discharge of the Fraser when the required escapement and size of the delaying sockeye population are known. The size of the delaying population is derived by comparing the catch per unit of effort of gill nets fishing in the zone of delay off the river mouth with catch per unit in previous years of dominant Adams River runs. The beginning date for the extended closure can be tentatively determined from FIGURE 13. The closure is then continued until the required numerical escapement, plus a safety factor for inaccuracies in population estimates, is obtained.

Prediction of the requisite length of the extended closure can be obtained from the smoothed and idealized time-abundance curves shown in FIGURE 15. Each curve expresses the percentage of delaying Adams River sockeye remaining in Georgia Strait on any day after the beginning of upstream migration for a given summer discharge of the Fraser. The set of curves in FIGURE 15 were interpolated between the two boundary curves which were derived from the upriver migrations of 1942 and 1954. The progress of the 1954 river migration was derived from catches made by test gill nets during the extended closure. In 1942, the latter part of the much extended migration was fished extensively and the curve was determined from the trend of the catches. Intermediate curves in FIGURE 15 were obtained by interpolation parallel to the time axis. Curves for years with lower summer discharge than 1942 would be obtained by extrapolation.

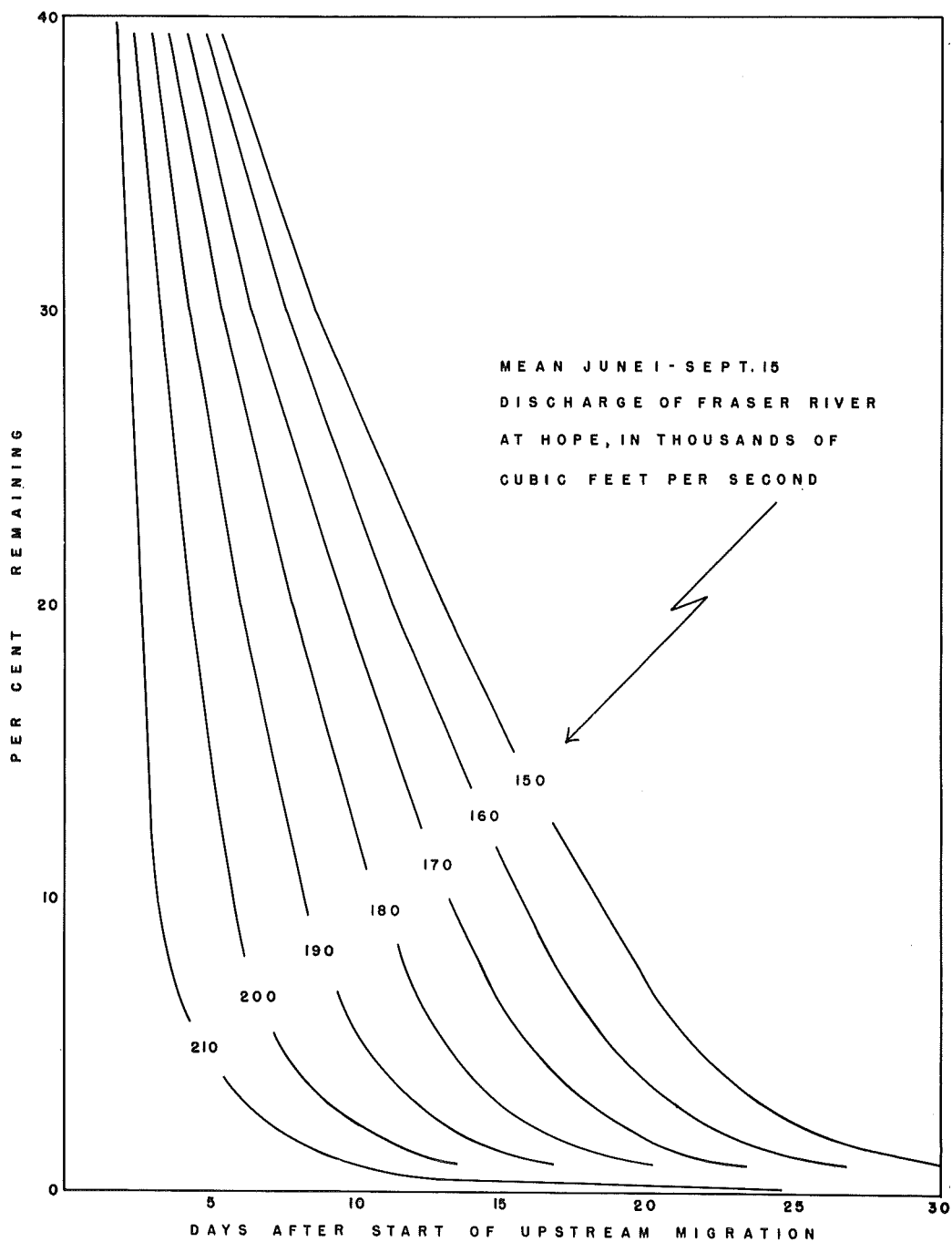


FIGURE 15 - Percentage of delaying Adams River sockeye remaining in Georgia Strait on any day after the beginning of upstream migration, for various means of Fraser River summer discharge.

The tentative date for the end of the extended closure can be obtained from FIGURE 15. From the estimated population of delaying sockeye present off the Fraser River mouth at the beginning of the extended closure, the percentage of surplus sockeye available as catch is calculated. This percentage is applied to the curve in FIGURE 15 corresponding to the river discharge in the summer of the year. The number of days of migration required to allow the necessary escapement are taken from the corresponding point on the time scale. Because Adams River sockeye require approximately three days to travel from Steveston to Mission, the extended closure will end on the date corresponding to three days more than the number of days obtained from FIGURE 15 after the beginning of upstream migration.

The curves in FIGURE 15 are approximate for several reasons. First the idealized curves exclude day to day variability which is known to occur. Second, the linear interpolation between the boundary curves assumes a straight line relationship between migration duration and river discharge whereas it may be curvilinear. Third, there appears to be considerable variation in duration of migration for any given mean of river discharge. An example is the increased duration which occurred in 1958. Thus, additional information is required during the upstream migration of the Adams River run to ensure the escapement of an optimum spawning population.

It has been customary to determine the progress of upstream migration of Adams River sockeye by test fishing with gill nets, which provide a measure of daily numerical escapement. While the necessary escapement could be obtained by the use of test fishing alone, it is desirable to have advance information concerning the upriver migration and the extended closure. The fishing industry prefers to plan its activities ahead and the Commission must obtain the escapement from the most productive part of the migration (Internat. Pacific Salmon Fish. Comm., 1959).

Delay and River Migration Related to Environment

The delay of a salmon population in salt water off the mouth of a river is not confined to certain races of Fraser River sockeye. Similar delays have been described for pink salmon (Pritchard, 1936; Davidson et al., 1943; Ward, 1959; and others). Comparison of seasonal occurrence of chum salmon in the traps north of Deception Pass with occurrence in Fraser River gill nets, in the data of Rounsefell and Kelez (1938), suggests a delay before river entry. Coho salmon delay for long periods when stream flows are exceptionally low (Washington Department of Fisheries, 1953). Undocumented reports by fishermen of delay behavior of pink, chum and coho salmon, in many areas, are plentiful. Evidence concerning delay in chinook salmon is quite limited. A delay of about a month in the mouth of the Columbia River was reported by Wendler (1959) for Columbia spring chinook salmon. Tagging data discussed by Schoning and Johnson (1956, p. 7) suggested a possible delay of a few days in the same area for

fall chinook of the Columbia. Delay behavior has not been reported in most of the major sockeye fisheries such as Bristol Bay, Karluk River, and Skeena River, but this does not preclude its existence. Fishermen report possible delay behavior in Rivers Inlet sockeye (undocumented). Delay of large runs of sockeye in areas of salt or brackish water is concluded to be less common than uninterrupted migration. Periods of delay commonly occur at some point closer to the spawning grounds as in Chilko sockeye (Killick, 1955), Baker Lake sockeye (Hamilton and Andrew, 1954) and Morice Lake sockeye (Vernon, 1952). It can be expected that more studies of delay behavior will be made on salmon in the future since it is of major importance in management.

The major differences in behavior between species of Pacific salmon might be explained as adaptations to different parts of the overall salmon habitat, to minimize competition between species and to exploit different niches of the environment. The major differences of behavior between races within a species of salmon might be adaptations for making most successful use of the environment which they encounter in the different areas of reproduction or at different seasons of the year. However, the value of specific adaptations of individual sockeye races is in most cases quite obscure. The delay behavior of Adams River sockeye is among these unexplained adaptations.

The apparent effect of summer discharge of the Fraser River on the variable migration of Adams River sockeye early in the following autumn is difficult to explain. One possibility is that river discharge

is merely an index of some other factor which is the basic cause of variability. Changes in salinity in the area of delay or even in areas to the seaward is a more attractive hypothesis, but no information is at hand to suggest the mechanism by which salinity affects subsequent behavior. Moreover, no close relationship over a period of years has been found between available data on the surface salinity of Georgia Strait and its approaches, and Fraser River discharge in the period of maximum runoff. Salinity of the surface layers occupied by sockeye will fluctuate considerably due to changeable amounts of vertical mixing by wind and tide, above and beyond the effect of diversity of discharge (Tully and Dodimead, 1957). Also, Waldichuck (1957) points out that salinity in Georgia Strait could vary significantly with changes in salinity of the ocean water drawn into Georgia Strait along the bottom to replace salt water taken to sea by the river discharge moving out at the surface. Whatever the basic mechanism, it appears to affect the migration pattern in the river without changing the characteristics of migration in salt water. For this reason, if for no other, it is logical that the discharge of the Fraser River is directly involved presuming the relationship is valid.

The behavior of Adams River sockeye in their upstream migration is quite different from other species. Certain stocks of pink salmon have been shown to enter their home stream from salt water in a manner determined in part by the discharge at the time of migration (Davidson et al., 1943). It is to be noted that Fraser River pink salmon apparently

do not show such behavior (Ward, 1959). A relationship of migration to factors (rainfall and barometric pressure) which vary concurrently with it has been shown for chinook and coho salmon by Allen (1959). The migration of these three species was studied at a point quite close to the area of reproduction. If certain stocks of pink salmon, for example, enter their home stream when rainfall increases flow, the basis for the behavior may be concluded to be the need to wait until the flow on the spawning grounds is sufficient to allow successful spawning. Such an adaptation may only be useful in years of extreme dryness, but the behavior could occur almost every year. A similar adaptation in Adams River sockeye would appear to be valueless, since the flow of the Fraser is not likely to be related to conditions in the home stream. Delaying Adams River sockeye are 300 miles from their spawning ground and water from their home stream forms but a small part of Fraser River flow at the mouth. The adaptation which Adams River sockeye appear to have developed, i.e., a response to variable summer discharge of the Fraser, cannot be as easily explained as the behavior of pink salmon.

River discharge does not appear to be the only factor influencing the variability of migration in the river. The possible effect of dispersion in the pattern of migration in salt water has already been mentioned. The occurrence of bimodal river migration in 1938 and in 1958 suggests that one or more other factors, operating during the period of upstream migration are involved. Examination of temperature and flow of the Fraser near the mouth has failed to uncover them.

Migration of Adams River sockeye in the Fraser River is unusual in certain respects. The great degree of variability from year to year is not found in other sockeye races from present observations. The highly asymmetrical pattern with sudden river entry is in sharp contrast to the symmetrical pattern of migration of other large racial runs. The dispersion of the migration of other sockeye races which have been isolated in commercial catches is relatively constant.

Another problem may arise as a result of the variable behavior if the Fraser River were dammed, independent of the direct effect on upstream migrants at the dam or dams. The storage of Fraser discharge by dams, or diversion of water from the Fraser River watershed will lower the volume of freshet discharge. This could lengthen the duration of river migration, causing many Adams River sockeye to delay excessively, thus lowering their desirability for canning. Allowing these late sockeye to escape will not solve the problem created, for besides being an economic waste if the spawning grounds are overcrowded, the late fish would very probably be unproductive spawners. Late migration produces late spawning which may lower survival of young if eggs are subjected to low temperatures too early in development. Also, overlong retention of ova or fertilization at low temperatures may reduce viability. Moreover, late emergence of surviving young ensues, curtailing their period of good growth in the lake in the following spring and summer.

MECHANISM OF SOCKEYE TIMING

The management of the fishery for Fraser River sockeye by the International Pacific Salmon Fisheries Commission has been based from the beginning on a realization of the existence of races (Thompson, 1945). Each race has been treated as having its own distinct time of migration and requirements for escapement. As investigations continue, the details of racial uniqueness and range of variability are becoming clearer. However the basic causes of unique racial characters and variation are still poorly understood. A consideration of the mechanism or mechanisms which control the timing of migration suggests certain avenues of investigation toward the goal of forecasting migration behavior.

Variation of timing within a sockeye race appears to center on a mean value which might be termed "normal timing". The mean would correspond to the mean effect of environmental variables which cause the variation. Assuming that the mean of timing arose through evolution by selective processes, the mean value can be interpreted as an optimum point for survival. For a given race, the occurrence of a rather sharp peak or mode in timing, both in migration and spawning, suggests that the fish in the peak usually encounter an advantageous set of conditions for survival (Royal, 1953). The existence of a sharp peak as a racial character infers that the period of optimum conditions is of short duration while a salmon migration which ordinarily has a broad peak of long duration suggests a similarly extended period of optimum survival conditions.

Maturation and Migration

Records kept of Fraser River sockeye spawning have yielded some interesting comparisons between migration and spawning. The most general relationship noted is that time of migration of sockeye races in the fishery is correlated with their time of spawning. Moreover, Killick (1955) has shown this to be true for the fish within a single race, at least for non-delaying sockeye races. A tendency has been noted for individual races to spawn early in years of early migration and late in years of late migration. An example of this tendency was found in 1958, in which year almost all of the Fraser sockeye races were 10 days later than usual in their migration time, and the Chilko race was approximately two weeks later than average (Henry, 1960). Spawning was quite late on most spawning grounds in 1958, and in the Seymour, Raft, Horsefly, Nadina (early race), Chilko and Middle Rivers, the reported period of peak spawning was completely outside any previously noted ranges (Internat. Pacific Salmon Fish. Comm., 1951 to 1959, Spawning Population tables).

Migration before and after a delay at the mouth of the Fraser appears to be correlated in a parallel fashion. It was shown in FIGURE 12 that the time of migration of Adams River sockeye in the river is related to the time of migration in salt water by a delay period which tends to be constant from year to year although modification of delay within a run by river discharge was indicated previously. With the tendency toward constant length of delay from year to year, it is

believed that there must be a tendency toward constancy of duration of delay for individual sockeye also. In other words, chronological order of migration before and after delay will be retained within an Adams River run. This is consistent with the relationship, indicated in the previous paragraph, between migration and spawning timing of sockeye.

It is concluded that not only spawning time but also migration time is a consequence of the process of maturation. Maturation, then, is a physiological process whereby sockeye become sensitive to certain facets of their environment, interacting with them to bring about the sequence of migration and spawning necessary for survival.

Although a close connection has been indicated between maturation, time of migration and time of spawning, both between races and within a race, the relationship is not inflexible. For example the previously mentioned extension of delay followed by late migration and spawning for certain individuals in many of the dominant Adams River runs may or may not be accompanied by a similar retardation of maturation. Either maturation is slowed in proportion to the lateness of migration or there is a prolonged retention of sex products after maturation has been accomplished. The occurrence of very late though apparently normal spawning in years of extended migration of the Adams River run suggests that some sockeye do have their maturation retarded. However, extended migration is usually accompanied by the failure of some of the late migrants to reach their intended spawning grounds, because energy reserves are exhausted or because spawning can no longer be delayed. In the 1958

Adams River run, the fish which did not reach the spawning grounds numbered many thousands although no serious obstructions occurred on the migration path. Evidence from the Early Stuart racial run of 1955 indicates that productive spawning, at least for this race, is obviated by delayed (obstructed) migration and the consequent extended retention of ova and milt (Internat. Pacific Salmon Fish. Comm., 1956, 1960). Most of the 1955 Early Stuart spawners did not reach their home streams and those that did were very late. This interfered with their reproduction, yielding a meager return in 1959. Whether some members of an Adams River run can tolerate overlong retention of sex products cannot be said at present. The poor return in 1950 from delayed Adams River spawning in 1946 (Internat. Pacific Salmon Fish. Comm., 1951) suggests that delays in migration affect the majority of this race much as the 1955 Early Stuart run was affected. Investigations concerning the relationships between maturation, consumption of energy reserves, and migration timing are not yet complete.

Photoperiodism in Sockeye

Early in the twentieth century, the idea arose that many animals were photoperiodic, i.e., their migrations and breeding seasons were set to a calendar provided by the annual variation of day length outside the equatorial zone (Rowan, 1926). Rowan confirmed this in birds and hypothesized a similar situation in migratory fish. The rearing of fish of the family Salmonidae (salmon, trout and char) in hatcheries has prompted experiments to change time of maturation to take advantage of

better growing conditions at warmer seasons, to shorten holding times, or to provide two or more separated egg acquisitions in a year. Hoover and Hubbard (1937) and Hazard and Eddy (1950) were able to advance the spawning time of brook trout (Salvelinus fontinalis) by as much as $3\frac{1}{2}$ months by exposing them to an exaggerated and accelerated pattern of artificial day lengths begun 10 months prior to the natural spawning time. Combs et al. (1959) were able to advance the maturity of sockeye ("blueback") salmon by almost a third of the normal holding period of two months by artificially shortening day lengths. The failure of a time control in one experiment showed that excessive day length could retard spawning proportionately. Temperature was eliminated as an important cause of change of maturation rate. It can be concluded that sockeye maturation is largely a response to the pattern of changing length of day and the resulting migration time, then, is also similarly related.

Sockeye originating and spawning in the same watershed (e.g., the Fraser River system) are presumably exposed during maturation to approximately the same length of day environment, since pattern of day length varies with latitude. Within such a group, individual populations which spawn at different times must differ genetically in their response to changes in day length. Time of spawning, which is seldom treated quantitatively, requires definition: time of spawning is the spawning frequency curve with time that is observed in a sockeye population in

its home stream. The spawning of stray sockeye displaced from other spawning grounds by overcrowding (termed "slop-over" by Royal, 1953) must be excluded. In the Fraser River system, most of the frequency curves of spawning time in the various sockeye home streams are so distinct as to allow no explanation other than the existence of genetically discrete races, each with its own unique time of migration and spawning.

Oceanographic Conditions and Migration

Variations in migration time for a given race appear to be determined before they enter the fishing areas in coastal waters. As previously noted, a racial run tends to maintain its relative earliness or lateness through migration to spawning. The cause of the variations in timing therefore appears to act during the period of ocean residence.

Two types of aberrations of timing appear to occur. The first type consists of usually small, independent variations for individual races. An example of the first is the apparent effect of population size on time of saltwater migration in the Adams River run (FIGURE 7). The second type often consists of large deviations in timing which affect most races similarly. An extreme example of this is the previously mentioned run of 1958 in which the majority of races were later than had ever been observed before.

The second or general type of variation appears to be the result of variable oceanic conditions. The coincidence of lateness in the 1958 run with high seawater temperatures described by Tully et al. (1960)

has been the starting point for such a conclusion. Further examinations revealed that the sockeye runs of 1957 and 1959 were also late but to a lesser degree than 1958. The oceanographic conditions in 1957 were building up to the extreme of 1958. In 1959 the anomalous situation had not fully subsided. The much increased temperatures in 1957-58-59 suggest a connection between ocean temperature and migration, possibly a direct causal relationship.

The discussion of periodic increases in the migration of Fraser River sockeye through Johnstone Strait has suggested that ocean temperatures may have been responsible for the large migration through that passage in 1958 and in certain other years. It was further concluded that increased Johnstone Strait migration and therefore above average ocean temperatures occurred at periods of sunspot maxima. An examination of available data on timing of cyclic runs of Fraser sockeye suggests that at least one yearly run at about the time of sunspot maximum will be abnormally late. The Pacific Fisherman (1927) reported that the sockeye salmon run of 1927 was very late in the fishery and this was confirmed for sockeye by comparison of catch records for 1927 with those of other cycle years of the cycle. The 1937 sockeye run, consisting mainly of Chilko River sockeye according to spawning ground reports, was a rather late run, especially so when it should have been early to agree with the alternate timing of successive generations (FIGURE 9). The sockeye runs of the period 1946 to 1948 did not appear to be abnormally late but fishing was so much

curtailed in American waters in 1947 that it cannot be judged whether the sub-dominant Adams River run of that year was normally timed. Catch records in years close to the sunspot maximum of 1917 do not indicate any extremely late runs. The effects of Hell's Gate blockades and probable large resultant changes in racial composition, makes the true timing difficult to ascertain during this period.

Because late spawning (retarded maturation) occurred in 1958 with the late racial migrations, a simple mechanical explanation of the retarded migration is insufficient. At least three processes can be hypothesized to explain acceleration or inhibition of maturation in the ocean. These are:

1. The direct physiological effect of seawater temperatures on the sockeye.
2. The direct effect of some unknown factor which may be correlated with temperature, such as salinity.
3. A change of photoperiodic response in maturation occasioned by a change in the latitudinal distribution of sockeye in the ocean.

Little evidence is available with which to judge the first two possibilities. Increased temperature generally tends to accelerate biological processes, whereas in 1958 maturation was retarded. Combs et al. (1959) could find no temperature effect in their data concerning sockeye photoperiodism. The second hypothesis covers many possibilities. Inhibition of maturation in the Adams River run following low Fraser discharge in the summer is a possible example of such a factor.

The third possibility postulates the effect of variable day length on maturation rate demonstrated by Combs et al. (1959). The increase of day length with increased latitude during the summer would retard the photoperiodic response. Unfortunately, available evidence concerning the distribution of sockeye in the Northeast Pacific are insufficient to allow confirmation or rejection. The northerly landfall in 1958 indicates more northerly distribution but this might have occurred for a very short time as the fish approached the coast. However, the recovery in waters adjacent to the Fraser River of tags applied in the vicinity of Kodiak Island in 1958 (Internat. North Pacific Fish. Comm., 1959) indicates northerly distribution in that year in the open ocean. The examination of scale samples from open ocean fishing suggests that most of the sockeye in that area in 1958, at the time the samples were obtained, were of Fraser River origin (Henry, 1958). Unfortunately, further evidence is not available to show whether ocean distribution in 1958 was different from other years. A better judgment may be possible when present and future information on sockeye distribution is closely examined and possibly related to the distribution of physical variables or planktonic "indicator" organisms.

Variable maturation resulting from changes of latitude during ocean residence could explain one other phenomenon of sockeye behavior, that of increased dispersion in large runs. This effect, observed in the very large sockeye run of 1958, might be due to the spreading of the fish into a wider range of latitudes in the Northeast Pacific

possibly as a result of the large size of the population or to oceanographic conditions or a combination of these factors. Difference in day lengths at the different latitudes would produce a wider variation in photoperiodic response than is found in other years.

Prospects for Better Prediction

The analysis of factors which influence the time of migration has, up to now, yielded mainly qualitative rather than quantitative predictions of behavior. Magnitude of the effects of such factors as size of population and the peculiar alternate timing of successive generations can only be guessed at. Possibly other contributing factors remain to be discovered and the effect of known factors must be clarified.

On the darker side is the apparent great complexity of the problem. Related external and internal influences seem to be at work. Each race of sockeye may be a problem in itself. The gamut of possible external environmental factors is very large. It might not be feasible or even possible to measure all the important influences.

On the lighter side is the growing fund of both biological and environmental information. Each year the Fraser River sockeye run is being separated into its racial components in the fishery as well as on the spawning grounds. Temperatures and flows are measured along the important freshwater migration routes. Oceanographic data is growing not only by yearly additions but also by expanded programs to measure biological as well as physical variables. There is a strong possibility that further useful and simple relationships will be found in the near future.

SUMMARY AND CONCLUSIONS

The analyses of this paper are based on the urgent need of the International Pacific Salmon Fisheries Commission for an understanding of variability in routes and time of migration of Fraser River sockeye races. The results are mainly qualitative but are a necessary step toward quantitative prediction of variable sockeye behavior needed in the design of regulations for the fishery.

The four year life span of the majority of Fraser sockeye gives rise to four relatively discrete lines of descent called cycles. Approximately $2\frac{1}{2}$ years of this life span are spent in the Northeast Pacific Ocean. The spawning migration or run appearing in the fishery is composed of successive, overlapping races, each with its own characteristic time of migration and particular home stream destination. A racial run ordinarily has a time-abundance curve at a point on the migration path similar to a normal (bell-shaped) curve. Racial runs are observed by means of catches in the fishery. Most racial runs vary in numerical size from cycle to cycle in a pattern termed quadrennial dominance. At present, the most important Fraser sockeye race is the Adams River run. The dominant cycle of this race produces very large runs which are not obscured by other racial runs. Variability of these large runs is an important source of information concerning behavior as well as a difficult regulatory problem.

Troll catches of sockeye off Vancouver Island offer evidence of the area of landfall in the shoreward migration. The 1958 landfall occurred far north of the usual area. The northerly landfall of the 1958 sockeye

run was associated with a heavy diversion of sockeye through Johnstone Strait. Catches in Johnstone Strait since 1926 showed considerable variability in the proportion of runs using this northern passage. Analysis of the proportion of the Fraser sockeye catch taken by Canada in Georgia Strait indicates certain other years of unusually heavy diversion through Johnstone Strait. All information combined indicate this phenomenon occurred in 1903, 1904, 1915, 1926, 1936, 1947, and 1958. These years are associated with sunspot maxima. The coincidence of the diversion with an intrusion of warm water northward along the British Columbia coast in 1958 and probably also in 1936 and 1947 suggests that the cause is oceanographic. Further study is important since the diversion strongly affects both required division of sockeye catch between Canada and the United States, and percentage escapement.

Variation of migration time in nine successive dominant runs of Adams River sockeye is shown by peak dates in the San Juan Islands. Time of peak migration (August or early September) tends to be later in the larger dominant runs. An alternation of migration time in successive generations of sockeye is demonstrated for the dominant Adams River run and for certain other races in two of the three other cycles. Alternation of timing of successive generations is possibly related to the phases of the moon, the only known factor which operates on an eight year "cycle". Variability of migration in the form of increased dispersion of the time-abundance curve was shown for the Adams River run of 1958.

The Adams River race, and certain other sockeye races, delay for a time off the mouth of the Fraser River before migrating upstream. River entry of Adams River sockeye after delay begins rather suddenly about mid-September and time of the beginning is related to time of marine migration. River migration is ordinarily strongly skewed with a quite variable extension of the latter end of the migration. Duration or spread of upstream migration at the river mouth was ascertained for the eight most recent dominant Adams River runs. Duration was found to be inversely correlated with Fraser River discharge in the summer of the same year. Highest value of the coefficient of correlation was for June 1-September 15 discharge. Varying interpretation of duration of river migration of certain of the years caused changes in numerical values of the several correlation coefficients but did not materially affect the overall conclusion.

Delay behavior of sockeye was compared with other Pacific salmon. The delay in Adams River sockeye and their variable upriver migration are adaptations without obvious survival value. Apparent production of greatly extended river migration by low Fraser summer discharge suggests adverse effects of controlled Fraser River runoff resulting from dams.

The mechanism of timing of sockeye migrations was considered. Migration time is indicated as being correlated with spawning time for Fraser River sockeye races in general, for a given race from year to year, and for the individual fish within a racial run. Migration time is concluded to be a consequence of maturation, which is under photoperiodic

control. Fraser River sockeye races are assumed to inhabit approximately the same latitude and therefore should be subject to the same seasonal pattern of length of day. Differences between races in migration and spawning time must therefore have a genetic origin.

Variations of migration time for a race of sockeye appear to be caused during ocean residence. Two types of variation are observed (1) relatively small, independent deviations limited to one or a very few racial runs, and (2) larger variations which affect most or all races similarly. The latter are attributable to unusual oceanographic conditions. One or more of the annual runs at about the time of the sunspot maximum may be unusually late. This is presumed to be the result of conditions occurring during periodic warm water intrusions off the British Columbia coast. The effect of warm water or associated factors on maturation is considered to be either (1) a direct physiological action or (2) the result of a changed photoperiodic response where oceanographic conditions alter sockeye distribution by latitude. It is hoped that future data, both oceanographic and biological, will allow more accurate prediction of migration timing for use in regulating the fishery.

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