Effects of the Fishery and of Obstacles to Migration on the Abundance of Fraser River Sockeye Salmon (*Oncorhynchus nerka*)

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FOREWORD

This account of the Fraser River sockeye is devoted mainly to shedding additional light on events and conditions during years long past; which conditions can still provide guidance for the future, particularly if greater levels of production are anticipated.

Several of the attached Appendices use methods of attacking estimation problems that have not been employed elsewhere, as far as I know. These could have been issued as separate papers, but it is both logical and economical to include them in a single publication, where the background need be described only once.

The principal sources of information used have been the publications of the British Columbia and Canadian Departments of Fisheries (including the Fisheries Research Board of Canada), of the United States Bureau of Fisheries, and of the International Pacific Salmon Fisheries Commission. In addition, Appendix 10 is from an informative manuscript written by D. S. Mitchell, a former employee of the Canadian Department of Fisheries. It contains an eye-witness account of the abundance of sockeye and pink salmon in the big years of their cycles before 1913, and of the great Indian fisheries that used to exist in the Shuswap region.

August, 1986 W. E. Ricker

RESUME ET SOMMAIRE

Le saumon rouge du fleuve Fraser atteint généralement la maturité à quatre ans. Jusqu'en 1913, les stocks peuplant les régions en amont du canyon étaient caractérisés par une remonte "dominante" en 1901, 1905, etc. dont l'abondance était de l'ordre de 100 millions. Dans l'ensemble du fleuve, les saumons rouges de la lignée de 1901 étaient environ 20 fois plus nombreux que ceux des trois autres lignées. Le nombre cumulatif des saumons rouges des grandes remontes allait de 25 à 35 millions de poissons tandis que le gaspillage a entraîné une augmentation des prises qui ont varié entre 35 et 50 millions. Ces immenses populations ont chuté à cause d'obstacles qui ont bloqué la remonte en 1913 surtout à Hell's Gate dans le canyon. Ces obstacles ont été dégagés en 1914-15 de sorte que la plupart des saumons rouges ont pu remonter vers les eaux d'amont à partir de 1915.

Après l'effondrement des prises en 1917 et 1918, il était évident pour la plupart des observateurs des États-Unis et du Canada qu'il était nécessaire de rétablir les remontes en diminuant la pression par pêche. Toutefois, les tentatives informelles dans ce sens n'ont par réussi même si une baisse de l'effort de pêche n'aurait entraîné qu'une faible diminution des prises effectives. Un programme international d'étiquetage mené en 1918 avait révélé que les stocks d'amont appauvris étaient surtout présents pendant la première moitié de la saison de pêche du saumon rouge tandis qu'après 1916, les stocks provenant de l'amont du canyon, non obstrué, et capturés principalement pendant la seconde moitié de la saison composaient la majeure partie des prises. En 1930, on a dressé une convention officielle qui n'a été entérinée par le Sénat américain qu'en 1937. Malgré ceci, la Commission ainsi établie n'a pu faire des recommandations de gestion que huit ans plus tard -- une restriction absurde étant donné qu' à l'évidence, il faillait réduire la pêche de toute urgence. À cause de ce long report des restrictions concernant les saisons de péche, des prises d'environ 100 millions de saumons rouges ont été perdues de 1920 à 1950. Ceci représente 25 millions de dollars pour ce qui est de la valeur au débarquement d'avant-guerre (25 cents par poisson) ou plus de 500 millions de dollars contemporains.

La plupart des saumons rouges pouvaient traverser Hell's Gate après 1914, mais le passage présentait des difficultés à certains niveaux d'eau. Ceux-ci ont été relevés par le ministère canadien des Pêches pendant les années 1920 et confirmés par la Commission internationale de la pêche du saumon du Pacifique en 1938. Toutefois, certains faits révèlent que, heureusement, le nombre de saumons rouges arrêtés ou nettement retardés n'a jamais été élevé de 1938 à 1944. Pendant la pire année (1941), des niveaux d'eau constamment problématiques ont entraîné un arrêt et une mortalité exceptionnelle d'environ 52 000 saumons rouges ou environ 15 % des effectifs qui se sont rendus à Hell's Gate cette année-là. Au cours d'une année moyenne de 1938 à 1944, le nombre estimatif de saumons rouges arrêtés à Hell's Gate variait de 1 à 3 % des arrivées. L'affirmation que les pertes étaient constamment plus élevées que ces chiffres va à l'encontre de certains faits. Par exemple, quand les niveaux d'eau à Hell's Gate étaient trop bas pour permettre le passage du saumon rouge de 1942 à 1944, on en a capturé en grand nombre à l'épuisette en amont de cet endroit et après la construction des échelles à poissons, ces captures n'ont pas augmenté.

Cependant, Hell's Gate a toujours représenté une menace potentielle pour la grande montaison tardive vers le lac Shuswap, qui, depuis 1922, a lieu tous les quatre ans à partir de la lignée de 1902. Hell's Gare aurait pu causer de déclin de cette remonte si les niveaux d'eau avaient toujours été bas à l'automne. Quioque cet événement rare n'ait jamais eu lieu au cours des importantes montaisons entre 1922 et 1944, de faibles niveaux d'eau en automne ont été observés au moins une fois depuis; par contre, des échelles à poissons étaient alors en place.

Pour les raisons susmentionnées et étant donné que le saumon rose ne s'était pas rétabli en amont du fleuve après 1913, Hell's Gate représentait un problème qu'il fallait approfondir. Vers la fin des années 1920, le ministère canadien des Pêches a élaboré des plans pour son amélioration, dont la construction d'une échelle à poissons et le déblaiement du passage, mais le gouvernement n'était pas disposé à engager de grandes sommes avant qu'un accord sur le partage des prises soit conclu avec les États-Unis. Après que la Convention internationale eut été entérinée en 1937, la Commission de la pêche du saumon a pris des mesures après la collecte de nouvelles données et la réalisation d'études hydrauliques et d'ingénierie qui ont permis de mettre au point un noveau type d'échelle à poissons.

Le déclin initial du saumon rouge des lignées non dominantes de 1903 et 1904, qui a débuté au début du siècle, et la rareté prolongée des remontées précoces et mi-saisonnières pendant les années 1920 ne peuvent être imputés dans une grand proportion à Hell's Gate ou à d'autres obstacles. Ils étaient plutôt le résultat d'une surexploitation que l'on estimait à 91-94 % pendant la période 1930-1934; depuis 1900, cette surexploitation s'est chiffrée à 85 % au moins. Le déclin précoce de la lignée de 1902 a été moins rapide quoiqu'elle ait beaucoup souffert de l'obstruction de Hell's Gate en 1914. Il serait fort surprenant qu'une surpêche n'ait pas eu lieu dans le fleuve Fraser alors qu'elle avait lieu dans un certain nombre d'autres grands cours d'eau des deux côtés de l'océan Pacifique, dont certains étaient plus isolés que le Fraser et n'offraient pas une aussi longue route migratoire où le saumon pouvait être facilement capturé. Toutefois, les remontes tardives du Fraser ont été assez bien protégées par la fermeture de la pêche à l'automne. Celles-ci comprennent les remontes dans la partie inférieure de la rivère Adams et d'autres remontes tardives vers le lac Shuswap qui avaient été réduites de façon catastrophique en 1913-1914. De 1922 à 1942, ces remontes ont centupluées pour devenir une nouvelle lignée dominante ceci a toutefois entraîné l'élimination simultanée des trois autres lignées du lac Shuswap.

La pression par pêche sur le saumon rouge du Fraser a diminué à partir de 1928 suite à de plus longues fermetures de la pêche en fin de semaine tandis que l'enlèvement des trappes mouillées dans les eaux américaines après 1934 a grandement amélioré l'échappée annuelle vers l'amont. Une protection supplémentaire a été apportée par la Commission internationale de la pêche du saumon du Pacifique quand elle a retardé l'ouverture de la pêche de 1946 à 1950 (surtout en 1947). Ceci a été suivi par la restriction régulière des saisons d'ouverture hebdomadaire et des fermetures spéciales qui sont maintenant utilisées afin d'asssurer la fraie voulue.

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ABSTRACT AND SUMMARY

The principal age of maturity among Fraser River sockeye is four years. Up to 1913 stocks in regions above the canyon were characterized by a "dominant" run in the 1901, 1905, etc. sequence or "line", whose abundance was of the order of 100 million. For the river as a whole, sockeye of the 1901 line were about 20 times as numerous as those of the other three lines. The sockeye packed from the big runs amounted to 25-35 million fish, and fish wasted increase the <u>catches</u> to 35-50 million. These huge populations came to an abrupt end because of obstructions to the run in 1913, particularly at Hell's Gate in the canyon. The obstructions were remedied in 1914-15, so that most sockeye could get through from 1915 onward.

After the catch failures of 1917 and 1918 the need to rebuild upriver runs by giving them relief from fishing was apparent to most observers in the United States and Canada, but attempts to arrange for this on an informal basis were not successful -- even though this could have been done with only a minor loss to the current catch. An international tagging program in 1918 had shown that the depleted upriver stocks were present mostly in the first half of the fishing season for sockeye, whereas after 1916 the unobstructed stocks below the canyon, taken mostly in the second half of the season, were supplying most of the catch. In 1930 a formal Convention was drawn up, but it was not ratified by the United States Senate until 1937. Even then, the Commission it established was instructed to refrain from making management recommendations until eight more years had passed -- a preposterous restriction when the need for less fishing was obvious and urgent. The long delay in imposing the necessary seasonal fishing restrictions meant that, over the 30 years starting in 1920, catches of about 100 million sockeye were forfeited, worth 25 million dollars at the prewar landed value of 25 cents each, or more than 500 million at today's prices.

Although most sockeye were getting through Hell's Gate after 1914, it appeared to present some difficulty at certain water levels. These difficult levels were identified by the Canadian Department of Fisheries during the 1920s, and were confirmed by the International Pacific Salmon Fisheries Commission in 1938. However several lines of evidence indicate that, fortunately, the number of sockeye stopped or importantly delayed was never of major importance, at any rate from 1938 through 1944. In the worst year, 1941, persistently difficult levels caused an unusual stoppage and mortality of about 52,000 sockeye, or about 15% of those that arrived at Hell's Gate that year. In the average year during 1938--1944 the number stopped was estimated to be in the range of 1 to 3% of the arrivals. The contention that losses were consistently much more serious than this goes against several lines of evidence. For example, throughout all the "impassable" water levels at Hell's Gate during 1942-44 sockeye were caught by dipping <u>above</u> the Gate in good numbers, and after the fishways were built these numbers did not increase.

However, Hell's Gate always represented a potential threat to the big late run to Shuswap Lake, which from 1922 onward occurred every fourth

year in the 1902 line. It might possibly have decimated that run if there had been continuous difficult levels in autumn. Although this rare event never happened to the big run between 1922 and 1944, poor autumn water levels have occurred in that line at least once since then, when fishways were available to get fish through.

For the above reasons, and because pink salmon had not become reestablished upriver after 1913, Hell's Gate was something that required further attention. In the late 1920s the Canadian Department of Fisheries developed plans for ameliorating it by a fishway and rock clearance, but the government was unwilling to undertake another major expenditure before a catch-sharing agreement was concluded with the United States. After the international convention was ratified in 1937, the Salmon Commission took action after additional observations and hydraulic and engineering studies, which developed a new type of fishway.

The initial decline of sockeye of the non-dominant 1903 and 1904 lines, which started at the turn of the century, and the continued scarcity of early and mid-season upriver runs during the 1920s, cannot be ascribed in any significant degree to Hell's Gate or other obstacles. Rather, it was mainly a result of too large a rate of harvest, which is estimated to have been 91 to 94% during 1930-34 and had probably been at least 85% ever since 1900. The early decline of the 1902 line was less rapid, but it suffered major damage from Hell's Gate in 1914. It would be most astonishing if overfishing had not occurred on the Fraser, when it did occur on a number of other large rivers on both sides of the Pacific, some of which were more remote than the Fraser and did not offer as long a migration route along which salmon could easily be caught. The late Fraser runs, however, were fairly well maintained by autumn fishing closures. These included the lower Adams and other late Shuswap runs upriver, which had been disastrously reduced in 1913-14. These runs increased 100-fold from 1922 to 1942, thus establishing a new dominant line; which, however, at the same time suppressed the other three lines throughout Shuswap Lake.

Fishing pressure on the Fraser sockeye began to be relieved in 1928 by somewhat longer weekend fishing closures, while the removal of traps from United States waters after 1934 greatly increased the escapement up the river each year. Additional protection was provided by the Salmon Commission when the opening of the fishing season was postponed during 1946-50 (particularly in 1947), followed by the regular curtailment of weekly open seasons and special closures that are now used to ensure the spawning desired.

HISTORY OF PACIFIC SALMON FISHERIES

There is one prevailing pattern among the salmon fisheries of the North Pacific Ocean. Typically the rate of utilization of the stocks has increased to a point where annual recruitment and yield have declined, sometimes quite drastically. This phase is then followed by a period of rather painful retrenchment that has stopped the decline and, in some cases, has succeeded in increasing the yield again. In no case, however, has the mean annual production of natural stocks been restored to the level that prevailed for a few years at the peak of the expansion phase. Today's sustained yields are typically no more than 60% of the peak landings, and sometimes much less, although catches from some Alaskan sockeye stocks apparently reached or exceeded historical levels during 1983-85.

A major contributor to the decline of salmon fisheries is of course the diversion of water to other uses. The preeminent villains are the dams that obstruct major rivers, notably the Sacramento and the Columbia. However, even rivers that lack major dams are producing much less than their peak yields. Some of the larger ones are the Amur and the Kamchatka in the USSR, and the Skeena and Fraser in British Columbia.

Many have been puzzled by this decline of great salmon fisheries because, when it occurred, harvesting of salmon was almost exclusively by "terminal" fisheries on maturing individuals in or near the rivers. Thus Baranov's "fishing-up" effect, that reduces accumulated stocks of older age-groups, had played no role. Why, then, were the valuable salmon species overfished at an early date? To some extent this is related to frontier exuberance and absence of effective restraints -- a way of life that seems more attractive now than it probably was at the time. In fisheries it meant free-wheeling optimism and a fast-buck psychology on the part of some, but not all, of the operators. Much more important, probably, was the fact that recognizable indications of overfishing have always lagged several salmon generations behind the time when the optimum rate of utilization was first exceeded. Thus overfishing could assume serious proportions before it was convincingly diagnosed.

The main reason for the delay in recognizing overfishing lies in two recently discovered "exploitation mechanisms" (Ricker 1973; 1975, Chapter 12). Mechanism 1 indicates that the catch from a stock at a given rate of fishing is greater when that rate has been increasing than when it is steady or decreasing. Mechanism 2 is the fact that mixtures of stocks of different productivities produce fewer recruits from a given number of spawners when rate of fishing has become stabilized or (still more) when it is decreasing than they did during the expansion phase of the fishery. The details of this sequence of events for Skeena sockeye have been documented by Ricker and Smith (1975).

Here we are concerned with the Fraser River. Its salmon have to swim through a long series of straits and channels between islands before reaching their home river, and all along this route, as well as in the river itself, there are excellent opportunities for the deployment of both fixed and mobile fishing gears. Thus it was inevitable that Fraser sockeye should be seriously overfished in the "off" years from about 1900, and in all years after 1913. From a consideration of the time series of catches and gear in use, Gilbert (1918) concluded that overfishing caused the decline of the off years, starting in 1898, and Rounsefell and Kelez (1938) reached a similar conclusion. The picture is complicated, however, by the effects of a major obstruction in the Fraser Canyon in 1913 and 1914, and by a question about its importance in later years.

"HOMING" OF FRASER RIVER SOCKEYE

During the first quarter of this century the validity of the "home stream theory" for salmon was hotly debated in scientific circles. Such prominent figures as David Starr Jordan in California and Archibald Gowanloch Huntsman in Canada never did accept the idea that salmon could return from a distance to their native river, let alone to a particular tributary. J. P. Babcock, a former student of Jordan's, thought that the theory's unsoundness was demonstrated by the quick recovery of the Quesnel sockeye run after a major stoppage in 1901, although he seems to have changed his mind later. However, from early years of the century hatchery operators like Alexander Robertson and David Mitchell became convinced that Fraser sockeye consisted of numerous separate stocks or races that differed in average body size, size of eggs, colour at maturity, time of migration through the fishery and time of arrival on the spawning grounds.

By the late 1920s the evidence for sockeye homing in the Fraser watershed was sufficient for its reality to be generally accepted. In 1918 C. H. Gilbert, another of Jordan's students, had correctly interpreted differences in freshwater and ocean ages and differences in body size of the sockeye of different streams as indications of the existence of discrete stocks. As early as 1901, when a hatchery was established on Shuswap Lake, it had been discovered that sockeye of the Scotch Creek stock, in addition to being brighter in colour, had smaller eggs than those of Morris (Weaver) Creek on the lower Fraser: many of the Shuswap eggs fell through the meshes of incubation baskets that were right for Morris Creek eggs. Later Robertson (1921) showed that sockeye of three downriver stocks differed in body size and in mean egg diameter, and that the stock having fish of the smallest average size produced eggs of the largest average size. Smolt marking experiments during the late 1920s showed that the Cultus Lake sockeye did not wander to three nearby regions (Weaver Creek, Birkenhead and Upper Pitt Rivers) where many of the adult sockeye were handled for hatchery use and were examined for marks (Foerster 1934). Finally, six transplantations of sockeye eggs to the Shuswap region from lower Fraser stocks failed to produce appreciable returns (summarized by Foerster 1946; Ricker 1972, p. 116). This picture provided the background for the statement by Rounsefell and Kelez (1938), with reference to the Fraser, that "the providing of large numbers of spawners, while of importance, cannot achieve permanent rehabilitation unless these spawners are members of several different "races" or "colonies" of sockeye, so that they will migrate to different lake systems".

SOCKEYE ABUNDANCE IN BIG YEARS AND IN OFF YEARS

Among the Fraser sockeye maturity at age 4 is the prevailing (although not invariable) life-history pattern for almost all stocks. Combined with intra-stock and environmental interactions, this resulted in a 4-year "cycle" of abundance (Ricker 1950; Ward and Larkin 1964). Throughout the 19th century and up to 1913 the 1901 line was far more abundant than any of the other three. How much more has been debated; the evidence now available is summarized below.

During the early years of this century the actual packs of the big years were about 5 times as great as the other years (Fig. 1), and the indices of abundance in Tables 31-34 of Rounsefell and Kelez (1938) yield a similar ratio. However, these indices assume that the fishing efficiency of the gear was the same in big years as in other years, whereas actually it was far less in a big year. With more than 5 times as many fish to handle, much more time was spent in clearing gill nets, brailing seines, running to the cannery, waiting to unload, and in actual unloading, so there was much else time with the net in the water. Moreover, according to Babcock and Prince, on the Fraser in every big year except 1909 daily limits were set on the number of sockeye that would be accepted from each boat, for a week or more at the height of the season. This limit was sometimes obtained in a single drift of a gillnet or a single set of a seine. Trap catches were similarly limited in Puget Sound, and some were closed off after the season got well under way.

In addition, some estimated that the number of sockeye caught and wasted in a big year was as great as the number packed. This is presumably an exaggeration, but there is no question that a great many of the fish captured are not represented in the statistics because they never got inside a can. Partly this was because canneries that owned traps would set generous limits or no limit on the number of fish to be brought in from each, "just to be sure", then discarded those that could not be handled. Quoting Prince (1906): "... in a big run the pot of a trap has been known to become so packed with living salmon, that the sheer weight of the uppermost fish crushed and killed those on the bottom of the net. It is said that some catches in Puget Sound were so enormous that the bottom could not be raised and the 'brailer'... could not be used. The pot had to be cut out and towed to the cannery." In 1933 oldtimers at Anacortes even said that some traps were abandoned -- left fishing but untended -- until the weight of dead salmon rotted out the webbing. No care was taken to pack the tail portions and other "scraps", so that the number of sockeye used per case probably rose, from about 12, to 15 or more. Seiners and gillnetters, for their part, usually caught more fish than they could reasonably hope to sell, on the remote chance of finding a buyer somewhere or other, or to be used as fertilizer in local gardens. Then, too, sockeye sold or given away for human consumption are not in the records, yet people in coastal towns consumed what they could and often smoked or salted a supply for the winter.

Adjustments for local use, for fish wasted, and especially for the markedly decreased fishing effort in a big year increase the abundance ratio of big years to off years from 5:1 to at least 15:1. In the first decade of the century off-year packs averaged 4.9 million sockeye, representing a total run of 5.8 million if the rate of commercial utilization averaged 85% (see Appendix 1 regarding this figure). Thus the big years could have had 90 million or more sockeye, of which 35 to 50 million were caught, and 25 to 35 million actually packed.

An independent estimate of relative abundance of sockeye in the big years and off years can be made from age samples reported in a series of papers by C. H. Gilbert (see Ricker 1950). He found that age 5 sockeye of the 5_2 growth type were common in several downriver stocks, whereas above the canyon they were very scarce. The percentage of 5_2s among the 4_2s and 5_2s in the catch samples taken in the first 4 years of sampling can be compared with the packs of the same years (in millions of sockeye, from Table 27 of Rounsefell and Kelez 1938), starting with 1911:

1 Year	2 Percent age 5_2	3 Pack	4 Total run	5 Estimated 1913 run
1911	46	2.179	2.564	337
1912	10	3.363	3.956	113
1913	0.35	31.343	-	-
1914	15	5.693	6.698	287
Mean			4.406	

The total run in the off years is estimated in column 4 by dividing the pack by the 85% rate of utilization. The percentage of 5_2s found in the off-year catch samples varies considerably, but all are much larger than the 0.35% observed in 1913, which represents 9 individuals out of 2575 examined. The spawning runs downriver in 1913 tended to be 2 or 3 times as large as in the off years of the upriver cycle because they were fished less heavily, so their total abundance (catch plus spawners) was much the same in big years as in off years; hence the ratio of the percentage 5_2 representation in catch samples of big years and off years is an estimate of the ratio of the river's total population in the two types of years. Column 5 above shows 1913 population estimates so obtained, from the three individual off years.

For an average figure, the GM of the 5_2 percentages (19%) can be used, together with the AM of their populations (4.406 million). This gives a 1913 population estimate of 4.406(19/0.35) = 220 million. A similar computation, based on the age 4_1 sockeye that go to sea in their first year, gives almost the same result, but it involves only a single 4_1 in the 1913 sample. The few 5_2s present in upriver stocks tend to reduce all these estimates slightly, the 220 million becoming about 210 million. The most important potential sampling error in these computations is for the 1913 sampling. For the ten 5_2 and 4_1 fish obtained, Poisson 95% confidence limits are 4.7 and 18.4 (from Appendix 2 of Ricker 1975). These correspond to population limits of 100-390 million about the 210 million estimate.

Thus Gilbert's age samples confirm that something of the order of 100 million is not all an unreasonable estimate of the sockeye present in the old big years.

A less satisfactory but semi-quantitative estimate of the relative abundance of big yeas and off years comes from the records of British Columbia's hatchery at Seton Creek. An attempt was made, sometimes successfully, to stop all the sockeye that entered that creek. In 1903 there were 981 sockeye, in 1904 about 1000, and in 1906, 16,000 arrived; the 3-year mean being 6000. In the big year 1905, however, "more than 200,000 passed into our pond", and in 1909 there were "fully a million". The ratio of average big years to average off years was therefore 600,000 to 6000, or 100 to 1. Rounsefell and Kelez's figure for the mean commercial catch in 1902-04 is 4.61 million sockeye. For 1901 and 1905 their average is 23.2 million, and adding the fish wasted increases this to at least 35 million. Assuming a rate of utilization of 85% for the three off years, their abundance averaged 5.42 million and their escapements averaged 0.81 million. From this and the 100:1 ratio of escapements given above, big-year escapements are estimated at 81 million. Adding the 35 million caught gives a total stock of 116 million, and a rate of utilization (including waste) of 30%.

Qualitative and roughly quantitative estimates of sockeye observed in upriver nursery areas suggest that they could easily have added up to 50 or 60 million in the big years. For example, Babcock (1914) observed 16 kilometers of Chilko River "entirely covered" by sockeye in 1909. This suggests at least 10 to 15 million in that watershed, considering that not nearly all of the spawners would be in sight at any one time, and that he did not observe the triubtary spawners or those that spawned in the lake itself. Timing the rate of ascent of sockeye through the Quesnel fishway in 1909, described by Babcock (1910), indicated a minimum run of 5 or 6 million (Babcock says 4,000,000+), and this only two generations after it had been seriously obstructed. A description of the great runs of Shuswap Lake and Adams Lake is given in Appendix 10. Little detail seems to be available from the Stuart system of lakes, but Babcock quotes a Hudson's Bay Company official as saying that in big years before 1913 "the tributaries of Stuart Lake were literally massed with them [sockeye]". In off years, on the other hand, the hatchery at Cunningham Creek did not even try to take eggs from local streams, but portaged them across from Beaver Creek on Babine Lake.

Individual stocks apparently had different degrees of dominance. For example, the stocks that entered Stuart Lake were evidently scarce in off years, but the fur traders at Fort St. James were able to get a considerable quantity of sockeye from Fraser Lake.

The picture of great abundance in the big years, obtained from the various sources above, contrasts sharply with the account given by Thomspon (1945, Section 1B). His presentation makes no allowance for the reduced fishing time of each unit of gear in a big year, or for fish wasted. Rates of utilization in all years are assumed to be proportional to a "weighted fishing intensity" expressed in "units of effort" based on the quantity of gear licensed (his Table 1). Consequently the percentage removals are of the same order of size in big years as in off years; in fact they are somewhat larger in big years because more gear was licensed. Thus it is suggested (page 32) that in 1913 the 31.3 million sockeye packed represented 90% of the total run, which means that there were only 3.5 million sockeye in that year's escapement. The escapement in 1909 would then be even less, about 2.6 million, because its pack was 30% smaller while the "units of effort" were only 6% less. Yet in his table 6 and elsewhere Thompson quotes, without comment, Babcock's computation of a minimum 1909 run of 4 million in a single spawning region, Quesnel -- apparently unaware that this is not compatible with his previous assumption of a large rate of utilization in the big years. Thompson did regard the Quesnel run as "originally the greatest in the Fraser watershed, as far as can now be ascertained"; however there is no objective basis for considering it larger than the run to each of the other three major regions.

Another casualty of failure to recognize the incommensurability of "catch per unit effort" in big years and off years is the computation of total runs to the Fraser made by Rounsefell (1949). He too obtained very small escapements (1.6-7.2 million) in the big years from 1897 to 1913. Noting that Babcock's figure of more than 4 million sockeye at Quesnel in 1909 greatly exceeded the computed estimate of 1.6 million for the total escapement that year, Rounsefell simply decided that the figure based on direct observation couldn't possibly be true! The opposite discrepancy occurs in years after 1920, when most of Rounsefell's escapement estimates are much larger than any possible total of spawners to be found in the watershed at that time.

To-day the picture of 50 million or more sockeye spawning in the Fraser system every fourth year during the early 1900s seems almost unbelievable. However, the spawning of 1954 produced about 19 million adult sockeye 4 years later, most of them from a single lake system (Shuswap), and mainly hatched in only one of its 3 or 4 historically important spawning tributaries. Thus with 4 major and several smaller lake systems above the Fraser canyon, all contributing sockeye to the old big years, a total run (catch plus escapement) of 100 million seems not unreasonable.

Under primitive conditions, before there was a commercial fishery, big-year reproduction must have been extremely inefficient because of overcrowding of the redds with eggs or of the lakes with fry. Each pair of the 100 million or so spawners produced only 2 adult sockeye, on the average, plus several million harvested by the Indians. Moreover, the abundance in the big years acted to suppress the off years by means of ecological interactions, probably mainly within the lakes (Ricker 1950; Ward and Larkin 1964).

THE COMMERCIAL FISHERY AND OBSTACLES TO MIGRATION

Rounsefell and Kelez (1938) have a comprehensive description of the gear used and the sites fished by the commercial fisheries in Puget Sound and the Fraser River from the earliest times. At least 95% of the sockeye caught in this region were spawned in tributaries of the Fraser. Gillnets, seines and traps were used to capture them along their extended migration route. For most of the season their only protection was the weekend closure. This, however, was originally less than two days long, and in early years there was widespread belief that many traps fished illegally right through the closure. Furthermore, the closed days occurred on the weekend all along the migration route, so that any salmon that got through United States waters safely on a weekend faced the full force of the Canadian fishery during the days ahead.

These fisheries reached a peak in 1899-1902, which had the best 4-year pack (Fig. 1). There was no sign that fishing ever took any large fraction of the sockeye present in the big years, nor were there any persistent major obstacles to migration before 1913. Construction of the federal government's railway in the 1880's had apparently not impeded the fish. A dam with an inadequate fishway was built at the outlet of Quesnel Lake in 1899 to dry up the river below in autumn for mining operations, and it blocked many sockeye during 1899-1902, but a good fishway built in 1903 permitted quick recovery of the dominant line in 1905 and subsequently. The largest single year's pack of sockeye from the Fraser was in 1913.

However, in the 1903 and 1904 lines the pack decreased gradually but substantially from the turn of the century to the early 1920s, indicating overfishing of these "off" years (Fig. 1). Another indication of the intensity of the off-year fishery during the first decade of the century is the prevalence of net marks on fish that managed to escape. According to Mitchell, "one season we did not get a single fish on the Shuswap spawning beds that did not have one or more of these well defined encircling marks" (Appendix 10). The 1902 line maintained its commercial pack better than the other off years up to 1914, perhaps because its members received some protection from predation by the great abundance of the previous year. It is true that the Scotch Creek and Anstey River stocks decreased seriously from 1906 to 1910 (Appendix 10), but fish-cultural activity may have been largely responsible: eggs taken from these streams were hatched in Granite Creek, so the fry did not become "imprinted" by their native waters.

In the big year 1913, sockeye and other salmon were obstructed and accumulated in eddies and creeks all along the canyon, both below and above Hell's Gate. The accounts of the time place less emphasis on Hell's Gate than on places such as Scuzzy Rapids, but the Gate was probably the principal obstacle.

Fish culturists were sent up to the canyon and salvaged what eggs the hatcheries could accommodate. Females were present in abundance, but males were scarce. Babcock (1914) quotes an estimate of 20 females to 1 male. A. Robertson stated that spawn-takers could "sit on the bank and pick females up all day long in our gloved hand, but to get enough milt we had to gaff individual males here and there; it kept one man busy looking for males" (quoted by Ricker 1947a). Spawning stocks in rivers above the canyon were far below previous big years; males were greatly in excess on the redds, and many of the females died without spawning (Appendix 10).

There was another local obstacle during 1913 (and subsequently), though it got little attention amid the general disaster. A dam had been built at the outlet of Adams Lake for log-driving, which at times may have been a complete obstacle to the ascent of salmon. Its effects on the spawning beds below are described by Mitchell (Appendix 10).

In February of 1914, much additional rock fell into the river just above Hell's Gate when part of a tunnel collapsed. Some of this rock was removed before salmon arrived that year, but passage was difficult. Remedial work was resumed during late fall and winter. A dragline was rigged and the fallen rock above the Gate was removed. About a third of it was piled in an old quarry on the right bank, where it still sits -- mostly covered now by the restaurant and other buildings. The gravel and smaller pieces of rock were dumped into the channel and carried down river. Underwater blasting shifted what had not been uncovered. The river's bed was not restored to its original state, but "the work resulted in a reduction of the head from 15 feet in 75 feet horizontally to 9 feet in 350 feet horizontally" (Jackson 1950).

Following the remedial work done at the Gate and elsewhere in the Canyon, during the years 1915 and 1916 large accumulations of sockeye were no longer to be seen at Hell's Gate or in the creeks below. However, both the catches (Fig. 1) and the seeding of upriver spawning areas continued the decline that began early in the century.

In 1917, unusually heavy fishing effort was mounted because wartime demand pushed the price of salmon higher than in any previous year (Babcock 1918), and because many refused to believe that the 1913 conditions had done really serious damage (Rounsefell and Kelez 1938). However the pack was very disappointing -- about a quarter of 1913. Few sockeye got to the spawning grounds, and in the Shuswap area at least, part of these few were harvested by settlers who were accustomed to salt down a barrel of salmon for the winter (Appendix 10). In 1918 also the sockeye pack decreased suddenly, because of the blockade 4 years earlier (Fig. 1).

These disastrous failures in number of sockeye caught finally convinced the doubters that really serious damage had been done in 1913 and 1914, so discussions were intensified to develop an international program of remedial action. An "American-Canadian Fisheries Commission" held meetings that were largely devoted to consideration of Fraser salmon problems. Public hearings were held, at which strong views were expressed both in favour of and in opposition to closing either the whole fishery, or the early part of it. The history of these protracted negotiations has never been brought together, as far as I know, but the upshot was that no common program could be agreed on without a formal international treaty. This was not concluded until 1930, and was not ratified by the United States Senate until 1937. The delay was because of the objections of some of the Puget Sound operators; who, however, changed their minds after 1934, when a State "Initiative" or referendum had outlawed their traps and Canada began to take the larger share of the sockeye catch.

THE FIRST INTERNATIONAL SALMON RESEARCH PROGRAM

Another result of the catch fiasco in 1917 was that it made possible an international program of sockeye tagging in 1918. Tags were put on at Sooke and at four sites in Washington waters (O'Malley and Rich 1919). Substantial returns were obtained from the fishery; for example, 18% of tags put on at Sooke were recovered and turned in, and 36% of those released at the Salmon Banks off San Juan Island. This reflected a much larger rate of utilization, because the tag used was a "bachelor button" on the tail, which was soon lost from many fish.

Because of the heavy fishing and the impermanent attachment of the tag there were only a few returns from above the commercial fishing boundary at Mission, a majority of them from the tagging that was closest to the mouth of the river. Tags were released at Point Roberts between July 25 and August 21, and produced 27 returns above Mission. Twelve were upriver fish taken from Hope to the Chilcotin River, and of these only two had been tagged later than August 2. Ten recaptures were from the Harrison-Lillooet system, and of these only two had been tagged before August 2. Thus a substantial degree of segregation between upriver and downriver races in the fishery was demonstrated, which would have been even more marked if tagging had been done throughout the whole of the sockeye migration. Similar differences were exhibited by the 23 recaptures above Mission from the other four tagging sites.

This work confirmed the view that most of the sockeye affected by the 1913-14 obstructions went through the fishery in the earlier half of the season, while downriver runs were caught mainly during the latter half. Thus it was possible to protect the severely depleted runs without interfering with the harvest of those below the canyon.

EVENTS AFTER 1918

The commercial sockeye packs of 1919 and 1920, from fish spawned after the remedial work had been done at Hell's gate and elsewhere, were 64% and 93%, respectively, of those 4 years earlier, continuing the slow irregular decline of these two lines (Fig. 1). <u>There was no sudden disastrous drop as in 1917 and 1918</u>, showing that the Gate was again passing most of the sockeye upriver without difficulty.

However, reports of a few sockeye obstructed at Hell's Gate came in from time to time during the 1920s, and pink salmon had failed to make a significant recovery (Withler 1982). A few blocked sockeye could be seen most years in creeks below the Gate, and another group sometimes accumulated in Seton creek above the Gate. So a new examination of the problem was undertaken in the latter part of the 1920s by the Canadian Department of

Fisheries under Chief Supervisor J. A. Motherwell; Fisheries Engineer John McHugh and Hatchery Superintendent Alexander Robertson were especially involved. Water levels at which passage appeared difficult were charted, and new hydraulic studies were made by a firm of consultants. Much additional rock had filled in the bay on the left bank above the Gate. Plans for a clean-out were prepared, and a fishway was recommended for a difficult interval on one side of the river. No action was taken, however, partly because of the tight-money situation during the depression, but also because of an understandable reluctance for Canada to undertake additional major expenditures while more than two-thirds of the catch was being harvested by another nation. Accordingly the government waited for a catch-sharing agreement to be ratified -- something that was anticipated from one year to the next during the 1930s.

It is convenient to divide the Fraser sockeye into upriver and downriver runs, those above and below the canyon, respectively. The upriver fish can be divided into early, mid-season, and late runs. Stocks that reached Hell's Gate mainly in July are called "early"; those arriving mainly in August are "mid-season"; while those from September 16 onward are "late". Not many sockeye arrived at the Gate during September 1-15. In years of the 1901, 1903 and 1904 lines most of these were from the "mid-season" runs, especially fish bound for the Stellako River (Killick 1955). However, in years of the 1902 sockeye line form 1926 onward, after the Adams River run had become abundant again, significant numbers of sockeye of that "late" run were present from about the beginning of September.

Among the downriver runs of sockeye, the largest one and several others ran late in the season (Birkenhead, Weaver, Cultus, etc.), while the runs to Pitt and Chilliwack Lakes were earlier. Two very early runs, to Coquitlam and Alouette Lakes, were exterminated by dams before 1930.

During the 1920s an intensive fishery on the early and mid-season runs continued. The late runs, however, had several advantages. Quoting Rounsefell and Kelez (1938): "first, during the earlier years the late run was seldom fished on account of its inferior quality; second, the Fraser River closed season, which began on August 25 during most years, was a protection; third, the 10-day fall closed season in odd-numbered years from 1921-29, and in all years since 1930 in Puget Sound waters, has enlarged the escapement of late-running fish". Most of these late runs were to lower Fraser tributaries, but there was one particularly important one upriver, the late run on the lower Adams River. This run reappeared in moderate numbers in 1922 and in large numbers in 1926.

Sockeye of the earlier runs first got a bit of relief in 1928 when the weekend closed season was increased from 42 to 48 hours. This would have had a more than proportional effect in increasing escapement, but it is difficult to say how much. I have heard, too, that enforcement of closed seasons became more effective toward the end of the 1920s, particularly in Puget Sound. At any rate, at about that time most of the spawning bed reports began to register increases, although these were mostly small and were quite uneven because of random effects and natural differences in the productivity of different stocks. The first mid-season run to reappear in good numbers was that to Chilko Lake, starting in 1929 and 1932.

RATE OF UTILIZATION OF FRASER SOCKEYE

Direct information on the rate of utilization of a Fraser sockeye stock became available in 1932, from marking experiments at Cultus Lake (Foerster 1936). Cultus Lake lies below Hell's Gate, so its fish were never blocked. They were almost the smallest sockeye in the system, they were not very numerous, and they were among the latest to arrive in the fishery -- all of which would tend to make them relatively lightly exploited. Females were always more numerous than males at the lake, usually about twice as many, the reason being that the average size of the females was much less than optimum for gilling in the nets used. The males were larger, but still somewhat below the optimum. In 1930 all of the smolts leaving Cultus Lake were marked by removing both ventral fins, and in 1931 both ventrals and the adipose were removed. A nearly complete check of sockeye in the Canadian and united States canneries was made in 1932, 1933, and 1934, as well as a complete count of those that returned to Cultus Lake (Foerster 1936, Table 1). Shown below are figures for the males only of the marked fish recovered, because the larger size of the males made them closer to the average vulnerability of the Fraser sockeye as a whole:

	1932	1933	1934
Fishery	916	4320	284
Cultus Lake	465	1025	127
Total	1381	5345	411
Rate of utilization	66.3%	80.8%	69.0%

The larger rate of utilization in the odd-numbered year 1933 was to be expected, because fishing for pink salmon was in progress then; the pink run overlapped that of the Cultus sockeye, and Fraser pinks are quite similar in size to male Cultus sockeye. However, even the 1933 figure should be regarded as substantially smaller than the mean odd-year rate of utilization for the whole Fraser sockeye run at that period, because of the small size of the Cultus fish and the fact that they were in the fisheries mainly in late summer and autumn.

In 1935 the salmon traps were removed from Washington waters, and other gear there did not take up the slack for some time, so all species of salmon got an important respite. The sockeye catch immediately shifted from about 71% taken by the United States to 62% taken by Canada. Most of the Canadian catch was taken after the fish had passed through the United States fishery, so if we find that the Canadian rate of utilization did not change much, it is possible to calculate the increase in the percentage of each year's run that escaped the fishery (Appendix 1). The average rate of utilization prior to 1935 is thus estimated as about 85% for years of the 1902 line, as compared with 79% observed in 1938. For the odd-year lines the figures are 91-94% before 1935 and 89% afterward. These figures are for the entire run; the early and mid-season stocks upriver were even more intensively fished because they did not benefit from the special autumn closures. Thus they got more relief from the cessation of trap fishing: their rate of escapement would have almost doubled after 1934, and this was quickly reflected in estimates made on the spawning grounds.

How did most of the early and mid-season sockeye runs above the Canyon manage to survive rates of utilization that exceeded 91-94%? For the 1901 line of (former) big years such rates began in 1917; for the off-year lines they probably date from the turn of the century. The only major runs that were completely exterminated suffered also from physical damage. The Salmon River, whose run is described in Appendix 10, is affected by diversion of water to other uses. A dam at the outlet of Adams Lake temporarily cut off access to the Upper Adams River, but in this case a new run has recently been started, having 3502 spawners in 1984.

Although most of the important early and mid-season runs still existed during the 1920s in at least one of their four lines, they were at very low levels of abundance. Some rivers contained less than 100 spawners, where once there had been hundreds of thousands or millions in the big years. The precarious survival of these runs was possible because of one or both of two factors. The first is that in the absence of "despensatory" effects, of which there is no sign in the Fraser sockeye statistics, the slope of a salmon recruitment curve is steep near the origin, and hence the sustainable rate of utilization is large at very low levels of population. For example, when the late Shuswap run was rebuilding a dominant line in the 1920s, a spawning of 20,000 fish in 1922 produced about 500,000 recruits in 1926 - a 25-fold increase. In three subsequent generations spawnings of 300,000 to 400,000 produced 4 to 5 million recruits - about 13-fold (see Fig. 23 of Ricker 1954). This group of stocks may have been more productive than most. However, similar spectacular increases occurred when the early runs were relieved from commercial fishing during 1946-50. The spawning ground returns for those years (marked by "a" in Appendix 11) exhibited many estimates of increases in the range of 5 to 30 times (in two cases even 70 times) their parent spawners, particularly for the early and mid-season runs from Quesnel north. Thus harvests up to 95% or so could be tolerated by some stocks, but only after they had been reduced to a very low level of abundance.

The second factor favoring survival is that even when a stock is being fished at a rate that will eventually exterminate it, it typically takes quite a number of generations for this to happen. As an illustration, consider a sockeye stock having a replacement abundance of 1,000,000 spawners. Suppose that the 1913 disaster and the 1917 fishery reduced this to 1000 spawners in 1917; and that thereafter it was fished at a 95% rate of utilization, whereas the maximum rate at which it could persist was 90%. That is, only 5% of the stock was reserved for reproduction, whereas 10% was needed for minimal survival. Thus the 1000 spawners would be halved in each generation, reaching 125 by 1929, but it would take another 20 years or so for them to finally disappear. Random environmental variability could hasten or delay this process, but even severe overfishing does not make a stock disappear immediately.

For one or both of the above reasons most of the early and mid-season upriver stocks survived, although at a very low level, until the upturn began at the end of the 1920s, starting with the Chilko stock.

THE SOCKEYE SALMON FISHERIES CONVENTION

When an international agreement concerning Fraser sockeye was finally ratified in 1937, everyone should have known that the first item of business was to give the depressed stocks relief from fishing. Any other activity could await further study. Some stocks that had numbered millions in the big years were still reduced to thousands, hundreds, or even less. The 1918 tagging had shown that adequate relief for the early and mid-season runs could be obtained by delaying the opening of the fishing season to some time in the first half of August (varying with the area). This would have meant the temporary sacrifice of only about 15% of the 4-year average sockeye catch at that time, because most of it came from late runs. As described earlier, such action had been urged for many years by responsible people in the State of Washington and in British Columbia, but the answer was always: "We can't do it unless the other side is going to too". How astonishing, then, that when a Convention was concluded for the express purpose of overcoming this obstacle, no provision was made for immediate reduction of the early fishery. Instead, the new Salmon Commission was empowered to make management recommendations only after eight more years had elapsed!

This preposterous limitation of the Commission's powers was not part of the Convention as originally negotiated, but was one of three "Understandings" that were added to it when it was ratified by the United States Senate. These had been drawn up in November, 1934, at an international meeting of representatives of fishing industries and governments called by the Washington State Planning Council (IPSFC Annual Report for 1946). Some of the United States participants had originally wanted to draft a new Convention; they may have had some of the same feeling of suspicion toward the recommendations of "bureaucrats" as is described in R. A. Cooley's 1961 book about the Alaska salmon fisheries. However, they were persuaded to embody their concerns in the three Understandings, which were eventually accepted by both countries. But if a segment of the fishing industry was in fact responsible for this particular Understanding, they were cutting their own throats. The eight years' additional delay in implementing protection for the early and mid-season runs cost the fishermen and processors of both countries a great many millions of dollars.

Actually, it seems likely that curtailment of the early and mid-season fishery could still have been achieved by the Commission if it had made a strong representation to the two governments, giving details for regarding the matter as extremely urgent. Recommendations may have been forbidden for eight years, but research findings and conclusions were not. At any rate this should have been attempted, particularly after the first year of investigations in 1938 confirmed the severity of the rate of utilization of the river's sockeye. This was 79% overall, and hence much greater for the early and mid-season runs that did not benefit from the autumn closures. After all, the Commission was able to obtain approval and funds for fishways -- a desirable but much less urgent project -- at a time when all the energies of both nations were directed to the war effort.

While the Commission let its main function lie in limbo for eight years, its staff, under the leadership of Dr. W. F. Thompson and Dr. R. E. Foerster, proceeded to add to available knowledge of the river, its sockeye, and its fishery. During the first year of investigations, 1938, it sent out field parties to the spawning grounds, which provided closer inspection and hence better estimates than those that had been made annually for many years by Fishery Guardians and other observers of the British Columbia and Canadian Departments of Fisheries. It undertook another saltwater tagging program, directed by Dr. J. L. Kask. And a canyon party, of which I was a member, once again checked water levels and accumulations of fish at Hell's Gate and for the first time tagged sockeye at that point. These and other activities were continued for many years and have provided an excellent body of information concerning the sockeye of the river. The spawning assessments continue to this day. Saltwater tagging was discontinued after 1947, when sufficient information had been accumulated.

During the course of the canyon work the same difficult water levels were observed at Hell's Gate as had been identified by Alexander Robertson and others 10 years earlier. In 1941 difficult levels persisted far into autumn, and an unusually large number of blocked sockeye were observed that year. This provided the impetus for constructing fishways at Hell's Gate which, because of the rapid and unpredictable changes in water level there, had to be of a radically new design that would operate over a broad vertical range. The first and most important fishway was completed in time for the 1945 run to use it, and others were quickly added. In a few years all water levels at the Gate were covered, on both banks of the river. Jackson (1950) has an excellent description and illustrations of the turbulence and flow patterns before and after the construction.

FISHWAYS AND CLOSED SEASONS

In 1945 Bulletin 1 of the International Pacific Salmon Fisheries Commission appeared, the first major publication concerning the research done with reference to the passage of sockeye salmon at Hell's Gate (Thompson

1945). Expecting a well-documented demonstration of serious stoppage and mortality, on reading it I was dismayed to discover major deficiencies. No quantitative basis was presented for the claim that the Gate had been a continuing important cause of sockeye mortality. Even for 1941 this demonstration was lacking, although that was the year of most difficult passage. And the fact that the upriver spawning populations in 1941 were estimated to be 4 times as large as those of the parental year 1937 did not suggest any major difficulty in migration[1].

As the war drew to a close, the unwarranted optimism engendered by the erroneous interpretations of data in Bulletin 1 assumed an ominous aspect. There was a rapidly increasing likelihood that the upper Fraser would be handed over to hydroelectric projects if most of its salmon stocks remained in their depressed condition. Even before the war the British Columbia Electric Company had proposed two dams to be built in the canyon itself, and these were averted with difficulty. Yet from Indiana, where I worked in 1946, it seemed that the Salmon Commission was so preoccupied with other matters that it had completely forgotten the need to let more early and mid-season fish get upriver. The obvious way to achieve this was to divert these sockeye away from nets and onto the spawning grounds. Yet the need for such action was never mentioned in any of the Commission's reports that I had seen. Instead, their popular and scientific releases all gave the impression that Hell's Gate and a few lesser obstacles were all that was wrong with the river, and that the fishways would quickly provide plenty of sockeye for everyone.

My assessment of the evidence in Bulletin 1, however, was that any improvement due to the fishways was likely to be less than a tenth of what could be achieved by closure of the early and mid-season fishery. Thus it appeared timely to call attention to the need for such a closure. If the Commission had closures in mind, outside support would make it no harder for them to act. If they weren't planning closures, it was time that someone spoke out publicly.

Accordingly, in the spring of 1946 I wrote a paper that expressed my misgivings, which was published early in 1947. To my surprise this elicted heated rejoinders from the Commission and from Dr. Thompson, who had recently retired as its Director. The latter produced a multigraphed reply (Thompson 1947a), and the matter was aired in the pages of a local trade magazine (IPSFC 1947; Thompson 1947b; Ricker 1947b,c). None of the "rebuttals" invalidated the points I had raised, and the principal one was never mentioned -- the urgent need for restrictions on the fishery. Instead it was made to appear that I objected to the fishways themselves. Another attempt at distraction was Dr. Thompson's enumeration of alleged inadequacies of Canadian research

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[1]The estimate of Chilko spawners in the 1941 Annual Report of IPSFC was 464,000, with maximum and minimum limits of 554,000 and 374,000. In the 1949 Annual Report, however, the 1941 estimate was reduced to 280,000. In 1946 I had, of course, only the original estimate, but at the reduced figure the 1941 spawners were still 2.4 times as numerous as the estimate for 1937. The Canada Department of Fisheries estimate was 350,000, intermediate between the above two but closer to the lower one. The Chilko estimate for 1940 was also reduced, in the 1952 Annual Report, from 545,000 to 300,000.

before 1938, which provoked a reply from Dr. W. A. Clemens, who was Director of the Pacific Biological Station during the 1930s (Clemens 1947).

This strong reaction was the more surprising because the Commission had already embarked on the course I was suggesting. This may have been prompted by the failure of the 1945 runs (the first that used a fishway at the Gate) to increase any faster than the runs of several previous years (Appendices 5, 11). A more spectacular blow to inflated expectations was the fact that the total upriver spawners actually decreased in 1945, as compared with 1941. This was because the major run, that to Chilko Lake, was down by 31%, or by 58% if the original estimate of its 1941 spawners was still being used.

Whether it was the poor showing in 1945 that threw a scare into the Commission may never be known. At any rate, during the next five years the fishery on the early and mid-season stocks was reduced to varying degrees. Their mean rate of utilization for 1946, 1948, 1949 and 1950 was 60%, as compared with 86% during the previous 5 years (Table 4). The corresponding escapement rates are 40% and 14%, so that an additional 40 - 14 = 26% of the run reached the spawning grounds, an increase to 2.9 times the level of 1941-45. In 1947 the escapement was 79% of the early and mid-season runs, and the increase was 65% of those runs or to 5.6 times the former level. These figures of course are averages for all early and mid-season runs. The earliest stocks to come in from the ocean received almost complete protection. The reason that it was only in 1947 that comprehensive early <u>and mid-season</u> closures were considered possible was, presumably, that between 1936 and 1944 the early and mid-season runs of all 4 lines had increased several-fold (Table 4). Thus a delayed opening of the fishing season now meant, in most years, an appreciable immediate sacrifice by the fishery. What could have been done painlessly during the 1920s and 1930s was no longer quite so easy.

Still, the closures of 1946-50, and subsequent careful control of the fishery under the leadership of the Commission's new Director, Loyd Royal, soon brought the early and mid-season upriver stocks close to their present level of yield. Whether they should be further increased, in some cases, is a matter for continued investigation and experiment. There are certainly possibilities. For example, the Eagle River, a tributary of Shuswap Lake, still had only 1642 sockeye in 1982, its best recent year. In the old big years a major Indian fishery existed on that river as far upstream as Three Valley Lake, and after a late autumn flood the sockeye carcasses that were exposed along its banks could be smelt 8 kilometres away (Appendix 10).

We would not, of course, want to have on any spawning ground as many sockeye as in the old big years. Theory and observation both indicate that maximum sustainable yields will be obtained when spawners are 1/4 to 1/3 as numerous as their unfished abundance, certainly less than half. And to support the young from even these levels of spawning the lakes will almost certainly require artificial fertilization to replace their former enrichment by 100,000 tons or so of dead sockeye every fourth year. In Shuswap Lake Ward (1957) showed that the crustacean foods of young sockeye were quickly cropped down in a dominant sockeye year, and smolts produced by dominant years were much smaller than those of other years (Ward and Larkin 1964; Figs. 7, 8). Both of these phenomena had also been observed and reported in the 1930s at Cultus Lake.

SOURCES OF CONFUSION

A series of Appendices to this report summarize the information now available concerning the passage of sockeye at Hell's Gate during the 1940s. Part of this information did not appear until after 1944, but by the end of that year all the data presented in Appendices 1, 3, 8, 9 and 10 were in existence, and part of what is in Appendix 6. Bulletin 1 of the Salmon Commission evidently received its final form late in 1944 or early in 1945. It is rather remarkable that it was possible to reach a wrong conclusion from such a large body of evidence. The principal points that were not considered, or not appreciated, are as follows:

1. Dr. Thompson may have been unaware of the great disparity in the sex ratios of sockeye spawners above Hell's Gate in 1913. The only direct report on the situation upriver seems to be by Mitchell for the Shuswap region, in a manuscript that Thompson does not cite (see Appendix 10). He must have seen Babcock's (1914) estimate of a 20:1 female to male ratio in creeks below Hell's Gate, but evidently did not deduce a complementary excess of males above the canyon. Thus there is no mention in Bulletin 1 of the significance of the approximately normal sex ratios that the Commission observed on upriver spawning grounds during 1938-1944. These, by themselves, indicated that no serious stoppages were occurring (Appendix 3).

2. The weakness and hence unrepresentativeness of the sockeye that accumulate below an obstacle was not realized. Even though the direct demonstration of this phenomenon at the Babine River was not yet available (Appendix 2), it is a logical and inevitable development whose effects should have been considered (Ricker 1947a). Failure to take this into account seems to be mainly responsible for the exaggerated estimates of numbers of sockeye permanently blocked in 1941 (Appendix 9).

3. The substantial numbers of sockeye captured by dipping in eddies immediately above Hell's Gate in 1942-1944 must have been known to Dr. Thompson, although they were not published until 1950 by Talbot. These indicated that many sockeye were passing through the Gate even during protracted "impassable" conditions. How many were ascending became evident after 1944, when it was possible to compare rates of capture before and after fishways were in place. The fishways failed to increase the number of sockeye that could be dipped just above the Gate, even at water levels that in pre-fishway days were said to be "impassable" (Appendix 6).

4. The choice of September and October water levels for comparison with the "index of return", C_4/C_0, was reasonable for years of the 1902 line, when the

late-running Shuswap sockeye dominated the fishery; although the exceptional year 1926 greatly exaggerates the relationship (Appendix 8). But to use the same levels for comparison with the runs of the other three lines defies logical explanation, for tags recaptured on the spawning grounds showed that they had arrived at and passed through the Gate mainly in July and August.

DISCUSSION

1. Most of the material in this paper was presented in two lectures at the University of Washington's College of Fisheries in 1974. To judge from some of the reactions, it is still difficult to attempt an independent assessment of the role of Hell's Gate without appearing to be "against the fishways". It should not be necessary to emphasize that the fishways have done the job they were planned for, and indeed much more. They permit the formerly delayed or blocked sockeye to continue their journey upriver promptly, although it is true that the number that needed this assistance was only a few thousand in most years, and consisted mainly of the weak and injured. More importantly, the fishways are insurance against a possible major catastrophe to the late sockeye runs, especially the late Shuswap run in the 1902 line, in the event of unusually high water levels in autumn -- which levels have occurred in that line at least once since 1950. Most important of all, the fishways have permitted pink salmon to become reestablished upriver, where several tens of millions used to spawn in odd-numbered years before 1913.

2. During the 1920s and 1930s the Canadian Department of Fisheries, including its research arm the Fisheries Research Board of Canada, and the Department of Fisheries of the Province of British Columbia, conducted a variety of types of studies on Fraser River sockeye. The more important ones included (1) demonstration of the distinctness and physical distinctiveness of various sockeye stocks in the Fraser system; (2) annual estimates of the abundance of the stocks on the spawning grounds made by special observers, by Fishery Guardians, and at the hatcheries; (3) annual sampling of sockeye caught in the Sooke traps, and determination of their length, weight, age and life-history types; (4) a comparison of different techniques of stripping and handling salmon eggs, and the effectiveness of transplanting different stocks of sockeye to new areas; (6) a demonstration that olfactory clues are important in guiding sockeye to their native river, and their almost perfect "homing" to Cultus Lake; (7) a direct determination of the rate of commercial utilization of the Cultus sockeye stock; (8) an ecological study of lacustrine production of sockeye, with an experiment in predator control; (9) the study of conditions at Hell's Gate that was described earlier.

The United States Bureau of Fisheries also had a long-standing interest in the sockeye of Puget Sound and the Fraser. After 1914 it sent sockeye eggs from Alaska with the idea of bolstering the Fraser runs, and it initiated the cooperative tagging program of 1918. During the early 1930s it undertook a systematic historical study of the commercial salmon fisheries of Puget Sound and the Fraser. A preliminary report, written by G. A. Rounsefell and G. B. Kelez, appeared in 1935, and in 1937 their excellent comprehensive analysis became available (published 1938). This documented the major role of the fishery in reducing the abundance of sockeye of the "off" years up to 1914, and in maintaining most stocks at a very low level afterward.

Thus in 1937 there was available a solid background of information to support immediate action to speed up the restoration of Fraser sockeye runs, instead of the long delay that actually occurred.

3. Interestingly enough, there was one fortuitous beneficial effect of the 1913-14 stoppage. One of its indirect results was that the dominant lines of different upriver sockeye stocks became distributed more evenly throughout the four lines of the cycle. Up to 1913 all dominant runs upriver were in the same line. On the view that sockeye dominance is an unavoidable ecological fact of life on the Fraser, it would have required heroic measures to intentionally shift dominance to other lines in 3 major regions. For example, the almost complete prevention of big-year spawning by several million sockeye of the run selected would likely have been necessary. Such a move would be sure to generate enormous "flak", as well as legitimate doubts as to whether it would be successful, and we can only conjecture whether it would ever have been attempted. In the actual event, the destruction of the big-year runs in 1913 made it possible for a dominant sequence to get started in other lines in some areas, without any special action by management.

The present distribution of dominant lines among most of the early and mid-season upriver runs can be seen in Appendix 11. Adding the late runs and a few others gives the following picture.

Early and mid-season runs

1901 line dominance: early and late (mid-season at Hell's Gate) Stuart runs; Horsefly and Mitchell Rivers in the Quesnel region.

1902 line dominance: Seymour, Eagle and Anstey Rivers in the Shuswap region; probably also Scotch Creek.

1903 line dominance: Stellako and Nadina Rivers in the Fraser-Francois region; Upper Bowron River in the Bowron region.

1904 line dominance: Chilko River, south end of Chilko Lake and Taseko Lake in the Chilcotin region; Upper Adams River and Momich-Cayenne Creek in the Shuswap region; Gates Creek in the Seton-Anderson region.

Late runs:

1902 line dominance: Lower Adams River, Little River, Middle and Lower Shuswap rivers in the Shuswap region; Portage Creek in the Seton-Anderson region.

Among some of the smaller runs listed above, the superiority of the "dominant" line is not outstanding; and shifts of dominance are still possible for them and even for large runs, in response to exceptional mortalities caused by high river temperatures or epidemics.

There is of course a question whether the 4-year average sustainable yield of sockeye produced by runs that are dominant in 4 different lines can be as large as the yield produced by synchronized dominance. The overwhelming abundance of young sockeye in the old big years evidently reduced percentage losses from predation by satiating the predators. This may have occurred in salt water as well as fresh, particularly in the Strait of Georgia. In early summer salmon predators there had overabundant food in the young sockeye of the 1901 line (i.e. in 1903, 1907, etc), and a more or less equally large biomass of young pink salmon in even years; while their numbers may have been limited by a relative scarcity of food at other seasons and in the other odd year. However, this is merely speculation; there is an alternative explanation for the synchronization of the big years upriver (Ricker 1950), and the only known dominant run downriver was in the 1903 line, not that of 1901.

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Appendix 1. Computation of rates of utilization from a change in fishing regimes

Consider two fisheries that operate in sequence on a run of N salmon. Under Fishing Regime 1 the fraction of the fish taken by the first fishery is x_1, and the fraction of the survivors taken by the second fishery is y_1. The corresponding escapement rates are $1 - x_1$ and $1 - y_1$, and the overall rate of escapement is $(1 - x_1)(1 - y_1)$. The catches are $W_1 = Nx_1$ taken by the first fishery, and $C_1 = Ny_1(1 - x_1)$ taken by the second. The ratio of these catches is:

$$\frac{W_1}{C_1} = \frac{x_1}{y_1(1 - x_1)} \qquad (1)$$

Suppose now that there is a sudden switch to Fishing Regime 2, in which x_1 decreases substantially to x_2, while y_1 changes little or not at all. The new catch ratio is:

$$\frac{W_2}{C_2} = \frac{x_2}{y_2(1 - x_2)} \qquad (2)$$

The commercial fisheries for Fraser River sockeye experienced a sudden change in "regimes" like the above when the use of traps in waters of the State of Washington was forbidden by law, starting in 1935. The result was that, in the successive 4-year periods of the cycle immediately before and immediately after the change, the average ratio of Washington to Canadian catches shifted from 2.08 to 0.63 (Table 1A). I had hoped to use the fraction of the Washington catch taken by trap to compute x and y in expressions (1) and (2). However, this fraction varied so much from year to year that consistent results were not obtainable (see Table 27 of Rounsefell and Kelez, in which at least 95% of the trap catches would be from Washington).

There are several minor ways in which the Fraser sockeye stocks and harvesting system of the 1930s deviated from the model used for expressions (1) and (2).

1. A certain fraction of the sockeye bound for the Fraser River entered the Strait of Georgia by way of Johnstone Strait instead of through the Strait of Juan de Fuca and Puget Sound. These fish were subject to practically the same Canadian rate of utilization as those that arrived from Puget Sound, although there was a small Canadian sockeye fishery in Johnstone Strait, part of whose catch was Fraser fish.

2. Fishing effort varied from year to year (Table 1A); it had a tendency to increase slowly during the 1930s, at least in Canada and, after the sharp decrease in 1935, probably in Washington as well.

3. The Canadian traps at Sooke took a small catch from the Puget Sound contingent before they arrived in the Sound.

4. The Puget Sound catch included some sockeye from local rivers, especially the Skagit.

Only the first two of the above deviations might have an appreciable effect on estimates of rate of commercial utilization during the 1930s. Let the fraction of Johnstone Strait migrants be represented by (1 - a); this means:

Washington catch: $$W = Nax \qquad (3)$$

Canadian catch: $$C = y(Na - Nax) + yN(1 - a) = yN(1 - ax) \qquad (4)$$

Ratios similar to expressions (1) and (2) are then:

$$\frac{W_1}{C_1} = \frac{a_1x_1}{y_1(1 - a_1x_1)} = p \qquad (5)$$

$$\frac{W_2}{C_2} = \frac{a_2x_2}{y_2(1 - a_2x_2)} = q \qquad (6)$$

Estimates of (1 - a) have been made for the early years by Hamilton (1985). Some of them are shown in Table 1A and are used below, although there are indications that they may tend to be too large.

Expressions (5) and (6) cannot by themselves reveal the rates of utilization by the two national fisheries before and after the United States traps were banned, but they can provide an upper limit. For the simplest example, consider the years 1933 and 1935 in Table 1A, in which the number of Canadian gillnet licences was almost the same, so that we can put $y_1 = y_2 = y$. Also, $a_1 = 0.896$, $a_2 = 0.973$, $p = 2.411$, and $q = 0.871$. Using these figures along with successive trial values of x_1 in (5) and (6), it turns out that if $x_1 > 0.788$, y will be greater than 1, which is impossible. Thus 79% is an estimate of the maximum possible value of the United States rates of harvest of sockeye that entered Puget Sound in 1933. In practice the value of y would have to be less than 1, because Canada could not capture all of the sockeye that entered its fisheries, and accordingly the maximum value of x_1 would be somewhat less than 79%.

Contrary to my original expectation, expressions (5) and (6) do not provide any minimum estimates of x_1, x_2, or y.

For actual estimates of rates of utilization by the two countries another piece of information is needed. This is available in the estimated numbers of sockeye that escaped the commercial fisheries: the spawners plus the subsistence catch. Table 1B shows three such estimates, made during the latter half of the 1930s. (After 1939 wartime events, especially the restrictions on and eventual relocation of fishermen of Japanese descent, tended to reduce fishing effort temporarily in both countries.) Of the three years shown in Table 1B, 1938 was a year of the 1902 line, when the great majority of the sockeye were of the late runs that benefitted from autumn fishing closures, and its rate of escapement from the commercial fisheries was about twice that of the other years. For the other two lines shown, an average rate of escapement after 1934 was 10.8%.

From expressions (3) and (4), the rate of escapement is $S = [N - Nax - yN(1 - ax)]/N$. For period 2, after 1934, this becomes:

$$S_2 = (1 - y_2)(1 - a_2x_2) \qquad (7)$$

Expressions (6) and (7) give:

$$x_2 = \frac{1 - S_2}{a_2(1 + 1/q)} \qquad (8)$$

Expressions (5) and (6) can be rearranged as:

$$y_2 = \frac{a_2x_2}{q(1 - a_2x_2)} \qquad (9)$$

$$x_1 = \frac{py_1}{a_1(1 + py_1)} \qquad (10)$$

Finally:

$$S_1 = (1 - y_1)(1 - a_1x_1) \qquad (11)$$

Of the years listed in Table 1A, 1933 and 1935 had almost the same number of Canadian gillnet licences, and the sockeye entering by Johnstone Strait were few. Thus for a first set of estimates, and perhaps the best available, we can take $W_1/C_1 = 2.411 = p$; $W_2/C_2 = 0.871 = q$; $S_2 = 0.096$; $a_1 = 0.896$; $a_2 = 0.973$; and $y_1 = y_2$. From expressions (8)-(11):

$$x_2 = 0.43; \quad y_1 = y_2 = 0.83; \quad x_1 = 0.75; \quad S_1 = 0.055.$$

The Washington rate of harvest of sockeye that entered by Juan de Fuca was reduced from 75% in 1933 to 43% in 1935; Canada's take was 83% of the remainder in both years; and only 5.5% of the sockeye survived the two fisheries in 1933.

For a comparison having a broader data base but considerable variability between years we can use the means of the odd-numbered years in Table 1A. A reason for treating the odd years separately is that their pattern of fishing was somewhat different from that of the even years, because of the presence of large numbers of pink salmon. Also, the odd years in Table 1A all happen to have small values of (1 - a), whereas two of the even years have unusually large values, 1936 especially. From Table 1A we have $p = 2.272$; $q = 0.758$; $a_1 = 0.888$; $a_2 = 0.901$. From Table 1B the mean escapement rate for 1935 and 1939 is $S_2 = 0.1076$. Using expressions (8) and (9), $x_2 = 0.4271$ and $y_2 = 0.8251$. The ratio of the mean number of odd-year Canadian gillnet licences in period 2 to that in period 1 is $f_2/f_1 = 1969/1508 = 1.3057$. This does not indicate a proportional increase in rate of utilization; rather, the instantaneous rate of fishing (F) should increase approximately in proportion to the amount of gear in use. If $y_2 = 0.8251$, $F_2 = -\ln(1 - 0.8251) = 1.744$; $F_1 = 1.744/1.3057 = 1.335$; and $y_1 = 1 - e^{-1.335} = 0.737$. Expressions (6) and (7) now complete the series:

$$x_2 = 0.43; \quad y_2 = 0.83; \quad y_1 = 0.74; \quad x_1 = 0.71; \quad S_1 = 0.098.$$

Actually the adjustment for increase in gear is almost certainly an over-correction, for it assumes that the new fishermen would be as effective as the old hands. Thus the 9.8% escapement rate obtained for period 1, above, is somewhat too large. We may conclude that the overall rate of commercial harvest in ordinary years before 1935 was between 91% and 95% for sockeye of the odd-numbered lines; in years when there was a large entry of sockeye through Johnstone Strait the percentage taken would be somewhat less, but never as low as 83%, which corresponds to no Washington fishery at all.

For the 1902 line we can compare 1930 and 1934 with 1938, using $S_2 = 0.212$ from Table 1B. The other statistics are, from Table 1A, $p = 2.964$; $q = 0.721$; $a_1 = 0.936$; $a_2 = 0.899$, and $f_2/f_1 = 1.394$. These yield:

$$x_2 = 0.37; \quad y_2 = 0.68; \quad y_1 = 0.56; \quad x_1 = 0.67; \quad S_1 = 0.164.$$

Allowing for the over-correction of effort the pre-1935 rate of utilization of sockeye of the 1902 line was close to 85%. The reason for the smaller rate of harvest in this line was of course that its principal stocks ran late and had the benefit of the autumn closures.

For sockeye of "ordinary" years of the 1904 line the pre-1935 overall rate of commercial harvest would be greater than the 85% of the 1902 line because it had no large late-Shuswap run, but it would be a little less than in the odd-numbered years because of the absence of pink salmon -- about 90% would be a good guess.

The above estimates are in general agreement with Hamilton's (1985) average figure of 91% utilization for all lines before 1935. However, all these figures apply to the whole run each year. The early and mid-season stocks would have been even more heavily harvested because they did not benefit from the autumn closures.

Appendix 2. Effects of a major obstruction on Skeena River sockeye.

In 1952 it was possible to obtain quantitative information concerning the effects of a serious obstruction upon salmon migrating upriver. A slide on the Babine River had stopped many sockeye in 1951, and in 1952 intensive field work was done using tagging methods like those used on the Fraser in 1938-47 (Godfrey et al. 1954). However, in this case there was the great advantage of having a counting fence at the outlet of the Babine Lake system, 65 km above the obstruction, at which all fish were counted and almost all tags checked.

The number of sockeye (excluding age 3) that arrived at the Babine Slide in 1952 could be estimated rather accurately by comparing the commercial catch and fishing effort with that of previous years when the Babine escapement had been enumerated, while the fence count showed that a third of these were able to get past the Slide (Godfrey et al. 1954). At the fence thee were 59% males in 1952 and 52% in 1951; whereas in the 4 years previous to the Slide the same ratio had varied between 40% and 45% (mean 43.1%).

Section A of Table 2 shows the percentage of sockeye, apparently uninjured when tagged below the Slide, that ascended the river and were inspected at the fence. The percentage increases with the size of the fish and, as expected from the increased proportion of males among untagged sockeye at the fence, it is greater for males than for females. Excluding the small age-3 males, the average recovery rate for uninjured tagged fish was 16.2% for males and 9.5% for females, 12.8% combined. This is to be compared with 33% for untagged fish. The large difference suggests that, even among sockeye not visibly injured, those accumulated below the obstacle included an unrepresentatively high proportion of the constitutionally weaker individuals. A small part of the difference, however, is ascribable to the fact that a few tags got through the fence without being inspected; while the presence of the tag or the process of tagging may have had some adverse effect.

For sockeye that had external injuries when tagged, the percentages checked through the fence were less again: 9.8% for males and 6.2% for females (Table 2-B). Of all the females that did pass the fence, about 30% were estimated to have died unspawned or only partially spawned; however surveys were made more frequently in the latter part of the season when conditions had improved, so the mean percentage was probably somewhat greater.

Appendix 3. Effects of Hell's Gate on sockeye sex ratios, and computation of number of fish blocked.

The picture of the difficulty of migration on the Babine River in 1951-52 resembles what happened to the Fraser sockeye in 1913, except that the Fraser obstructions were evidently more serious. The 1913 spawning-ground estimates by Babcock (1914) were of 1/4 to 1/10 as many fish as in 1909. Mitchell (1925) estimated only 1/200 of a normal big-year run at Adams River, and only 600 fish in Eagle River -- two major spawning tributaries of Shuswap Lake. In the same two rivers he found that females made up only 13-17% of the run, and many of these died unspawned (Appendix 10). In creeks below the canyon, on the other hand, the blocked fish were estimated to include 20 females to 1 male (Babcock 1914), and A. Robertson's similar observation was mentioned earlier. Evidently some appreciable part of the male sockeye got past the 1913 obstruction, but far fewer females, and those in poor condition.

Thus at the two known serious obstructions three main effects were observed: (1) a majority of the fish were prevented from getting upriver; (2) among those that did, females were in a considerable minority; and (3) these females were in poor condition and many died unspawned or only partly spawned, so that the number of progeny produced per spawner was much less than it would otherwise have been.

How do the conditions of 1938-44 at Hell's Gate comapare with this picture? A point of resemblance is that the sockeye that were permanently blocked and ascended the canyon creeks below Hell's Gate included an excess of females (75% in 1938 and 78% in 1942, the only figures published). On the other hand, the average percentage of males on the various spawning grounds upriver was not far from 50%; more important, it was much the same after fishways were constructed as it was immediately before (Table 3). This can only mean that the number of fish blocked was a small fraction of the total. In fact, for 1942-44 the average (GM) percentage of males on 5 different spawning grounds was slightly <u>less</u> before fishways were constructed than it was during 1945-48 (44.16% as compared with 45.12%), so there is no indication of significant stoppage in these years. This is in agreement with the observation of only a few hundred blocked sockeye in the canyon creeks in most years. In 1941, however, the year of most difficult passage, there was a somewhat larger than average percentage of males on all four spawning grounds for which data are available (Table 3).

These data can be used for an estimate of the percentage of fish blocked. Assume that after fishways were available, in 1945 and subsequently, the male and female fish ascended the river equally well, as was postulated by Thompson (1947b) for passable water levels even before 1945. Thus the sex ratio for each stock on the spawning grounds would be the same as at the time its fish had just left the commercial fishery. Let the mean fraction of males (age 3 excluded) on the spawning grounds in 1945-48 be y, and assume that this can be used as an estimate of the mean fraction of males in the stock as it arrived at Hell's Gate in 1941-44 as well as in 1945-48, because fishing methods and gear had changed little over that period.

In 1941-44 a mean fraction a of the arriving males were permanently blocked at Hell's Gate, and fraction b of the females. Finally, let N be the mean number of fish in the run as it reached the Gate. Then during the years 1941-44:

Nay males were blocked
Nb(1 - y) females were blocked
Ny(1 - a) males passed through the Gate
N(1 - y)(1 - b) females passed through the Gate.

We estimate the mean sex ratio of blocked fish before 1945 as 0.235:0.765 (from observation of 75% females among early and mid-season fish blocked in 1938, and 78% in 1942). Then:

$$\frac{ay}{b(1 - y)} = \frac{0.235}{0.765} = 0.3072 \qquad (1)$$

During 1941-44 by far the largest early or mid-season upriver stock was that at Chilko, so the computation can be made in the first instance for that stock. The observed GM fraction of males at Chilko in 1941-44 was 0.4618 (Table 3); hence:

$$\frac{y(1 - a)}{(1 - y)(1 - b)} = \frac{0.4618}{0.5382} = 0.8580 \qquad (2)$$

Finally, the mean fraction of Chilko males in 1945-48 was 0.4578; hence:

$$y = 0.4578 \qquad (3)$$

Equations (1)-(3) can be solved for the two unknowns, giving:

$$a = 0.0091; \quad b = 0.0249$$

Thus about 1% of the males and 2 or 3% of the females are estimated to have been blocked, on the average for the years 1941-44. If the geometric mean of the ratios for all five runs in Table 3 be used, the resulting percentages are slightly smaller.

The year of unusual difficulty, 1941, can also be compared with the 1945-48 mean, provided the above 76.5% of females is assumed for blocked fish of that year. Equations (1) and (3) above are the same, and (2) becomes:

$$\frac{y(1 - a)}{(1 - y)(1 - b)} = \frac{0.498}{0.502} = 0.9920 \qquad (4)$$

This gives:

$a = 0.078; \quad b = 0.216.$

From (3), of 1000 Chilko sockeye that reached the Gate in 1941, 458 were males and 542 were females. Of these, 0.078 x 458 = 36 males were stopped, and 0.216 x 542 = 117 females, 153 in all. Thus 15.3% of the 1941 escapement to the Gate is estimated to have been permanently blocked. This means 49,000 sockeye, using the revised estimate of 280,000 spawners at Chilko Lake.

If the Chilko picture applies also to the other, much smaller, runs of 1941, the corresponding estimate of total blocked fish becomes 52,000. The sampling variability inherent in the computation would permit estimates from about half to twice as large.

In the 1941 Chilko computation, the assumption that the percentage of females among permanently blocked sockeye was 76.5 is questionable, because with more severe conditions we might expect the ratio of females to males to become greater. However, any such larger ratio <u>reduces</u> the computed number of fish of both sexes. For example, if 90% females were blocked, a = 0.0183, b = 0.1645, so that 3000 males and 28,000 females were blocked, 31,000 in all -- as compared with 49,000 using the smaller ratio.

Appendix 4. Production of recruits by the early and mid-season upriver runs.

Because both of the known major stoppages (Fraser 1913-14 and Babine 1951-52) greatly reduced the egg deposition per sockeye that reached the spawning tributaries, it should be informative to compare the progeny produced by the Fraser's early and mid-season runs just before and just after the fishways were built. These include all upriver runs except the late Shuswap group and Portage Creek. The difficulty in making such a comparison is to know what fraction of the total Fraser catch consisted of sockeye from these runs. However Royal (1953) has published estimates of the catch from six runs (Seymour, Raft, Chilko, Nechako, Stuart, and Bowron) for 1943, 1947, and 1951, together with the spawning stocks of the same years. Adding to these the spawners of 1939 (from the 1950 Annual Report of IPSFC), we have the picture below:

	1939	1943	1947	1951
Spawners (E)	8447	36,149	166,847	334,300
Catch (C)	--	105,000	10,000	1,337,200
Total run (R)	--	141,149	176,847	1,671,500
R_4/E_0	16.7	4.9	10.0	--

The spawners of 1939 and 1943 had no fishways to assist them, whereas those of 1947 used fishways on both banks. The largest rate of recruitment was from the 1939 escapement, which yielded 17 adult sockeye per spawner. The geometric mean for the two pre-fishway years is 9.0, as compared with 10.0 for the post-fishway year. Thus there is little evidence of increased productivity per spawner following fishway construction.

To obtain a picture for all early and mid-season runs and for a longer series of years, an approximate division between these and the late runs in the catch can be made using the rates of migration described by Killick (1955). These indicate that the United States catch through August 7, and the Canadian catch through August 15, were mainly from the early and mid-season runs. There is of course some overlap between these and the late run in the catch, but the relative picture is little changed by shifting the point of division a week either way.

Figure 2 and Table 4 show the recruitment per spawner (R_4/E_0 ratio), including the commercial catch, subsistence catch and spawning escapement in the recruitment. The 1936-39 spawnings have exceptionally good recruitment ratios. Presumably this was mainly because spawning stocks were still quite small, but these ratios are probably inflated because the catch classified as early or mid-season in 1940-43 would have included a greater fraction of fish from the Skagit and other non-Fraser runs, as well as from the earliest portion of the late runs. However, even if the R_4/E_0 values for 1936-39 were to be cut in half, they would still be much larger than those of later years.

The geometric mean of recruitments per spawner during the 4 years immediately before the fishways was 6.2, as compared with 5.7 during the 4 years immediately afterward, confirming the picture presented earlier from Royal's data. Subsequently this ratio fell even more, as a number of stocks approached the abundance considered optimum.

The main point is that there was no sudden increase in R_4/E_0 after fishways were built, thus discounting the hypothesis that in the years just before 1945 most of the females that reached the spawning grounds were in poor condition and spawned less effectively. Notice particularly that the spawning year 1941 had an average R_4/E_0 for that period.

Appendix 5. Escapements and spawning runs above Hell's Gate

Appendix 4 examined the effects of Hell's Gate upon the reproductive potential of the sockeye passing it, and detected no harmful results. In this section we examine an index that has been used to measure the success of the sockeye in getting through the Gate. This is the E_4/E_0 index -- the ratio of escapements above the Gate in successive generations. The last column of Table 4 shows the ratios for the early and mid-season upriver runs as a whole. The geometric mean is 2.85 for the brood years 1937-40, 2.39 for 1941-44, and 1.50 for 1945-48: there is no sign of improvement after fishways were constructed, in fact the contrary. However these ratios are heavily weighted by the largest stock in each year, and as stocks become larger we expect E_4/E_0 to decrease.

A more informative comparison is given in Figure 3, which shows the unweighted geometric mean of the E_4/E_0 ratios for most of the individual stocks or groups of related stocks, using years that were estimated to have at least 100 spawners both as parents and as progeny (Appendix 11). During 1946-50 early fishing closures of varying lengths were in force, and it is only during two of these closure years that E_4/E_0 exceeds what had been observed earlier.

The benefit to the early and mid-season runs of delaying the fishing season can be estimated quantitatively by comparing rates of escapement in Table 4. During 1946-50, with fishways in operation and with early closures, the geometric mean of E_0/R_0 was 0.450; in 1951-55, with fishways but without major closures, it was 0.178. The average rate of escapement was 2.5 times as great during the closure years.

If the years of early fishing closures be ignored, Figure 3 indicates a slow decrease in E_4/E_0 from the early 1940s to the decade of 1960-69, when stocks had become approximately stabilized in most cases. There was no sudden improvement in E_4/E_0 after fishways were built, apart from what occurred when fishing was delayed.

Appendix 6. Abundance of sockeye dipped immediately above Hell's Gate, in relation to water levels

Another criterion that has been suggested to evaluate the degree of obstruction at Hell's Gate is a comparison of the sockeye taken by dipping above the Gate before and after the construction of fishways (Talbot 1950). Figure 4 compares the mean catch of sockeye per hour from July 10 to September 15, taken by dipping above Hell's Gate, with the total spawners of the early and mid-season stocks. The limiting dates were chosen because few sockeye arrived at the Gate before July 10, and it was about September 15 when the last sockeye of the early and mid-season stocks arrived. The two indices fluctuate more or less in parallel, the average catch/spawner ratio being somewhat smaller after fishways were built. The best comparison is between 1940 and 1946, which had similar numbers of spawners before and after the fishways, and catches per hour that were not greatly different.

More informative is a comparison of catches above the Gate with the periods during which passage was said to be blocked, in the three years before the fishways, 1942-44. Actually there is some ambiguity concerning what were considered to be blocked conditions. Thompson (1945) uses the words difficult, impassable and blocked more or less interchangeably. He included the 41 to 49 foot interval on the right bank in the blocked category in his Figure 28, but has it passable in Figures 26 and 30 (if I interpret them correctly). Jackson (1950) has this interval passable but "difficult". Both authors consider that a "window" of a foot or so at either end of this interval was passable. Here I will use the term "blocked" only for levels so indicated on Jackson's Figure 6:

Left bank	Blocked:	61-25 feet
	Passable:	25-12
Right bank	Blocked:	61-51, 39-12
	Passable:	51-39
Combined	Blocked:	61-51, 39-25
	Passable:	51-39, 25-12

Note that Jackson did not distinguish blocked from passable conditions on the basis of his hydraulic studies, but depended on reports of biological observations.

The number of sockeye caught by dipping above Hell's Gate, shown in Talbot's Figures 26 to 31, varies with the season and from day to day in response to the sequence of stocks going upriver and the times of fishing closure downriver. There are days of good catch and days of little or no catch, and both occurred when water levels were "passable" and also when they were "blocked". When the guage was above 51 feet, as happened in July of 1943, sockeye avoided the left bank but went up along the right bank even though it too was "blocked". Below 26 feet there was easy passage along the left bank that was used by most of the sockeye going through at that stage. Between 26 and 51 feet sockeye were caught above the Gate at both "passable" and "blocked" levels on both sides of the river, in all three years. The largest left-bank rate of catch from the early and mid-season runs was on August 19, 1944, when 27 sockeye per hour were taken right in the middle of a "blocked" period that lasted 3 months, and this figure was never equalled during July-August after the fishways were in operation. Some good catches were made on both sides even during the 39-26 foot interval when both sides were "blocked"; for example during late August of 1943, and August 21 to September 15, 1944.

The sockeye tagged below the Gate included enough vigorous fresh arrivals that tagged fish too were able to pass through in fairly good numbers during "blocked" periods: compare Talbot's Figures 14 and 15 with the sequence of water levels in 1943 and 1944 (his Figs. 26-29).

But in spite of all this evidence to the contrary, Talbot twice states that "few or no sockeye could be caught during block levels above the Gate before the installation of the fishways". His graphs show that it simply isn't so: just as many were caught before as afterward[1].

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[1] I have wondered whether the erroneous statements could have been editorial additions made by someone not closely familiar with the actual data.

Appendix 7. Comparison of two estimates of rate utilization

Figure 5 compares estimates of rate of commercial utilization (u) from the whole run of sockeye to the Fraser, calculated in two ways: (1) from the commercial return (T) of tags put on sockeye at Sooke (M), and (2) from the catch (C) and the sum of catch and spawners (C + E) past the commercial fishing boundary. The two formulae are u = T/M and u = C/(C + E). (The total commercial catch and total spawners are used in this Figure, both early and late runs, upriver and downriver.) For several reasons we expect the tag estimate to be the smaller of the two. The ratio T/M is less than the true rate of utilization by the commercial fishery because of any loss of tags from the fish, incomplete reporting of tags recaptured, and because a small part of the run had been captured before the tags were put on. The ratio C/(C + E) is greater than the true rate of commercial utilization because E has been somewhat reduced by the small subsistence fishery in the river, and by any natural mortality that occurs between the commercial fishery and the spawning grounds -- including that due to obstacles to migration. Figure 5 shows the relation between the two estimates. For the pre-fishway years 1938-44 a geometric mean regression line has been fitted, which meets the ordinate at C/(C + E) = 0.262. This does not differ significantly from a straight line through the origin, which would indicate direct proportionality between the two indices; however, proportionality is not a necessary part of the present argument.

The years 1946 and 1947 have smaller values of T/M than the others, reflecting the delay in opening the fishing season in those years -- that of 1947 being much longer and of substantial benefit to many more stocks.

Two aspects of Figure 5 are pertinent to our enquiry. If in 1945 and subsequently a lot of fish that formerly were blocked were now reaching the spawning grounds, the points for those three years should tend to fall below the trend line established by the earlier years; this is because E would be increased and hence C/(C + E) would be decreased. In fact, however, the points for 1945 and 1946 lie well above the trend line shown, and only that for 1947 is below it. On balance there is no indication of mortality due to obstacles to migration.

Another comparison concerns 1941, the year of the largest canyon mortality during the period of the Commission's studies. Thompson (1947a) made a "rough estimate" of 1 to 2 million sockeye killed, but this was later reduced to "hundreds of thousands" in the IPSFC Annual Report for 1952. If a much larger than usual percentage of sockeye was blocked in 1941, E would be decreased and hence C/(C + E) would be increased so that its point would lie well above the trend line set by the other six years. In fact, however, it lies a little below that trend (which is a little steeper than but very similar to the 7-year trend shown in the figure).

Appendix 8. The "index of return", C_4/C_0.

A piece of information that is given prominence in the Commission's Bulletin 1 (pages 162-168) is a relation between water levels and an "index of return", C_4/C_0, which is the ratio of one year's commercial catch to that of 4 years previously. Unfortunately this index confounds two effects: in a given year a small catch will correspond to a small escapement if it results from the total run being less numerous than average, but it will correspond to a large escapement if it results from a fishery less intensive than average. Dr. Thompson's use of the index is based on the first of these two relations: it implies that there was approximately the same level of fishing effort in the two years being compared, for he uses C_4/C_0 to estimate the success that the escapement of year 0 had in getting by Hell's Gate.

In Figure 54 of Bulletin 1, water levels are divided into the two categories "passable" and "difficult"; the latter including the 41-49 ft interval on the right bank (see Appendix 6). In later figures these difficult levels are called "impassable". In Figure 55 the C_4/C_0 index is compared with the number of days in September and October that Hell's gate was "impassable", from 1912 to 1939. In Figures 57 and 58, C_4/C_0 is related to the number of "impassable" days, both straightforwardly and in logarithms, but for no explained reason the years before 1920 are omitted. Figure 6 here is a comparison of the logarithms of C_4/C_0 with the number of "passable" days, using all parental years from 1915 to 1939; that is, after the remedial work was completed during the winter of 1914-15, and of course before the new fishways were built.

There is an apparent direct relationship between $\log(C_4/C_0)$ and the number of "passable" days, which was shown also in Figure 1 of Ricker (1947a). However, in 1947 I failed to notice the major inconsistency in this presentation, which is that in the 1901, 1903, and 1904 sockeye lines no important runs reached Hell's Gate mainly in September and October. Because the apparent relationship was opposed by other evidence, I suggested that it might be an indirect effect, such as a correlation between high autumn water levels and damage by flooding to eggs deposited in parts of the watershed. However, neither this effect nor any other need be postulated for the above 3 lines. They are represented by open dots in Figure 6, for which points the correlation is non-significant and almost non-existent ($r = 0.058$), simply because the wrong months are used on the abscissa. (However, when the right months are used, the correlations are no better; in fact, they tend to be weakly negative.)

In the 1902 line, shown by black dots on Figure 6, late runs dominated the fishery and their sockeye passed the Gate mainly in September and October. Hence the black-dot trend in Figure 6 could have some direct significance, particularly because on biological grounds we would expect that if any sockeye run had important trouble at difficult water levels it would be this one: its fish are much closer to maturity when migrating than are the earlier runs, and need to get to their spawning grounds promptly. Unfortunately, in 1926 the assumption of proportionality between catch and escapement broke down badly. An unexpectedly large late run appeared at Shuswap Lake (estimated as 300,000 fish). Part of the reason for this good showing was that it was an even year, when there were no pink salmon to maintain a strong late fishery, and in 1926 there was no expectation of a large late sockeye run. Even more important, probably, is the fact that in 1926 a large fraction (estimated as 49% by Hamilton 1985) of the sockeye entered the Strait of Georgia by the northern route and largely escaped the United States fishery. Rounsefell and Kelez (1938) note that in 1926 there was a very small late catch in Washington waters, though a fair number were taken by Canada.

For the reasons above the point "22" in Figure 6, for which the 1926 catch was C_4, is much too low because that catch was unrepresentatively small; and for the same reason the "26" point, when the 1926 catch was C_0, is much too high. Thus the correlation for the 1902 line is greatly weakened. And considering the overall picture, it is clear that there was no serious Gate trouble for the big late run from 1922 to 1942: its spawners increased more than 100-fold during that pre-fishway period, while at the same time providing catches that, after 1926, were consistently several times as large as the escapements.

It is difficult to understand why Dr. Thompson included the other three sockeye lines in his comparison of C_4/C_0 with water levels in September and October. The 1901, 1903, and 1904 lines reached the Gate mainly in July and August, as shown by the spawning ground returns of tags in Figure 22, 23, and 25 of Thompson (1945 - note that the cuts of Figures 21 and 25 interchanged) and by Killick's (1955) study. Thus they would be affected by any stoppages that might occur during those months, but not by those of September and October. Weak fish of these lines that were delayed until the water level fell below 26 feet in September had neither time nor energy to reach their spawning grounds. Some of them got upriver as far as Lillooet, where in some years there was an accumulation of up to a thousand or so colored sockeye late in the season -- conspicuous in the clear water of Seton Creek. These had presumably found the Bridge River rapids of the Fraser too great an additional obstacle.

Appendix 9. Condition of salmon tagged at obstacles.

A situation that was not taken into consideration in Bulletin 1 is that the sockeye captured for tagging below Hell's Gate were a motley assortment; many of them had scars or lesions, and many showed some degree of spawning colour. Thus they were not at all representative of the fish as they arrived fresh from the ocean. The sockeye that were delayed or stopped at "blocked" water levels were mainly the naturally weaker individuals, and those that had sustained injury in the ocean or in the fishery. While they were battling the obstacle they would eventually acquire red colour, and some developed lesions on the head, fungus patches, and so on.

Non-representativeness of sockeye taken below an obstacle was confirmed at the Babine River slide. As shown in Appendix 2, fish tagged from the accumulation below the slide ascended that obstacle less than half as well as did newly arriving (and untagged) fish. Moreover, among those tagged, fish with an injury or scar or any sort were only about half as successful in passing the Slide as were those apparently uninjured.

A similar situation existed at Hell's Gate during the years just before 1945. The weak fish were available for tagging for a period of up to several weeks, as shown by numerous delayed recaptures at the tagging sites below the Gate during "blocked" periods; whereas strong fish went right on through, as shown by substantial numbers of recaptures made above the "blocked" Gate within a very few days, sometimes even on the same day (Talbot 1950; Figs. 14, 15).

Thus the sockeye tagged below Hell's Gate were not in the least representative of the run as a whole. If this is taken into account, the tag recapture data in all years agree with what is expected on the basis that most newly-arrived sockeye went through the Gate promptly at all water levels. Thompson's (1945) Figures 24 and 47 show the picture for 1941 -- the difficult year. In that year there were two principal groups of upriver runs. Those to the Stuart region went through the Gate mainly in July, and those to Chilko mainly in August. There were substantial recoveries of July and August tags, put on sockeye below Hell's Gate, in both of these spawning areas; although not as many Chilko fish as in 1940 (Fig. 23), because in 1941 a larger proportion of the tags were put on the accumulating weak fish. Few new fish arrived after September 1st, so the tagging from that time onward was done almost exclusively on the fraction of the fish that had been stopped earlier, and there were no recoveries above the Gate from these September-tagged sockeye because in 1941 the water remained above the 25-foot level until late in the autumn.

The graphs for other years in Thompson (1945) show that even among the tagged fish a large majority got upriver, which means that very few of the newly-arriving sockeye were delayed appreciably. For example, Figures 49 and 50 for 1939 and 1940 show that a large majority of the recaptures of tagged sockeye were from above Hell's Gate, in spite of almost continuous "blocked" or difficult levels there from the middle of July to the middle or end of

September. In 1942 most tagged fish got through in spite of similar conditions up to the end of August (Fig. 51).

A similar interpretation is to be put on Figures 14-18 of Talbot (1950), showing recaptures of tags put on below Hell's Gate and caught in the Indian fishery upriver as far as Lillooet. In 1945-47, when the fishways prevented appreciable delay of salmon below the Gate, the sockeye tagged there were fresh arrivals, and nearly all the recaptures were made within 10 days. In 1943 and 1944, when many of the tags were put on delayed fish, there were many recaptures up to 20 days after tagging, and some much later. These represented the weak fish that had been held up until easier water levels were available, especially those below 25 feet.

Appendix 10. Excerpts from a manuscript by David Salmond Mitchell (1925).

The Indians' dried sockeye salmon trade

Salmon was the main Indian food, dried it was their money, as blankets used to be on the coast.

The Kweekwillie holes along the Thompson River are archaeological evidence of a great population that had towns straggling for miles along the river banks.

A population living on salmon, and drying in sun, and smoke, great quatitities for winter food, and for barter with the Indians to the south.

In the autumn the trails were busy with mounted Indians, singing as they jogged along, or whooping as the galloped from one troop to another, while trains or processions of pack horses, toddling along under tremendous loads of baled, dried, salmon, bit at the herbage along the way.

Behind them would come squaws, papooses, colts and cayuses, gay with colour, buckskin, beads and dyed horsehair.

Every little while came the pounding of more and more hoofs, along the ridges and benches, with more yelling, laughter and song.

It was the southward movement of great quantities of dried salmon, some of it for Indians over on the American side, whose forebears had traded in it, long before there was a boundary line, or white man in the country.

* * *

The salmon trails

It was only a twelve mile pack by Eagle Pass from sockeye salmon fisheries at Three Valley Lake to the Columbia River, opposite where Revelstoke now stands.

From there it required little effort to take baled dry salmon by canoe, away through a great region lying on both sides of the Internatinal boundary line. They could drift much of the way only using the paddle enough to steer.

From Kum-tche-tche-tchin (Enderby) on the Shuswap River it was sixteen miles pack to Okanagan Lake. From fish trap rapids on the Shuswap River to Okanagan Lake was thirty-six miles. From the head of Okanagan Lake another great water route lay open.

Another route, between the Shuswap Lakes and the upper Columbia River was by Schwn-a-meen, or Seymour, thirty miles.

In the dry belt, horses were more plentiful than canoes. Individuals among Indians in the South owned hundreds, that would paw on the ranges for their feed all winter. Cayuses could be bought for two dollars and a half (10 dried sockeye).

A few mounted Indians could keep long trains of these salmon packers moving on the trail.

Some of the dried salmon purchased, or won at the game of slik-a-mious in the Shuswaps, after reaching Colville would be relost at Tis-lalikum (Okanagan for the same game) to Indians from still farther south.

It was eaten after being toasted on a pointed stick jabbed into the ground, and leaning forward by the fire.

The foregoing portrays the old conditions around the nursery of the Fraser River's great sockeye salmon runs, the home of the reddest fleshed tribe of sockeye salmon.

A large Indian population, of which there now remains only a remnant, using it as their staple food and their exchange in southern trade, the annual salmon harvest being the most important incident in the Northern Pacific Indian's life, while great numbers of otters, mink, eagles, herons, loons, mergansers and grebes fed upon the ling, suckers, squawfish, etc., that ate the salmon eggs and fry.

The otters killed some salmon during the run, and trout that followed to eat the salmon spawn, but for the great part of the year they preyed upon the fish that devoured the salmon fry...

There was a natural balance, that was broken, when the white man came, and threw his rifle into it. He came, bang, bang, bang, at every living thing.... The mink and otter were killed for their skins, and the eagles, ospreys, herons, loons, etc., perished as targets. As a consequence the coarse fish (ling, suckers, squawfish, etc.) eating the salmon eggs and fry, now increased enormously.

With the development of canning at the coast the salmon runs were assailed at both ends.

Then came settlers who ran amok when they saw the salmon run, killing them for pleasure after they had their barrels full, and slaughtering them for fertilizer. Then came lumbermen's sluice dams.

As the country settled up, the demand on the spawning beds became very heavy. It was an unsatisfied demand, as the canners allowed so few to pass, during three years out of four, that the settlers could only lay in a supply once in four years, when they used their chances to satiety.

When the Indian struck at a salmon with his spear he got that salmon, and when he had enough he quit; not so the white man. They got after them with pitchforks, iron spikes, or pieces of thick telegraph wire fastened on poles, and with gaffs. After wounding several they would get one pinned to the bottom then lose it trying to get it ashore.... For every ten they got, they injured a hundred that escaped.

Indians not to blame for the loss of the salmon

The Indians did not deplete the salmon.

Their barricades across the streams were opened at the ends as soon as they had as many fish as the women could prepare for drying that day. They were opened, as the Indians said, to let the salmon go upstream to "mammok papoose" (jargon for reproduce). (Correct Chinook, mammok tenas).

I have gone to their barricades at all times, unexpectedly, and in the middle of the night, and found that it was so.

When the Indian population was great, salmon were in abundance. It was after the Indians had become greatly reduced, that export commerce depleted the three smaller years of each four, and the dumping of rock out of Hell's Gate tunnel bore, cut off the big quandrennial runs that had made the Fraser's fame.

A sockeye run of the Salmon River

Many years ago I rowed in the moonlight up the Salmon River. About a mile from its mouth I tied the bow to a long stake that was driven in the bed of the stream. There was no sign of salmon. I unrolled my blankets in the stern and went to sleep. Several times I awoke to listen and look around; there was no sound but the faint gurgle of the passing water around the bow.

In the grey of early morning I was aroused by a commotion, and found the river full of sockeye running upstream. I put in an oar and felt that the river was half fish. The increasing light soon showed that it was red from bank to bank.

Then a stampede or panic occurred, and salmon came surging down, but the river was so full of ascending fish that they blockaded and made a great flat wriggling dam. So jammed were they that they crowded out, and were rushed up the sloping banks out of water. Where the banks steepened, these struggling flapping fish were rolled down onto the backs of the fish in the river bed below, into the mass of which they would again sink. The boat was on fish, on a red, flapping squirming mass.

The fish lower down stream, suffocating for oxygen, had turned and were rushing back to the lake to breathe fresh water through their gills, and the mass subsided. They rushed down stream creating a great noise, like the roar of a storm, or the noise of thousands of wild ducks rising from a lake, and followed down stream by a succession of waves. The river was quiet again, flowing by the stake fourteen inches below the wet high water mark reached a few minutes before. Not a fish was in sight.

In about twenty minutes or so they came back, filling the river again from bank to bank. Lightly clad Indians then appeared along the wooded banks, with their long slender-shafted fish spears, to take as many fish as the women could prepare in one day for drying, while the men would be erecting more drying racks.

I took aboard the few fish I needed and unhitched from the stake. I could not row, the oars only can down on sockeye backs, so taking an oar to push with on a bank, and use as a paddle, I worked down and out of the river.

Some people may think this unbelievable; let them come to Salmon River and ask the settlers, not necessarily those who lived there at the time of which I write, but any settlers who came there as recently as 1909, the last big salmon run to reach these spawning beds. When they tell you of having seen sockeye salmon so thick in the river that one could walk across on their backs, they have reference to these jams, and at the commencement of the run, when the fish were liable to panic and stampede. I never heard of anything attempting to cross. They would have sunk and smothered in the seething slippery mass.

The Fraser was the greatest salmon river in the world

Every fourth year the Shuswap region gave it [the Fraser] the great excess that made its fame. These salmon runs were one of the Wonders of the World, and their loss has been one of the World's Greatest Disasters. These now lost salmon were everywhere described as "inexhaustible".

Every stream was full of spawning fish. Little creeks or drains, too narrow for a salmon to turn in, and too shallow to cover the salmons' backs, were used to the utmost.

People may think that there might have been too many salmon, and that the last of the run must have disturbed and destroyed the eggs of the first, but Nature was still protecting, rather than checking their numbers. When a stream was fully seeded, later coming salmon seemed to know, and leaving it undisturbed they sought another spawning ground along the gravelly lake shores.

The lake spawners that used the shore from the mouth of the Scotch Creek eastwards, were of the same type of red fleshed sockeye that used the creek, and undoubtedly part of the same tribe....

The first salmon to enter the streams were those that had farthest to go to reach the native gravel where they had been hatched. Those that had been hatched nearest the outlet, entered latest.

Natural death of the Pacific salmon

After spawning they made no effort to return to the sea. With tails almost worn away, and skin no longer exuding slime, hardening as if only the fibre of their contracting flesh remained, blotched with patches of white fungus that kept extending over their skin, a fungus or white mould that grows on dead animal tissue in water, they would lie in some still spot with just the gills moving, or were carried unresisting by the current, to be left stranded on some driftwood pile or carried by the stream back to the lake, where the waves would wash them ashore, and pile them up in long bars, banks or mounds, extending around the beaches.

The atmosphere was heavy with the stench, through which flew gulls that had followed up the river over 300 miles from the Fraser's mouth, to feast upon the dead salmons' eyes. After big runs the mouths of streams were hardly approachable for the stench; for miles beyond the deep bars of dead salmon, the shores were strewn.

On the 14th of December, 1905, we steamed through the awful stench into the wide bay at the mouth of the Lower Adams River[1]. With mouths tightly closed we communicated only by signals. The shore was banked with a wide deep double bar of putrid salmon, extending around the bay until it faded out of view in the distance. The parallel furrows in this bar of dead spent salmon, marked the interval between the two separate storms, that had piled on the beach these spawned out fish, swept by the current out of one of the three mouths of the Lower Adams River, while the level of the lake was gradually falling. The difference between the lake's high water in June, and low water in mid-winter, being from 11 to 14 feet.

We dropped a stern anchor, and crossing the slippery, putrid mound of rotting fish, in hip rubberboots, passed a bowline to a big cottonwood tree ashore.

The Indians had all cleared out from the reserve. The water in the connecting channel between Great and Little Shuswap lakes was not fit to use; boiling only aroused the flavour. We kept our fire on, in case of sudden storm, and filled our boiler there.

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[1]The Granite Creek Hatchery's report for 1905 (page 256 of the Annual Report of the Canadian Department of Fisheries) shows that an egg-taking camp was established at Adams River on October 30 and closed on December 4, after taking 3.5 million eggs from the latter part of that run. These were sent down to the Harrison Lake and Bon Accord Hatcheries, which had not been filled to capacity from their local runs. Granite Creek Hatchery had earlier been filled with 12 million eggs from the Scotch Creek run, and a great many more eggs could have been taken there. In "off" years, on the other hand, sockeye eggs were shipped from downriver stocks up to Granite Creek, because the Shuswap tributaries would supply no more than 5 million in the 1902 line, and less than a million in the 1903 and 1904 lines. The trip on December 14 was presumably to pick up equipment that had been used by the spawn takers.-W.E.R.

On leaving we found our anchor rope slippery with slime like a thin jelly.

Our journey back with a tow was fifty-two miles, interrupted half way by sheltering in a bay over night. On the following day we could smell the Eagle River when passing five miles away with the wind right.

During this journey since leaving Adams River we had filled the boiler many times, but on our arrival at Kualt, people who came aboard, got right off again, owing to the stench of dead fish coming with the steam from our pipes.

We could not detect it ourselves then, and our engineer told them: "At Adams River the stench is so strong, that you can lean against it."

No worse to kill salmon the spawning beds than in the Straits

Killing sockeye for food on the spawning beds is not a bit worse than killing them in the Strait of Juan de Fuca. Some people who believe it is right to kill them in the Straits, are shocked at such an "outrageous crime" as killing them on the spawning beds.

It all amounts to the same thing as far as perpetuation of the salmon is concerned; the difference only lies in the people for which they are killed...

[Mitchell labels the four lines of sockeye alphabetically. The big years or 1901 line are family A, and the others follow in succession.]

In order of their numerical weakness, the three families D, C, and B, rapidly vanished before the thoroughness of coast fishing, which left little opportunity for the growing unfavourable conditions that accompany settlement on and near the spawning beds to play much part in bringing them to extinction.

The evidence indicating overfishing as the main cause of so few fish reaching the spawning beds in the B, C, and D years, was the net mark. These breeding fish had one, two or three lines imprinted on the skin, and encircling their bodies, showing how often they had escaped through nets, the mesh of which had broken. One season we did not get a single fish on the Shuswap spawning beds that did not have one or more of these well defined encircling marks.

Improved methods in taking salmon at the coast, with a growing knowledge of their movements, was cutting the hatchery at Tappen off from a breeding supply.

A comparison between the years 1906 and 1910, both of which were in family B, will illustrate the rate of depletion.

Scotch Creek, Sockeye salmon eggs
1906 - 4,704,000 1910 - 1,263,500
Anstey River, Sockeye salmon eggs
1906 - 1,539,000 1910 - 298,300

The depletion of other species was just as rapid. In 1910 only 9 Cohoes, all males, came to Granite Creek.

The severity of the railway construction blow on the spawning beds during 1913

There were very few females among the sockeye that got past Hell's Gate before the water fell.

The Salmon River, a run which I described in the foregoing, was a complete blank in 1913. Not a sockeye, coho, or pink salmon spawned in it. It was estimated that about one thousand sockeye entered, but these were all speared by settlers, below a saw mill dam.

At Eagle River about six hundred sockeyes entered; but of these about one hundred would be females.

Anstey River had been red with sockeye in 1909; but in 1913 an old settler with his sons rowed there and back, 86 miles, with their barrel and salt; and only found eight fish in the whole river. At Seymour River and Sil-sa-leitsa Creek, settlers were equally disappointed.

In 1913 I only found one dead sockeye, a male, on the shore of Skwa-am Bay at Adams Lake; where, after former big runs, the bar of dead spawned out salmon used to go a wagon-load to every five feet.

Scotch Creek, Lower Adams River, and Little River were the only streams where a fair supply of breeding fish arrived.

Of those that ascended Scotch Creek, many of the females were so exhausted, that they were brought back dead with a flood; quite hard, having died without ripening to spawn.

The Lower Adams River sockeye were of the pale fleshed tribe. In former years this river was blocked at intervals with great jams of uprooted trees and drift, on which great quantities of dead, spawned out fish used to remain. These driftwood jams acted like sieves for dead fish drifting down stream, but through which ascending fish used to pass without any difficulty, for if there is a hole big enough for a sockeye to pass through they will find it. A log jam never stopped living sockeye. The flowing water keeps channels scoured out underneath.

These great jams used to catch a lot of the dead fish drifting back, and in that way prevented great quantities from being swept out by the current. In 1913 there were no jams in the river, they having been all cleaned out by a logging company. Six days a week a great flood was let loose from a dam above, to sweep out saw logs, and it swept out everything else.

When the run was over in 1913, I walked around the shores of the bay where the great bar of dead, spawned out fish used to pollute the air after former big runs. The dead salmon thinly strewn, and not being in contact with each other, were drying out, with heads and tails curling upwards; through drying more rapidly on the upper side. I estimated that the quantity there, was only one/two hundredth (1/200) of the quantity there after former big runs.

I counted them, males and females; they came only two females to each thirteen males (or 1 to 6-1/2). This again multiplies the difference; but what was worse, the females that I examined hadn't spawned; no doubt owing to the operation of the logging company's sluice dam.

The blow fell not only on sockeye; it caught everything; and completely exterminated the tremendous run of humpbacks, or pinks, to the Upper Country.

* * *

In 1917 some escaped the nets, quite a few reached Scotch Creek; several boat loads. It was a dry season. Scotch Creek was so low, that half a mile from its mouth the people set a dyke of stepping stones across and speared most of them. Killing a sockeye in the Straits did just as much harm as killing one in Scotch Creek. They were worth thousands of dollars each in the Straits.

* * *

I have seen a good many big fourth year runs on the Fraser River, and can measure the extent of the loss.

In 1889 I saw the big run on the lower Fraser, from Pit River to Hope; moving from there to the Salmon River and Shuswap Lakes, where we surveyed until Christmas when the run was over. In 1887 I was prospecting on the Shuswap Lakes. In 1901-9 and 13, I was in the service of the Department of Marine and Fisheries, working at Granite Creek Hatchery on the Shuswap Lakes; the home of the Fraser's big sockeye runs, and the brightest coloured tribe of sockeye salmon.

There are now only priceless museum specimens of the rich coloured Fraser River sockeye left. These are worth millions of dollars for breeding purposes.

Appendix 11.

Estimates of the spawners (E) in most of the early and mid-season upriver sockeye runs or groups of runs. Data are from the Annual Reports of the International Pacific Salmon Fisheries Commission, except for 1936 and 1937, which are from the Canada Department of Fisheries. The ratio E_4/E_0 is calculated whenever there are at least 100 spawners both as parents and as progeny. In some cases revised estimates have been published by the Commission in later Annual Reports. These have been used whenever they were noticed, but they rarely make any substantial difference, the exceptions being the two Chilko estimates that were mentioned earlier. Note that the runs called "late" in the Stuart region were of the "mid-season" category at Hell's Gate.

Superscript Symbols

[a]Years of delayed opening of the fishing season.

[b]Early and late runs are combined.

[c]Jack (age 3) sockeye were exceptionally numerous, but are excluded from these figures. In all other cases jacks are included in the total.

[d]The first year of the line in which an artificial spawning channel was operated. The figures include both creek and channel spawners.

[e]Interpolated figures.

Table.

Region	Run	1937	1941	1945	1949[a]	1901 Line 1953	1957	1961	1965	1969	1973	1977	1981
Stuart	Early		6216	26341	579412	154122	235033	201220	23045	125662	300671	118017	129498
		6000[b]	1.91[b]	4.24	22.00	0.27	1.52	0.86	0.115	5.45	2.39	0.39	1.10
	Late		5245	24507	147900	354843	526920	411105	214958	204969	213770	146629	249699
				4.52	6.03	2.40	1.48	0.78	0.52	0.95	1.04	0.69	1.70
Nechako	Stellako		5230	20826	104800	45057	38922	47241	39418	49341	30755	23452	22021
				3.98	5.03	0.43	0.86	1.21	0.83	1.25	0.62	0.76	0.94
	Nadina		200	300	21600	38574	59146	36429	15177	36439	19442[d]	18349	19737
				1.50	72.00	1.79	1.53	0.62	0.42	2.40	0.53	0.94	1.08
Bowron			1199	4094	22283	13517	12069	7460	2660	3872	4700	2500	1170
				3.41	5.44	0.61	0.89	0.62	0.36	1.46	1.21	0.53	0.47
Quesnel	Horsefly		1065	3000	20000	105218	226378	295705	359232	270023	253384	473008	477389
				2.81	6.67	5.26	2.15	1.31	1.21	0.75	0.94	1.87	1.01
	Mitchell		40		350	2344	2677	6601	5335	8939	24673	42396	66106
						6.70	1.14	2.47	0.81	1.67	2.76	1.72	1.56
Chilcotin	Chilko	110000	280000	192884	59000	197660	140765	40315	39902	76518	61707	54322	35909
			2.55	0.69	0.31	3.35	0.71	0.29	0.99	1.92	0.81	0.88	0.66
	Taseko				100	4422	3667	80	+	+			
						4.42	0.83						
N. Thompson	Raft		250	3300	5900	8242	7264	7301	6624	5594	2729	648	873
				13.20	1.79	1.40	0.88	1.01	0.91	0.84	0.49	0.24	1.35
	Fennell									52	205	355	2113
												1.73	5.95
Shuswap	Seymour		0	150	10722	5947	14095	5822	6954	7327	2856	5911	11529
					71.48	0.55	2.37	0.41	1.19	1.05	0.39	2.07	1.95
Seton	Gates					78	1112	252	1679	881[d]	899	2889	4809
								0.23	6.66	0.52	1.02	3.21	1.66
Ratios available			2	8	9	11	11	11	11	11	11	12	12
GM of ratios			2.21	3.16	7.43	1.55	1.87	0.72	0.77	1.34	0.92	0.98	1.30
Logarithm of GM			0.34	0.50	0.87	0.19	0.27	-0.14	-0.12	0.13	-0.04	-0.01	0.12

Table.

Region	Run	1938	1942	1946[a]	1950[a]	1902 Line 1954	1958	1962	1966	1970	1974	1978	1982
Stuart	Early	4260	8006	9554	59666	35286	34633	25446	10850	32747	39644	50097	4560
			1.88	1.19	6.24	0.59	0.98	0.73	0.43	3.02	1.21	1.26	0.091
	Late	33	1+	562	3277	5544	22719	18689	8737	15055	14627	13027	16758
					5.83	1.69	4.10	0.82	0.47	1.72	0.97	0.89	1.29
Nechako	Stellako	3077	48064	245200	145100	142632	112273	124495	101684	45876	41473	60421	69434
			15.62	5.10	0.59	0.98	0.79	1.11	0.82	0.45	0.90	1.46	1.15
	Nadina	30	62	66	1950	2219	804	2133	1867	4764	3825[d]	2782	2350
						1.14	0.36	2.65	0.88	2.55	0.80	0.73	0.84
Bowron		1305	1826	6951	16266	10774	14871	6292	2480	1341	1850	3150	1647
			1.40	3.81	2.33	0.66	1.38	0.42	0.39	0.54	1.38	1.70	0.52
Quesnel	Horsefly	0	0	58	400	279	1784	1001	1607	1350	4459	7287	30317
						0.70	6.39	0.56	1.61	0.84	3.30	1.63	4.16
	Mitchell	0	0	2	0	18	65	5	142	23	-	1237	3829
													3.10
Chilcotin	Chilko	6000	34100	58600	29800	36354	137081	92467	226702	145049	128131	151835	242263
			5.68	1.72	0.51	1.23	3.77	0.67	2.40	0.64	0.88	1.18	1.60
	Taseko				500	3500	7538	657	353	+			
						7.00	2.15	0.087	0.54				
N. Thompson	Raft	500	450	3000	6400	10551	10215	7613	6250	4474	2396	2500	2992
			0.90	6.67	2.13	1.65	0.97	0.75	0.82	0.72	0.54	1.04	1.20
	Fennell									9	243	675	1139
												2.78	1.69
Shuswap	Seymour		1950	2600	12000	26258	78575	58104	28754	14375	45189	62929	63306
				1.33	4.62	2.19	2.99	0.73	0.49	0.50	3.14	1.39	1.01
Seton	Gates[c]					(47)	61	159	65	78[d]	70	1158	930
													0.78
Ratios available			5	6	7	10	10	10	10	9	9	10	12
GM of ratios			2.91	2.66	2.20	1.32	1.73	0.65	0.74	0.95	1.21	1.32	1.06
Logarithm of GM			0.46	0.42	0.34	-0.12	0.24	-0.19	-0.13	-0.02	0.08	0.11	0.02

Table.

Region	Run	1939	1943	1947[a]	1951	1903 Line 1955	1959	1963	1967	1971	1975	1979	1983
Stuart	Early	553	3005	14200	61023	2139	2663	4627	21069	95942	65767	92763	23874
			5.43	4.72	4.30	0.035	1.24	1.74	4.55	4.55	0.59	1.41	0.26
	Late	2	2	60	2300	7614	6007	3237	1642	1535	14229	31918	2246
						3.31	0.79	0.54	0.51	0.93	9.27	2.24	0.070
Nechako	Stellako	1446	9142	55000	96200	51971	79355	138805	91525	39726	176079	290116	121739
			6.32	6.02	1.75	0.54	1.53	1.75	0.66	0.43	4.54	1.65	0.42
	Nadina			90	326	202	1634	8323	9385	15747	15800[d]	57585	28215
						0.62	6.75	6.10	1.13	1.68	1.00	3.64	0.50
Bowrun		2695	6215	23945	21770	9355	29247	25144	31695	25497	29700	35000	6451
			2.31	3.85	0.91	0.43	3.13	0.86	1.26	0.80	1.16	1.18	0.184
Quesnel	Horsefly			6	51	62	+	86	119	171	101	511	1998
										1.44	0.59	5.06	3.91
Chilcotin	Chilko	2000	13546	55000	118100	123081	470621	1002252	176337	161943	220554	240294	331510
			6.77	4.06	2.15	1.04	3.82	2.13	0.18	0.92	1.36	1.09	1.38
	Taseko			6	500	4400	16410	31667	5700	10500	4394	-	1630
						8.80	3.73	1.93	0.18	1.84	0.42	0.61[e]	0.61[e]
N. Thompson	Raft	1490	4000	8000	8561	5364	10210	8724	1303	840	2664	1708	2857
			2.76	2.00	1.07	0.63	1.90	0.85	0.15	0.64	3.17	0.64	1.67
	Fennell							439	920	1300	4127	15590	5018
									2.10	1.41	3.17	3.78	0.32
Shuswap	Seymour	250	+	10000	24344	9516	52325	71690	13361	19028	37024	49321	29838
					2.43	0.39	5.50	1.37	0.17	1.42	1.95	1.33	0.60
Seton	Gates[c]					86	581	4113	1138	426[d]	1982	3830	7384
								7.08	0.28	0.37	4.65	1.93	1.93
Ratios available			5	5	6	9	9	10	11	12	12	12	12
GM of ratios			4.31	3.89	1.84	0.69	2.56	1.76	0.54	1.09	1.76	1.67	0.58
Logarithm of GM			0.63	0.59	0.26	-0.16	0.41	0.25	-0.27	0.04	0.25	0.22	-0.24

Table.

					1904 Line								
Region	Run	1936	1940	1944	1948[a]	1952	1956	1960	1964	1968	1972	1976	1980
Stuart	Early		290	398	12000	33580	25157	14572	2421	1587	5086	16445	17026
				1.37	30.15	2.79	0.75	0.58	0.17	0.66	3.20	3.23	1.04
	Late		310	25	300	1211	1454	2748	1900	470	8564	3000	979
						4.04	1.20	1.89	0.69	0.25	18.22	0.35	0.33
Nechako	Stellako		2600	3294	16000	40462	38459	38884	31047	30420	36771	150741	72073
				1.27	4.86	2.53	0.95	1.01	0.80	0.98	1.21	4.10	0.48
	Nadina				30	1677	1311	1723	1629	2398	3529	1774[d]	3284
							0.78	1.31	0.95	1.47	1.48	0.50	1.85
Bowron		1000	4625	1700	25218	18672	6996	7620	1500	3634	4138	2250	2894
			4.62	0.37	14.83	0.74	0.37	1.09	0.20	2.42	1.14	0.54	1.29
Quesnel	Horsefly[c]		90	3	50	184	84	339	1206	690	108	298	308
									3.56	0.57	0.16	2.76	1.03
	Mitchell[c]				0	0	0	0	0	4	3	7	0
Chilcotin	Chilko	74000	300000	328655	670000	489473	647479	420746	138601	414446	564465	364311	469658
			4.05	1.10	2.04	0.73	1.32	0.65	0.57	1.74	1.36	0.65	1.29
	Taseko				+	3647	1995	2521	433	-	16068	634	679
							0.55	1.26	0.17	6.09[e]	6.09[e]	0.039	1.07
N. Thompson	Raft		11400	1082	10500	15819	9582	5553	5500	10697	11151	8684	5418
				0.09	9.70	1.51	0.61	0.58	0.99	1.94	1.04	0.78	0.62
	Fennell							0	146	954	1931	4000	8437
										6.53	2.02	2.07	2.11
Shuswap	Seymour		600	200	4000	6785	2684	3047	2784	3870	2889	8489	8390
				0.33	20.00	1.70	0.40	1.14	0.91	1.39	0.75	2.94	0.99
Seton	Gates					6883	9059	5449	19971	10289[d]	8569	17744	25494
							1.32	0.60	3.67	0.52	0.83	2.07	1.44
Ratios available			2	6	6	7	10	10	11	12	12	12	12
GM of ratios			4.34	0.53	9.76	1.69	0.75	0.94	0.70	1.33	1.56	0.99	1.00
Logarithm of GM			0.64	-0.28	0.99	0.23	-0.12	-0.03	-0.15	0.13	0.19	-0.01	.00

Table 1A. Canadian and United States packs of Fraser sockeye, in hundreds of 48-pound cases, and number of Canadian gillnet licences in District 1, from Annual Reports of the Canadian and British Columbia Departments of Fisheries; also, the estimates of (1 - a), the fraction of sockeye that migrated by Johnstone Strait, made by Hamilton (1985, Table 3).

Year	Canada	Washington	W/C	Licences	1 - a
1930	1037	3522	3.396	1523	0.040
1931	409	872	2.132	1358	0.121
1932	658	812	1.234	1446	0.261
1933	525	1266	2.411	1658	0.104
1934	1392	3526	2.533	1803	0.089
1935	628	547	0.871	1663	0.027
1936	1849	595	0.322	1784	0.419
1937	1003	603	0.601	2082	0.174
1938	1868	1346	0.721	2319	0.101
1939	543	435	0.801	2161	0.094
Arithmetic means					
1931-34			2.078	1566	0.144
1935-38			0.629	1962	0.180
1931 and 1933			2.272	1508	0.112
1935, 1937 and 1939			0.758	1969	0.099
1930 and 1934			2.964	1663	0.064

Table 1B. Estimates of the escapement (in thousands) of Fraser sockeye from the commercial fishery in 4 years, made from estimates of spawners and from a reasonable subsistence catch based on comparisons with later years (1941 and onward). From records of the Canadian Deparment of Fisheries for 1935, and from Annual Reports of IPSFC for 1938 and 1939.

	1935	1938	1939
Commercial catch (W + C)	1410	3309	1214
Escapement (spawners plus subsistence catch -- E)	150	890	164
Total run (N = E + W + C)	1560	4199	1378
Escapement rate (E/N = S)	0.0962	0.2120	0.1190

Table 2. Number of tags put on sockeye salmon immediately below the Babine River Slide in 1952, and the number that were checked through the fence 65 km upriver. A. Comparison of uninjured sockeye of different fork lengths, and of the two sexes. B. Comparison of injured and uninjured sockeye larger than 45 cm, by sex. (Data from Tables 13 and 17 of Godfrey et al. 1954.)

A.	Length range (cm)			
	20-45	46-59	60-75	46-75
Males				
Tagged	110	1279	1869	3148
Recovered	6	204	306	510
Percent recovered	5.5	15.9	16.4	16.2
Females				
Tagged		1958	1351	3309
Recovered		151	164	315
Percent recovered		7.7	12.1	9.5

B.	Number tagged	Number recovered	Percent recovered
Males			
Not injured	3148	510	16.2
Injured	888	87	9.8
Females			
Not injured	3309	315	9.5
Injured	1251	77	6.2

Table 3. Percentage of males among sockeye age 4 and older on five upriver spawning grounds, 1941-1948. (Data from Annual Reports of IPSFC.)

Year	Bowron	Chilko	Kynock	Raft	Stellako	GM
1941	58.4	49.8	49.7	--	43.2	-
1942	--	50.0	49.1	42.9	36.0	-
1943	39.3	35.8	43.6	49.3	33.6	-
1944	57.9	51.0	--	41.3	45.7	-
GM	51.03	46.18	47.39	44.37	39.31	45.49
1945	62.8	50.6	49.6	49.4	43.2	-
1946	47.0	51.7	41.7	39.8	37.9	-
1947	45.6	42.2	69.3	46.0	43.9	-
1948	46.5	39.8	31.0	40.6	38.0	-
GM	50.02	45.78	45.91	43.77	40.65	45.12

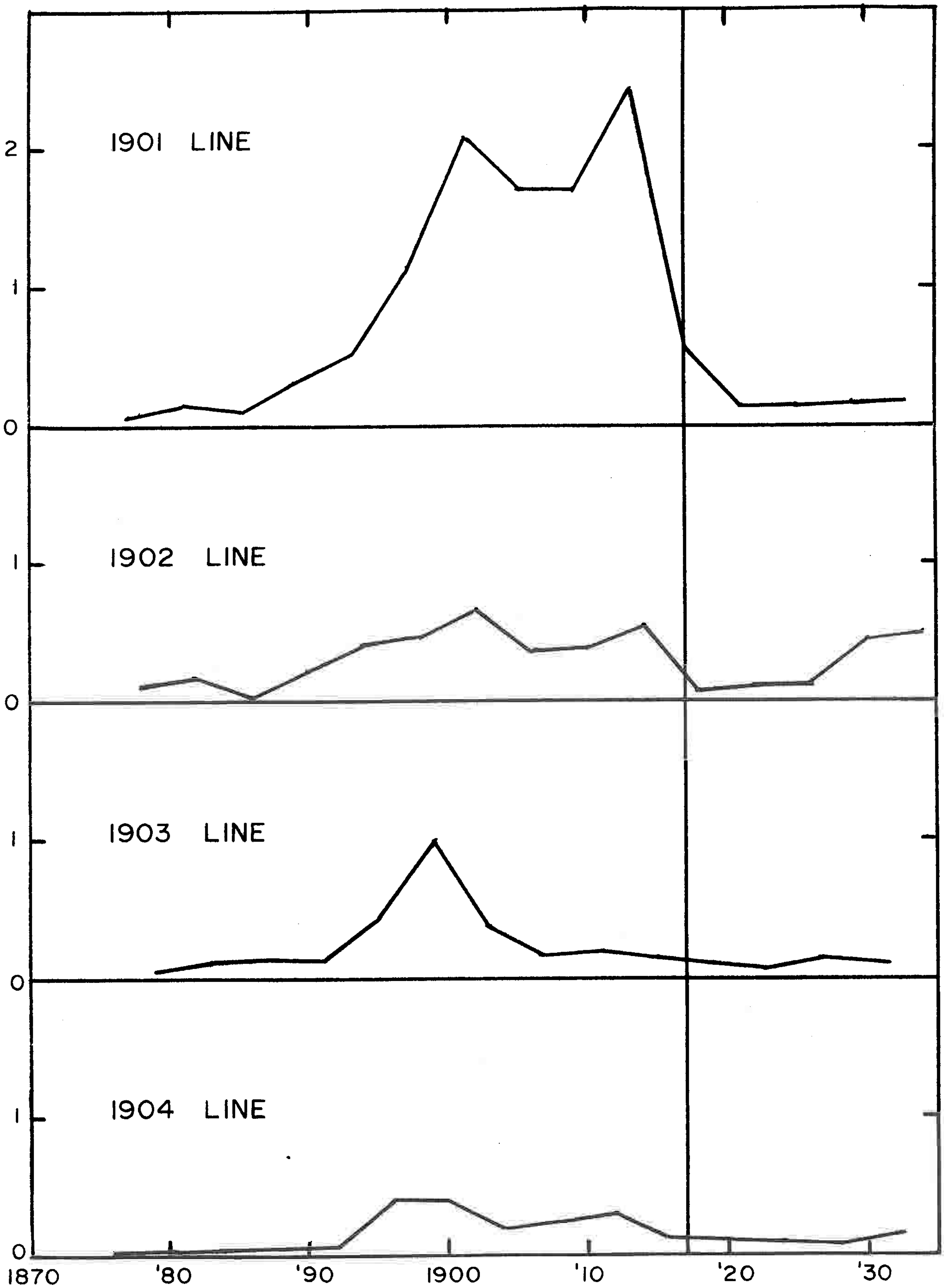
Table 4. Spawning stock, commercial and subsistence catch, and total recruitment of early and mid-season sockeye stocks, in thousands of fish. Data are from Annual Reports of IPSFC, except the spawners of 1936 and 1937, which are from records of the Canada Department of Fisheries.

Year	Spawners E	Catch C	Recruit-ment R=E+C	Rate of utili-zation C_0/R_0	Rate of escape-ment E_0/R_0	Rate of recruit-ment R_4/E_0	Rate of replace-ment E_4/E_0
1936	80	-	-	-	-	20.2	4.00
1937	125	-	-	-	-	28.9	2.38
1938	15.2	-	-	-	-	46.2	6.18
1939	8.4	-	-	-	-	34.7	4.28
1940	320	1299	1619	0.802	0.198	5.2	1.05
1941	298	3311	3609	0.917	0.083	5.9	0.93
1942	94	608	702	0.866	0.134	6.6	3.49
1943	36	255	291	0.876	0.124	5.9	4.64
1944	335	1340	1675	0.800	0.200	6.5	2.17
1945	276	1493	1769	0.844	0.156	8.9	3.53
1946	328	296	624	0.474	0.526	2.5	0.84
1947	167	45	212	0.212	0.788	12.2	2.00
1948	728	1452	2180	0.666	0.334	3.8	0.85
1949	976	1482	2458	0.603	0.397	4.7	0.96
1950	276	543	819	0.663	0.337	6.4	1.01
1951	334	1698	2032	0.836	0.164	4.4	0.66
1952	620	2152	2773	0.776	0.224	3.9	1.20
1953	938	3649	4587	0.796	0.204	3.7	1.35
1954	278	1485	1763	0.842	0.158	3.0	1.51
1955	220	1254	1474	0.851	0.149	9.5	3.03
1956	747	1686	2433	0.693	0.307	2.9	0.67
1957	1267	2235	3502	0.638	0.362	2.9	0.84
1958	421	401	822	0.488	0.512	2.4	0.80
1959	668	1417	2085	0.680	0.320	4.7	1.94
1960	498	1701	2199	0.774	0.226	2.5	0.58
1961	1059	2622	3681	0.712	0.288	2.4	0.67
1962	337	685	1022	0.670	0.330	6.4	1.15
1963	1295	1831	3126	0.586	0.414	1.8	2.71
1964	287	960	1247	0.770	0.230	7.0	1.63
1965	713	1867	2580	0.724	0.276	5.4	1.11
1966	389	1760	2149	0.819	0.181	3.8	0.69
1967	351	1939	2290	0.847	0.153	8.2	1.08

Table 4 (cont'd)

Year	Spawners E	Catch C	Recruit-ment R=E+C	Rate of utili-zation C_0/R_0	Rate of escape-ment E_0/R_0	Rate of recruit-ment R_4/E_0	Rate of replace-ment E_4/E_0
1968	468	1551	2019	0.768	0.232	4.9	1.40
1969	789	3093	3882	0.797	0.203	--	--
1970	267	1231	1498	0.822	0.178	--	--
1971	381	2513	2894	0.868	0.132	--	--
1972	653	1624	2277	0.713	0.287	--	--

Fig. 1. Packs of Puget Sound and Fraser sockeye, 1878-1934. The vertical line at 1917 marks the first of the two years, of the 1901 and 1902 lines, that were immediately affected by the canyon obstructions of 1913 and 1914. From Rounsefell and Kelez 1938, Table 26.


1901 LINE
1902 LINE
1903 LINE
1904 LINE
0
1
2
1870
'80
'90
1900
'10
'20
'30

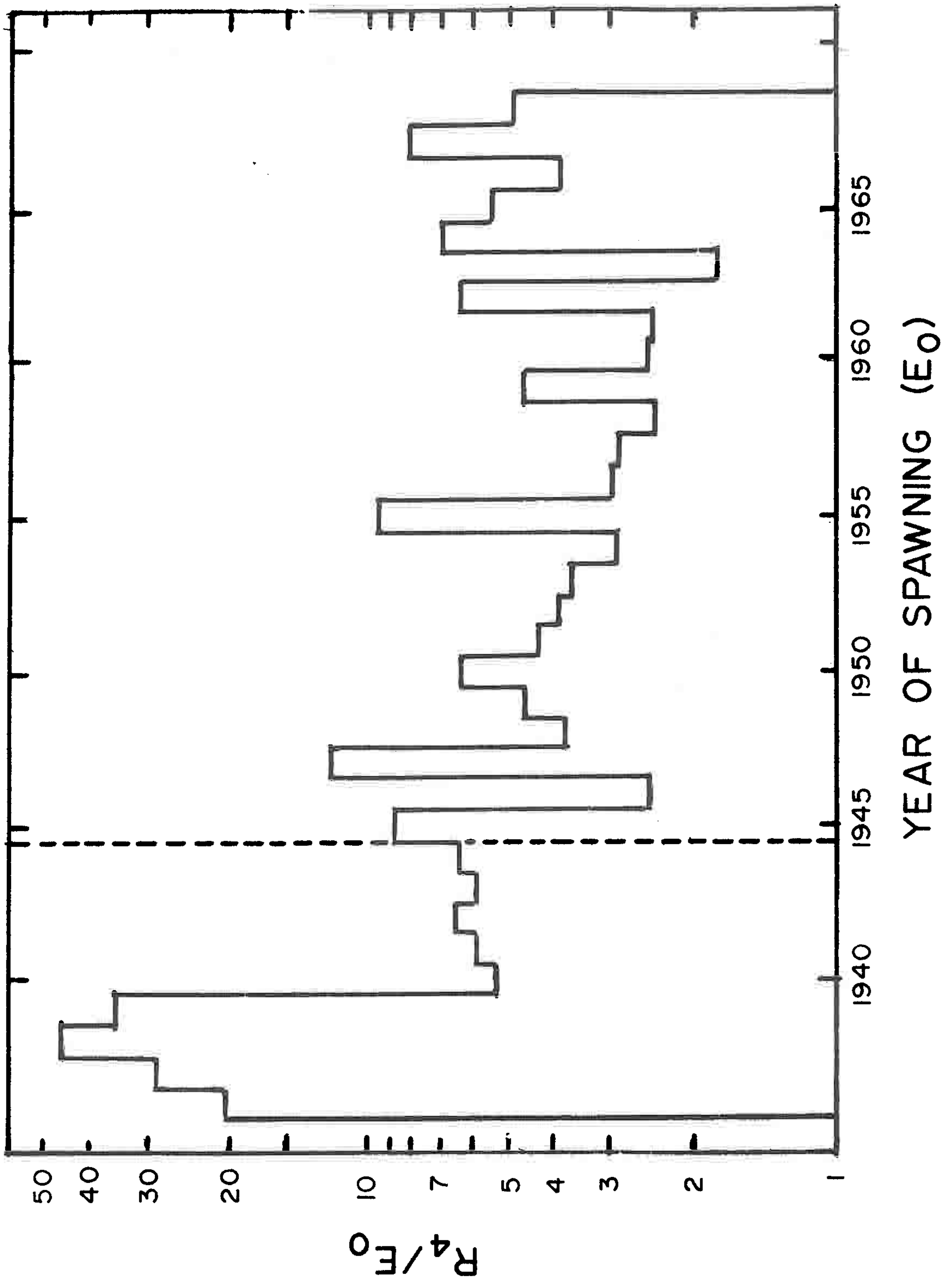


Fig. 2. Ratio of total recruitment produced by early and mid-season upriver runs (R_4) to the number of parent spawners (E_0). Data from Table 4.

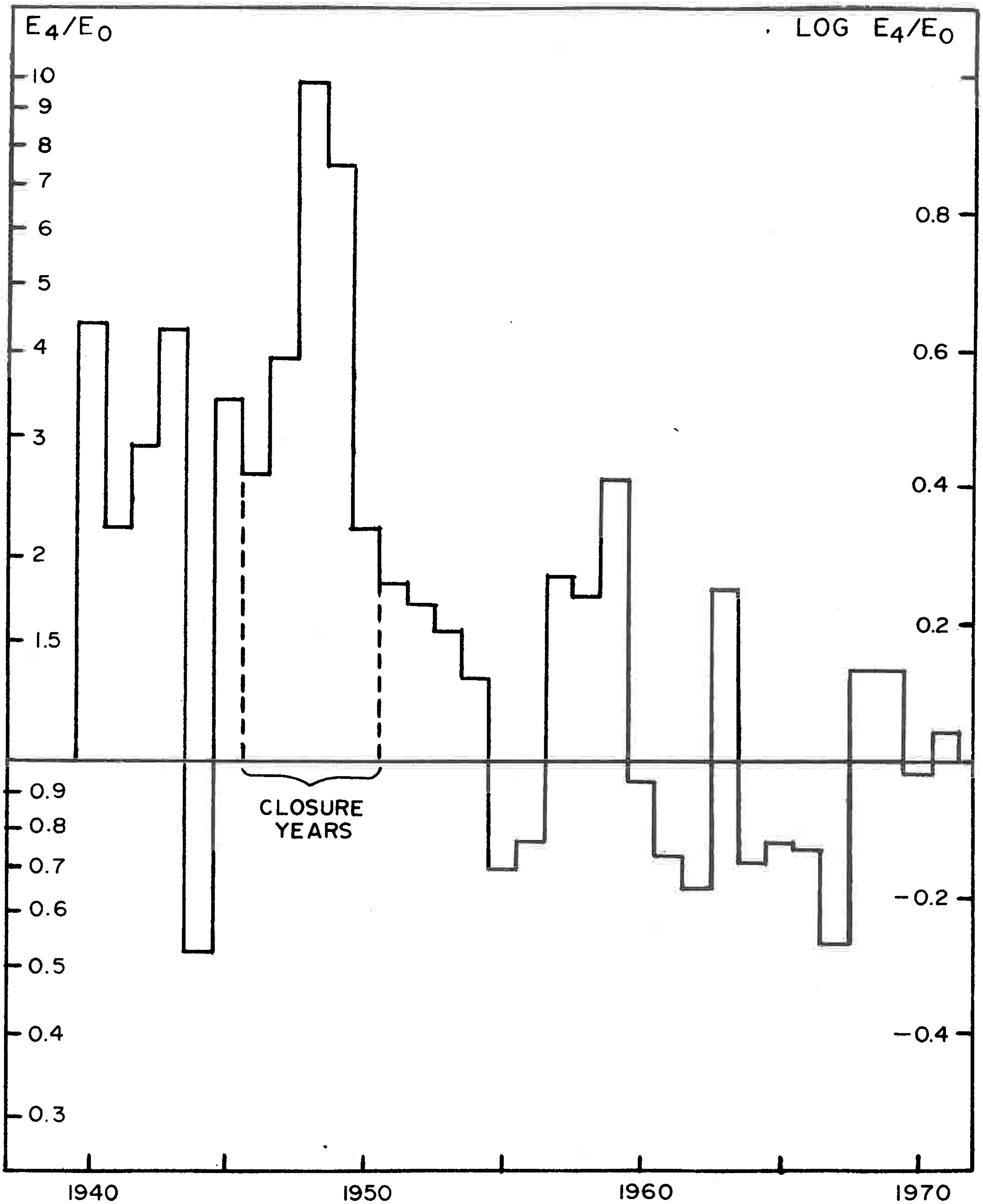


Fig. 3. Geometric means of the rate of replacement, E_4/E_0, for the early and mid-season upriver stocks, from the last line of Appendix 11. See the text regarding the years of early fishing closures, 1946-50.

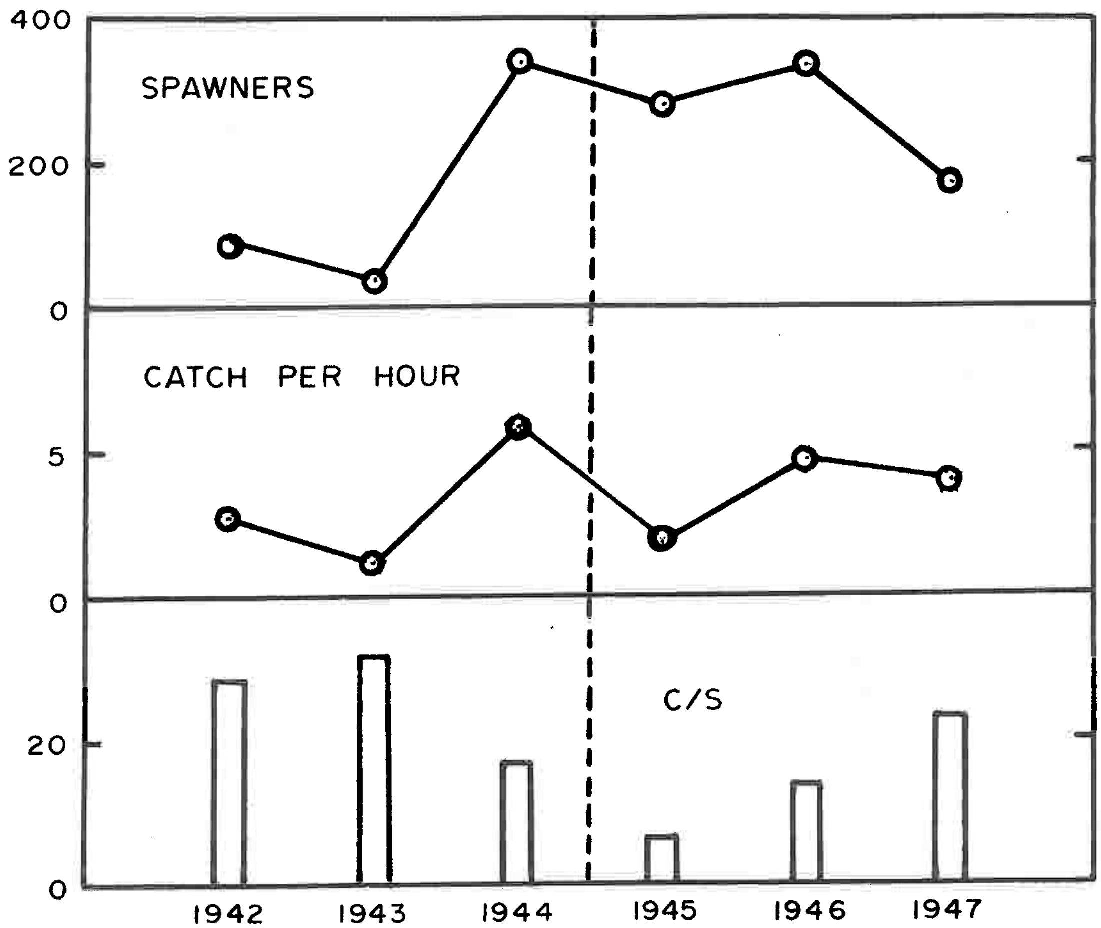


Fig. 4. Top: Number of early and mid-season upriver sockeye (in thousands) that were observed on spawning beds above Hell's Gate. Middle: Mean catch per hour taken by dipnet above Hells Gate from July 10 to September 15. Bottom: Ratio of dipnet catch per hour to number of spawners ($x10^6$). From Fig. 26-31 of Talbot (1950), and the spawning stocks shown in Table 4 here.

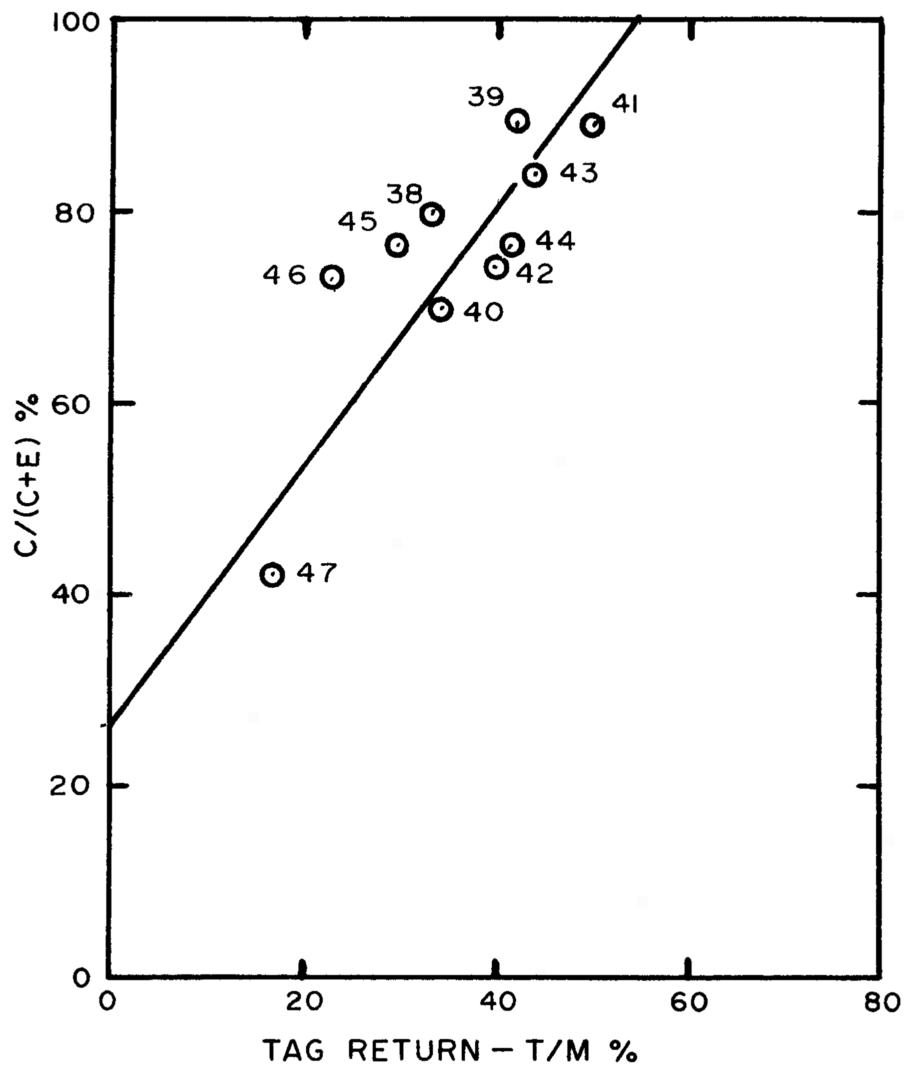


Fig. 5. Relation between two estimates of the rate of commercial utilization of the whole Fraser run: 1) from catch (C) and spawners (E); and 2) from the commercial return (T) of tags put on at Sooke (M). The line is the geometric mean regression fitted to the pre-fishway years 1938-44. Tag returns are from Verhoeven and Davidoff (1962); catches and escapements are from Annual Reports of the IPSFC.

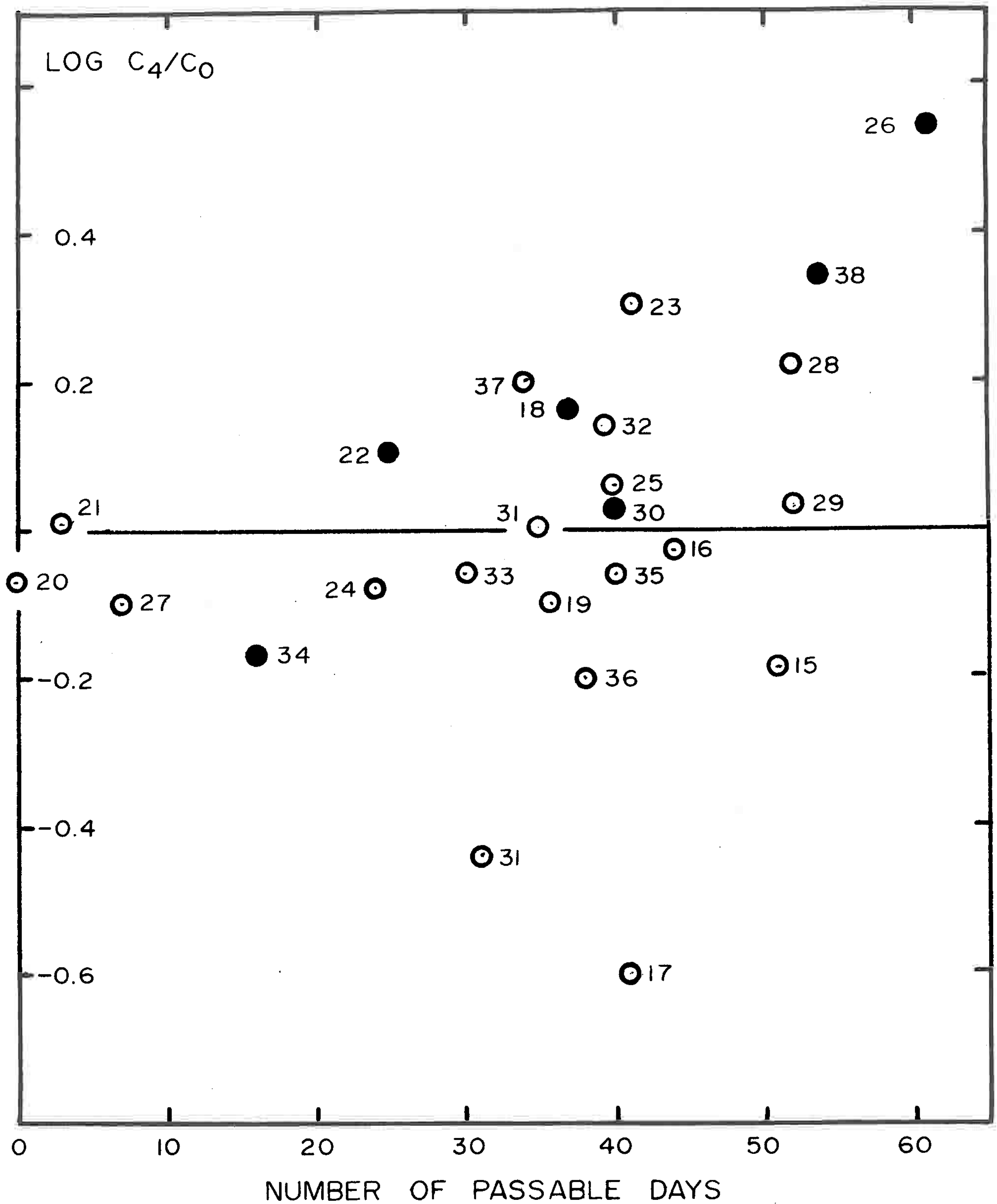


Fig. 6. Relation between the logarithm of the C_4/C_0 index and the number of days when Hell's Gate was passable by sockeye in September and October, as estimated by Thompson (1945). Numbers by the points indicate the parental year of catch (C_0). Black points are for the 1902 line of sockeye, which includes the dominant late Shuswap run that became abundant first in 1926.