

**INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION**

BULLETIN I

**Effect of the Obstruction at Hell's
Gate on the Sockeye Salmon
Of the Fraser River**

**BY
WILLIAM F. THOMPSON**

**NEW WESTMINSTER, B.C.
CANADA
1945**

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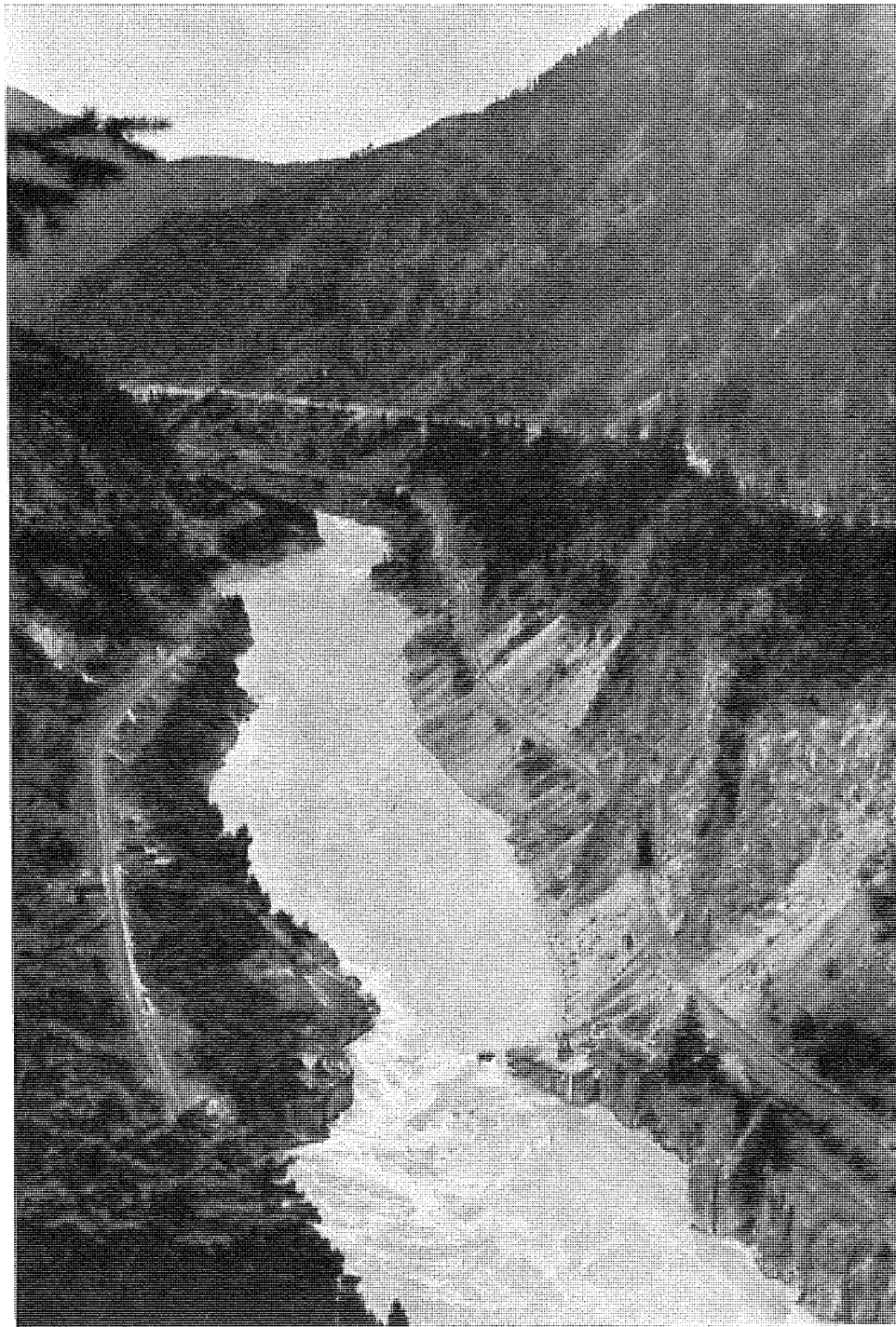
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FRASER RIVER CANYON AT HELL'S GATE, LOOKING UPSTREAM.

FOREWORD

Canada and the United States have led the world in practical international cooperation with reference to ocean fisheries. The International Fisheries Commission created by treaty between these two nations had already made such progress in restoring the badly depleted halibut fishery of the Northwest Coast, that its success gave sharp stimulus to action for another treaty to restore the once great Fraser sockeye salmon fishery of the boundary region of British Columbia and the State of Washington.

This treaty provides for the appointment of the International Pacific Salmon Fisheries Commission consisting of six members, three from Canada and three from the United States. The Commission is required to investigate the natural history of the sockeye salmon of the Fraser River system, hatchery methods, spawning ground conditions, and other related matters. It is given authority to recommend the "removing or otherwise overcoming obstructions to the ascent of sockeye salmon, that may now exist or may from time to time occur, in any of the waters covered by this Convention, where investigation may show such removal of or other action to remove obstructions to be desirable". Commencing with the year 1946, the Commission is granted power to adopt regulations for the conservation and management of the fishery.

Promptly after organizing, the Commission commenced an investigation covering the migratory route of the sockeye from the open sea to the spawning grounds in the head waters of the Fraser River basin. Data thus were collected and tabulated including statistics of the catch and of the escapement, records of biological observations of the runs of sockeye from the sea to the spawning grounds, collections of scales for age analysis, measurements for identification of races, returns from extensive salt and fresh water tagging, and a large amount of historical data. Much of this has been put to immediate use; much of it will furnish material for the use of staff scientists charged with specific lines of investigation.

Although preliminary reports have been presented on salt water tagging and on the enumeration of the escapements, what follows is the first comprehensive report to be made on investigations thus far conducted. It is concerned with one of the first and most urgent problems faced by the Commission—the cause of the failure of the great run which disappeared after the disaster to the run which occurred in 1913.

During the course of investigation, extensive tagging experiments were carried on in salt water and in the lower Fraser to study the migrations from the standpoint of the timing of different races of sockeye, rates of movement, and the mortality en route. The latter was of particular interest as it was thought that the persistent low level of catch since 1913 must be due to some continuing adverse condition. Tagging in fresh water disclosed the existence of a serious obstruction at Hell's Gate. There was indisputable evidence that enormous losses

occurring there synchronized with particular water levels. In the report which follows, these heavy mortalities are shown to have been largely responsible for the continued depletion of the runs to the upper Fraser.

In addition, the report contributes much that is fundamental to other phases of the Commission's duties. It was inevitable that this should be so, as the effects of the Hell's Gate obstruction could be understood and described only through a clear understanding of the existence of the many races, of their return to their "home streams", of the effect of heavy mortalities upon them, and of their habits and the history of their present condition.

Among other things, the report sets out a basis for statistical investigations in the form of an index to the success-of-returns of the successive cycle runs. Such an index should prove to be most useful in future studies of the effect of fishing and the adequacy of regulations.

This report conclusively shows that resort to remedial measures at Hell's Gate to eliminate the recurring salmon mortality at that point was a first and absolute essential to the carrying out of the Commission's duty to restore the Fraser River sockeye run.

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION.

EDWARD W. ALLEN, *Chairman*

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EFFECT OF THE OBSTRUCTION AT HELL'S GATE
ON THE SOCKEYE SALMON OF THE
FRASER RIVER

by

WILLIAM F. THOMPSON

FRASER RIVER WATERSHED

This map illustrates the extensive Fraser River watershed, showing the river's course from the interior of British Columbia to its confluence with the Pacific Ocean at Vancouver. The Fraser River is the central feature, with numerous tributaries feeding into it from the north and east. Key tributaries shown include the Bulkley River, Nechako River, Chilko River, Lillooet River, and Kamloops River. Major lakes such as Stuart Lake, Quesnel Lake, Bulkley Lake, Kamloops Lake, and Harrison Lake are depicted. The map also shows the city of Vancouver and the surrounding area, including the Fraser Delta and the city of Hope. The title 'FRASER RIVER WATERSHED' is prominently displayed at the top right.

VANCOUVER

ERRATA

Page 99, line 9: Change "page 16" to "page 20".

Pages 100 and 107: The graphs of Figures 21 and 25 should be interchanged.

Page 174, line 32: The last reference under Motherwell, J. A., should be dated 1933-1943.

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INTRODUCTION

In 1913 one of the largest runs of salmon to any river yielded a great catch for the last time to the fishermen of Puget Sound and the Gulf of Georgia. The run of that year to the Fraser River faded with abruptness into a low level of production which has persisted with some irregularity until today (*see* Figure 1). From a pack of nearly two and one-half million cases, the fishery fell to one which has never since exceeded three-quarters of a million.

The catch up to 1913 showed a well-marked cycle, that of every fourth year being very large. Because of its magnitude, the failure of this "big" year almost monopolized attention. That of the three remaining or "off" years caused little comment, although no less real.

Had the "big" year only been maintained, it would have recurred seven times since 1913 to give a total of 17 million cases, over 2 million a year, whereas these same seven years have actually yielded 1,630,000 cases in all. The loss has been over 90 per cent. At \$18.00 to the case¹, this loss was 279 million dollars. The estimate is a minimum since the three "off" years of the cycles have not been included.

But the decline included these lesser annual runs. The four-year period ending in 1901 was the greatest in the history of the fishery with almost four million cases, whereas that ending in 1942 totalled one and one-quarter million, a decline approaching 70 per cent. Each of these four-year periods included one "big" year. The "off" years in the two periods yielded about the same proportion of the total, 47 and 42 per cent respectively. The decline was shared by "big" and "off" years and was not far from 70 per cent in any case. It must be held responsible for a loss far in excess of 279 million dollars during seven four-year cycles following 1913.

There is present in the minds of many men in the industry the hope that every year can be made a "big" year such as 1913. If this is possible the world has already missed the opportunity to secure one and a quarter billion dollars worth of salmon (at our present prices) since 1913. Whatever the likelihood of fulfilling this hope may be, the least that can be done is to explore its possibility.

These figures emphasize the cumulative importance of a lost resource. But there is also the existing fishery, and the cause of the former disaster may still exist, ready to strike again. It may threaten the present yield. This, from 1939 to 1942, averaged over 300,000 cases a year, with a value of \$5,400,000 at \$18.00 per case, a yield well worthy of preservation.

In this report proof has been produced that an obstruction to the migration of sockeye salmon at Hell's Gate, 135 miles up the Fraser River, causes damage which accounts for the present depleted condition of the run. It is of a variable nature, and may at any time cause further damage.

¹ Pacific Fisherman Year Book, 1943, v. 41, no. 2, p. 137. (U. S. Government price for 1942).

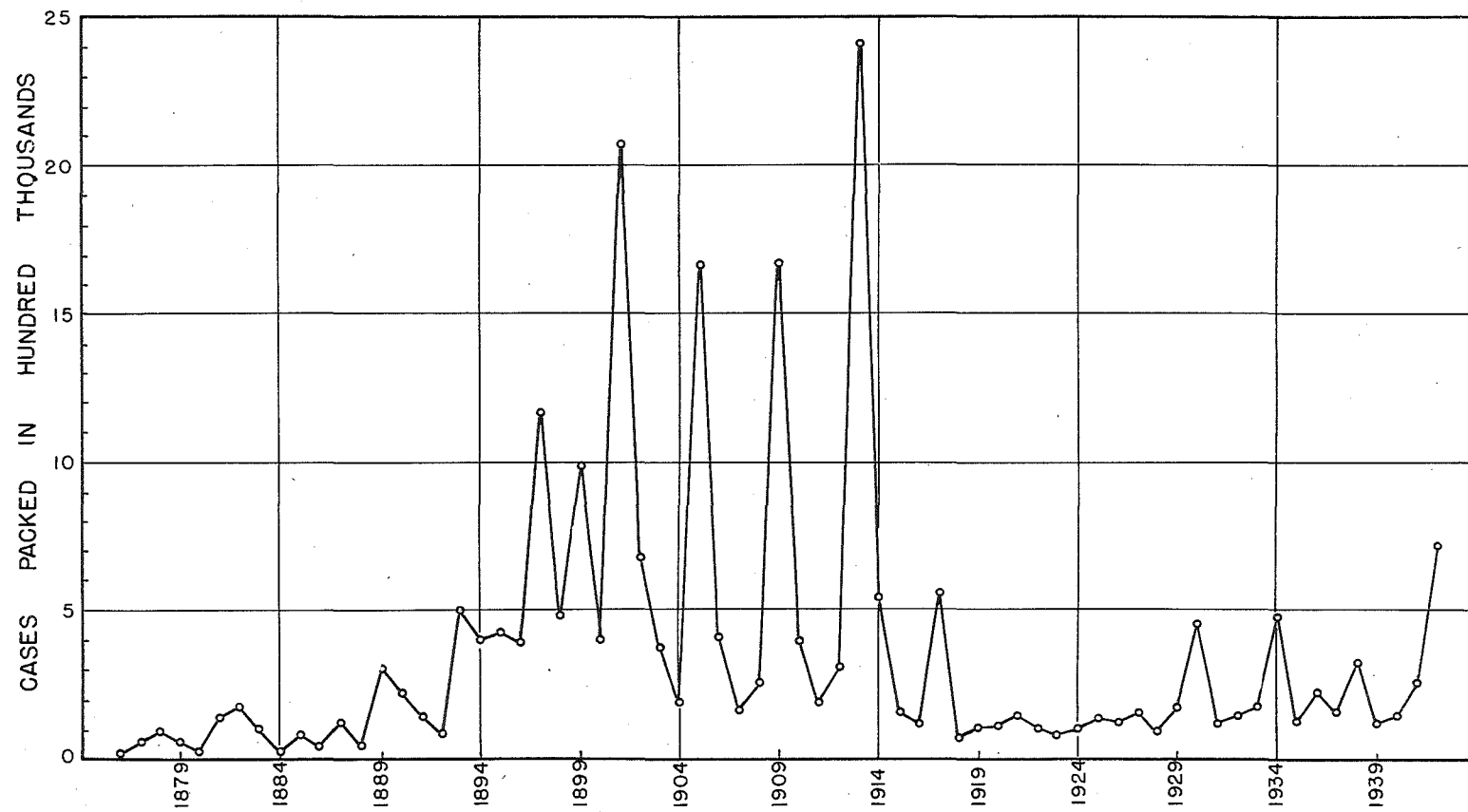


Fig. 1

PACK OF FRASER RIVER SOCKEYE, 1876 TO 1942, IN 48-POUND CASES. (After Rounsefell and Kelez, and Pacific Fisherman)

It is shown that: (1) The river at that point is impassable to most sockeye at certain water levels. (2) The consequent delay causes a mortality increasing with the length of delay. (3) The mortality occurs annually, varying in extent with the duration of the impassable water levels. (4) It is of such magnitude as to affect the maintenance of the catch.

The proof has required the development of two indices, one derived from the commercial catch and one from conditions at Hell's Gate. The first is an index to the relative success of each annual run in reproducing itself. The second shows the extent to which the obstruction has been passable each year since 1912, when records of water levels were first obtained. In the final pages of the report these two indices are brought together. The character of their relationship is evidence of the dependence of the commercial catch on the freedom of the sockeye to pass up the river at Hell's Gate.

The occasional, or even annual, death of sockeye below a point difficult of passage does not in itself mean disaster to the runs. All species of living things suffer heavy mortalities at most stages of life under natural conditions. It is here shown that the effect of the obstruction is sufficient to cause a decline in the catch, not only because of the number of fish dying but because of the way the species is constituted.

The report traces depletion through the history of the fishery and to each spawning ground, showing its reality, and its manner and time of occurrence. Its effect took the form it did because of the existence of races known each by a "home stream", or more correctly, a home spawning ground. Depletion was partial because it was selective in its action on these races. It has been long continued because these races are independent, so that some of the most important are damaged and remain beyond the power of nature to rebuild them, while others are untouched and maintain that small part of the catch which remains. The report thus has its only possible logical basis in the concept of races, each known by its home stream and its habits, each independent in its reaction, and with its own history of abundance and scarcity. The report should be read for its contribution to this concept, as well as its bearing on the obstruction.

It need hardly be said that the evidence of the validity of this concept, and a knowledge of the conditions which have resulted in all the races throughout the Fraser, are vital to any consideration of what will happen when the obstruction is removed.

The report goes even further. In the index which it develops there is provided a means whereby changes in the catch can be related to the facts of salmon biology and of economics. The effects of overfishing and of events on the spawning grounds, on the route of migration, or in the sea can be studied. Logically it should be possible to proceed from a study of some definite well defined change in the catch, searching into the causes whether biological or otherwise, rather than to probe blindly into life history for something that might be significant. An index of this kind, perfected statistically, should give direction to research, and its year-by-year values should give evidence of the success or failure of action taken.

It will be found that this report lays before the reader the changes in the values of the index and gives explanation for them. The major features in the varying fortunes of the sockeye of the Fraser River from the beginning of fishing to the present, fall into five distinct periods: the growth to maturity, from 1872 to 1899; the first great depletion caused by the Quesnel Dam, from 1899 to 1903; the recovery, ending in 1910; the second long period of depletion due to railroad construction in the canyon, beginning in 1911 (not in 1913); and the continuing final period of reduced catches, fluctuating widely with changing conditions at Hell's Gate. The present condition of the sockeye fishing is the summation of what has happened in these periods, and a knowledge of them points to definite steps toward rehabilitation of the run.

Literature dealing with the Fraser River sockeye includes several series of publications important to our purpose. First and most important were the surveys of the spawning grounds for the British Columbia Fisheries Department, reported upon by J. P. Babcock² through the critical years from 1901 to 1931. J. A. Motherwell³ of the Dominion Department of Fisheries has continued them. The report for the year 1910 is lacking. Studies of the age composition as bearing upon the races and runs of sockeye were made for the Provincial Department by C. H. Gilbert⁴ from 1913 to 1924 and were continued by W. A. Clemens and Lucy S. Clemens⁵ until 1937. Reports on the catch of sockeye, the hatcheries, and the spawning grounds were made annually from 1882 to date by the Dominion Department of Fisheries⁶ under its various designations, hence throughout the whole period covered by the study. The Pacific Fisherman⁷ contributed many pertinent articles, news, and statistics from 1903 to date. In 1938 the United States Bureau of Fisheries (now the United States Fish and Wildlife Service) produced a review of the statistics and methods of the fishery by G. A. Rounsefell and G. B. Kelez.⁸ Other contributions were made, but the above constitute the main reliance of anyone studying the past records of the sockeye fishery of the Fraser River.

We have used the statistics given by Rounsefell and Kelez as the most recent and complete compilation. Their records of total catches are so nearly those given by Clemens⁹ that the differences are immaterial to our present purposes. Unless otherwise noted, references to total catches or amount of fishing according to gear are to those of Rounsefell and Kelez.

² Spawning-beds of the Fraser. (British Columbia. Fisheries Dept. Report, 1901-09, 1911-31. Victoria, B. C., 1902-10, 1912-32).

³ Spawning report, British Columbia, 1932-42. (British Columbia. Fisheries Dept. Report, 1932-42. Victoria, B. C., 1933-43).

⁴ Contributions to the life-history of the sockeye-salmon, no. 1-10. (British Columbia. Fisheries Dept. Report, 1913-24. Victoria, B. C., 1914-25).

⁵ Contributions to the life-history of the sockeye salmon, no. 11-23. (British Columbia. Fisheries Dept. Report, 1925-37. Victoria, B. C., 1926-38).

⁶ Canada. Dept. of Marine and Fisheries. Fisheries Branch. Annual Report, v. 17-63, 1883/84-1929/30. Ottawa, 1885-1930.

Canada. Dept. of Fisheries. Annual Report, v. 1-12, 1930/31-1941/42. Ottawa, 1931-42.

⁷ Pacific Fisherman, v. 1-41, 1903-43. Seattle, Washington. Pacific Fisherman Year Book, v. 1-41, 1903-43. Seattle, Washington.

⁸ Rounsefell, G. A., and Kelez, G. B. The salmon and salmon fisheries of Swiftsure bank, Puget Sound, and the Fraser river. (U. S. Bureau of Fisheries. Bulletin, v. 48, no. 27, p. 693-823. Washington, U. S. Govt. print. off., 1938).

⁹ B. C. Fish. Dept. Rept., 1937, p. T 34.

The water levels at Hell's Gate for years previous to the beginning of work there by the Commission have been calculated from those at Hope. The records for Hope and Adams River have been given us by the Dominion Water and Power Bureau¹⁰ through its District Chief Engineer, C. E. Webb, and the calculations were made by R. I. Jackson.

To those able men who have supplied these long-continued studies and records there is owing well-deserved thanks for material which must serve as a basis for all future studies. This is particularly true of J. P. Babcock, who was until his death in the Provincial Fisheries Department of British Columbia, whose own efforts and those which he inspired through the critical years of depletion have been of the greatest use.

¹⁰ Canada. Water and Power Bureau. Surface water supply of Canada, Pacific drainage, British Columbia and Yukon territory, 1911/12-1937/38. Ottawa, 1914-43. (Its Water Resources Papers, no. 1, 8, 14, 18, 21, 23, 25, 30, 39, 43, 47, 51, 53, 59, 61, 65, 67, 72, 78, 80, and 86).

ACKNOWLEDGMENTS

This report presents but a fraction of the great amount of data regarding the sockeye and its fisheries which were collected in the four-year cycle from 1939 to 1942 inclusive. Efficient organization has required that material for several different phases of the program of the Commission be collected simultaneously by those men in a position to do it. Thus men on the spawning grounds each summer not only enumerated the spawners and collected biological data, but recovered tags which had been placed on salmon in salt water and in the lower Fraser at Hell's Gate. The results of this cooperative work were deposited in the headquarters at New Westminster, B. C., tabulated, and filed. The writer has been responsible for the analysis of that part of the data used in this report, for its text and its conclusions, with assistance at various times from members of the staff. It is therefore necessary to acknowledge the assistance of many persons in collecting and filing the information required for this report.

The tagging was begun at Yale in 1938 by Drs. R. E. Foerster and W. E. Ricker, assisted by Messrs. W. F. Baxter and G. G. Thompson. The tagging program was subsequently much expanded, that in salt water being under the supervision of Dr. J. L. Kask, while that in fresh water was centered at a point immediately below Hell's Gate and is dealt with in this report. The following have supervised the work there: Messrs. Roy Hamilton, R. I. Jackson, J. L. Kask, Phillip Olson, Gerald B. Talbot, H. S. Tremper, and A. W. Welander.

Recovery of the tags has been due in large part to the spawning ground observers, Messrs. C. E. Atkinson, Jackson, Donald Johnson, S. R. Killick, James Mason, Allyn Seymour, Talbot, Tremper and L. E. Whitesel. The returned tags have been tabulated and filed by Agnes Gwyn, Hilary Foskett, Eileen Peterson, and Geraldine MacAdam.

The writer was assisted in analysis of the tags by Messrs. Johnson, Mason, and Tremper during the winter of 1941 and especially by Mr. Talbot in the winters of 1942 and 1943. Mr. Welander assisted by analysis of the Adams River returns. Messrs. Talbot, Mason, Johnson, Tremper, and Robert Mausolf assisted in the preparation of charts and graphs. The compilation of historical material under the supervision of Mr. Atkinson, has furnished much help.

The author wishes also to acknowledge the constant interest and assistance of the various officials of the Canadian Department of Fisheries, including Chief Supervisor J. A. Motherwell, Supervisor R. W. MacLeod, and Inspectors Cherry, Ferrier, Forsythe, Harvey, Kew, Scott, and Winlow.

The completed manuscript has been read by Dr. D. C. G. MacKay, Messrs. M. B. Schaefer, Atkinson, Talbot, Hamilton, and Clarence P. Idyll. Drs. A. F. Carpenter and W. Z. Birnbaum, professors of mathematics at the University of Washington, have kindly reviewed the mathematical sections of the report. Sections of the report have been discussed with Drs. W. A. Clemens, R. E. Foerster and A. L. Pritchard.

Bibliographical sources and manuscript have been checked by Geraldine MacAdam and Grace Vanderford.

SECTION I.

PERIODS OF DECLINE IN THE FISHERY

A. BIOLOGY OF THE SOCKEYE SALMON

The sockeye (*Oncorhynchus nerka* Walbaum) is one of five species of anadromous salmon which die after spawning. Each generation gives rise to another, and in doing so vanishes. The catch is of adult migrants, en route from the sea to the spawning grounds in fresh water.

Spawning of sockeye usually takes place in those streams of the Fraser system from which lakes are accessible. It also occurs in the lakes themselves. The eggs are laid in nests, or redds, made by the parent fish in the gravel during the fall months in each locality according to the time of the run. In the early spring months of the following year the fry emerge. In certain important spawning streams, such as the Chilko River, these fry migrate upstream into a lake; in others, such as lower Adams River, they pass down into one; and some remain in the lake where they were spawned. Gilbert¹¹ concluded from examination of scales, that a race spawning in the Harrison Rapids goes to sea during its first year. The evidence is indirect. In other known cases it is after a year, sometimes two, in fresh water that the young go to sea to return as adults four years after being spawned.

In this series of events the mortalities which occur are of first importance. Between the catches made from successive generations lie the variable mortalities of gravel, lake, and sea life. The mortality during the first year of life in fresh water seems to be accepted as the most important. The reports of R. E. Foerster¹² deal with this for Cultus Lake. But there is no reason why that during the latter years of sea life should not be equally so. If 90 per cent of the salmon die in each of the first three years, there would still be left to begin another 4 out of 4,000 eggs produced by the female and male or males, enough to allow a 50 per cent mortality in the final year of return to the stream and still provide two spawners. This succession of high death rates is modified by variability and possibly by compensatory increases in survival rates. Desirable as the exact

¹¹ B. C. Fish Dept. Rept. 1918, p. X 29.

¹² Foerster, R. E. An investigation of the life history and propagation of the sockeye salmon (*Oncorhynchus nerka*) at Cultus lake, British Columbia, no. 1-5. (Canada. Biological Board. Contributions to Canadian Biology and Fisheries, n.s., v. 5, no. 1-3, 82 p.; v. 8, no. 27, p. 345-55; Journal, v. 2, no. 3, p. 311-33. Toronto, 1929-36).

—Experiment on pond retention of sockeye salmon. (Canada. Biological Board. Progress Reports of the Pacific Biological Station, no. 10, p. 10-13. Prince Rupert, B. C., 1931).

—Increasing the survival rate of young sockeye salmon by removing predatory fishes. (Canada. Biological Board. Progress Reports of the Pacific Biological Station, no. 32, p. 21-22. Prince Rupert, B. C., 1937).

—Removal of the predatory fishes to save young sockeye salmon. (Pacific Fisherman, v. 35, no. 12, November 1937, p. 31. Seattle).

measurement of all of these rates and their changes may be, it is far from possible now. For that reason it is not known what damage the mechanism of survival built into this species is capable of overcoming. The suggestion can be made that when fish get scarce their mortality rates in various life stages decrease, leading to greater survival. It is as yet possible only to measure the final effect on the catch, or return.

As has already been said in the Introduction, the occasional, or even annual, death of sockeye below an obstruction would not in itself mean disaster to the runs. All species of living things suffer heavy mortalities at most stages of life under natural conditions. They are so constituted that these losses are compensated for by one means or another, such as increased survival rates of young with scarcity of adults. Even the machinery of exploitation is restrained by the reduction of the fishery when it becomes less profitable. The loss of a part of the escapement might well have entailed a later reduction of the commercial catch, sufficient to compensate. Since the whole escapement is thought to be on the order of 10 to 25 per cent of the total run, the loss to the fishermen of a fraction of the catch to replace a part of this would not have been serious. To explain a continuing disastrous reduction despite the existence of these natural and economic checks on depletion requires proof that the obstruction causes something more than the death of even a considerable number of sockeye. The present report answers this requirement by showing how the units, or races, composing the run have suffered most unequally. The analysis is carried directly to the commercial catch itself with proof that existing natural or regulatory compensation is not adequate to maintain the yield from those surviving races to which damage is still occurring at Hell's Gate.

In the Fraser River acceptable statistics are available only for the commercial catch, which is made from adult migrants. It is not practical to build weirs to count all sea-bound young, nor to determine survivals of eggs or fry, and during the years of residence in the sea the stocks of sockeye are beyond our ken. Only in the catch can there be secured a clue to the numbers in the succession of generations. For that reason the present report starts its analysis with the catch and must begin with development of an index to its changes. This procedure has advantages which are worthy of comment here.

An index to the success of the catch is of vital importance because it provides a method of studying the most fundamental problem in salmon regulation, that of the escapement necessary. The counts of spawning fish in such a system as the Fraser River can be made only with difficulty. It is not known, even from experience in other streams, what number of spawning adults are required for the maintenance of the various runs. Presumably the number will be found to vary widely with the conditions met in each cycle by each race, and will not be the same for all runs within a river system, nor for the several years. Just as the number of eggs produced by a female varies from river to river so must it be expected that the number of adults necessary will vary. Both eggs and adults are means to the same end. Even were it possible to count the spawners on the redds, the problem would still remain as to how many were needed there. There

must be developed some method of judging directly whether the run is reproducing itself, not necessarily whether the number of spawners is large or small. It might, in fact, not be vitally necessary to count the spawning adults if some direct and sensitive index were available which would show whether or not fishing of a certain intensity or during a limited season left them sufficiently numerous to reproduce the run at the most profitable level of abundance.

The value of such an index is most apparent in dealing with special problems such as obstructions, because it gives a year by year picture which can be extended into past years.

There is some reason to believe that the total catch will vary more widely than the escapement and form a more sensitive index to the changes in numbers of adults. The salmon pass through a series of fishing grounds, in each of which they may remain for varying periods of time. Each fishing area is like a reservoir, in which the abundance, as the fisherman sees it, is the accumulation due to delay in passage as well as to the magnitude of the stock of fish.¹³ Delay may vary with the season or the race. Upon the residue of the accumulation, after the catch is taken, or upon its size at the moment of upstream movement, must depend the escapement. Fishing operations tend to reduce this residue to where the profit becomes insufficient. In a year with big runs there are many men fishing full seasons, reducing the accumulation. In a year of poor runs there are few fishermen, easily discouraged. The accumulation and therefore the escapement remains correspondingly higher, perhaps proportionately equal to that in a big year. The resultant effect may be a regulatory one tending toward, but not attaining, a constant escapement, and shifting to the catch many of the major natural variations in the runs. If so, an index based on the catch should be more sensitive to the fluctuations we are studying, than would the total run.

Until migration is studied by tagging experiments for each fishing area, and possibly for each race of fish, and until the effect of economic conditions on the fishing fleet is known, this reservoir action must remain a useful and suggestive hypothesis. Its measurement is a major objective necessitating special research, and one that cannot be attained in this report.

Moreover, it is the catch in which we are interested, even when our attention is, for the time being, focused on the escapement. The variations which are brought to light can be studied for correlation with what industrial and natural environmental factors we can measure. Perhaps as a result, more satisfactory indices can be devised later. That based on catch must serve as a means to the end.

Such an index should be best when based on a comparison of the parent run and an analysis of the returning offspring according to their age in the catch. The catch derived from a parent run should be determined according to its year of return, whether three, four, or five years later. The sockeye salmon of the Fraser River is predominantly four years old when it spawns and dies. Gilbert,¹⁴

¹³ Compare Thompson, W. F. Theory of the effect of fishing on the stock of halibut. (International Fisheries Commission. Report, no. 12, 22 p. Seattle, 1937).

¹⁴ Gilbert, C. H. Age at maturity of the Pacific coast salmon of the genus *Oncorhynchus*. (B. C. Fish Dept. Rept., 1912, p. I 57-70, pl. I-XIX. Victoria, 1913).

and later Clemens,¹⁵ carried out annual analyses of the age composition of the commercial catch. Their results indicate that about 80 per cent were four-year-olds, the proportion varying widely at times.

But, as will be seen, all the necessary facts are not at our command. Age analyses were not made for the earlier and crucial years. The study must therefore begin by a calculation of the index in its crudest form, a comparison of the catch of one year with that of four years later. Such an index, based on 80 per cent of the fish sampled, may be sufficiently sensitive for the present purposes. As to that, the reasoning on the following pages will speak for itself.

As basic as age in the problem of rehabilitation are the races¹⁶ of which the Fraser sockeye is composed. The run of the sockeye in each season is not a unit, but a group of units. The sockeye which are born in a particular spawning ground spend their first year in a nearby lake, go to sea, and return as adults to that same river and lake except for an unknown proportion of strays. There is, in fact, reason to doubt whether what are now known as individual races are really homogeneous. So in referring to an individual race the reservation is made that it may include several.

If an index to the condition of the fishery is calculated from data as to age and catch, its changes must be correlated with the fortunes of the various races which go to make up the commercial catch. These changes can be traced to the races which contribute to them only by examination of the spawning grounds.

The race returning season after season to Adams River (*see* page 43) is a good instance. As do others of its kind, it possesses a high degree of individuality whether it is a unit or a group of units. It migrates from salt water and passes through the river canyon at its own particular time each year, soon after September 15. It arrives on its own schedule and uses the same spawning grounds as its parents, not those closely adjacent, unless as overflow when its own grounds are overpopulated. It tends to preserve its abundance relative to that of other races in each four-year return of its cycle, and when it varies in abundance it does so in its own individual way. One of the four cyclic years in the run is dominant

¹⁵ B. C. Fish. Dept. Repts., 1913-37.

¹⁶ The term "race" is used here despite the preference of certain authors for "stock". The populations which make up the sockeye of the Fraser River may possibly inherit distinguishing characters. That is not certain, but they are largely self-perpetuating and have distinguishing characters whether these arise anew each generation as environmental effects or not. It is very hard to conceive that a characteristic time of adult migration is other than an inherited response; certainly it is not a "memory". The term "stock" carries no connotation of such continuity between generations, and it does not imply a possible genetic basis. But "race" does. We therefore prefer it. Discussions of the term "race" are found in: Dobzhansky, Theodosius. *Genetics and the origin of species*. New York, Columbia University press, 1937, p. 60-63; American Association for the Advancement of Science. *The migration and conservation of salmon* [a symposium], Washington, Pub. for the Association, 1939. (See W. H. Rich, p. 45; H. B. Ward, p. 60; and Summary, p. 106, fourth paragraph.)

Among papers presented in the above mentioned symposium are two bearing particularly on the "home stream" theory: Rich, W. H. Local populations and migration in relation to the conservation of Pacific salmon in the western states and Alaska; and Clemens, W. A., Foerster, R. E., and Pritchard, A. L. The migration of Pacific salmon in British Columbia waters.

The continuity of these populations by return of offspring to their "home streams" is discussed in some detail in the following: Gilbert, B. C. Fish. Dept. Repts., 1915-24; Clemens and Clemens. B. C. Fish. Dept. Repts., 1925-37; [Thompson, W. F.] Return of Pacific salmon to their home streams. (*Pacific Fisherman*, Sep.-Nov., 1937, v. 35, no. 10, p. 31-32, no. 11, p. 38-40, no. 12, p. 24-25.

over the other three in abundance and it has preserved this dominance since 1922. It is the only race present in the Fraser River in great numbers in that cycle year. It has persisted despite the depletion and disappearance of an earlier migrating race which passed through the lower Adams River before this race arrived, to spawn in a different section of the watershed. The present Adams River race is capable of distinction from its fellow races not only in numbers, but also as a biological unit, in habits and to some degree in structure. No other race is known which varies with it or accompanies it in such way as to indicate racial identity with it, nor is anything known which implies that it has more than one home stream.

If many returning adults stray from this "home", the very marked individuality of race and cycle year would be expected to vanish; and simply because it persists it is known there must be influences which perpetuate it. Often strays do not reproduce adequately in a foreign environment, sometimes not even laying their eggs, as happens when the reaches at Hell's Gate or Bridge River are blocked and fish find refuge in canyon streams below. Straying may well be only a seeming, but not an actual intermingling of races, and hence entirely consistent with the "home stream theory". In the end, it is necessary to deal with a unit which is called a race, although it is not known what influences, external or internal, hold it together and perpetuate it, or whether it can be subdivided still further. The persistent individuality shown by each such race forces its recognition in a practical sense as a unit known by its "home" stream, whatever its genetic background.

The report shows clearly that all phases of the life history of the sockeye are involved in any particular problem, such as that of the effect of an obstruction. It has been necessary to study the nature of the races, their individuality, the times at which they migrate, the numbers which reach their spawning grounds, and the effect of the heavy mortality at the obstruction upon their reproduction. It has been necessary to understand the way in which they respond to variations in the mortality produced by the obstruction and by the fishery. All of these things determine the relative success or failure of the runs to perpetuate themselves, and have been given expression in the index.

The same methods of study and the same facts must be vital to regulation and to artificial propagation. The particular races depleted, the manner in which they respond to any variations in mortality, the amount of this they can endure, the way in which they have been affected by the obstruction in the past, are just as vital to any use of artificial propagation or regulation of the fishery as they are to the study of an obstruction. Their effects, too, must be evident in an index to the condition of the fishery, if they are of importance to the catch.

For these reasons, particular care has been taken to develop the index, which will serve to give purpose and meaning to the various investigations required by the treaty under which the work is done. It should serve as a coordinating basis for these investigations, and should show the success or failure of action based upon them. It should be of much the same significance as the catch per unit of gear in studies of other fisheries.

B. EVIDENCE FROM THE COMMERCIAL CATCH AS TO DEPLETION AND DEVELOPMENT OF AN INDEX OF SUCCESS OF RETURN

In the following section an index to the success of reproduction of the runs will be derived from the catch records. This will be carefully examined for its validity as upon this depends the proof that the sockeye was depleted during two distinct periods of time, not in the spectacular failure of one year.

It is convenient to express the return of any given spawning as the catch four years hence. Thus if the catch in 1900 were 400,000 cases, a return four years later of 400,000 cases, or 100 per cent, would indicate that the catch was being maintained. If the catch were 50 per cent of the parent year, that would indicate a decline, or partial failure of the catch—whatever the cause. Such a value constitutes an *index to the success of the return*. This method of stating the success or failure of a catch is in common use, but it has not been used consistently in studying the history of the fishery, and its validity for that purpose has not been examined.

The index values as given hereafter are actually percentages unless otherwise stated. Thus the ratio of the catch in the year of return to that of the parent year is given as 100, and not 1.00. If C_0 is the catch of the parent year, and C_4 that of the return, the index is $\frac{C_4}{C_0}$

This percentage index of success of return has been calculated here for the numbers of fish taken between 1890 and 1930¹⁷. The result is given in Figure 2A.

This graph should be interpreted with care. As already noted, it expresses only the degree to which the catches of the individual years of the four-year cycle are reproduced, *at whatever level of abundance the races concerned may be at the time*. Once the catch has risen or fallen to a new level the index merely shows whether or not that level is maintained. This is a necessary characteristic of such an index.

Moreover, the value of the index rises and falls accordingly as the catch of the return year represents a larger or smaller fraction of the total run for the year than does the catch of the parent year. A correction for this is given on page 29. The effect of this is seen in the peculiar shape of the first part of the index graph, and this must be disregarded until corrected. The record prior to 1899 is of a new fishery which at first used an increasing portion of the fish in the run, each increase in gear taking more fish. This portion could not increase indefinitely, and the falling line to 1898 simply expresses the period of the fishery between its beginning and its maturity during which the fraction of the run taken as catch rose to near its maximum. The change shown should be characteristic of all fisheries during first development and is a useful expression of the approach to full utilization. In 1898 there was a catch more nearly equal to the return catch four years later and the index approached 100.

¹⁷ Data from Rounsefell and Kelez, p. 761-62.

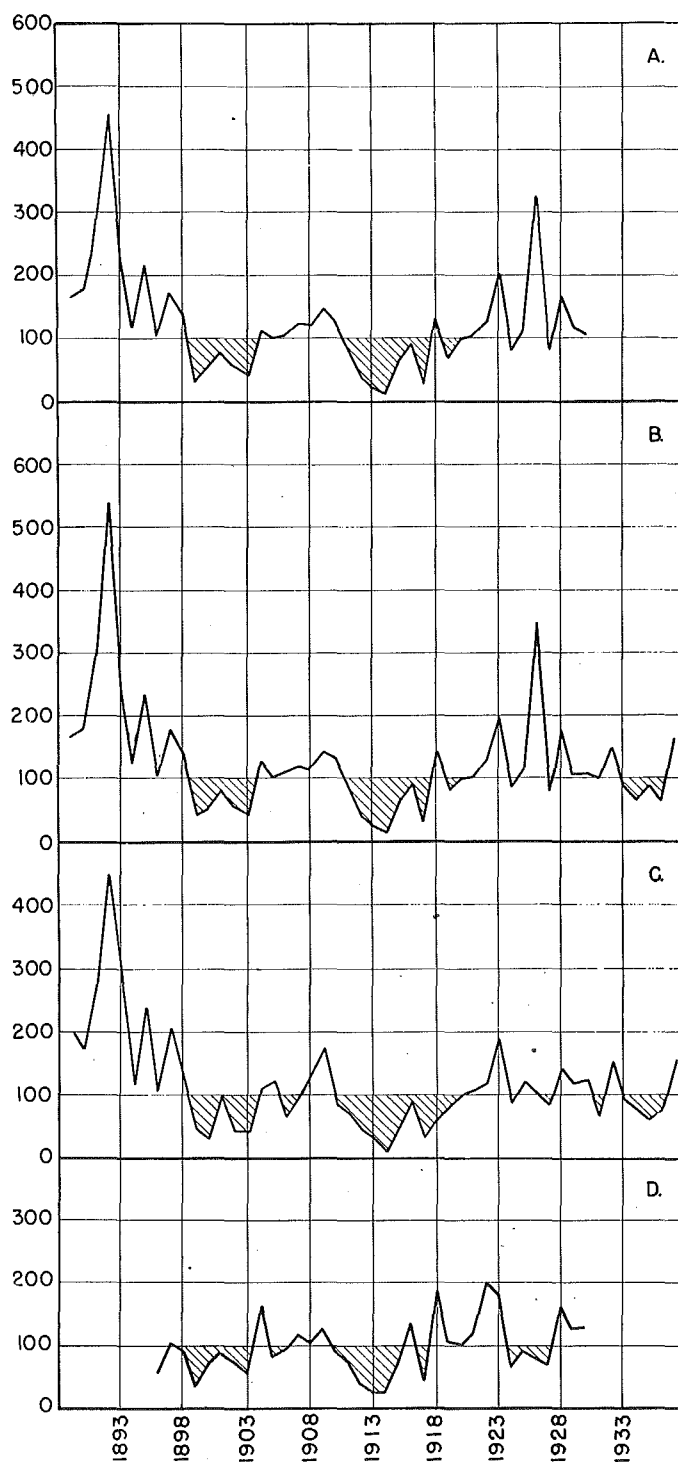


Fig. 2

INDEX VALUES OF SUCCESS OF RETURN GIVEN IN PERCENTAGES,
based on

- A. Number of fish caught and an assumed age of four years. Data to 1930 only.
- B. Cases packed and an assumed age of four years.
- C. Cases packed and an assumed age composition of 80% four-year, and 20% five-year-olds.
- D. Indices of abundance according to Rounsefell and Kelez and an assumed age of four years.

The index fell below 100 for two distinct periods in the fishery—from 1899 to 1903 inclusive, and from 1911 to 1919, with the exception of 1918.

These periods during which the returns from the fishery were below 100 per cent of that of the parent years represent two periods of decline in the total catch. Once this has been pointed out, a close study of the unmodified total catches of Figure 1 will show the same changes. They are clearer if the four-year cycles are dealt with separately. This has been done in Figure 3 where the catches in each cycle are graphed.

There are two types of statistics available, one of the number of cases packed, the other of the number of fish caught. However, the number of fish required to produce a 48-pound case was used in calculating the number of fish taken per year, and any error in determining this number would be reflected in the index. The only record currently collected through past years was of the number of cases, and it can be assumed safely that the number of fish per case was highly variable. The same index can be calculated from both types of statistics. The result for our present purpose is the same (*see* Figure 2B).

The indices calculated from cases and from numbers of fish should be comparable except for the errors due to changing efficiency of utilization and to changing average sizes. It might, in fact, be expected that the runs of the parent and return years of the successive cycles would tend to have the same size of fish because the same races tend to be present. The index calculated from the case pack has been used in this report unless otherwise stated.

Before using this index freely, it must be examined with care. The possible alternative of a direct measure of the total run in the form of a measurement of relative abundance, such as return by a unit of gear or effort, must be considered. And two sources of possible error in the index deserve special attention. The first is the existence of other than four-year-olds in the return runs. The second is the direct effect of the amount of fishing on the proportion of the total run taken as catch.

Use of Catch per Unit of Effort

If a measurement of "abundance" reflects the changes in the total run, then it can be used as another basis for calculation of the index which was derived above directly from the catch. There is available for use thus the "index of abundance" given by Rounsefell and Kelez.¹⁸

These authors made an exhaustive examination of available data and they indicate the possibilities in such a measurement. This was designed to discount changes in amount of fishing effort and is essentially a calculated catch per unit to reflect the year by year changes in the total runs. Their measure of "abundance" in the parent year has been compared here with that in the year of return. This gives an index derived from an index, a rather unsatisfactory procedure from the standpoint of compounded errors.

¹⁸ Rounsefell and Kelez, p. 772.

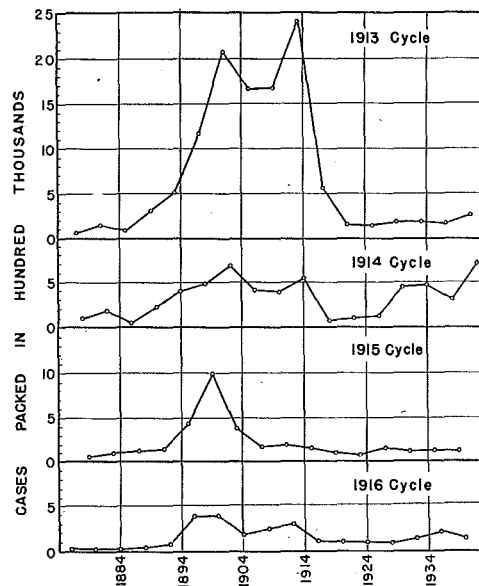


Fig. 3

PACK OF FRASER RIVER SOCKEYE, EACH FOUR-YEAR CYCLE SHOWN SEPARATELY.

The changes shown by use of this "index of abundance" for years prior to 1926, hence during the two main periods of depletion, are roughly the same as the index from the pack. It is plain that the corrections available to Rounsefell and Kelez have not destroyed the evidence of depletion in the two periods (see Figure 2D).

However, this "index of abundance" cannot logically be used in this way. In various other fisheries, such as halibut, the catch per unit is regarded as reflecting the size of the accumulated stock present at the time the catch was made. But in the salmon the case is entirely different. The catch per unit cannot reflect the magnitude of the year's run in any simple direct way. When the catch approaches 80 or 90 per cent of the whole run, as is deemed probable in these salmon rivers, there is not much scope left for the increasing number of boats, fishermen, or traps to enlarge the catch. So doubling or trebling their number simply divides the catch accordingly. To do so gives an average catch per boat or per man or per trap reduced nearly to a half or third, even though the total run is as large. Hence the average catch per unit correspondingly fails to represent the "abundance". That latter term must in the last analysis be defined as the size of the run (catch plus escapement), if it has any biological significance at all. Yet there is only one moment during a run when the catch per unit would indicate this size of run for any school of migrating salmon, and that is when the catch begins. By the very nature of the fishery this moment cannot be defined by any means now at our command. There are too many schools and too many moments of beginning for the several races or stocks. The average catch per unit for a season therefore cannot give any fair measure of "abundance", except as the fisherman sees it from an economic standpoint. Perhaps the catches of the last fishermen to sample the run might give a relative measure of escapement, but here again the moment at which this happens cannot be determined.

But the catch per unit of gear, neglecting competition between gear, does give the theoretical limit to the relative abundance in case the escapement is very large in proportion to the catch, and it is used below in this way.

Effect of Age on the Index

There is a possible defect in the index of success of return in the fact that each year's catch is composed of five-year-old fish as well as four-year-olds, and some threes and sixes. The average percentages of threes, fours, fives, and sixes, according to Clemens¹⁹, are respectively 3 per cent, 77.1 per cent, 19.2 per cent, and 0.5 per cent, as determined from the scales of samples taken at the Sooke traps on the southern end of Vancouver Island.

The scale readings, as far as they have been made from the catches of individual years, can be used to determine the years of origin of each such catch, and thus to assign each fraction of it to its parent year. Age readings were made for this purpose over a period of many years, and it is proper that they be carefully examined since they have been considered as of importance.

C. H. Gilbert²⁰ began in 1911 to determine the age composition of Fraser River sockeye, usually by samples obtained from the traps at the south end of Vancouver Island. In 1925, W. A. Clemens and L. S. Clemens continued Gilbert's work. For the year 1937 W. A. Clemens published a table giving the age composition of the Fraser River catches at the Sooke traps from 1920 to 1937 inclusive.²¹ To use these records it will be assumed that the samples from which scales were taken represented the catch as a whole, and that age determinations from scales are correct. It is then possible to divide each year's catch into those parts which originated three, four, five, and six years earlier. This we have done.

We therefore have available the yield from each year's spawning, as shown by the sum of suitable fractions of catches three, four, five, or six years later. Representing this composite yield as percentages of the parent year, an index value is obtained for the years when ages are available (*see* Figure 4). This can be compared with that obtained on the assumption that the whole catch of each year originated four years earlier from the run of a single year. It will be observed that the graphs are not essentially different. The distribution of the offspring over several years does not obscure the major changes in more than a minor and random fashion. That the four-year-olds so nearly dominate as to justify use of the four-year cycle alone is seemingly an acceptable assumption.

The long series by Gilbert and Clemens was begun, in part, because of a possibility that there is a certain constancy in the ratio of various ages among the migrating adults produced by any spawning. Three-year-olds of one year and the four-year-olds of the next would be from the same spawning and would be expected to vary together in relative abundance. There should then be an unusual

¹⁹ From data 1920 to 1937. The unweighted average percentages have been used. (B. C. Fish. Dept. Rept. 1937, p. T 35).

²⁰ B. C. Fish. Dept. Rept. 1914, p. N 46.

²¹ B. C. Fish. Dept. Rept. 1937, p. T 35.

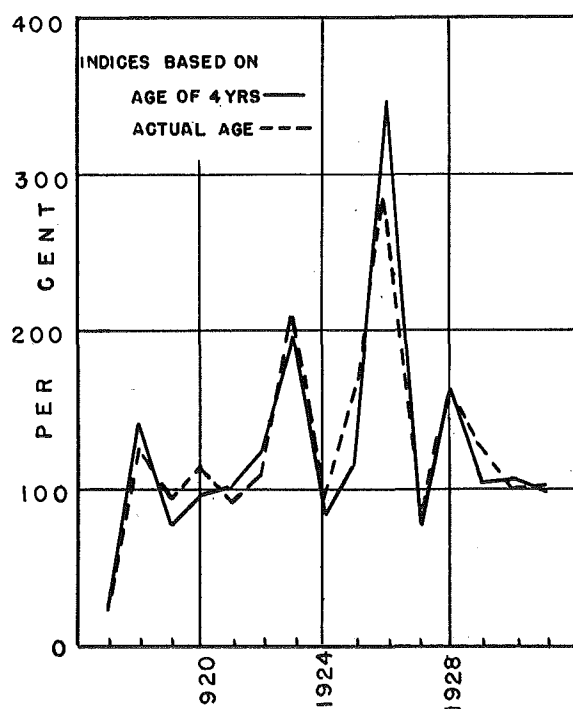


Fig. 4

COMPARISON OF INDICES OF SUCCESS OF RETURN, BASED ON AN ASSUMED AGE OF FOUR YEARS AND ON THE AGE COMPOSITION GIVEN BY GILBERT AND BY CLEMENS.

abundance of three-year-olds the year preceding a large run of four-year-olds. On the Fraser River the year preceding such a large run was for many years a small one. When this was so, the three-year-olds would form a large proportion of this small run. Their numbers would thus indicate what could be expected the next year when the four-year-olds would return. This would have provided a means of forecasting the catch in the big year from that of the previous year. This seems to have been possible in the case of the big years of 1909 and 1913, when there were great disparities in the abundance in successive years. But the forecast made was only that the big year of the cycle was about to occur, and did not reflect accurately the magnitude of such a big year as compared to its parent year.

It would also be expected that the proportions of five-year-old fish in the years following the big catches of 1930 and 1934 would be higher than the average of 19.2 per cent. This was not true in 1931 (14.4 per cent) but was true to a certain degree in 1935 (25.2 per cent). Yet even in 1935 this proportion was not sufficiently high to provide the expected large catch of five-year-old fish. For, if the catches of each year given in Clemens' Table I are divided among the age groups shown in his Table II, a set of figures can be obtained which should represent the amount of fish packed annually from each age category. These figures for the four- and five-year-olds are plotted in Figure 5 according to the year in which the scale samples were taken. The pack of five-year-olds varied with the pack of

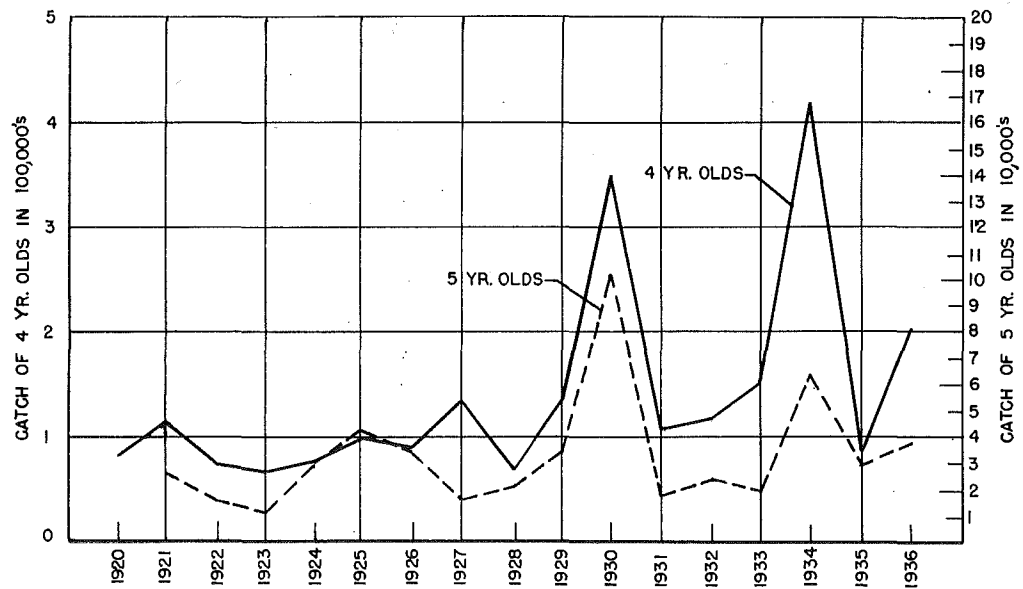


Fig. 5

ANNUAL CATCH OF FOUR- AND FIVE-YEAR-OLD SOCKEYE, OBTAINED BY DIVISION OF THE ANNUAL CASE PACK ACCORDING TO AGE ANALYSES BY GILBERT AND CLEMENS.

four-year-olds in 1930 and 1934, and the greatest numbers of five-year-olds have not followed the large runs of four-year-olds. If an age cycle controls the abundance, then what has occurred requires explanation from two aspects. First, the simultaneous occurrence of large runs of five-year-olds and four-year-olds in two cycle years points to a high survival rate of two year classes, 1925 and 1926 to produce the run of 1930, and 1929 and 1930 to produce the run of 1934. This is a remarkable coincidence. Second, the failure of a big five-year run to follow a big four-year run indicates a selective survival of four-year-olds in one year class and of five-year-olds in another. In either some explanation other than the usual one of an age cycle must be found. The five-year fish have a four-year cycle!

There are several possible explanations. The catch sampled at Sooke trap may not represent the whole run. Or the conditions in the home lake which favor the production of four-year-olds may also favor the production of five-year-olds from the previous year class. The class of 1925 would thus furnish the five-year-olds, the class of 1926 the four-year-olds. If so, it would be necessary to abandon the concept of a four-year cycle originating solely in age and adopt one of the same length dictated by the environment. If these alternatives do not prove to be acceptable, then the percentage of fives determined for the samples may contain errors. But whatever the explanation, the available facts indicate that we may legitimately compare the five-year-olds of 1930 with the five-year-olds of 1934, rather than with those of 1935, to show the condition of the run. In short, the use of an index based on a four-year cycle seems justifiable, whether it is due to age or to other factors.

The concept that the catch of any year is composed of fish of various ages is based on marking experiments as well as age determinations from scales. It is too

firmly grounded to dismiss. While the series of samples discussed above may not have given results conforming to expectations, the age determinations may be correct. The effect of differing ages should, then, be tested in theory if not from actual samples.

This suggests that the migrants of any given year, assuming that they vary in number in proportion to the catch, might be divided in constant ratio between those which subsequently produced four-year-olds and those which produced five-year-olds, neglecting the rare three- and six-year-olds for simplicity's sake. Thus the catch of 1900 might originate from the runs of 1896 and 1895, both of which could be divided on the assumption that 80 per cent of the eggs later produced four-year-olds, and 20 per cent produced five-year-olds. If the catch of 1900 was not on a par with the resultant expectation which was a run equal to the sum of four-year-olds from 1896 (80 per cent) and five-year-olds from 1895 (20 per cent), the inference would be that the runs were not being maintained. The percentage, nearly 100, which the actual catch of 402,000 cases formed of the expected 403,000 cases, should be an index of the same nature as that previously used. The parent year can be assumed to be 1896.

The effect of this distribution of ages can be compared with what was obtained by assuming that there were four-year-olds only. In Figure 2C the age-corrected graph is given to compare with that of Figure 2B, obtained by the four-year assumption.

It will be noted that there is no substantial difference between the general pictures given by the two methods. The most obvious is that the periods of depletion are visible a year earlier in the case of distributed age classes. For instance, the age correction indicates that the decline in returns began in 1910, whereas by the simple four-year cycle index, 1911 was the first year.

Since age determinations are not available for the years of most crucial importance to this study, and since they are of doubtful application, they are not used here. The theory of their effect is dealt with below.

Effect of Amount of Fishing on the Index

The index is subject to correction for the varying amount of fishing in the parent and return years. An increase or decrease in return may be due in part to an altered fishery, which may take a larger or smaller part of the total run in the year of return than was the case in the parent year. The correction for this gives a definite limit within which the index values must lie. It can be made in two ways, depending upon whether the gear is competitive or not.

If the numbers of fish in the runs were without limit so that the units of gear would not interfere with one another, and the escapement would be very large, the catch should increase or decrease in proportion to the amount of fishing.

In comparing the catch of the year of return, C_4 , with that of the parent year, C_0 , the change in the amounts of fishing, f_4 and f_0 , would then have to be discounted to arrive at the true values of the total runs, T_4 and T_0 .

TABLE 1
INDEX OF SUCCESS OF RETURN

	CATCH		WEIGHTED FISHING INTENSITY	INDEX FROM CATCH	INDEX FROM CATCH **	INDEX VALUES CORRECTED BY			
	<i>Clemens*</i>	<i>Rounsefell and Kelez*</i>	<i>Licenses</i>	<i>Units of Effort</i>		<i>Licenses</i>		<i>Units of Effort</i>	
						A***	B***	A***	B***
1897	1172507	1162048	5855	5064	179	120	153	104	142
1898	508101	468000	5189	5508	143	98	121	117	131
1899	980131	998909	6871	6482	37	40	36	32	35
1900	458504	402417	9048	8129	49	75	58	68	56
1901	2033765	2081554	8707	8745	81	100	82	97	86
1902	633033	667980	7568	6720	55	71	61	68	60
1903	372020	372059	7421	7551	43	53	47	62	51
1904	196107	196594	5878	5859	128	139	133	168	147
1905	1674611	1675935	8224	7318	101	96	99	92	98
1906	365248	367681	5892	5449	109	106	108	110	109
1907	156789	162035	6047	5212	119	110	115	117	118
1908	245525	250162	5398	4473	124	99	112	96	109
1909	1683339	1688334	8609	7997	143	125	138	135	140
1910	398446	399636	6061	5394	134	92	116	83	109
1911	186248	192231	6565	5319	83	56	72	46	66
1912	308559	309647	6736	5748	39	34	37	28	34
1913	2392895	2412700	9823	8466	23	21	22	18	22
1914	533413	536728	8798	8680	13	17	14	16	14
1915	155714	159991	9663	9670	64	87	71	89	71
1916	116783	119707	7757	8045	93	136	110	145	111
1917	559702	565953	10612	10699	25	42	30	38	29
1918	70420	72321	6901	7143	143	281	205	213	172
1919	103200	103200	7098	6978	79	131	101	113	93
1920	111053	111838	5298	5264	98	157	129	128	114
1921	142598	144698	6249	7026	103	126	113	134	116
1922	100398	103395	3513	4805	127	106	113	126	126
1923	79057	81976	4295	4881	199	168	181	164	181
1924	109112	109101	3309	4022	84	60	68	63	71
1925	147408	148977	5114	5389	116	93	104	91	104
1926	130362	131438	4203	4858	347	252	293	274	308
1927	158987	162748	5101	5919	79	70	74	73	76
1928	90343	91172	4650	5386	166	176	172	169	169
1929	173467	172721	6367	6853	106	119	116	107	106
1930	455886	455856	5785	6160	107	104	105	100	104
1931	128158	128158	5766	6409	100				
1932	146957	150980	4375	5296	149				
1933	179069	182664	5689	6802	88				
1934	491817	488878	5979	6582	67				

* Clemens, British Columbia Fisheries Dept. Report for 1937, p. T 34.
Rounsefell & Kelez, U. S. Bureau of Fisheries, Bulletin no. 27, 1938, p. 759.

** Uncorrected index, $\frac{C_t}{C_0}$, using catch given by Rounsefell & Kelez.

*** A. Index corrected by $\frac{f_0}{f_t}$.

B. Index corrected by $\frac{1-e^{-f_0 r}}{1-e^{-f_t r}}$, assuming a 10 per cent escapement in 1913.

If the catch of a unit of gear is c , then $f_0 c_0 = C_0$, and $f_4 c_4 = C_4$. It can be assumed that the catch of a unit of gear will vary with the total run of fish available to it. Then if gear is not competitive

$$\frac{T_4}{T_0} = \frac{c_4}{c_0}$$

or
$$\frac{T_4}{T_0} = \frac{f_4 c_4}{f_0 c_0} \cdot \frac{f_0}{f_4} = \frac{C_4}{C_0} \cdot \frac{f_0}{f_4} \quad (1)$$

and $\frac{T_4}{T_0}$ represents the corrected index of success of return. The values of $\frac{T_4}{T_0}$ are shown by the dotted line in Figures 7 and 8, for comparison with the uncorrected index. This correction is the maximum which can be suggested to account for changes in amount of fishing.

A more acceptable correction which is consistently less can be made by recognizing that the gear fished competes for the catch. The size of the run, including catch and escapement, provides a limit to the increase of the catch and the gear used becomes competitive. Each unit of gear, when not interfered with, has its own rate of fishing. But due to interference the combined rates of all gear do not equal the sum of these rates. Rather, the appropriate relationship between the total run (T), the escapement (E), the units of gear or effort (f), and the average fishing rate (r), is given by the equation $T e^{-fr} = E$ then

$$T(1 - e^{-fr}) = C$$

The corrected index of success of return is given by the percentage which T_4 forms of T_0 . This can be determined from the ratio

$$\frac{T_4(1 - e^{-f_4 r})}{T_0(1 - e^{-f_0 r})} = \frac{C_4}{C_0},$$

then

$$\frac{T_4}{T_0} = \frac{C_4}{C_0} \cdot \frac{1 - e^{-f_0 r}}{1 - e^{-f_4 r}} \quad (2)$$

The ratio $\frac{1 - e^{-f_0 r}}{1 - e^{-f_4 r}}$ should be compared to that of $\frac{f_0}{f_4}$, given above.

The use of these corrections in a precise manner would require knowledge as to the degree to which gear is competitive, and as to the amount of fishing determined by a correction for varying efficiency. For the use of the second method (competitive gear) there must also be known the intensity of fishing, r , per unit of effort or gear and r can be determined if the escapement is known for any one year.

It is not necessarily true that the gear can be considered completely competitive. Thus runs approaching through Johnstone Straits are not subjected to fishing by the American fleet. Schools of fish, particularly those early in the season, may not appear on the surface until they approach the river, and hence they may escape a section of the fishery. Segregation of runs in these ways renders the fishery in

part non-competitive. It is suggested, therefore, that neither correction is necessarily acceptable to the exclusion of the other.

The amount of fishing is derived from the number of licenses issued for each important type of gear, trap, purse-seine, and gill-net, by the governments of Canada and the State of Washington. These were combined for present purposes by a process of weighting. The number of licenses in each type of fishery for each year were weighted by the average catch made by that type during the years utilized. The sum of the weighted values for the three fisheries gave a total in terms of a hypothetical unit of fishing effort.

Rounsefell and Kelez, whose figures have been used, have attempted on various grounds to correct these statistics for variations in efficiency. They have derived measures of "abundance" for each fishery which are actually catches per unit of effort derived from the number of licenses by means of various corrections. These catches per unit can be divided into the total catch made by each type of gear to give a number representing the number of units of effort for each fishery. These can be weighted and combined as were the licenses described in the preceding paragraph. The result should give the amount of fishing as corrected for variations in efficiency. (See Figure 6 for comparison of values thus calculated. Also see Figures 7 and 8 for comparison of the corrections based on the corrected and uncorrected values of amount of fishing according to number of licenses and to units of effort.)

Using the second method on an assumption that the fishery is competitive, it is necessary to solve for r the equation:

$$T(1 - e^{-fr}) = C$$

This can be done only if the values of T and C , or their ratio to one another, are known for at least one year, so that r can be obtained. In 1913 the units of effort approximated 10,000. It can be estimated that the escapement in such a year of intensive fishing might approach 10 per cent. Then

$$100(1 - e^{-10000r}) = 90$$

The value of r obtained from this equation is .0004605 and can be applied to other years, on the assumption that varying efficiency has been corrected or is non-

existent. The index value $\frac{C_4}{C_0}$ for 1911 (see Table 1) is .83 and the values of f in 1911 and 1915 were 5319 and 9670. Then

$$\frac{C_4}{C_0} \cdot \frac{f_0}{f_4} = .83 \cdot \frac{5319}{9670} = .4565$$

$$\text{And} \quad \frac{C_4}{C_0} \cdot \frac{1 - e^{-f_0 r}}{1 - e^{-f_4 r}} = .6570$$

These three values are indicated on the graphs referred to, the correction for competitive gear being intermediate. The other two, the extremes, have a special significance. They constitute the limits of variation which the correction for competitive gear given in equation (2), page 31, will show when the escapement varies between 0 and 100 per cent.

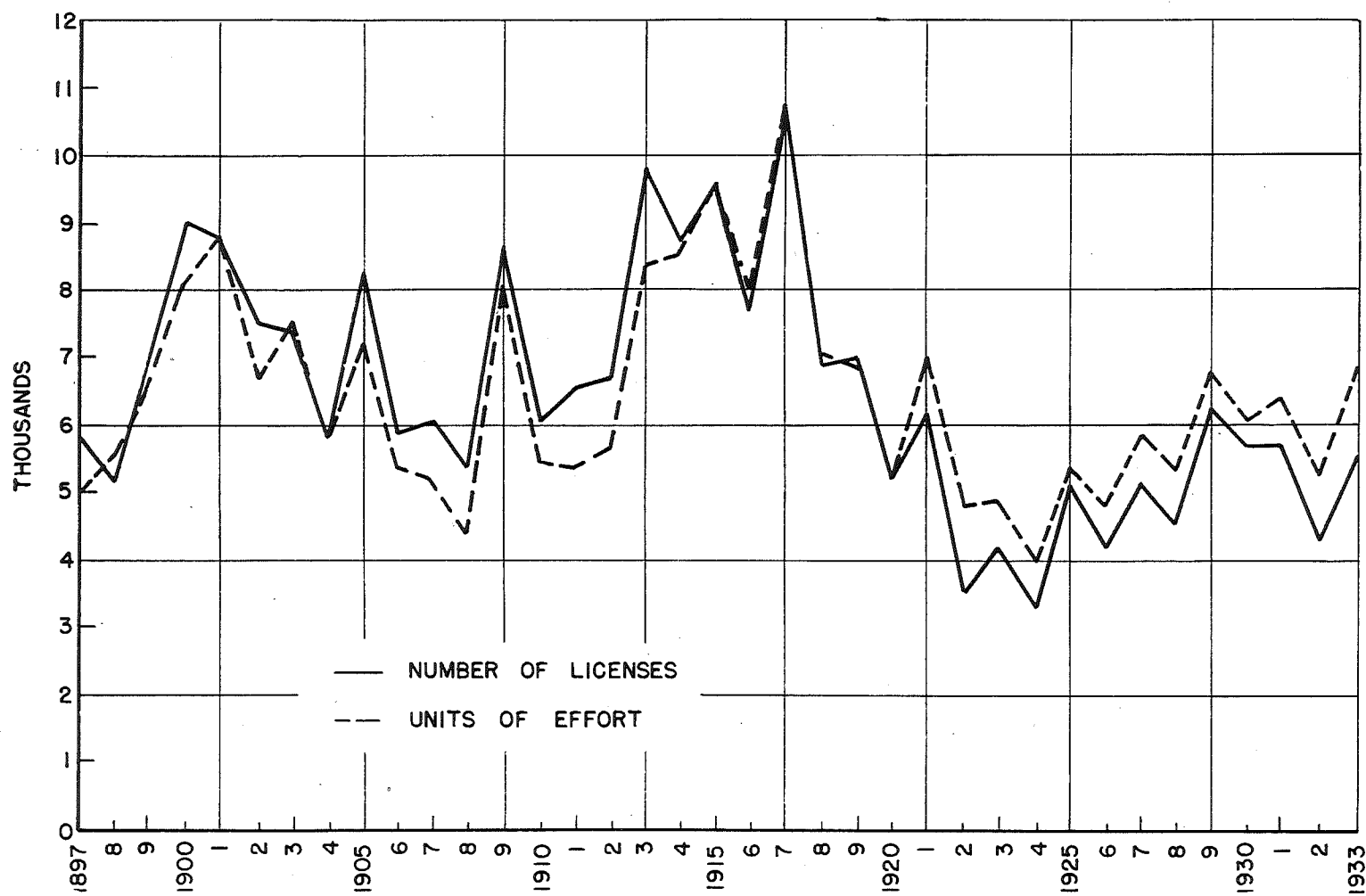


Fig. 6
 AMOUNT OF FISHING FOR FRASER RIVER SOCKEYE, 1897 TO 1933, IN TERMS OF LICENSES ISSUED
 AND OF UNITS OF EFFORT AS DERIVED FROM DATA OF ROUNSEFELL AND KELEZ.

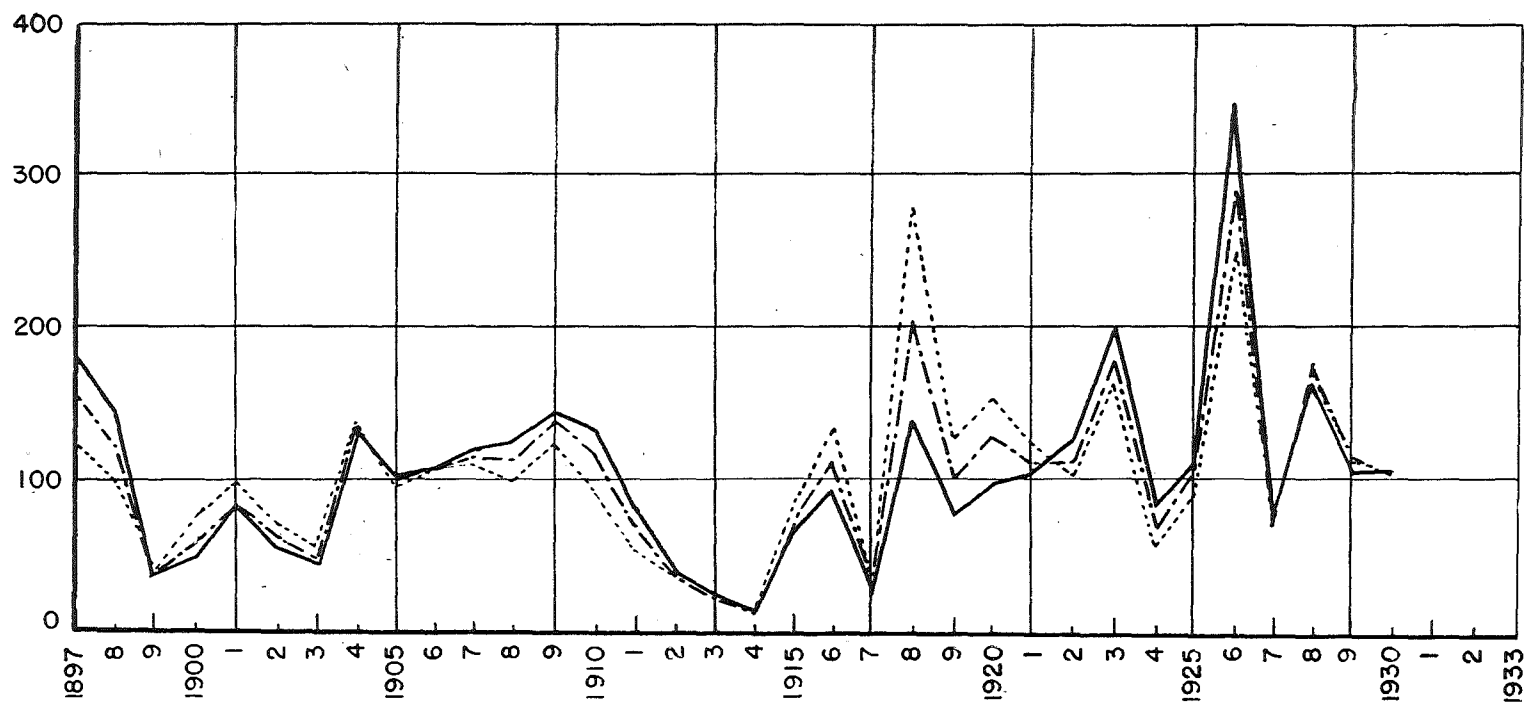


Fig. 7

INDEX VALUES OF PERCENTAGE SUCCESS OF RETURN FOR FRASER RIVER SOCKEYE, 1897 TO 1930, BASED ON CASES PACKED AND LICENSES ISSUED.

$\frac{C_4}{C_0}$	—————
$\frac{C_4}{C_0} \cdot \frac{f_0}{f_4}$	-----
$\frac{C_4}{C_0} \cdot \frac{1-e^{-f_0 r}}{1-e^{-f_4 r}}$	-----

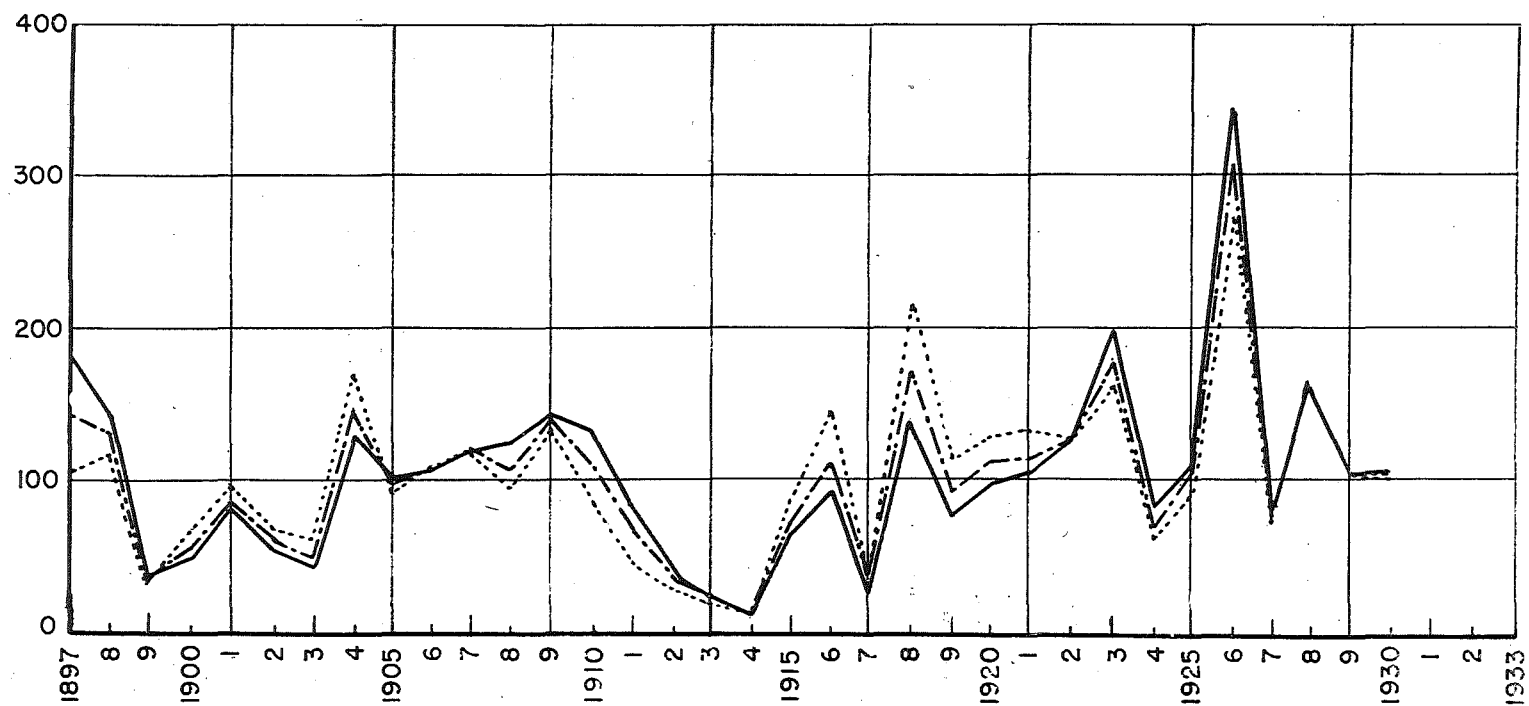


Fig. 8

INDEX VALUES OF PERCENTAGE SUCCESS OF RETURN FOR FRASER RIVER SOCKEYE, 1897 TO 1930,
BASED ON CASES PACKED AND UNITS OF EFFORT (see text).

$$\begin{array}{l} \frac{C_4}{C_0} \quad \text{—————} \\ \frac{C_4}{C_0} \cdot \frac{f_0}{f_4} \quad \text{.....} \\ \frac{C_4}{C_0} \cdot \frac{1-e^{-f_0 r}}{1-e^{-f_4 r}} \quad \text{- - - - -} \end{array}$$

If the escapement approaches 0 the catch approaches the total run. The term $1-e^{-fr}$ becomes equal to 1, and

$$\frac{C_4}{C_0} \cdot \frac{1-e^{-f_0r}}{1-e^{-f_4r}} = \frac{C_4}{C_0}$$

If increasing proportions of the runs are assumed to escape the fishery, with given values for C and f , then r diminishes, with 0 as its limit. Then the ratio $\frac{1-e^{-f_0r}}{1-e^{-f_4r}}$ approaches $\frac{f_0}{f_4}$ as a limit since in that case $f_0 dr$ and $f_4 dr$ are the differentials of $1-e^{-f_0r}$ and $1-e^{-f_4r}$.

The ratios $\frac{C_4}{C_0}$ and $\frac{C_4}{C_0} \cdot \frac{f_0}{f_4}$ are therefore the limiting values of the index when the escapement, E , is varied between its greatest possible extremes.

If the correction for competitive gear is calculated on a basis of various escapements other than 10 per cent in the base year 1913, it will be found that the values actually approach these limits. For instance, if the escapement in the base year is estimated as 99 per cent, the value of r becomes very small, and the index value (2) becomes .4573 or almost that of the index corrected by the factor, $\frac{f_0}{f_4}$, when it is .4565. The values are shown in Figure 9.

We may therefore regard the index calculated on a basis of non-competitive gear, $\left(\frac{C_4}{C_0} \frac{f_0}{f_4}\right)$, and the index calculated direct from the catches, $\left(\frac{C_4}{C_0}\right)$, as the limits to the possible values of the index based on competitive gear. *If in any instance the limits thus calculated do not alter our conclusions, it will then be immaterial for the purpose of calculating the index what the escapement is.* This renders the index a practical and usable one, in view of the magnitude of the fluctuations to be observed.

In the correction of this index for the gear used, there may arise two problems which are worthy of attention here. They are: (1) That which arises as the result of catches by sections of the fishery for which gear records are not available or usable; and (2) that which arises because of the presence of other than four-year-old fish among the migrants.

Effect of Incomplete Statistics of Gear on Index Corrections

The first problem arises when a catch is made before the fishery under observation has access to the fish. We have assumed that $T(1-e^{-fr}) = C$, so that

$$T = \frac{C}{1-e^{-fr}}$$

But to T there must be added an extra catch, C_e , to arrive at a total run, R , so that

$T + C_x = R$. The corresponding index would be

$$\frac{R_4}{R_0} = \frac{T_4 + C_{x4}}{T_0 + C_{x0}}$$

Substituting for T_4 and T_0 the value given above for T , we have

$$\frac{R_4}{R_0} = \frac{\frac{C_4}{1 - e^{-f_4 r}} + C_{x4}}{\frac{C_0}{1 - e^{-f_0 r}} + C_{x0}} \quad (3)$$

The variable of most concern, on the basis that gear is competitive, is the escapement, E , which determines the value of $1 - e^{-fr}$

If E of the base year becomes very large, r diminishes, so the value of $\frac{C}{1 - e^{-fr}}$ becomes very large, and C_x then is comparatively very small. In the limit the value of the index becomes by the same reasoning as before, page 31.

$$\frac{R_4}{R_0} = \frac{C_4}{C_0} \cdot \frac{f_0}{f_4} \quad (4)$$

If E becomes very small the value of $1 - e^{-fr}$ approaches 1, and $\frac{C}{1 - e^{-fr}}$ approaches C . Then in the limit the index becomes $\frac{R_4}{R_0} = \frac{C_4 + C_{x4}}{C_0 + C_{x0}}$

As a result of this, when the gear used is known for a part of the fishery only, the limiting index value $\frac{C_4}{C_0}$ should be continued as $\frac{C_4 + C_{x4}}{C_0 + C_{x0}}$. The other limiting value should continue to be $\frac{C_4}{C_0} \cdot \frac{f_0}{f_4}$. But the most probable value of the index can be calculated from the equation (3), given for $\frac{R_4}{R_0}$, using the known or assumed values of E , as derived from some base year between or as near as possible to the two years used in the ratio.

To illustrate the use of the index, the years 1911 and 1915 were chosen with an escapement based upon 1913 and with no extra catch. The correction is near a maximum for the index value for 1911. In Figure 9 the values of the index, regarding gear as competitive, have been calculated for various escapements, between 0 and 100 per cent. They are shown as the unbroken line. They illustrate the variation in the index which can be expected as the result of variations in the escapement.

The same calculations have been made on the assumption that there was an extra catch, C_{x4} , of 50,000 in 1915, in addition to the 159,991 of C_4 ; and that $C_{x0} = 10,000$, to be added to $C_0 = 192,231$. The resultant index values, when the escapement was varied, are also shown in Figure 9, as a broken line.

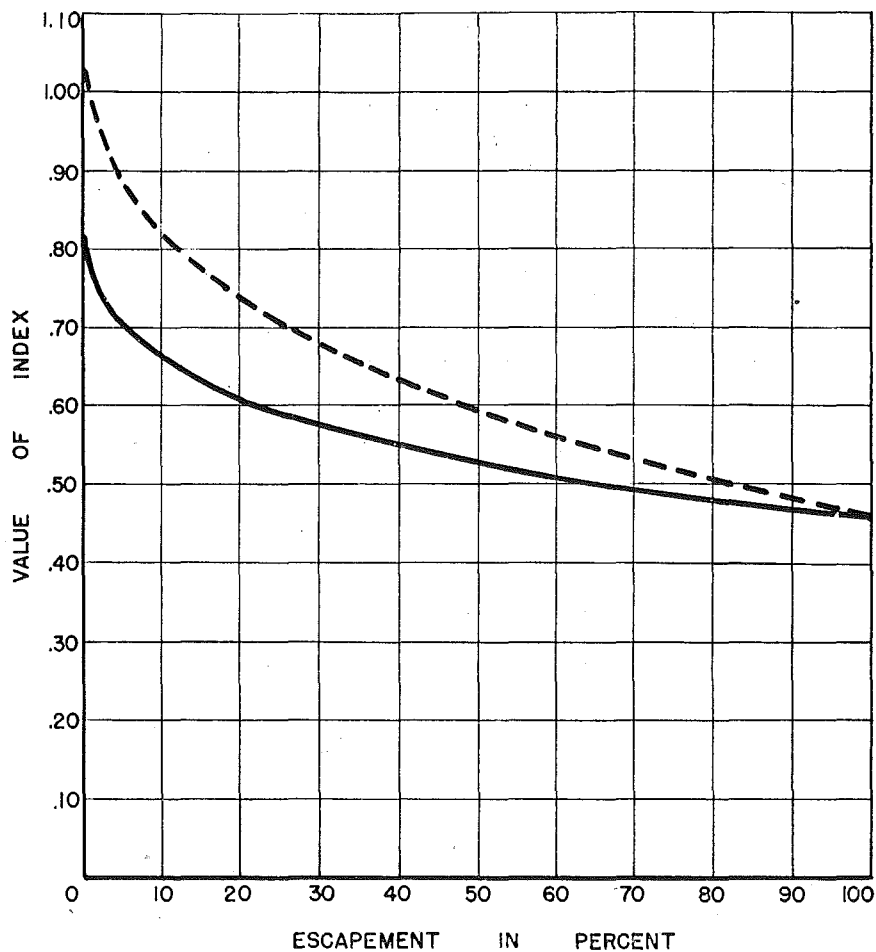


Fig. 9

THEORETICAL VARIATIONS IN THE INDEX OF SUCCESS OF RETURN PRODUCED BY VARYING THE ASSUMED ESCAPEMENT, USING THE RATIO

$$\frac{C_d}{C_0} \cdot \frac{1 - e^{-f_0 r}}{1 - e^{-f_d r}}$$

Without extra catch —————

With extra catch - - - - -

The error, due to unknown escapement, does not seem excessive at median values of the latter. Thus if an escapement of 60 per cent were postulated instead of one of 20 per cent, the index would be dropped from .73 to .56 in the case involving the extra catch, and from .61 to .50 in that of the main catch only. The actual error in estimating the escapement would be expected to be much smaller, such as the use of 30 per cent instead of 20 per cent. Moreover, it would apply generally throughout the index figures and would not alter radically their comparative values.

Since there are at present no available statistics as to the extra catch, it is not further considered in use of the index. In any case it would give values falling within the limits shown in Figures 7 and 8.

The case will arise when one section of the fishery occurs simultaneously with another, and when the gear used is known for one and not for the other. The catch per unit of gear will be known for the one section. If the total catch of the other section is divided by this catch per unit of gear, the result will give the number of units of gear of a known kind required to make the equivalent of the unknown fishery. Then the entire fishery can be expressed in terms of the known gear. The resultant correction is in the end the same as though the term C_w were used.

Effect of Diverse Ages on Index Corrections

As has been stated previously, the age determinations have not been used in the indices, partly because they are not available for all years, and partly because their significance is in doubt. But there should be a method of using them when they are available, if they are based upon adequate samples of the catch.

To facilitate this use of age, the total catch R is expressed as the sum of: ${}_4R_4$, the catch of four-year-olds returning in the year 4, and ${}_5R_5$, the catch of five-year-olds returning in year 5. As before R_0 is the catch of the parent year. Then

$$\frac{{}_4R_4 + {}_5R_5}{R_0} = \frac{{}_4T_4 + {}_5T_5 + {}_4C_{w4} + {}_5C_{w5}}{T_0 + C_{w0}}$$

$$\text{As already noted } T = \frac{C}{1 - e^{-fr}}$$

$$\text{Then } \frac{{}_4R_4 + {}_5R_5}{R_0} = \frac{\frac{{}_4C_4}{1 - e^{-f_4r}} + {}_4C_{w4}}{\frac{C_0}{1 - e^{-f_0r}} + C_{w0}} + \frac{\frac{{}_5C_5}{1 - e^{-f_5r}} + {}_5C_{w5}}{\frac{C_0}{1 - e^{-f_0r}} + C_{w0}}$$

The limit of this expression, as the escapement E approaches C in the base year, is

$$\frac{{}_4R_4 + {}_5R_5}{R_0} = \frac{{}_4C_4}{C_0} \cdot \frac{f_0}{f_4} + \frac{{}_5C_5}{C_0} \cdot \frac{f_0}{f_5}$$

Its limit, as E approaches 0 is

$$\frac{{}_4R_4 + {}_5R_5}{R_0} = \frac{{}_4C_4 + {}_5C_5 + {}_4C_{w4} + {}_5C_{w5}}{C_0 + C_{w0}}$$

The corrections discussed do not give rise to any question as to the reality and extent of the periods of depletion. For example, each correction for age, for gear efficiency, or for amount of gear tends only to shift the beginning of the second period to an earlier date, not to weaken the evidence as to its seriousness and its duration.

It may be pointed out that, if perfectly evaluated statistics were available, the correction might conceivably be used to determine the escapement. This is well

illustrated by the beginning of the record for the sockeye fishery. The index as derived from the catch is very high during the early days and the graph representing it falls rapidly until 1900 due to the constantly increasing size of the catch made by the increasing amount of gear (*see* Figure 2). By applying the corrections proposed for fishing intensity, this falling graph should be made to approach the horizontal. It could do so only if the escapement assumed for some base year were correct. This has been tried experimentally, using the statistics for gill-nets only, since that was the type mainly in use at that time. It was apparent that the correction on a basis of non-competitive gear was in excess of what was necessary; the resultant index values rose instead of fell, prior to 1900. The equation for competitive gear was therefore used and the percentage of escapement in the base year was varied until the correction approached adequacy. But since the gear used was in rapid process of change and new types of gear were being introduced, it is obvious that proper correction for efficiency could not be made. As a result the number of units of gear, or effort, were really unknown, and such calculations could have only a theoretical value.

The amount of fishing, denoted by the symbol f in the index, is not known accurately for any year in our records. The number of licenses issued is known. But not all licensees actually fish, and of those who do fish, some are active only during the part of the season when operations are most profitable. Economic conditions may affect the several types of fishermen differently in the different years, and with them the value of f . The efficiency of the gear may change. It will be necessary to measure these disturbing factors.

For the years here considered this cannot be done as completely as is desirable. The proper data are not available, even in the form of the number of vessels operating during each part of the season and their respective catches.

The effect on the index of such refinement of values of f should not be overestimated. Each point in the index is determined by comparison of two seasons four years apart, so that errors which are in the same direction in these two will have little effect. Radical changes in efficiency in such a period are not likely to occur without becoming obvious to the observer. A gradual and uniform increase of efficiency might change the general level of the index without affecting the large variations due to other factors. Moreover, conditions are likely to vary alike in years of the same cycle due to the presence of the same races. The nature of the index, as based upon a four-year cycle, is such as to favor accuracy of comparison.

It is also true that the index must be studied from more than one aspect. It may not only reflect the success of spawning, overfishing, and the effect of obstructions, but it will reflect changes in the amount and effectiveness of the gear used, consequently also any errors in the statistical treatment. There will be problems in statistical procedure brought to light as well as problems of other sorts.

In other fisheries, such indices as the catch per unit of gear are affected in a cumulative way by the mortalities, natural and otherwise. Factors such as intensive fishing alter the accumulated stock upon which the catch per unit depends. In the salmon, however, each value of the index depends upon the fish present in a pair

of years, and reflects directly the conditions for reproduction in the parent year. This renders adjacent values of the index independent of each other, and of peculiar value in reflecting variations of conditions in these adjacent years. Where the amount of fishing varies widely from year to year, or the effect of an obstruction fluctuates similarly, the range of variation in the resultant mortalities should give a better basis for determining the amount which the species can endure. In that way the index should be of greatest value.

As shown in this section of the report, the index has been calculated from all types of data available, including age determinations, and has been corrected, as far as possible, for the amount of gear fished. Both the numbers of licenses, and the units of effort derived from the data of Rounsefell and Kelez have been used. The result is shown in Figures 7 and 8. Comparison will show that the periods of depletion are little altered by the choice of these two.

What has been written should be summarized. The index is a simple one, made usable by definition of the limits within which it holds true. (1) It is based on the catch as the most usable record of the runs. (2) The effect of variation in age at return has been shown not to affect radically the conclusions drawn at present from the index. (3) The index can be calculated in ways which give the extremes, or limits, of the possible values, by taking into account the escapement, the amount of fishing, and the competitive nature of fishing gear. (4) The error due to incorrect estimation of the escapement is relatively small, does not radically alter comparative values of the index numbers, and is included in the limits calculated. (5) If in any instance these limits do not alter the conclusions, it will be immaterial as far as the index is concerned what the escapement is, or to what extent the gear is competitive, providing always that the measurement of amount of fishing is relatively correct in years of the same cycle. (6) The calculation is described in cases where the fishery might be incompletely known and where several age classes might have to be accounted for. (7) The index is presented in Figures 7 and 8, showing the calculated limits and the intermediate most probable values.

It can be concluded that the commercial catch shows the existence of two periods of depletion, one from 1899 to 1903, the other from 1911 to 1917. A third, and minor period, seems to have been present after 1933. It is shown in Figure 2. The origin of fluctuations after the second period will be discussed later.

TABLE 2

RECOVERIES AT ADAMS RIVER OF SOCKEYE SALMON TAGGED
IN THE FLUME AT HELL'S GATE IN 1942

<i>No. of Days Before Recovery</i>	<i>Tagged October 1, 2, 3</i>	<i>Tagged October 13</i>
10		2
11		7
12	1	11
13	2	4
14	5	3
15	19	5
16	15	8
17	23	2
18	30	1
19	12	3
20	20	1
21	12	1
22	8	
23	6	
24	2	
25	7	
26	0	
27	4	
28	1	
29	0	
30	2	
31	1	
32	0	
33	2	
34	0	
35		
36		
37		
38	1	
39		
40		
41		
42		
43		
44		
45		
46	1	
47		
48	1	
49	1	
Total Number	176	48
Average Days	19.6	14.0

C. EVIDENCE FROM SPAWNING GROUNDS AS TO DEPLETION

When depletion was referred to in the preceding section, it meant decline of the catch, whatever its causes. Something as to the nature of these causes can be surmised if it can be determined at what stage of the life cycle depletion first appeared, and what section of each year's run was damaged. Answers should be sought also to the questions as to what races were injured, what their habits of migration were and when the damage occurred.

To inform us as to these, there are two series of records which were maintained during most of the crucial years. One was loosely descriptive of the relative abundance from year to year in the more important spawning areas and the times at which the runs occurred. The other gave the take of eggs by the hatcheries which was a quantitative measure of the results of efforts to fill the troughs. There was an upper limit to their capacity, but within this the abundance of spawners was reflected.

It will be possible to understand these records and their limitations much better if the nature of a particular spawning run and its timing is known.

Description of a Spawning Run

To give an understanding of a run, especially one not obstructed in passage, an earnest effort was made in 1942 at lower Adams River to secure the greatest possible number of recoveries of fish tagged at Hell's Gate. In the normal year of 1942, this run was too late in the season to encounter difficult water levels. In this report an analysis of these recoveries can be presented only in the barest outline as required for an understanding of the depletion of the several places. The following is in part from material prepared by A. D. Welander for the writer.

The run to lower Adams River is shown by tagged fish marked at Hell's Gate during the season of 1942. In Figure 25 the numbers tagged each day at Hell's Gate are shown in the lower section, A. Recoveries are shown above according to the section of the river in which they were made, again by the day of tagging. The recoveries in the Shuswap region are given in the upper section, C. As will be seen, the fish tagged at Hell's Gate after September 20 were recovered either in the Shuswap area (principally Adams and Little Rivers) or en route thereto. The Adams River run, as it is called, is well marked at Hell's Gate. It began to pass Hell's Gate shortly after September 10 and lasted until the last week in October, a period of 45 days. Unfortunately, there were no means of counting these fish at Hell's Gate. The catch by tagging crews did not reflect the numbers passing because these crews were limited in their ability to handle fish when they were abundant. The recoveries therefore give no idea of the numerical importance of different sections of the run, except when the fish became very scarce.

The recoveries in lower Adams River were spread over a slightly longer time than they required to pass Hell's Gate—from the first days of October to November 20—a period under 50 days.

There was a lag of about 24 days between the initiation of the run at Hell's Gate and its beginning at Adams River. This did not mean that each fish required 24 days to go that distance. It meant that the most rapid of the early migrants required a minimum period of that length. The fish tagged at Hell's Gate on any given day were recovered in Adams River over a period of more than 25 days after the first arrivals. The recoveries included salmon which apparently migrated at different rates, or which were recovered at very different intervals after arrival. Constant watch was kept for tags. There is no way of distinguishing between delays in recovery and rates of movement, a fact which is of first importance because it makes the *average* length of time between tagging and recovery less significant.

To illustrate this, fish tagged on October 1, 2, and 3 of 1942 are used. These were passed through a flume at Hell's Gate and recovered in Adams River

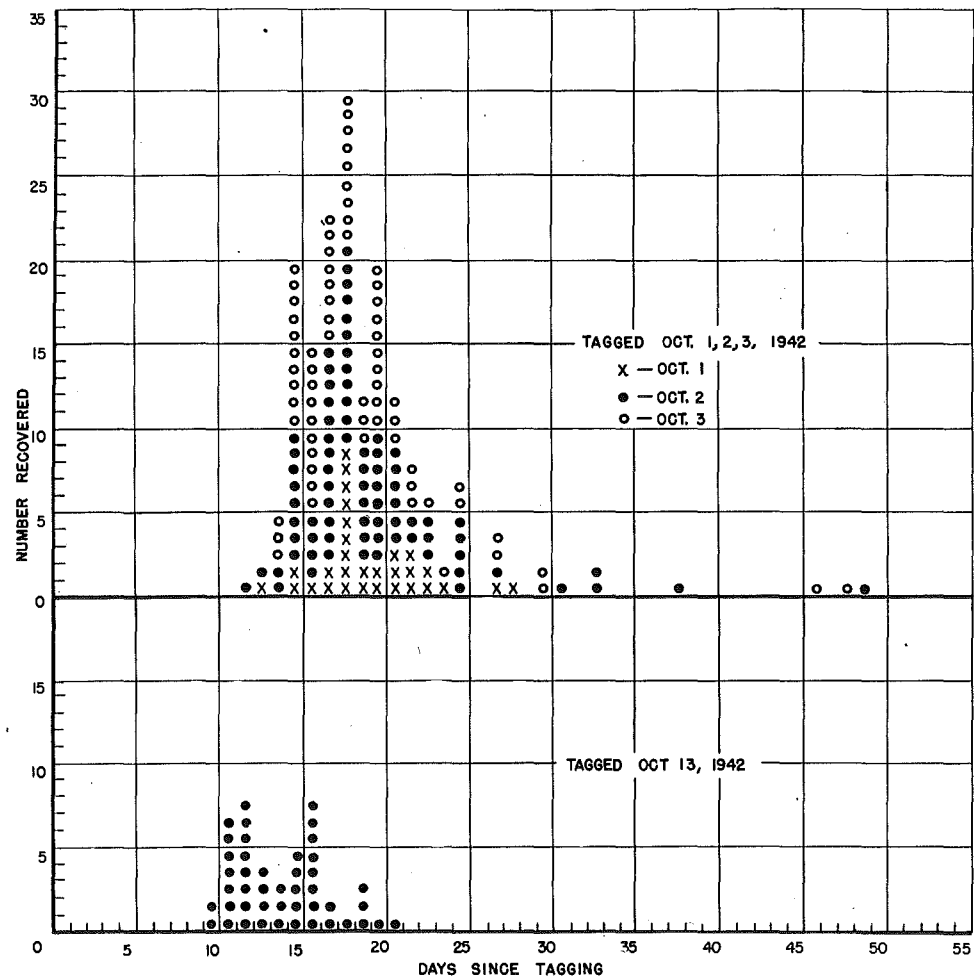


Fig. 10

TIME BETWEEN TAGGING OF SOCKEYE AT HELL'S GATE AND RECOVERY IN LOWER ADAMS RIVER, COMPARING TWO SAMPLES TAGGED ABOUT TEN DAYS APART.

as soon as discovered by the Indians who were employed to carry out an intensive search. The recoveries are arranged to show the frequency of recovery by the number of days after tagging, and are shown in Figure 10 and the middle column of Table 2. In this a fish tagged on October 1 and recovered October 10 is regarded as taken 10 days after tagging.

The curve of recoveries is quite skewed. The first arrivals required 12 days. The maximum numbers were taken after 17 or 18 days. The returns diminished gradually to an extreme of 49 days. The curve can be described as having 14.5 days for the first decile, 17.7 for the fifth, or median, and 19.6 days for the average. The first decile can be regarded as the most significant value, as it is free of the extreme variation shown by the first arrivals, and yet includes a minimum of the delay in recapture after arrival.

Another lot of sockeye was tagged in 1942 at Hell's Gate on October 13, ten to twelve days later. These are also presented in Figure 10 and the last column of Table 2, according to the number of days before recovery in Adams River, for comparison with those tagged October 1 to 3. They were recovered in a shorter time, the first after 10 days instead of 12. The first decile was 10.4 instead of 14.5, the median 13.5 instead of 17.7, and the average 14.0 instead of 19.6. This indicates a pronounced difference between various sections of the run. The 10 or 12 days' difference in date of tagging had meant a 4 days' shorter migration time.

TABLE 3
RECOVERIES AT ADAMS RIVER AND VICINITY OF HELL'S GATE
TAGS, 1942, ACCORDING TO DAYS AFTER TAGGING

<i>Date of Tagging</i>	<i>Number of Recoveries</i>	<i>Mini- mum</i>	<i>Days After Tagging Deciles</i>			<i>Maxi- mum</i>
			<i>1</i>	<i>5</i>	<i>9</i>	
Sept. 19-21.....	24	14	15.7	21.0	28.8	42
22-24.....	95	13	16.2	21.9	28.9	57
25-27.....	75	14	14.7	20.9	30.7	47
28-30.....	49	13	15.0	19.5	28.6	37
Oct. 1-3.....	73	11	13.6	16.8	23.2	50
4-6.....	64	11	12.3	15.4	23.6	46
7-9.....	48	10	10.2	12.8	17.6	30
10-12.....	51	9	10.6	13.6	17.4	39
13-15.....	55	7	9.4	12.5	19.5	30
16-18.....	40	8	9.1	11.3	15.0	29
19-21.....	18	8	9.4	12.7	17.2	25

To show this in detail for the whole Adams River run, the returns have been compiled for each 3 days of tagging. The maximum, minimum, first, fifth, and ninth deciles have been calculated and are given in Table 3 and Figure 11. The scattered early migrants prior to September 19 are hardly representative. The first decile seems a better point to define the commencement of returns from each

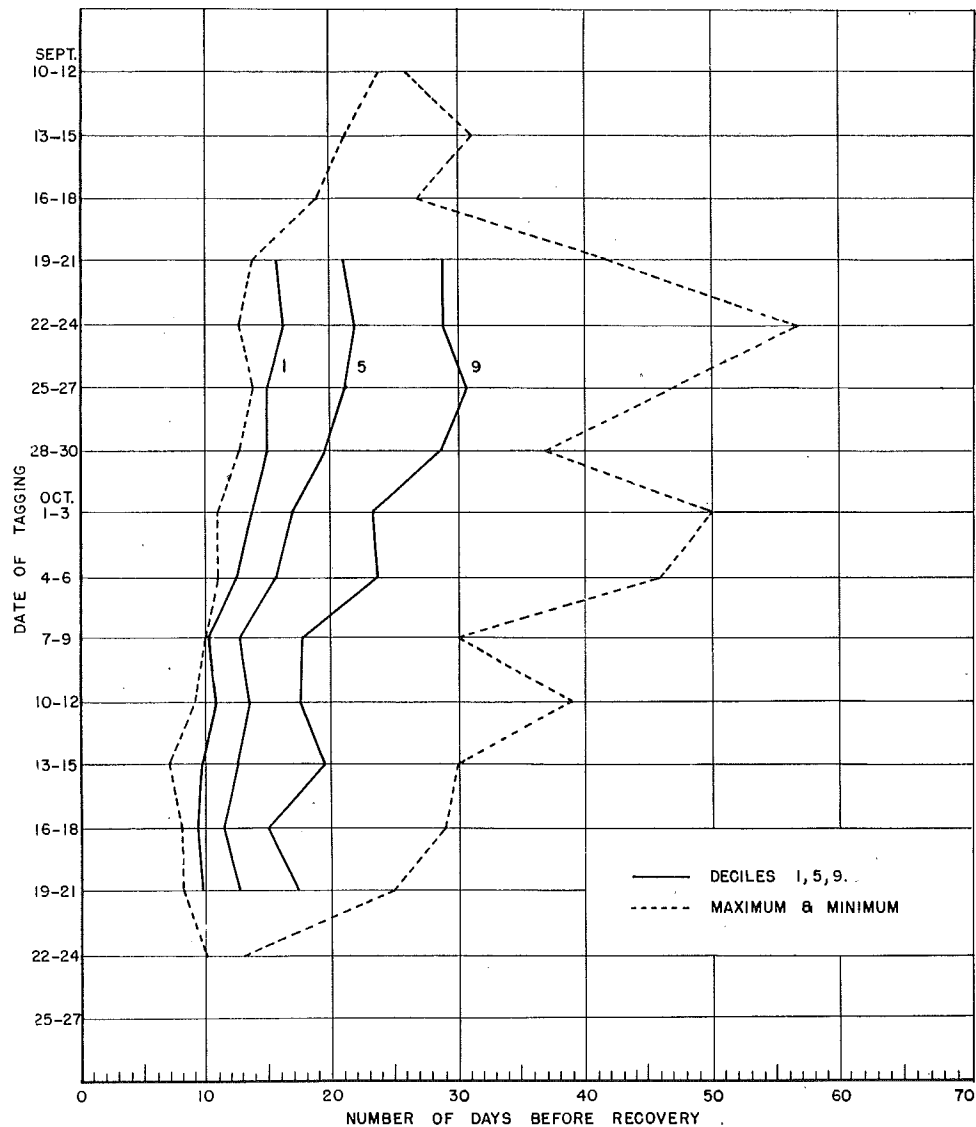


Fig. 11

TIME BETWEEN TAGGING OF SOCKEYE AT HELL'S GATE AND RECOVERY IN LOWER ADAMS RIVER, SHOWING FOR FISH TAGGED IN THREE DAY GROUPS, THE MAXIMUM, THE MINIMUM AND THE 1, 5 AND 9 DECILES OF FREQUENCIES OF TIMES BETWEEN TAGGING AND RECOVERY.

day's tagging than the very earliest arrivals provide. If this decile is used, the time of migration was at least one and two-thirds times as long early in the season as it was later. Approximately the same multiple may be applied to the median, to the ninth decile, and to the maximum times of recovery when comparing late and early season migrants. In short, the time required, including delays in movement and in recovery, lessened in about the same proportion for quick and slow recoveries as the season progressed.

TABLE 4

NUMBER OF SOCKEYE TAGGED DAILY IN SEPTEMBER
AND OCTOBER 1942

and

RECOVERED FROM THE SHUSWAP DISTRICT
(ADAMS RIVER AND VICINITY)

Date	Number Tagged	SEPTEMBER		Number Tagged	OCTOBER		
		Recovered Shuswap	Elsewhere		Recovered Shuswap	Elsewhere	
1.....	133		40	58	24		
2.....	144		51	80	44		
3.....	145		51	50	29		
4.....	123	2	42	80	41		
5.....	36	1	6	50	29		
6.....	20		3	83	45		
7.....	5			36	10		
8.....	3			94	51		
9.....	10		3	50	24	1	
10.....	60	3	27	100	52	1	
11.....	33	5	7	50	18		
12.....	12	4	3	82	35	2	
13.....	24	1	5	50	20		
14.....	51	18	5	100	46	3	
15.....	43	16	5	50	26	1	
16.....	25	9		100	48	1	
17.....	22	4	2	50	15		
18.....	31	7	3	56	23	2	
19.....	16	9		50	18		
20.....	13	3		55	15		
21.....	109	31	5	42	6		
22.....	118	39	3	13	1		
23.....	137	61	1	22	4		
24.....	135	56	2	5			
25.....	150	60	2	16			
26.....	100	46	1	26	2		
27.....	50	23	2	42	1		
28.....	100	52		3			
29.....	50	16		27			
30.....	55	27		8			

The Adams run as it now exists may thus be described as follows: The lower Adams River run of 1942 began to pass Hell's Gate September 10 and appeared at lower Adams River about 24 days later. The first of the heavy run, of most concern in case of damage, began to pass Hell's Gate September 21 and reached the river October 4, about 15 days later. The run ended at Hell's Gate October 20, and the first arrivals of that day's fish were taken in the Adams October 29, about 9 days later. This may be assumed to be the arrival of the last of the run, whatever delay occurred thereafter. The migration time of the run therefore varied between 24 and 9 days, as the season progressed. Since the lower Adams River is about 170 miles above Hell's Gate, migration a greater distance would have required increased time.

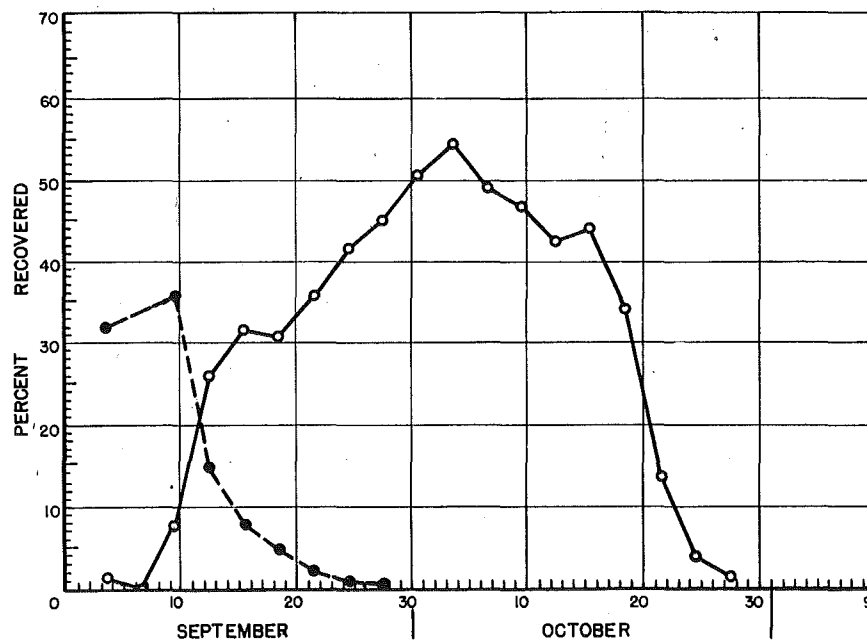


Fig. 12

PERCENTAGE RECOVERED OF SOCKEYE TAGGED IN THREE-DAY PERIODS AT HELL'S GATE
IN SEPTEMBER AND OCTOBER, 1942.

Shuswap District (including Adams River) —————
Elsewhere - - - - -

The last migrants spawned and died very quickly, in a time after arrival roughly proportionate to their reduced time of migration. Had they been delayed but a short time they could not have spawned even had they reached the grounds. The damage done by delay must accordingly be more serious later in the season, and the possibility exists that when a run is delayed large numbers of fish may not complete their migration and may die in places where they do not belong and where they do not reproduce themselves. They might be regarded as strays if marked in experiments designed to study the homing of salmon. Over-late migrants of this kind may possibly occur in unobstructed runs as natural variants which do not survive because they are part of the wastage of nature. Their

existence may explain the occurrence of ripe, inactive fish at the very end of a season in such places as Hell's Gate, and failure to find them later on any spawning ground.

When the Adams River run, including that to the adjacent Shuswap district, is examined from this standpoint, it is apparent that the recoveries are not equal from all parts of the run. They are shown in Figure 12 and Table 4. The recoveries rise from the beginning of the run, coincident in part with a decline in recoveries from other parts of the Fraser. The recoveries reach a maximum percentage for the fish tagged October 3, 4, and 5, and fall very rapidly to zero at the end of the run. A few fish are retaken in October en route to the Shuswap, but they may be ignored. It is hardly likely that the very low percentage recoveries at the end of the season can be caused by the presence of races bound for other parts of the Fraser, because in four years observation no such late races have been detected or indicated by a single recovery anywhere. Nor can the lack of recoveries be due to failure to search for them, as the search went on well into November, with recoveries from earlier tagging.

There is accordingly much difficulty in giving a single value to the range of migration time. It varies within the bounds of a pattern which may differ from locality to locality. It varies with the amount of delay in recovery, depending on the efficiency and speed with which tagged fish are taken. For instance, recoveries at Chilco may be largely after death, those at Adams more usually before. Accordingly only those individuals which can be assumed to have been retaken without delay in recovery will reflect variations between races in the true rates of migration. These individuals would be the first returns from any day's sample of tagged fish, provided continuous watch had been kept for tags. The minimum time required for the first fish of the season to go from Hell's Gate to the spawning ground should give the time between commencement of the run at Hell's Gate and its arrival at the redds. On such a basis, some comparison of our tagging results with the observations made in early years may be possible.

TABLE 5
MINIMUM TIME BETWEEN TAGGING AT HELL'S GATE
AND RECOVERY AT POINTS UPRIVER, 1942

<i>Locality</i>	<i>Distance Above Hell's Gate</i>	<i>Time*</i>	<i>Miles per Day</i>
Bridge River Rapids	76	4	25
Lower Adams River**.....	170	9	21
Farwell Bridge (Chilcotin).....	172	8	25
Siwash Bridge (Chilcotin).....	229	10	25
Nautley and Stella	467	20	25
Stuart Lake	475	16	32
Stellako River	480	20	25
Middle River (Stuart).....	540	20	28

* Inclusive of day of tagging. This was subtracted in calculating the miles per day.

** Using first decile of two days of quickest recovery with 42 recoveries.

In Table 5, the time between tagging and recovery of the fastest migrants is given for a number of localities. There is a probability that in each case these times are a minimum because they are for fish migrating at the end of a run. But it must be remembered that the pattern of behavior within each run may have been destroyed in varying degrees by an obstruction acting unequally on the first and last of each run, that the number of recoveries in small runs are usually very few, and the recovery far from uniform in promptness on redds which are only occasionally visited.

The number of days en route includes in each case the day of tagging and the day of recovery. It is therefore necessary to reduce the given time by one day on the average, to get the rate of movement. This has been done in Table 5.

The characteristics of the Adams River run may not be the same as those of other runs, but they should serve as an approximation in rate of movement, duration of run, and liability of damage by delay. They thus furnish a means of understanding disconnected observations in early years.

Spawning Ground Surveys by Districts

The spawning ground surveys were begun by Babcock in 1901 for the Province of British Columbia and have been continued. They are the only consistent records of what happened and are largely relied upon in this section.

Babcock said that 74 per cent of the spawning of the Fraser sockeye occurred in those grounds adjacent to the lakes of Quesnel, Shuswap-Adams, Chilco, and Seton-Anderson. They are here put in a supposed order of importance, but whether this was the correct ranking in early days is subject to question.

The observations made were not quantitative as a rule. Comparison was made of each run with the run four years earlier, or with some other in a very general way, as by saying it was "larger" or "a failure." The records have been carefully read, and what follows on each main spawning area is as conservative an interpretation of the evidence as possible. Answers to these questions were attempted: (1) What spawning grounds were affected by depletion? (2) At what times did the depleted races pass through the Fraser Canyon below Lytton? (3) What individual peculiarities in the history of the several races indicated the degree to which they were self-perpetuating units?

(1) Quesnel

The sockeye run to Quesnel Lake and thence into its tributaries was originally the greatest in the Fraser watershed as far as can now be ascertained. Its history gives as good a picture of the depleted runs as can be obtained from any source.

The Quesnel district includes the lakes and streams tributary to the Quesnel River, mainly Quesnel Lake, Horsefly River and Lake, and the Mitchell River. At the outlet of Quesnel Lake, and intercepting the runs to the tributaries mentioned, a dam was constructed in 1897 by the Golden River Quesnelle Company.

This was designed to hold back the water in the Quesnel River so that gold mining could be carried out in its bed. When in 1899 the dam was closed it was found that the tailings from the hydraulic operations at Bullion so closed the river that the bed could not be worked. The venture was a failure but it had a serious effect on the run of sockeye. The dam and its fishways are fully described by Babcock²² and by the reports of the Minister of Mines for British Columbia²³ for 1897.

The runs began to arrive at the dam in August, occasionally the last of July. The main runs fell during the last two weeks of August. Specific dates as to beginnings, maxima, and ends of the runs are given by Babcock and are reproduced in Table 6. The dates are obviously irregular, as might be expected of observations which were often obtained second-hand and casually. The beginning of the run is, as a rule, an event of note, and should have been rather precisely recorded.

From this, and our knowledge of the rate of travel of sockeye, it should be possible to estimate when the Quesnel runs passed through the canyon of the lower Fraser River. The distance to be traversed was 325 miles. If this were done at the minimum rate shown in Table 5, about 21 miles per day, some 15 days would be required. But this would be the time required by fast migrants, possibly at the end of the run. At the beginning of the Adams River run the time required was one and two-thirds that at the end. If so, a period of 25 days between first appearances at Hell's Gate and at Quesnel is indicated. If arrival at Quesnel in the seasons prior to 1913 was August 1 the run past Hell's Gate must have begun shortly after the first of July. In the same way the end of the run through Hell's Gate would be estimated as September 8 which would be 16 days before the last arrivals at the dam on September 24, a date which is the latest recorded and may have been unusual. The length of the run at Hell's Gate thus calculated is much longer for the Quesnel race than that for the Adams. It may be in error because the dates used are near the extreme early and late records given by Babcock.

As will later be seen, these dates, July 1 and September 8, are of great significance in explaining the depletion of the Quesnel run. They correspond to the season when the river at Hell's Gate is difficult of passage. They do not indicate that the early runs were in the river in May or June, despite the occasional belief that this was true.

There was no record of any other than the one run. Because more than one spawning ground lay above the lake, it must be surmised that this run consisted of more than one race, as races are defined in this report. The migration of these races, however, must have been at nearly the same time.

The record of the size of runs into Quesnel Lake is given in Table 6. The four-year cyclic returns should be followed through, and it will be seen that but one of them, that of 1901, 1905, 1909, etc., was of much importance at any time. There was no clear-cut record of what years were dominant before 1899. But

²² B. C. Fish. Dept. Rept., 1902, p. G 13.

²³ British Columbia. Dept. of Mines. Annual Report, 1897, p. 481-82, plate opposite p. 488. Victoria, B. C., 1898. (British Columbia. 7th Parliament, 4th session. Sessional papers, 1898).

those of 1905 and 1909 were decidedly so. There was a tendency, however, to regard runs as insignificant just because the big years had so many fish.

There has been much argument as to whether the inadequate fishway, replaced in 1904, allowed any sockeye at all to pass into the lake between 1899 and 1904. Doubt as to this would be expected as there would have been much difficulty in determining what percentage died below the dam, just as there had been at Hell's Gate over a long period.

TABLE 6

SOCKEYE RUNS AT QUESNEL DAM
FROM REPORTS OF BABCOCK

	<i>First</i>	ARRIVALS		<i>Numbers Entering Lake</i>
		<i>Maximum</i>	<i>Last</i>	
1899	"Noted" Aug. 24			Few, if any.
1900				Few, if any.
*1901	Last wk. of Aug.		October?	Evidence conflicting. Part only of large run passed dam.
1902	Aug. 5		Sept. 24	Few.
1903				Failure.
1904				"None".
*1905	Aug. 10		Sept. 1?	"Countless thousands thru new fishway"
1906	Jul. 26	Aug. 13-18	Aug. 20	Great many.
1907				Few hundred.
1908	Aug. 13		Sept. 18	20 per day.
*1909	Aug. 5		After Aug. 31	4,000,000 in Aug.
1910	No Report Published			
1911	Aug. 10	Aug. 29- Sept. 3	Sept. 15	Lightest in 20 yrs.
1912	Jul. 30	Aug. 4-28	Sept. 12	A big run.
*1913			Sept. 7	552,000.
1914	Aug. 7	Aug. 18-21	After Aug. 29	Poorest since 1898.
1915	Aug. 26	Aug. 26- Sept. 4	Sept. 4	Less than 3,000.
1916	Aug. 24	Aug. 27-30	Sept. 12	600.
*1917	Aug. 14	Aug. 23-29	Sept. 12	26,246.
1918				Less than 50.
1919				3.
1920	Sept. 2		Sept. 17	500.
*1921	Dam Removed in May			Very small run.

* Dominant cycle years.

There were differing views, possibly because some men wanted a new fishway and others did not. As far as 1901 was concerned the evidence was conflicting. But reliable observers quoted by Babcock stated that considerable numbers did pass in that year, and this they must have done to produce the large run of 1905.

It seems certain that relatively few passed in the other years between 1899 and 1904. The coincidence of this near closure with that of the first period of depletion is very striking. Anything which affected spawning grounds as important as those in the Quesnel district may well have been responsible for the depletion of the Fraser River.

At all events, from 1905 to the removal of the dam in 1921, there has been no question raised in any printed report as to the efficiency of the fishway. In the absence of scientific observation or experiment, no contrary opinion can be given whatever the actual condition.

The big years have been starred in Table 6. In 1901 only part of a large run is recorded as having passed. In 1905 there were "countless thousands"; in 1909, a count of 4,000,000 in August; in 1913, only 552,000; in 1917, but 26,246; and in 1921, a "very small run".

Babcock²⁴ elsewhere gives a slightly different count of adult migrants of these dominant years into Quesnel Lake. They are shown in the third column as follows:

<i>Year</i>	<i>Catch (cases)</i>	<i>Migrants</i>	<i>Ratio of Migrants to cases</i>
1909.....	1,688,334	4,000,000+	50:20
1913.....	2,395,000	550,000	5:20
1917.....	565,953	28,000	1:20
1921.....	144,698	Very few

The decline in adults reaching the lake in 1913 to less than 14 per cent of the number in 1909 shows beyond question the effect of a block in the river. But the number in 1917 is only 5 per cent of that in 1913. This is good evidence of the continuing effect of a block in 1917.

It will be noted that *in its proportion to the total catch*, shown by the last column, the migration into the lake was but a fifth of what it should have been in 1917 compared to what it was in 1913, small as the latter was, and a fiftieth of that in 1909. This plainly indicates that the escapement to Quesnel was being reduced at a rate far faster than the Fraser run as a whole.

The catch was coming to an increasing extent from other and undepleted or less depleted races, and whatever the factor decreasing the escapement, it was still operative in 1917. A possibly increased intensity of the fishery provides no complete answer, as the fishery in 1917 could not conceivably be 50 times as effec-

²⁴ Babcock, J. P. Periodicity of the Fraser river sockeye. (Pacific Fisherman, v. 16, no. 6, June 1918, p. 39).

tive in reducing the escapement as in 1909. The cause of depletion was affecting the Quesnel race to a greater extent than others.

The mere magnitude of the decline at Quesnel from the escapement of 1909 to that of 1913 seems to have diverted attention from the relatively greater rate of decline from 1913 to 1917. However great the chance of so-called accidental variations and errors in calculation, it should have raised an immediate question as to whether the river was clear in 1917, but it did not. It confirms the evidence already given from the commercial catch that the cause or causes of the period of depletion, including 1913 and 1914, continued until after 1917, that certain groups of races were damaged while others were not, and that the early runs were most affected.

These runs passed Hell's Gate largely in July and August, a fact which will be found to be of great significance.

It is possible that local causes of depletion were operative, in addition to the dam and to the block of 1913 in the canyon of the Fraser. There is now no way of testing the efficiency of the new fishway installed in 1904. While fish may have been able to use it at certain times, it does not follow that they were always able to pass. There were also extensive hydraulic mining operations which carried gravel and silt into the Quesnel below Likely. This may have injured not only the migrating adults, but also the young passing downstream, because of suspended silt.

Since it may be felt that the great hydraulic gold mine at Bullion may have caused such conditions and was responsible for the second period of depletion, the following history of the operation by Douglas Lay²⁵ has been taken from the Reports of the Minister of Mines of British Columbia for 1935. The property was worked for many years by a Chinese company. In 1892 it was acquired by J. B. Hobson and transferred to the Consolidated Cariboo Hydraulic Mining Company, incorporated in 1897. Up to the year 1905, a total of 12,000,000 cubic yards had been moved, but "the enterprise was not a success financially owing to an insufficient supply of water". The property was sold in 1906, and operations were suspended in 1907. "Subsequently, except for very brief periods of resumption in 1914 and 1921, nothing was done until 1926, and in the interim flumes, ditches, and equipment generally decayed from long disuse." In 1926 and 1927 it was reopened, partly repaired, and sold in 1928. It was further developed and sold again in 1930, and subsequently passed through the hands of various companies. It was operated several years between 1933 and 1941. It is, in 1944, not in operation.

The large runs of 1909, 1913, and 1917 could therefore not have been affected by the mine. It was not actually operating between 1907 and 1926. The run of 1909 was very large and a large return passed through the commercial fishery in 1913. The spawning run of 1905 must therefore have passed both mine and dam in sufficient numbers to increase the run in 1909. The latter must also have passed because the return catch in 1913 was hardly likely to have been so

²⁵ Lay, Douglas. North-eastern mineral survey district (no. 2). (British Columbia. Dept. of Mines. Annual report, 1935, pt. C, p. C 17. Victoria, 1936).

great were the Quesnel fish lacking. There is no reason to think that conditions in the river were altered between 1909 and 1913 by operation of this mine, and some other cause must be sought for the second period of depletion.

There is now no way of observing the damage because the mines are not operating, the fishway is gone, and there are too few fish left for observation.

It must be concluded that there were two periods of poor spawning escape-ments to the Quesnel district. One was from 1899 to 1904 inclusive, the other included the year 1913, but may have begun in 1911.

The way in which the index reflects damage is illustrated by the first period of depletion, due to the dam. This began in 1899 and ended in 1903, according to the index, because the value for 1904 is high. But the latter was based upon comparison of catches in the years 1904 and 1908, to which Quesnel contributed little. What damage had been done to the catches had occurred prior to 1904, and in that year the index no longer reflected conditions at Quesnel, but rather those in the remainder of the Fraser River. The level of the index was high, but it did not indicate that in 1904 the dam was passable. As a matter of fact, Babcock, in his report for that year, states that the fishway was not completed until September, and at a time when no spawning sockeye were below the dam.

The second period of depletion could not be assigned to any factor in the Quesnel district. But the resultant lack of spawners was evident there in 1913 and perhaps in 1911. The damage was done before the spawning adults reached Quesnel, and yet the Quesnel run suffered to a greater extent than other runs in the Fraser. If these conclusions are true, the damage must have occurred in the river en route to Quesnel, and at a time or at a place which affected Quesnel migrants particularly. This strongly suggests seasonal occurrence of an obstruction in the Fraser.

(2) Districts North of Quesnel

Above the junction of the Quesnel River with the Fraser River lie several large tributary systems. No spawning has been recorded in the Blackwater. Into the Nechako River on the west flows the Stellako, the Chilako, and the lakes and streams tributary to the Stuart. Farther upstream and to the east is the Bowron, containing the sockeye race which goes farthest up the main Fraser, although not as far in actual mileage as those of the Stuart system.

The runs to the districts north of Quesnel were very similar in time of migration to the run into Quesnel Lake. Those into Fraser Lake usually took place in August, but sockeye were seen occasionally in mid-July. They ended in September, but at times a new run began and ended in that month. In the Bowron district and Stuart Lake the timing was the same. Mention was made of an early and a late run into Stuart Lake. For example, in 1914 there was one in early August and another from September 15 to 22. In 1929 an early run occurred July 17 to 30 and a smaller one August 2 to 29. These runs were apparently brief and not at all of the character of runs such as have been studied at lower Adams River. No consistency can be discovered which would lead to a distinction between

natural early and late runs each year. These runs to the northernmost districts may well have passed through the Fraser Canyon in July.

The information at hand is too fragmentary to throw any light on depletion of these grounds. No information is at hand as to which years were dominant.

(3) The Chilcotin

The Chilcotin district has always been known as one of the major spawning areas above the canyon of the Fraser River. It was said to rank with the Shuswap-Adams Lakes, and to be near Quesnel in the size of its runs. It is far from equal to the run into the lower Adams now. The main, if not the only spawning area, is that at the outlet of Chilko Lake, which seems at present to be well seeded in the years of good runs. Spawning may occur in the lake itself. But lacking any exact quantitative estimates of the former runs, it is not possible in this report to state what the former or the present potential value of the district is.

TABLE 7
DATES OF SOCKEYE RUNS IN THE LOWER CHILCOTIN
ACCORDING TO BABCOCK

<i>Year</i>	<i>Dates</i>
1908	Aug. 18 - Sept. 1
1909	Aug. 15 - 27; Sept. 7 - 21
1910	
1911	Aug. 1; Aug. 15 - 18; Sept. 1 - 8
1912	July 28 - Aug. 11; Aug. 3
1913	Aug. 1; Aug. 10 - 28; ended Sept. 7
1914	Aug. 7 - 17
1915	
1916	Aug. 12 - 29
1917	Aug. 9; Aug. 20 - Sept. 5
1918	
1919	
1920	
1921	Aug. 4 - 18

It is worthy of a more careful examination than can be given here, because its runs have not been subject to local interference by dams, mining, etc. Whatever it indicates as to depletion in corroboration of what is found in the Quesnel and Adams districts will be of the utmost value, and indispensable to the conclusions in this report.

Observations on the time of occurrence of the early Chilcotin runs to Chilko Lake have been published only by Babcock in the series of reports already repeatedly cited. The references were much more fragmentary than those to Quesnel. They pertained mainly to the Indian catches at Fish Canyon (now

Farwell Canyon) and Hanceville. These are respectively 10 and 30 miles above the confluence of the Chilcotin and the Fraser River and no distinction between them need be made here.

The dates given by Babcock are listed in Table 7. The runs seem to have varied in length from three days to two weeks. This suggests either that the runs have always been subject to interruption or that they were recorded from statements by the Indians as to when their fish were taken. It is most unlikely that runs were actually as short as stated because unobstructed runs take a longer time to pass points such as Hell's Gate or Bridge River Rapids under the most favorable conditions. The best that can be done with the information is to regard it as indicating the beginning of the runs during the first half of August and their termination after September 8, thus including most of the dates listed.

On this rather insecure basis and with the help of the rates of migration given in Table 5, some surmise as to the time Chilcotin fish passed Hell's Gate can be ventured. It requires but 8 or 10 days for the most rapid migrants to go from Hell's Gate to the lower Chilcotin fishing stations. To be conservative this can be assumed to be the latter part of the run, and the time could be increased to 13 or 17 days for the early fish. If so, the beginning of the Chilcotin run at Hell's Gate must have been during late July. It must have ended in early or mid-September.

This contrasts with the Quesnel run which by the same type of calculation should have begun to pass Hell's Gate at the beginning instead of at the end of July. This is a point of great significance in explaining the survival of the run to the Chilcotin.

The timing of the Chilcotin run can be confirmed by the tagging experiments of 1940 and 1941. The recoveries in 1940 were 162 in number, sufficient to give a reliable picture. The fish were tagged at Hell's Gate between August 1 and September 10, if the isolated early and late strays are excepted. The recoveries (84) in 1941 had a very different distribution as to dates of tagging, the greater number being tagged between August 20 and 31. But scattered tags were placed over the whole period between August 1 and September 15. Thus, while the two seasons were similar, the daily distribution of the fish as they passed Hell's Gate was different. This difference will be shown to be an important indication of the effect of the existing obstruction as it varies from year to year. For our present purposes it will suffice that the general season of migration past Hell's Gate is at present much the same as that indicated by Babcock's reports.

The numbers reaching Chilko Lake are at present greater in two out of each four years. This has been true since the first recorded observations for the district. Thus there were more fish in 1908 and 1909, 1912 and 1913, 1916 and 1917, etc., than in the other adjacent years. The years 1908 and 1909 were both good. In 1912 and 1913 a change occurred. Whereas the run in 1912 had been better than that in its parent year 1908, the run in 1913 "did not nearly equal the number which ran there in 1905 or 1909". The runs were "little better" than in "lean" years.

The runs in the off years also declined. Those in 1914 and 1915 were small, but in 1918 and 1919 the runs were almost failures. In 1920 and 1921 they were somewhat better, in the latter year possibly "better than to any other section above Hell's Gate", which was not favorable comment in view of what was said about those other sections.

During the following years, until 1928, the reports indicate extreme scarcity in the Chilcotin.

TABLE 8
SCKEYE RUNS AT CHILKO LAKE

	<i>Estimated Spawners</i>
*1928	20,000
*1929	70,000
1930	900
1931	2,500
*1932	70,000
*1933	100,000
1934	3,500
1935	2,500
*1936	74,000
*1937	110,000
1938	7,000

From the records of the Canadian Department of Fisheries. Dominant years starred.

These observations do not lend themselves to any exact comparison, but their indications of depletion beginning in 1913 are unmistakable. They confirm the evidence from Quesnel and Shuswap that there was a general depletion of spawning grounds above the Fraser canyon (Hell's Gate).

Since 1928 the estimates have been made by the Canadian Department of Fisheries. The observers have attempted to be more exact and have given numerical values for each year. A comparison of visual estimates made in two years as far apart as 1929 and 1937 is necessarily difficult and estimates of the number present in such grounds as those below Chilko Lake cannot be free from error. But the comparisons between adjacent years should be acceptable and seem most significant as showing the persistent dominance of two out of each four yearly runs. The two are starred in Table 8.

The evidence from the Chilcotin shows the effect of depletion in 1913 plainly. No local causes were in evidence. This depletion occurred both in the Chilcotin and the Quesnel districts. This strengthens the opinion expressed as regards the latter that local obstructions were not responsible. The Chilcotin run did not disappear even for one year. It has improved in more recent seasons. This may have been due to the passage of the Chilcotin fish through the Fraser Canyon at a date later than that of the Quesnel fish so that it was not subject to the same difficulties in passage.

The characteristics and history of the runs to Quesnel and to Chilko are distinctive. The large runs to Chilko occurred in two successive years out of each four, that to Quesnel in but one. The time of migration was different, the Quesnel run beginning to pass Hell's Gate a month earlier. Perhaps as a result one improved while the other vanished. The various races have been subject to a depletion which has affected them unequally, and their rehabilitation has been distinctly different. These differences strongly support the concept that each race of salmon seeks its home stream.

(4) Seton-Anderson District

Two lakes, Seton and Anderson, are drained by Seton Creek which unites with Cayoosh Creek and joins the Fraser some 70 miles above Hell's Gate and just below the town of Lillooet. There are several small spawning grounds in tributaries to these lakes, and spawning has been recorded in the lakes themselves. The runs in Seton Creek are in large part of fish en route to spawning grounds on streams tributary to the lake above.

The hatchery on Seton Creek, the outlet of Seton Lake, was built in 1903 after one season's observation of spawning and was from the first a disappointment. For that reason a relatively close account of the runs there was given in the reports of Babcock. In studying the records, care is necessary as to the time of the runs because these early fish were held in weirs and their eggs were taken later. The egg take was not a measure of their numbers at any particular part of the season.

There were apparently two more or less distinct runs to this district. While there may be some question as to the origin of the two runs there can be little as to the effect of depletion on them. The two runs should be considered separately.

The first run arrived the last week in July and ceased generally the middle of August. The run was observed by Babcock mainly in Seton Creek, but a few miles from the Fraser River, and this creek was just below Bridge River Rapids. The time of migration from Hell's Gate to Bridge River Rapids, given in Table 5, was 4 days. There is little likelihood that the time to Seton Creek was longer. If so, the run passed Hell's Gate during the last half of July and the first part of August.

The early run was present until 1912 and 1913, with a few fish in 1914. It has never returned. The dominant cycle years should have been 1901, 1905, 1909, and 1913. In 1901 there was said to be a great spawning. What part of this belonged to the early and what to the late runs was not stated beyond the fact that there were great numbers of spawning fish present in October. Babcock reports an abundance of young migrating downstream in 1903 from this spawning, but no one had at that time, or has since, any means of evaluating the magnitude of such migrations. It does not necessarily indicate that the run in 1901 was exceptional. The return in 1905 from the spawning of 1901 was an early run only and was a disappointment. It totalled 200,000 which is but a small fraction of a really great run, such as was recorded for Quesnel. It was held in weirs at the entrance of both Seton and Anderson Lakes in order to complete the take of eggs for the hatchery. What damage was done by this delay and the mixture of races in the hatchery

TABLE 9

SOCKEYE RUN TO SETON-ANDERSON DISTRICT
FROM REPORTS OF BABCOCK

<i>Year</i>	EARLY RUN (<i>July and August</i>)		<i>Number</i>	LATE RUN (<i>September to November</i>)
	<i>Arrived</i>	<i>Stopped</i>		<i>Number</i>
1901				"Big" in October
1902	Last week in July	First week in Aug.	Many thousands	Light
1903			None	971
1904			500 or 600	About 1,000
1905	July 28	Sept. 30	200,000	None
1906	July 25	Aug. 17	15,000	Few hundred
1907			?	
1908	July 25	Aug. 15.	Main run of season. No better than 1907	Few
1909	Aug. 10	?	Few thousand	1,000,000
1910	No Report for this Year			
1911			90	
1912	July 25	Aug. 17	2,000	Over 10,000 blocked at Bridge River Rapids
1913			Under 2,000	Less than 30,000 mainly October
1914			100	400
1915				200
1916				100
1917				200
1918				
1919				
1920				
1921				None
1922				
1923				
1924				
1925				5,000
1926				Few hundred
1927				
1928				
1929				
1930				
1931				
1932				2,000
1933				
1934				
1935				
1936				12,000
1937				60,000

cannot be readily assessed. At all events the early season return four years later in 1909 was a few thousand only. Hence in 1905, 1909, and most certainly in 1913, this early part of the runs was not a major factor in the yield of the Fraser River. It is plain that it had declined from the beginning of observations until its final appearance in 1913. The disappearance of this dominant run and that of the runs in the adjacent off years of the cycle corroborates the existence of the second period of depletion of the races spawning above Hell's Gate.

The late run of September to November has been erratic in its appearance and character. It was said to have been large in 1901 and to have failed to appear in 1905. It was present in 1909 and 1912 and to some extent in 1913. It continued thereafter as but a few hundred fish annually until 1925, 1936, and 1937 in which years considerable runs took place. No commensurate return from the runs of the latter years has reached this district. The run has not been cyclic in character nor consistent in magnitude.

It is necessary to regard this late run as of irregular origin. It must have been distinct from the early run because two runs differing by two months in their maxima can hardly be the same in view of the consistency of runs elsewhere. If it was distinct, there was no return in 1905 from the great run of 1901, no explanation of the origin of that of 1909, nor of the occasional later appearances. But if it was not distinct, the sequence of generations was hardly more logical, because the early run in 1905 was relatively small, a fifth that of 1909, and provides a poor transition between the large runs of 1901 and 1909.

The late run in 1912 was said to have consisted of fish which had failed to pass a blockade at Bridge River Rapids, a difficult point in the Fraser above Seton Creek. Babcock²⁶ stated that the accumulation of fish at Bridge River Canyon became noticeable on September 10, 1912. This leads to an explanation of events at Seton Creek which is extremely interesting in view of conclusions reached later in this report. The water levels at Hell's Gate, as derived from readings at Hope, were above 26 feet until September 7. This is the level below which blocked salmon, accumulated during higher unfavorable water levels, are now known to be able to pass (*see* page 133 of this report). If the delayed fish were then released, this would have allowed three or four days time to reach Bridge River by September 10, a rate of travel corresponding to that shown by recently tagged fish. Babcock stated also that battered and disabled salmon appeared in Seton Creek soon after September 10. This could only be understood if these fish had been previously delayed at Hell's Gate. Fish midway in a normal migration could not be expected to fall back from Bridge River so quickly. The whole sequence of events is strikingly like that observed in recent years in connection with the obstructions at Hell's Gate and Bridge River Canyon, and hints strongly the existence of an obstruction in the Fraser Canyon, possibly at Hell's Gate, in 1912.

The late run in 1913 was also of ripe fish delayed by the blockades in the canyon near Hell's Gate. There was virtually no return in 1917. The run in October of 1925 was of fish in an "advanced condition" and many were said to

²⁶ B. C. Fish. Dept. Rept., 1912, p. 128.

have spawned in Seton Creek, not entering the lake. There was no return in 1929. Many of the fish of 1936 and 1937 failed to spawn, and there was no return four years later from either. Since 1937 the Commission observers have each year recorded strays from fish delayed at Hell's Gate and later blocked at Bridge River Rapids. The conclusion thus seems probable that this late run has been composed of strays and has been a delayed or obstructed part of runs en route farther up the Fraser, runs which should have passed earlier to spawn in October on their own grounds.

The late run therefore reflected the magnitude of the large runs to Quesnel and other grounds in the big year cycle, and did not reproduce itself. The failure in 1913 is consistent with that of the upriver runs in general and was a consequence of some factor delaying the early or mid-season runs. No conclusions can be drawn from the runs in 1910, 1911, and 1912 as to depletion other than the evidence of a blocked run, but the failures of 1913 and 1917 are consistent with the evidence of depletion.

After this lapse of time it cannot be said with certainty that the whole of this interpretation of the records is correct. It confirms the conclusion that the upriver races were depleted during the second period as shown by the index derived from the commercial catch. It points to damage lower in the Fraser to those runs normally running there before September and October. It points urgently toward an investigation of conditions at Bridge River Rapids and to the existence of difficulties in the lower Fraser Canyon as early as 1912.

(5) Shuswap-Adams District

The Thompson River is the largest branch of the Fraser River. Tributary to it are the Nicola, North Thompson, Adams, and several rivers entering the Shuswap Lakes. The Nicola had a large run of pink salmon prior to 1913 but no sockeye. The North Thompson has sockeye spawning grounds of small extent, such as those of Raft River, for which no reports exist for the early years. The lower Adams River, a tributary to Shuswap Lake, drains Adams Lake into which flow the upper Adams River and smaller creeks. The main sockeye spawning of the Shuswap district has occurred in Adams River from the beginning. Other streams tributary to Shuswap Lake are frequently mentioned as having runs prior to 1913, namely, Scotch Creek, Eagle River, Anesty River, Granite Creek, and Salmon River. The best record exists for Adams River and its tributaries.

The Adams-Shuswap run of sockeye was a large one prior to the second period of depletion. It occurred every fourth year as part of the big years in the catch records of the Fraser River. No runs are stated to have occurred in the off years of the cycle. This does not mean that they did not exist, but rather that at the time they were not worthy of note in comparison to the big runs. The dominance of the big years 1901, 1905, and 1909 was very marked.

There were two distinct runs to the Shuswap district. The runs usually began in August but sockeye had been noted in July of 1906. These early runs were similar in timing to those of Quesnel and other northern districts but were recorded

as early as May and June in the Thompson River. Unlike other districts the Adams-Shuswap area had a distinct late run appearing in the Fraser and lower Thompson about September 15. This was at times as great as the run in July and August. Spawning lasted well into October or November as was the case in 1909.

The two runs utilized different spawning areas. The early run spawned in Adams Lake and upper Adams River as well as other streams tributary to the Shuswap Lakes, such as Scotch Creek and Eagle River. To quote Babcock²⁷: "The run of sockeye to Adams Lake in August and September of 1901, 1905, and 1909 was so great that every tributary of the lake extending to Tumtum Lake, at the head of the watershed, was crowded with spawning sockeye. I visited the headwaters in 1905 and 1909, and saw countless thousands of dead and spawning fish there." This early run was very small in 1913 and 1917 and has never reappeared in numbers. The disappearance was common to all sections of the Shuswap, such as Eagle River and Scotch Creek, hence was not the result of local conditions on Adams River. The early run may have been present in small numbers in such years as 1919 and 1920, but the reports are not clear as to the time of the runs in those years.

TABLE 10
ESTIMATES OF LATE RUNS OF SOCKEYE TO
LOWER ADAMS RIVER

1901	?	1922	20,000
1902		1923	few
1903		1924	few
1904		1925	15,000
1905	very large	1926	300,000
1906		1927	100,000
1907		1928	10,000
1908		1929	?
1909	very large	1930	large
1910		1931	100,000
1911		1932	2,000
1912		1933	more than '29
1913	less than '09	1934	larger
1914	present	1935	100,000
1915		1936	4,000
1916		1937	same as '33
1917	some	1938	1,000,000+
1918		1939	100,000
1919		1940	
1920		1941	50
1921	few	1942	2,000,000±

²⁷ B. C. Fish. Dept. Rept. 1913, p. R 35.

There was left the late run, spawning in the lower Adams and Little Rivers (see Table 10). This was present in the early years of the big year cycle. In 1905 the run which began about September 15 was as great as that of August. In 1909 the late as well as the early runs were large. In 1913 there was no run up to September 25, and very few sockeye reached Adams Lake. But in that same year Babcock states:

"During October and November this year a considerable number of sockeye spawned in the lower-end of Adams River. For several miles above the river's mouth its waters were filled with thousands of spawning sockeye from the middle of October until the end of November . . . The gravel-beds of Little River were thickly crowded with spawning sockeye throughout October and November, . . . The gravel-beds of Little River do not appear to attract the sockeye of the early run, possibly because of the depth of water at that period."²⁸

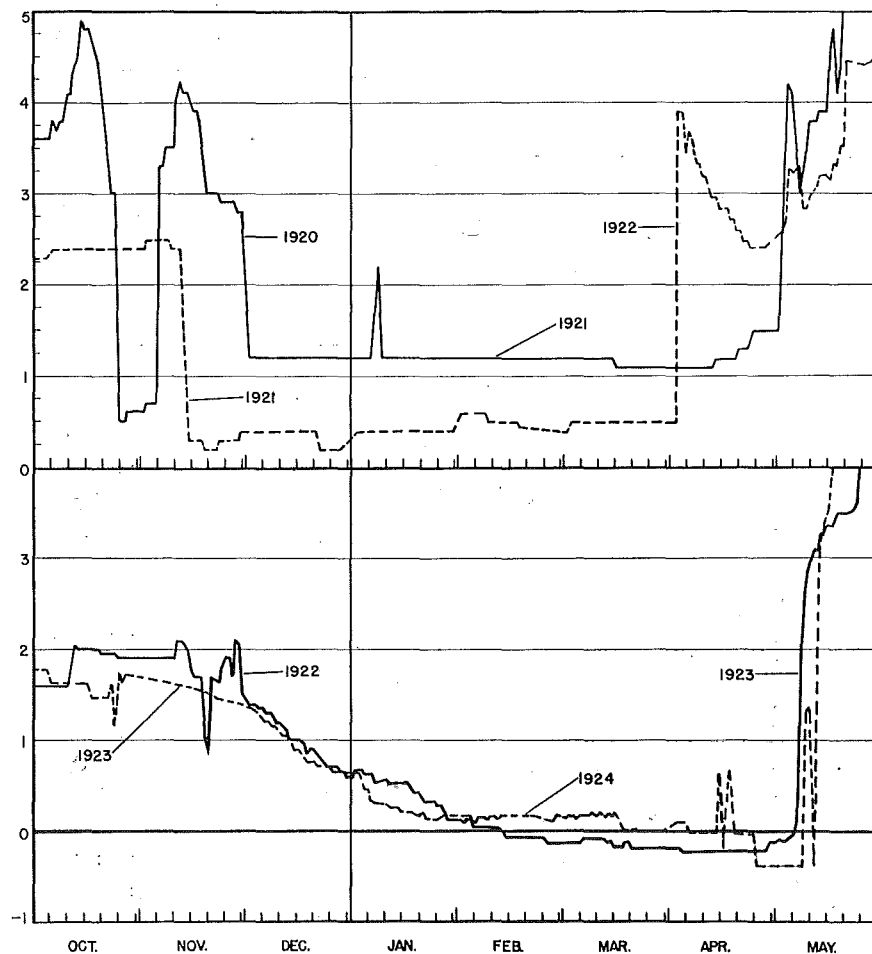


Fig. 13

WATER LEVELS IN LOWER ADAMS RIVER FOR YEARS 1920/21 AND 1921/22 CONTRASTED WITH YEARS 1922/23 AND 1923/24, TO SHOW RESUMPTION OF NORMAL LEVELS IN 1922/23.

²⁸ B. C. Fish. Dept. Rept. 1913, p. R 35-36.

This late run diminished in importance in 1913 and 1917. In 1913 it was large, in 1917 there were "some" fish, in 1921 "few", and in 1941 but 50.

To replace it a different, but also a late run, developed in one of the off years. At first these lesser years had not been worth much attention in comparison with the big year. One of the latter should have had a large late run in 1921. But it was a failure. Instead, in 1922 there were 20,000 recorded in the late run. Four years afterward this had risen to over 300,000, overshadowing the other three years of the cycle. In subsequent seasons it came to dominate the runs of the other three years of each cycle with the truly great spawning runs of 1938 and 1942, the greatest in the Fraser River. The cycle years 1913, 1921, 1941 had become off years, replaced by 1922-1942.

The disappearance of the early run into Adams Lake is consistent with the widespread failure of 1913 and of subsequent years in that cycle sequence. So, too, is the diminution of the late run of the same years. Its reappearance resembles that of the Chilcotin, but it was peculiar in that the dominant year in the cycle came a year later in each four-year period. This shift must have been due to changes in the lower Adams River, because it was confined to the run of that stream.

A dam built at the outlet of Adams Lake, hence at the head of the lower Adams River, may have been responsible. This was built to store water in Adams Lake so that logs could be flushed through Adams River into Shuswap Lake. It was constructed in 1907 and relocated in 1908 at its present site. As a consequence the water levels in lower Adams River were made to rise and fall sharply and frequently during the spawning season and during the later fall, winter, and spring months when eggs were in the gravel.

Although a fishway existed in the dam, it is possible that the dam may have contributed in part to the failure of the early run which passed through it to reach Adams Lake. The fishway appears to pass fish at present when the dam gates are inoperative and may have always done so. Violent changes in level, as great as 5 feet, due to storage and abrupt release of water occurred during August and September when sockeye must have been passing. At this late date there is no method of measuring the damage, and little complaint was made at the time.

It is most probable that the dam may have adversely affected the late runs, spawning in lower Adams in October and November, the more so as the eggs were in the gravel during the following winter. Sharp fluctuations in level would have either exposed the eggs and fry to drying or freezing, or washed them out of the redds. It was not until 1922 that the water levels approached normal in October and the following months. In Figure 13 the levels of that year are contrasted with those for 1921 when there should have been a large run, and for 1923 when the spawning must have been successful because of the increased return in 1927.

The coincidence between the first approach of water levels to normal and the subsequent dominance of the late runs from that cycle year is significant, because it was in 1922 that the present dominance of the cycle 1922-1926-1942 had its origin. It should have begun in 1921, had the earlier "big" year persisted.

The other off year runs, 1923, 1924, and 1925 did not increase as much. The water levels during the season of 1923 also approached normal, and the run increased in 1927. The water levels were allowed to fall sharply at the last of November in 1924, and perhaps as a result, no increase appeared in 1928. The spawning season of 1925 was followed by two months of very small flow in January and February, but we do not know what the return was in 1929.

It is necessary to conclude that we do not know with any exactness just how the spawning run through the Adams Dam and the spawning below it was damaged in the years from 1908 to 1930 by the violent fluctuations of water level, and drying and flooding of redds. We do know that after the dam had fallen into disrepair and its regulation of water levels had ceased, a different run, one late in the season, emerged. Access to the upper Adams spawning grounds by the fish running in August has not rebuilt the race native to that river. Perhaps it is extinct, but perhaps also the cause of depletion was at Hell's Gate and has persisted.

The existence of a dam on the Adams River cannot, however, explain the failure of 1913 which was general throughout the upper Fraser River. In that year the adults were present in the sea, as the large catch attests. They failed to reach the spawning grounds. In that year the great early run was absent below the Adams River Dam and in Little River through which they must have passed. The fish disappeared from all the streams tributary to the Shuswap Lakes, such as Scotch Creek and Eagle River, and these were not affected by the Adams River Dam. The widespread damage was therefore done en route to these spawning grounds, not on them, and not in the brood year 1909.

The timing of the late run now present, has already been discussed in detail (*see* page 43). That of the early run is not precisely stated, but in 1902 it was said to have arrived in early August, and in 1906 sockeye were present in Kamloops Lake and Little Shuswap in June and early July. If so, the main early run must have passed Hell's Gate in June and July.

It may be concluded that the early run to the Shuswap district, including Adams Lake and River, was lost during the second period of depletion. It passed Hell's Gate earlier than other runs. In some years the first of its migrants reached there as early as the last of May. The later run to the lower Adams was also lost, but probably as a result of the use of a dam in the lower Adams. It was replaced by a run in a different cycle year. The evidence here, as elsewhere, points toward damage to the runs during the early part of the season, and the disappearance of certain upriver races.

(6) Harrison-Birkenhead District

The Harrison River joins the Fraser well below the Fraser Canyon. It includes two spawning areas frequently mentioned in official reports of the British Columbia and Canadian governments, which have been used as a basis for the comments following. As elsewhere, those of Babcock for the Provincial Government are the principal source.

The hatchery on Harrison Lake secured eggs from a number of small spawning grounds. These included Morris Creek, Cultus Lake, Pitt River, Silver Creek,

and at times others. These were all relatively small spawning grounds which formed one district, from an administrative standpoint, including the streams tributary to Harrison Lake with the exception of the Lillooet River at its head.

The latter is traversed by a run which spawns in the Birkenhead River, and is the largest in the Harrison system. A hatchery was operated for many years on this river, at Owl Creek, by the Canadian government. Consequently, enough mention is made of the run there to justify discussion of its changes.

The records are so fragmentary and relative in terms that they cannot be satisfactorily tabulated or quoted. Perhaps they will fall into more useful patterns when an intensive study of the district is made. They are reviewed here to show that they give us no indication of the periods of depletion which so plainly affect the upriver runs.

HARRISON LAKE. The various spawning areas near Harrison Lake are relatively small and have been regarded as a unit only because they were used to obtain eggs, first for the hatchery at New Westminster and then for that at Harrison Lake. The races inhabiting them have probably had very different individual histories, which might be followed if the records had been adequate and precise. Because of this diversity, the total yield of eggs has been reliable but the runs of each locality have varied so that disappointing years have come for each sooner or later. As a result there has always been reason for complaint by the hatchery men, if not on one score, then on another. Of these sources of eggs, Morris Creek has yielded more consistently, but not heavily, from 1885 on. The record as a whole seems as discouraging before 1913 as after, and is difficult to interpret.

The year of the disaster in Hell's Gate, 1913, had a better run than did 1909. But 1914 was poorer than 1910. In 1915 the run was better than in 1911. There is no evidence of the periods of depletion noted for districts of the upper Fraser. The failures which came were for individual years.

The runs to the lower streams were said to be later than those to the upper Fraser. A run was said to have been developed for the small stream at the hatchery on Lake Harrison, where none previously existed. Other than this, evidence of individuality bearing on the existence of separate races has not been recorded.

BIRKENHEAD. This has been one of the most consistent spawning areas in the Fraser River system. The annual reports give no indication of any such periods of depletion as have been noted for the runs to the Fraser above the canyon. As elsewhere, there has been no exact enumeration of the spawners, and comparison was a matter of memory. Babcock's reports state that the runs of 1920, 1923, and 1925 were as large as any since 1902. Runs in 1915, 1919, 1922, 1931, 1935, and 1936 were very good. It was true that 1913, 1917, 1918, and perhaps other years were below expectations, but they formed no part of periods of depletion.

There seems to have been no single dominant year in the four-year cycle. There appear to have been two of the four which averaged better than the others, from 1915 and 1916 to 1935 and 1936. But it is not clear that this was true of

earlier years. The big year on the Fraser did not coincide with either of these, nor were the two dominant in every cycle.

There are indications that the Birkenhead spawning was originally both early and late, that the early part of the run was often to the streams above the hatchery weir, and that this section of the run disappeared in later years. If so, it may have been due to the weir. This has not been erected for several years, certainly not since 1936 when the hatchery was abandoned.

The Harrison-Birkenhead district has thus given no indication of the periods of depletion which were common to the districts above the lower canyon of the Fraser.

Hatchery Records

Information confirming the existence and duration of the periods of depletion can be obtained from records of the number of eggs taken in hatcheries on the Fraser River when such are consistent throughout the years. To this end the available hatchery records for the Fraser system have been collected insofar as this is possible from published reports. Records of sufficient continuity were available from the hatcheries at Harrison Lake, Birkenhead River, Seton Lake, and Granite Creek. The first two of these hatcheries were on streams joining the Fraser below Hell's Gate and the last two on streams above. A good deal of what is definite in the evidence as to the decline in the runs to sections of the Fraser came from the interest in these hatcheries.

The first fact which is apparent is that both of the hatcheries in the upper Fraser at Seton Lake and Granite Creek were founded shortly after, and perhaps as a result of, the first period of depletion. They showed high egg takes during the period of recovery and failed with the coming of the second period of depletion during which they were closed. Their history is strikingly unlike that of the two hatcheries on the lower Fraser.

The evidence from the hatcheries is particularly significant because they were so located as to depend on eggs from streams not affected by dams, mining, etc.

There was only one hatchery above Hell's Gate, namely, that at Granite Creek, Shuswap Lake, which could be regarded as giving a reliable year by year indication of the spawning runs. The take of eggs is shown in Table 11 and Figure 14.

The graph may be somewhat misleading because of the great dominance of the 1909 cycle. Each year's take should be compared with its own cyclic recurrence every fourth year. The take of eggs each year for the Granite Creek hatchery has been shown accordingly as a percentage of the average return of that year of the cycle during the 14 years of hatchery operation. Thus the average take of eggs in the cycle years 1901, 1905, and 1909 was approximately 19 million. The yield was 58 per cent of this in 1901; 96 per cent in 1905; and 146 per cent in 1909. The same calculation of percentage was made for each of the four cycles. The resultant percentage curve is shown in Figure 14.

In the same figure the index of success of return as already calculated from the commercial catch is shown for comparison.

TABLE 11

TAKE OF EGGS AT FRASER RIVER HATCHERIES

<i>Year</i>	<i>Granite Creek</i>	<i>Seton Creek</i>	<i>Birkenhead</i>
1901	11,000,000		
1902	796,000		
1903	770,000	2,068,000	
1904	189,000	827,000	
1905	17,978,000	44,150,000	28,000,000
1906	7,193,000	1,887,000	21,500,000
1907	828,000	827,000	28,000,000
1908	635,000	825,000	20,757,000
1909	27,500,000	30,500,000	28,000,000
1910	2,337,700	2,177,000	7,000,000
1911	50,000	163,000	12,500,000
1912	50,000	11,026,000	25,000,000
1913	4,034,000	26,540,000	25,000,000
1914	105,000	200,000	15,220,000
1915			25,250,000
1916			25,750,000
1917			5,270,000
1918			11,960,000
1919			31,655,000
1920			26,000,000
1921			26,053,000
1922			26,000,000
1923			30,629,000
1924			31,200,000
1925			40,418,000
1926			45,350,000
1927			37,000,000
1928			35,010,000
1929			18,000,000
1930			35,209,925
1931			20,425,000
1932			22,710,000
1933			10,680,000
1934			20,400,000
1935			24,410,000

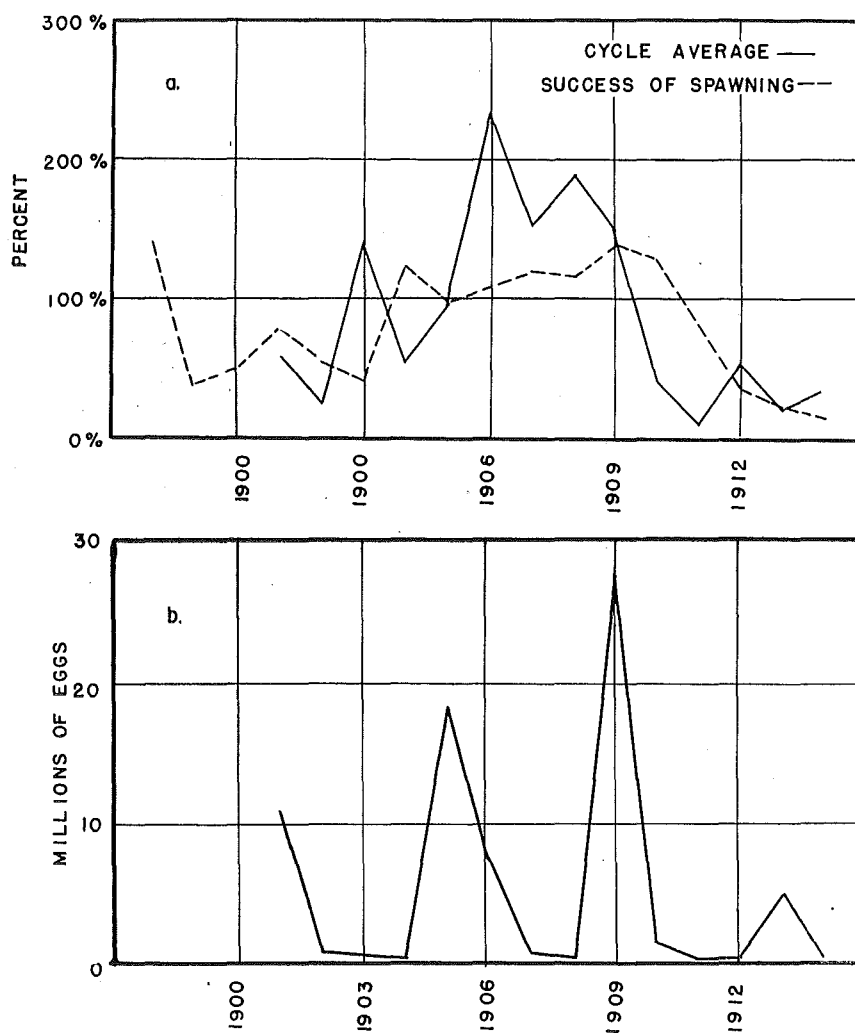


Fig. 14

COMPARISON OF TAKE OF EGGS AT GRANITE CREEK HATCHERY WITH INDEX OF SUCCESS OF RETURN, 1899 TO 1914.

$$\left(\text{Index} = \frac{C_1}{C_0}\right)$$

It should be noted that this is a comparison between a sample of the number which spawned and the catch (total for the river) of returning adults. As might be expected, the two indices correspond only roughly. There is hardly more than a coincidence between the period of runs having good returns separating the two periods of depletion, and the general period of successful operation of the Granite Creek hatchery.

The decline of egg production at Granite Creek in 1910 rather than 1911 is interesting since the indices based on an age composition of 80 per cent four-year-olds and 20 per cent five-year-olds show the same.

Of the two hatcheries above Hell's Gate, that at Seton Creek was subject to extraordinary conditions. As shown elsewhere in this report, fish obstructed in passing a point just above the junction of Bridge River and the Fraser drifted downstream and were occasionally taken in great numbers in Seton Creek.

Babcock stated that in 1912 the greater number of eggs was obtained from fish en route up the Fraser which had taken refuge in Seton Creek. Judging from his description of the hatchery operations in 1913, the egg take of that year had the same origin, as it was from fish advanced in ripeness and arriving much later than the usual run. No runs returned in 1916 and 1917 from the takes of eggs in 1912 and 1913. There is no reason to question the origin of the eggs in other years, and in 1905 and 1909 the takes were limited only by the capacity of the hatchery. Moreover, the take in 1911 was far below that of the cycle year 1907. Understanding this, the records are then consistent with those at Granite Creek and confirm

the evidence of depletion beginning in 1911. Babcock was of this opinion, as he states:

"... Hatcheries located at Shuswap and Seton Lakes, the only hatcheries in the upper section, have been closed because a sufficient number of Sockeye have not reached those lakes in recent years to afford a supply of eggs. No eggs were or could have been collected at either of those lakes in the last three years."²⁰

The mention of the last three years, presumably 1915, 1916, and 1917, should be particularly noted as indicating years during which spawners were absent and which had not yet been associated with the difficulties of 1913 and 1914 in the Fraser Canyon. The parent years of 1915 and 1916 were 1911 and 1912, before the difficulty was supposed to have occurred in the canyon, and 1915 and 1916 were after the difficulty was

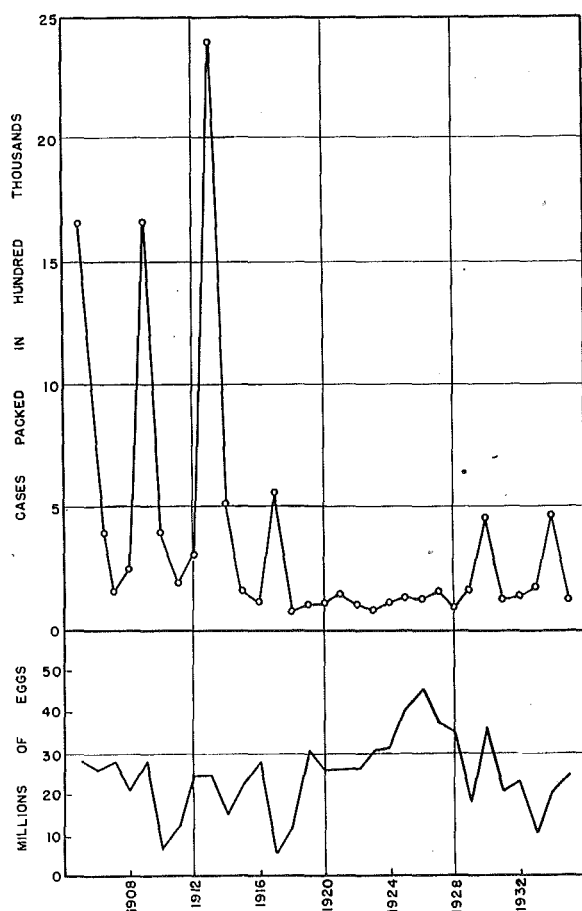


Fig. 15

COMPARISON OF TAKE OF EGGS AT BIRKENHEAD HATCHERY
WITH PACK OF FRASER RIVER SOCKEYE, 1905 TO 1935.

²⁰ (Pacific Fisherman, June 1918, p. 39).

supposed to have been removed. It is apparent by this evidence that depletion covered a period of several years, probably 1911 to 1917. This bears out the evidence from the commercial catch.

The hatchery records for the Fraser River below Hell's Gate have also been examined. Two of the hatcheries are worthy of attention, namely, Harrison Lake and Birkenhead, since they have the longest continuous records. At both there was no real lack of eggs in later years although at times greater effort was necessary to secure them. The Harrison Lake hatchery drew from many spawning grounds in the lower Fraser, and its troughs were frequently filled with imported eggs so that the total eggs in the hatchery can hardly be used as an index to the escapement. But there was no general failure of the supply of eggs, such as there was of the catch as a whole. The take of eggs at Birkenhead is shown in Figure 15. It does not show the prolonged periods of depletion indicated by the commercial catch. Its poor years are not so distributed as to show any cause of failure. There were good and bad years but no persistent or continuous failure to secure eggs. At Birkenhead (*see* Table 11) the years 1910, 1914, and 1917 were low, with 1911 and 1918 but slightly better. It may be concluded that if the hatcheries reflected conditions general to their districts, the lower Fraser did not suffer a period of depletion while the upper Fraser did.

The continuation of a run sufficient to supply eggs below the canyon is in sharp contrast to the failure of the hatcheries above. The fact that races spawning above the canyon of the Fraser were depleted and those below were not indicates that the depletion was due to mortality in the canyon through which the injured races passed.

Opinion of J. P. Babcock

The early reports on the spawning grounds during the second period of depletion between 1911 and 1917, are in large part those of J. P. Babcock already cited repeatedly. His opinion as to the particular races which were depleted is therefore worthy of special note.

His surveys in 1913, in his opinion, proved decisively that the big run of that year did not reach its spawning grounds in those sections of the Fraser above the lower canyon. His observations of conditions in the canyon were sufficient to indicate very clearly the cause of this failure for that year and will be reviewed later.

In Babcock's opinion the spawning above the canyon had been and has continued to be greatly reduced for a period of years following 1913 while that below has been sustained. This uneven depletion of the grounds since 1913 has not been confined to the big years as he clearly shows in his annual reports. The report of 1924 states:

"The present run of sockeye to the Fraser River system must certainly be attributed to the races that spawn in the Birkenhead-Harrison-Pitt-Cultus Lakes section of the Lower Fraser basin. The numbers of sockeye that have spawned in the basins above Hell's Gate in the last ten years have been too small to be a factor in the run that now seeks the Fraser. The greater part of the present run must be attributed to the Birkenhead spawners."³⁰

³⁰ B. C. Fish. Dept. Rept. 1924, p. I 41; *see also* Rept. 1920, p. S 13.

Prior to 1913, the spawning in each big year, 1901, 1905, and 1909, was abundant above the canyon. The contribution of that area in off years was overshadowed by that of the big years.

In 1907 Babcock³¹ had seen six seasons since he began to observe, but his comparisons to show decline in that time carry him back to still earlier runs, and he spoke of the off years in particular. If we read his text correctly, he was convinced that the relatively good runs of early off years, which he did not personally observe, must logically have been produced in the upper Fraser. In his experience the spawning grounds in the lower Fraser were always "well seeded"; that is, to their capacity, even during the years of the poor runs which he had seen. Hence he was at a loss to explain the earlier larger runs of the off years otherwise than by spawning in the upper Fraser. "... no one section is of sufficient extent to have produced so many fish."

If this is correct, the depletion of 1899 to 1904 was confined to the upper Fraser just as was that of 1911 to 1917, and as is that of the continued low level of production to the present date.

Despite his conclusions as to depletion being confined to the upper Fraser, Babcock throughout his reports in years subsequent to 1913 maintained that the run to the river was overfished. In support he gave no factual proof but urged international action to restore the run.

D. DISCUSSION OF CAUSES

The evidence thus far presented may be summarized.

The various spawning grounds of the Fraser River have been occupied by races which have had their own characteristic cycles of abundance, their own times of migration, and their own individually distinct histories. Strong support is given to the "home stream" theory and it is evident that these races exist and must be dealt with as self-perpetuating units, capable of separate depletion and rehabilitation.

There have been two main periods of depletion, both longer than one year. The first lasted 5 years, the second 7. Each was limited to those races spawning above the canyon of the lower Fraser River.

The depletion of 1899 to 1903 coincided with an inefficient fishway in the dam at Quesnel Lake. It did not persist after the improved way was installed. Each cycle affected recuperated prior to 1913 except that of 1899-1903-1915. The latter run took place twice within the period and because of this seemed to have been more seriously hurt than those which took place once within the period. This cyclic run has continued to be the poorest year in the four as late as 1939 and 1943 (*see* Figure 3).

The second and more important period was from 1911 to 1917. It occurred in all spawning grounds above the canyon on which information is now available, either as direct observations or hatchery records. Possible local causes of damage

³¹ B. C. Fish. Dept. Rept. 1907, p. 16; 1908, p. 18.

do not appear to have been primarily responsible, although they may have contributed.

The damaged races most probably passed through the canyon in June, July, and early August. Those left to produce the existing large runs to Chilko and Adams River were later in passage, particularly that to Adams River, which began in August or later. These have recuperated since the second period of depletion. The replacement of an early season run to the upper Adams by a late season run to the lower Adams lends particular emphasis to the more favorable conditions given the late season runs.

It is definitely known that the run of one year, 1913, was blocked by rock dumped into the canyon during railroad construction. There is also evidence from Seton Creek that the run of 1912 was delayed by conditions in the canyon, a fact for which explanation must be found.

It would seem, from the evidence thus far presented, that the cause of the second period of depletion lay in the canyon of the lower Fraser River, that it was effective over a period of years, if not still so, and that it was most effective on the early runs passing through the canyon, consequently at higher water levels. This description would seem to define quite precisely an obstruction which varied in effectiveness with the stage of the water.

No published report or comment has been found which offers proof that a continuing obstruction in the lower Fraser was responsible for the depletion and the continued low level of production. But through the years alternate explanations, especially overfishing, have been advanced and these must be considered.

Overfishing

There are only two explanations for the depletion of sockeye in the Fraser River which have been regarded as possible. One is overfishing, the other the obstruction of the canyon in 1913 which was presumed effective for but two years, 1913 and 1914.

The situation is stated concisely by Babcock³² and Gilbert³³. It was their opinion that the great run was injured by the catastrophe of 1913, but that its continued decline in 1917, and the decline of the off years of cycles other than 1913, was due to overfishing. They regarded the continued low level of production as due to persistent overfishing since 1913. Their conclusion was based, it would appear, primarily on the assumption that the river was clear, as Babcock stated emphatically and repeatedly. They regarded the blockade of 1913 as an isolated catastrophe which occurred once and was completely removed. There was left only the explanation of overfishing.

This conclusion was understandable in view of the great fishery which existed, the uninjured condition of the spawning grounds themselves, and the undeniable

³² B. C. Fish. Dept. Rept. 1919, p. U 79.

³³ The sockeye run on the Fraser River. (B. C. Fish. Dept. Rept. 1917, p. Q 113-15).

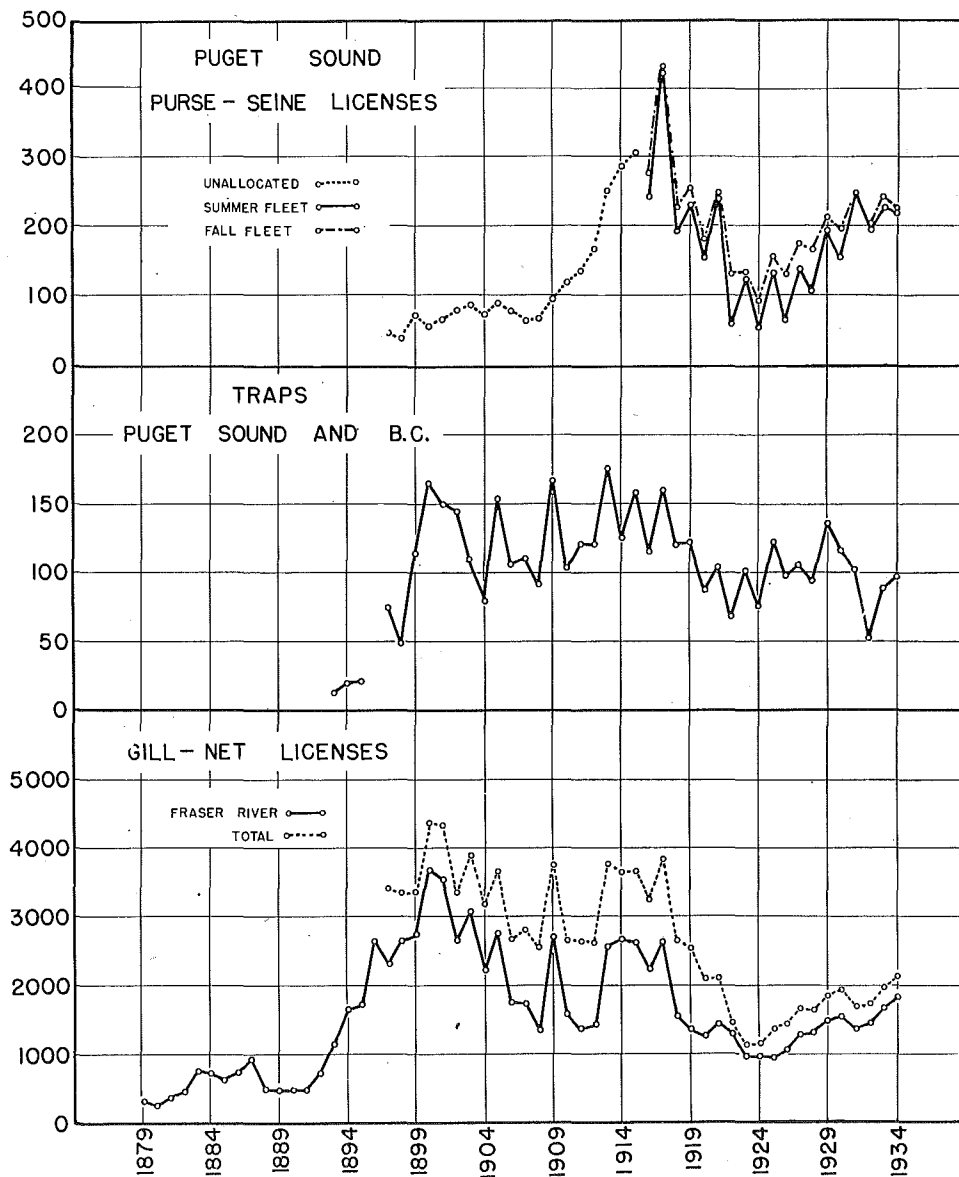


Fig. 16

NUMBERS OF GILL-NET, PURSE-SEINE, AND TRAP LICENSES IN DISTRICTS YIELDING
FRASER RIVER SOCKEYE, 1879 TO 1934.
(After Rounsefell and Kelez)

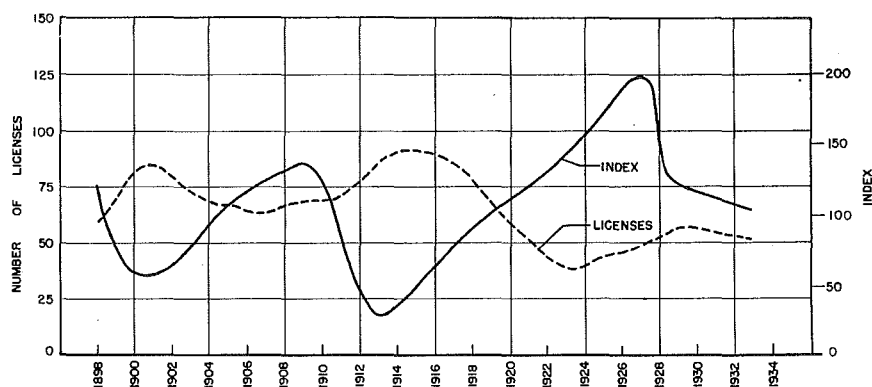


Fig. 17

COMPARISON OF TRENDS OF INDEX VALUES, $\frac{C_4}{C_0}$, AND OF AMOUNT OF FISHING AS DERIVED FROM A COMBINATION OF LICENSES ISSUED FOR VARIOUS GEARS, AS SHOWN IN FIG. 6, FROM 1898 TO 1933.

passage of sockeye in some numbers, at least. The great battle was for adequate regulations. It was embittered by the failure to secure international cooperative efforts.

The primary assumption was that the blockade of the river in 1913 and 1914 had been removed and that the river was as passable as ever. If this does not prove to be true, the direct assumption of overfishing becomes subject to question. As to that, the second section of this report may be consulted for evidence that the river is not, and has not been clear.

The strongest evidence that can yet be given for overfishing is the simple coincidence in the time at which depletion and intense fishing occurred. This can be seen by a direct visual comparison of the graphs in Figure 18, giving the index of success of return and the numbers of licenses issued for the three principal types of gear. The fishing reached one maximum in 1900, another in the period of 1913 to 1917, and it rose steadily again as it approached 1934. The index values had an inverse relationship to this, reaching their lowest values when the various fisheries were most intense, and their highest when the fisheries were least.

The relationship is obscured by the need to compare three types of gear separately with the index. The three have been combined after a process of weighting, as described on page 32. This has been done for the number of licenses without correction for changing efficiency of gear, and for the number of units of effort obtained by correcting for that purpose. The two resultant series of totals do not differ greatly but have both been used in order that no doubt may remain as to whether or not the correction is significant. They have been compared with the index values obtained after correction on the assumption that the gear is competitive, and that the escapement is 10 per cent in the year of the greatest amount of fishing.

The correlation coefficient, r , obtained by comparison of the index and the

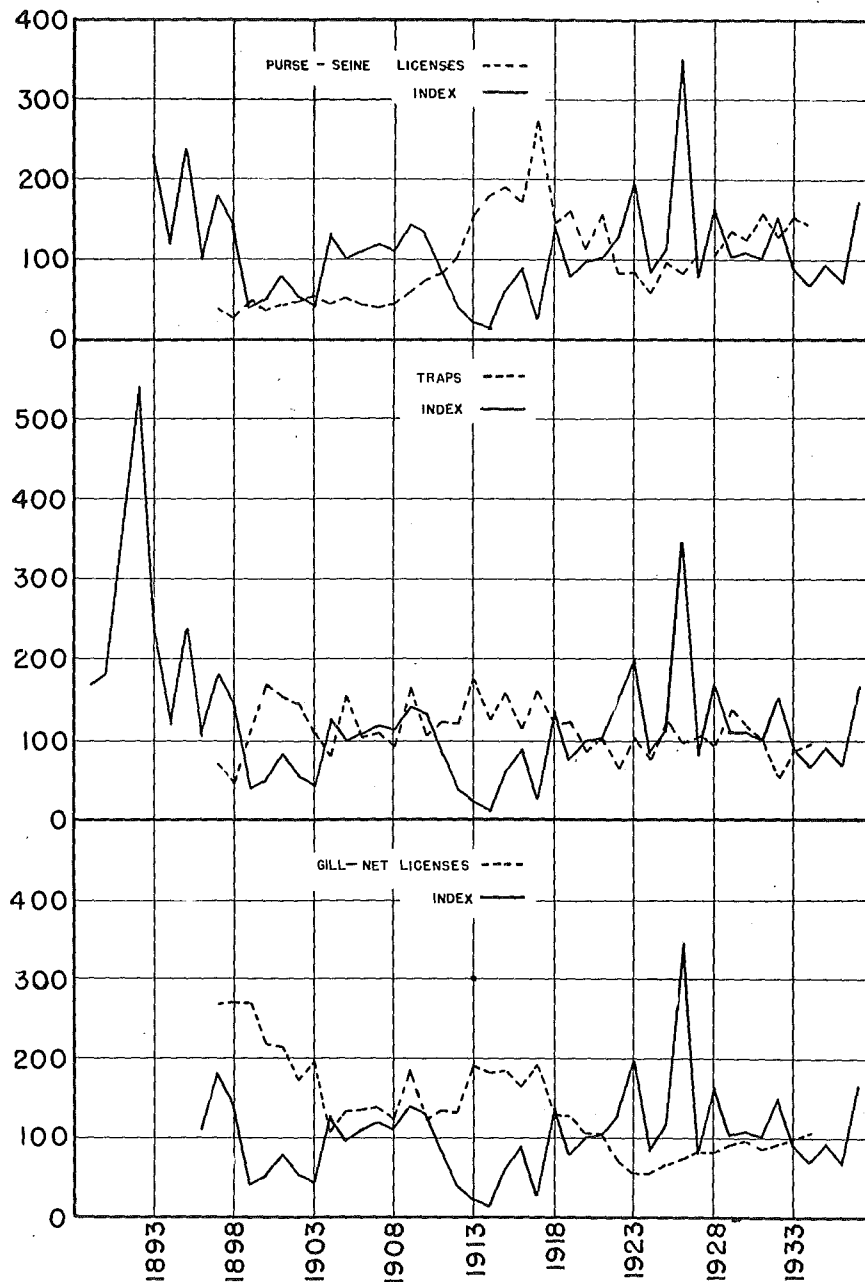


Fig. 18

COMPARISON OF INDEX VALUES OF SUCCESS OF RETURN AND NUMBER OF LICENSES ISSUED FOR PURSE-SEINE, TRAP, AND GILL-NETS, IN DISTRICTS YIELDING FRASER RIVER SOCKEYE.

$$\left(\text{Index} = \frac{C}{C_0} \right)$$

number of licenses is $-.538 \pm .122$. That for the index and the units of effort is $-.458 \pm .135$. The data are shown as graphs in Figures 6, 7, and 8.

At first glance the correlation seems good. The conclusion is near that the success of reproduction depends on the amount of fishing, in other words that over-fishing has occurred. But before it is accepted, the correlation must be examined more closely.

The correlation arises in major part from the opposed general trends of the two sets of data. The trend can be determined by calculating a series of means, each of three adjacent items, each assumed to represent the middle item of the three.

The deviations of the actual individual values from this trend should be of particular significance in view of the high degree of independence which exists between adjacent variates in the index of success of return. This, as will be remembered, is calculated by comparison of values four years apart, representing distinct generations.

The correlation coefficient, r , between the trends of the two series of data for 36 years is $-.838 \pm .050$ which has a very high statistical significance, the probability of its occurrence by chance alone being much less than 1 per cent. But the correlation coefficient between the deviations from the trends is $-.352 \pm .146$ which is slightly more than that for the 5 per cent level of significance. It is apparent that the value of $-.538$ given above for the original data arises more from the correlation of the trends than from that of the deviations of the individual variates.

The correlation between the trends finds its origin in the incidence of two periods of intense fishing with two periods of low index values. The trends are compared in Figure 17. The two periods of low index values were each followed by a return of such values to normal levels of 100 or above. These periods of low index values were from the year 1899 to 1903, and from 1911 to 1917. The meaning of the correlation depends upon the reasons (1) for the opposite trends during the two periods of intense fishing, and (2) for the following reversals of trend.

The opposed reversals of trend following these two periods may be seen at once to be due in part to the nature of the index so that the resultant correlation is in a certain sense an artifact. As soon as the catch became more or less stabilized at a lower level, the index values resulted from the comparison of poor catch with poor catch, so that they again approximated 100. To this rise was added a degree of recovery, probably due to cessation of the use of the dam in Adams River. After each period of depletion the index consequently rose while the catch remained low, showing only that the damage which had been done continued, or was permanent. The catch, as shown in Figure 1, was then positively correlated with the intensity of fishing, the index negatively.

The high correlation between the two trends therefore arose in large part because of the coincidence of the two periods of low index values with the two periods of intense fishing. As a result, the cause of the high negative correlation

must be sought in an examination of the periods of low index values, and in the reason for the permanence of their effects.

As to this, a close examination of the incidence of the periods, as they occurred in the index and in the fishing, will be decisive. The detail of the correlation indicates that depletion came first and that periods of intense fishing followed. In Figures 6 and 7 the index figures for the periods can be compared to those for the fishing. The first year of depletion was 1911, but the first year of intense fishing was 1913, or *midway* in the period of depletion. It is also apparent from the discussion of age corrections to the index, that errors in the latter would, if existent, probably shift the beginning date of depletion to 1910. The same relationship is obvious, but not so decisively shown, in the first period of depletion. This commenced in 1899 and was notably less in 1901, but intense fishing came in 1900 and 1901.

It should also be pointed out in this connection that during the years 1910, 1911 and 1912, beginning the depletion, the amount of fishing can hardly be regarded as too great in comparison with that in 1905, 1909, 1916, and 1918, and yet each of these last named years was characterized by high index values. The individual items of the compared series therefore do not clearly support the possibility of overfishing, despite the value of the correlation coefficient between the deviations from the trends.

The permanence, or continuance of the depletion, shown by the continued low catches and by the return of the index values to near normal needs special explanation. It has not hitherto been shown in any species that the effects of overfishing would have this permanent character. It would appear far more logical to look for a cause of depletion which still persists despite the lessening of the fishing and its total catch.

The evidence is consequently against the sole cause of depletion being overfishing. But it may still be a contributing cause, as will be pointed out below. There still remains, in the above analysis of the existing correlation, room for the effects of intense fishing.

There are, however, a number of good additional reasons why some cause other than overfishing must be sought.

1. As has been often and repeatedly pointed out, the periods of depletion did not reduce the races which spawned in the lower Fraser, but did reduce those in the upper Fraser. This was evident from the hatchery records as discussed on pages 68 to 72, and from the recorded observations of spawning grounds on pages 50 to 68. There was and is no apparent reason given in the literature for this discrimination. The dilemma was commented upon by Babcock in a notable passage in his report for 1920. It is well worth quoting. Speaking of the Harrison-Lillooet Lake section of the Fraser (below the canyon):

"... The number of sockeye that spawn in that section has not declined; on the contrary, there is evidence that it has increased. The question then naturally arises, why has the sockeye run to that section been maintained while the runs to all other sections have declined? The annual appearance of undimin-

ished numbers of sockeye in the Lillooet Lake section must apparently be attributed to one of two causes: Either it is due to the successful operation of the hatchery, or the races of sockeye that spawn there have not been subject to the great drain made on all the other races that spawn in the Fraser by the traps and nets on the fishing-grounds. Since it has not been shown that the sockeye that spawn in the Lillooet Lake section enter the Fraser before the fishing season opens on July 1st, it is not apparent why they should be less subject to the heavy drain by fishing than those that spawn in other sections. Fishing for sockeye in the Fraser before July 1st has not been permitted for over thirty years. It is a matter of record that when fishing for sockeye was permitted in May and June good catches were made in those months. Alex. Ewen, in the early days of the canning industry, packed as high as 10,000 sockeye in the month of May. Canning was not at that time extensively conducted, and those engaged in the industry found it more profitable to operate later in the season when the run was more extensive. There may still be runs of sockeye in May and June. The fact that sockeye have not been observed in the river at Hell's Gate until July does not prove that none enter the river much earlier, because earlier runs could easily pass into the tributaries of the Fraser below the canyon. Sockeye may still enter the Fraser in May or June and turn from the Fraser into the Harrison River en route to the waters of Lillooet Lake and the Birkenhead River. If such is the case it is obvious that such a run would not be subject to the drain of the traps and nets, and in consequence would easily maintain itself. It therefore becomes a matter of importance to establish when the runs to that section enter the Fraser. The Department hopes to do this during the coming year."³⁴

The surmise that sockeye enter the Harrison system early and thus evade the fishery is not plausible. This Commission has found the contrary in its extensive work in the Harrison system, the fish not appearing earlier than August³⁵. As far as the hatcheries are concerned, Foerster³⁶ has pointed out that the number of eggs handled by them has always been a very minor part of the total run to the Fraser and their efficiency has not been sufficiently in excess of natural propagation to compensate for numbers.

There seems indeed to be no escape from the question which Babcock put so frankly in this report. Its answer is that some cause of depletion other than overfishing must be sought, even if the latter exists, and that the cause must lie in the canyon between the Harrison River and the junction of the Fraser and Thompson Rivers.

2. The unevenness of effect noted was not confined to the contrast between the upper and lower Fraser runs. It has shown itself within the runs to the upper Fraser, and in such fashion as to favor unmistakably those runs which occur later in the season. The early run to Adams and Shuswap Lakes vanished and a late run was left on a different cycle year and to the lower Adams River. This cycle of 1926-1942 was the only one to be rebuilt. While there is no exact analysis of what happened throughout the river system, the general opinion seems to be that

³⁴ B. C. Fish. Dept. Rept. 1920, p. S 13-14.

³⁵ Thompson, W. F. Report... on the Fraser river sockeye, 1940. (International Pacific Salmon Fisheries Commission, Annual Report, 1940, p. 11).

³⁶ Foerster, R. E. Propagation's part in the conservation of the sockeye salmon. (American Fisheries Society. Transactions, v. 58, 1928, p. 52-67).

this is typical of the changes made by the second period of depletion. They are not of the character expected in case overfishing were the cause.

3. The correlation shown between the index and the amount of fishing may be one of several which may exist between different conditions, so that both fishing and depletion may vary as effects of some other cause. The amount of fishing has been dependent upon changes accompanying the development of the Northwest, and it in turn has reflected the use of power in transportation and industry. The Canadian Pacific Railway was completed through the Fraser River Canyon in 1885. In the United States the Northern Pacific was completed in 1888, and the Great Northern in 1893. Population and fishing industry both grew rapidly. This growth was paralleled by increase in both the halibut and salmon fisheries. It extended into the mines and forests throughout the Fraser watershed as well. In 1911 construction of another railroad, now the Canadian National, was begun. It passed through the Fraser Canyon with the Canadian Pacific so that both banks along which salmon migrate were occupied. It was completed in 1915. After the very intense fishery in 1913 which always accompanied a big year on the Fraser, the first World War with its high prices and great demand stimulated an intense fishery not only for salmon but for other species. There followed a period of depression and subsequent gradual rise. In the periods of rapid development a number of things happened which had an effect on the fish, things other than the growth of the fishery, but occurring at the same time. Some of these may have affected the salmon runs adversely and at the same time as fishing was intensified. They included mining, deforestation, and building of railroads along streams through which salmon migrated.

4. The amount of fishing has varied as the result rather than as the cause of the changes in abundance of salmon. This is clear from the contrast in numbers of licenses in adjacent years of large and small runs (*see* Figure 6). In the big years of 1901, 1905, 1909, 1913, and 1917 there were many issued, far exceeding those in the intermediate or off years. If this is true of individual years there seems no good reason why it should not be true of periods of years during which the fishery was poor and did not attract many men.

While this would be true of normal years, it was not true of the period of the first World War, 1914 to 1918. The high prices obtained then caused intense fishing. This coincided with the period of depletion, and it is this coincidence which has been regarded as evidence of depletion.

In fact, each period of depletion caused a decline in the yield of the fishery to a new low level (*see* Figure 1). This is particularly clear in the 20 years following 1913. This low level could support fewer fishermen, with a reduced number of licenses. There resulted a positive correlation between the catch and the amount of fishing, and, as has already been shown, a negative correlation between the index of return and the amount of fishing.

There is thus good reason to regard the changes in the fishery as effects and not causes of depletion.

5. Very intense fishing occurred in each of the big years, yet those of 1905 and 1909 must have reproduced successfully, while those of 1901, 1913, and 1917 did not. In each of these cases the success of return shown by the index was more similar to that of adjacent off years than to that of the other years of big runs, despite the extreme difference in the amount of fishing between those adjacent years. Yet the adjacent years in each four-year cycle are necessarily independent as far as the fishery is concerned, because of the age at which sockeye return. Some factors varying in a more regular and consistent fashion than the fishery must have been the causes of depletion.

6. It is known that the loss of the big year run of 1913 was due to the heavy mortality in the canyon. There was a large escapement from the fishery and the effect of the canyon was observed closely by many men. But the question may well be asked, in what respect does that year differ from others in the relationship of the index and the fishing in the second period of depletion?

7. The corrections to the index from 1917 to 1921, which were made on account of the amount of gear, are large and diminish the inverse correlation of the trends which lie between 1917 and 1934.

There is, however, room for overfishing to exist. If the odd and even years since 1915 are examined, it will be found that some of their deviations from the trend vary inversely to the index values. The odd, or pink salmon years, have been subject to a heavier fishery and if overfished should show poorer reproduction, hence lower index values. The index and the intensity of fishing vary in the expected direction 13 times in 19 cases of comparison after 1911. These deviations are shown in Figures 6 and 7. The evidence, so far as it goes, is in favor of a negative correlation between fishing and reproduction. Against this, it may be argued that the effect should be cumulative, yet it is not clear from the catches (*see* Figure 1) that the runs in even numbered years have increased much beyond those in odd years. The races returning in the years 1930, 1934, 1938, 1942 have done so, but those of 1932, 1936, 1940 do not seem to have improved more rapidly than those of 1933, 1937, 1941. The evidence is far from decisive; and what increases have been shown are lesser variations within the great reduction in yield after 1913.

It must be remembered that the facts cited here against overfishing as a sole cause of depletion do not mean that it cannot have been a contributory cause. The heavy fishing must have been added to the sum total of the mortalities suffered by the species. It is now well recognized that a species can survive high and unusual death rates by virtue of compensating effects on survival rates in certain life stages. In fact, a block in itself might not have been serious nor its mortalities more than the species could support. The effects of a serious block, for instance, might have been overcome by the surplus which the catch has taken. But had the margin of safety been reduced by the fishery, a particularly unfavorable year in the canyon could have been expected to produce depletion.

If this is true, it follows that the obstruction in the canyon may have always existed, that its bad effects need not have been serious until the fishery was added,

and that an increase in the obstruction could have made the effects too great to be overcome by the several races most injured. A combination of heavy fishing, unfavorable water levels, new obstructions, and the passage of more than usually susceptible races, could occur long after any one or several of these contributing causes of damage had come into existence.

It may well be that overfishing will show itself in this way by abrupt failure of the runs at some weak place in the life history rather than by gradual decline. Some of the races may be under greater strain, as by unfavorable conditions at the time of their migration. They may be damaged in years which are particularly unfavorable in regard to natural conditions. This effect of overfishing would then not be gradual, but would appear as the health of the races and the conditions they meet would vary. The Quesnel race might meet disaster when that at Chilko would survive.

Thus overfishing may exist and it may show only indirectly through damage done by other conditions. If the damage is correlated with one of these conditions, and this one is remedied, then sooner or later as the fishery intensifies, new causes of depletion will appear. This concept of overfishing can therefore be logically consistent with demonstration of damage done by an obstruction. The two do not exclude, but supplement each other. Whatever the correlation that appears, it will not prove that overfishing does not exist.

SECTION II

HISTORY OF THE OBSTRUCTION IN THE FRASER CANYON

It is hard to believe that an obstruction has existed in the canyon of the much observed Fraser River without detection, certainly since 1913, and perhaps before that. It seems improbable that such a thing could have happened without being noticed. If it were real, it would seem that its damage would have been seen, studied, and remedied.

A review of the existing literature shows, however, that doubt of its reality on this score is untenable. There is what could be expected in the way of evidence as to the existence of the obstruction and records of at least occasional damage. This evidence, buried in official reports which reiterated that the river was open to the passage of sockeye, must be reviewed here to leave the way clear for the experimental proof of delay and mortality.

A. THE OBSTRUCTION IN 1913 AND 1914

The run of the year 1913 provided the first and most spectacular evidence of an obstruction in the Fraser Canyon at Hell's Gate and vicinity. Since that time no such great run has occurred nor until 1941 has observation been centered on the remaining runs to give an adequate basis of comparison.

The Fraser River passes through the Coast and Cascade ranges of mountains on its way to the sea, through one of the great river canyons in America. From Yale to Lytton, 108 and 160 miles above the mouth, the currents of the river are extremely rapid, between rocky cliffs and canyon walls.

Through this canyon pass two of the transcontinental railroads of Canada on their way to the coast. The Canadian Pacific was built first, having been completed in 1885. The present Canadian National was built between 1910 and 1915 as the Canadian Northern Railway. The Canadian Pacific follows the western bank of the river, the Canadian National the eastern bank. In building these railroads, rock from cuts and tunnels was dumped into the river at the nearest convenient point.

In this canyon there are several points at which the currents are extremely rapid. The worst of these is at Hell's Gate, 130 miles up the Fraser River. At other points such as White's Creek, China Bar, and Scuzzy Rapids, the river channel is contracted and passage difficult. The rock displaced by the railroad operations during the construction of the Canadian National Railways increased the difficulty of passage at these various points. Inquiry shows that rock work was commenced in the canyon between Yale and

Lytton about June of 1911, and that the work was completed near the end of 1912. The track was connected with the east at Ashcroft in early 1915.³⁷ Mr. W. K. Gwyer states: "In the years when I was at Yale, 1911 to 1916, invariably every year the beach in front of my house was littered with dead fish. For the past ten years I have not seen one."³⁸ There is no evidence as to damage done to runs of the earlier years of 1911 and 1912 when there were minor runs to the upper Fraser although much of the rock work was done then. For all that is known they too may have been subjected to blocks. The conditions at Seton Lake Hatchery have already been referred to on page 61 as showing a delay at Bridge River Rapids and its probable connection with the obstruction at Hell's Gate. But in 1913 the effect on the so-called big run was so spectacular as to attract immediate attention.

The obstruction caused by railroad construction at these points was first noticed because of an accumulation of fish in the canyon in July 1913. Temporary amelioration of conditions is described in the British Columbia Department of Fisheries Report for that year.

The Provincial and Dominion authorities took such action as was possible to remove the obstructions, beginning work on September 28. Temporary passageways were blasted through the obstructions by breaking up the individual great masses of rock which prevented passage. Constant attention was necessary to keep new channels open as the river fell. It is stated that subsequent to October 22, passageways were opened at all the points obstructed and were maintained with some intermissions until the end of the run in December. This work was undoubtedly responsible for the passage of considerable numbers of salmon, and explains the presence of remnants of a big year in 1917.

On February 23, 1914, a great rock slide occurred at Hell's Gate on the east side where a tunnel was being built. Removal of this was commenced in March 1914. During the run of that year fish were aided by dip-net and flume at Hell's Gate. Removal was completed by February 1915. Work had in the meantime been done at the other points of difficult passage, the high water of 1914 had aided, and what was left was removed by March 1915. The details of engineering action are reported by McHugh.³⁹

The effect on the run of salmon is of primary interest to this study. The description given by J. P. Babcock⁴⁰ in 1913, a summary of which follows, should be compared with the events in 1941, as proof that the obstruction still had the same character in the latter year and could be expected to do damage also. The report itself should be read by close students of the obstruction.

³⁷ Wilson, A. L. Letter of September 12, 1944.

³⁸ Gwyer, W. K. Letter of October 17, 1944. He was engineer for the British Columbia government.

³⁹ McHugh, J. Report on . . . removal of obstructions to the ascent of salmon on the Fraser River. (Canada, Dept. of Naval Service. Fisheries Branch. Annual Report, v. 48, 1914/15, p. 263-75).

⁴⁰ B. C. Fish. Dept. Rept. 1913, p. R 20-31.

Accumulation of fish began in July. The water was unusually high and continued so until late in the season. Early in August the Provincial authorities found large numbers of salmon in all stretches of the river below the points mentioned above, but particularly below Hell's Gate. It is stated that the great schools of fish could be seen in the eddies below Hell's Gate, extending downstream for over ten miles. The Indians above the obstructions were not securing their usual catches, the few on their racks had been taken before July 15. This accumulation continued throughout August and it became obvious that the expected numbers of a big year were not materializing on the spawning grounds.

On August 19, the sockeye were massed in incredible numbers immediately below Hell's Gate and for 10 miles downstream. The passage of Hell's Gate appeared to be much more difficult than Scuzzy Rapids, three and one-half miles above, but countless thousands were successful in passing and were present below the rapids. The numbers below Hell's Gate did not diminish during the last of August, although the water was falling rapidly and the passage at Hell's Gate was apparently less difficult. "In the eddies and quiet stretches the sockeye were still circling in a helpless kind of way, being quite different from the actions of any sockeye I had ever seen in the Fraser in former years."

On September 18 the eddies and quiet stretches of the river from Scuzzy Rapids to the Spuzzum were still filled with vast numbers of milling sockeye and humpbacks. The obstruction at Scuzzy Rapids appeared impassible. Those at China Bar and White's Creek did not appear until later.

While unquestionably large numbers of sockeye passed through the canyon during October and November, a great many did not do so. Below the rapids, and especially at Hell's Gate, the numbers of sockeye observed drifting downstream were even more pronounced in October than in September. "From Hell's Gate to the Spuzzum, a distance of eight miles, the surface of every eddy and quiet stretch of river was covered with milling sockeye and humpbacks." Because of the clear water in the Spuzzum and in the lagoon at its mouth, the fish could be distinctly seen, while in the discolored water of the Fraser only the fish which showed themselves in the surface could be seen. "Beginning with October, the large schools of milling sockeye seen in the eddies in the canyon gradually faded away. Throughout October large numbers of sockeye remained in the lagoon in the mouth of the Spuzzum and in that creek's channel for a mile above. At the riffles there was steady movement both up and down. A considerable number spawned there in November. The fish in the canyon in October were noticeably different in colour from those seen there in August and September. They were far more highly coloured, especially the males. Many ripe fish were noticed in November." Eggs were taken from these fish in the canyon. "The fish from which the eggs were taken were making no effort to spawn or pass farther upstream but were simply lingering in the less rapid currents and eddies."

The creeks and rivers from Hell's Gate to Ruby Creek were full of sockeye, living and dead, during the remainder of the year. Late in September vast numbers of dead sockeye had died without spawning, and others were drifting helplessly downstream. They died all through October and November. Dead and living fish were found in the creeks into December. Many of them had spawned in Spuzzum Creek, but not in others.

During the season following, in 1914, Babcock⁴¹ states that the obstructions at Scuzzy Rapids, China Bar, and White's Creek were entirely removed. But those at Hell's Gate were so extensive they could not be removed in time for the run of 1914. In consequence a block existed from August 10 to 25. It was necessary to work constantly at new channels and to pass fish by means of a flume around the difficult place at Hell's Gate. The run at Bridge River Rapids, above Hell's Gate, was very light until the end of August, and increased during the first part of September.

The description by McHugh of this blockade at Hell's Gate during 1914 is good evidence that the conditions were much the same as have been shown to prevail at present. The report itself should be read in this connection.

"Until August 14 the passage of Hell's Gate had seemingly been successfully accomplished by all the fish which had attempted it . . . On this day, however, with the steady lowering of the water, a new condition presented itself at Hell's Gate."⁴²

He here describes the projecting point on the east side of the river. A flume was built around this point in 7 days, and 4 days were necessary for an additional section. Salmon were dip-netted for 8 days. This would bring the block up to September 2. At that time the river was becoming easier of passage.

This should place the beginning of the block between August 10 (Babcock's date) and August 14 (McHugh's), and its end September 2. For comparison, a graph, Figure 19, is given of water levels for 1914 calculated from the river gauge at Hope by courtesy of the Dominion Water and Power Bureau.⁴³ The correspondence with the levels found by our investigation, as will be told later, indicating a block between approximately 40 and 26 feet, is too close to be accidental, and leads us to suspect that conditions at Hell's Gate proper were in 1914 much the same as they are today.

The marginal conditions immediately above the Gate on the foot of the slide and at other points in the Fraser River Canyon seem to have caused the greatest concern at the time, and to have been remedied by continual work. McHugh and Babcock speak repeatedly of the great damage done by these places, and the latter is particularly emphatic in ascribing the 1913 catastrophe to them.

⁴¹ B. C. Fish. Dept. Rept. 1914, p. N 16.

⁴² Canada. Dept. of Naval Service. Fish. Branch. Ann. Rept. 1914/15, p. 271-72.

⁴³ Canada. Dept. of the Interior. Water Power Branch. British Columbia Hydrographic Survey, 1914, p. 82-83. (Its Water Resources Paper, no. 14).

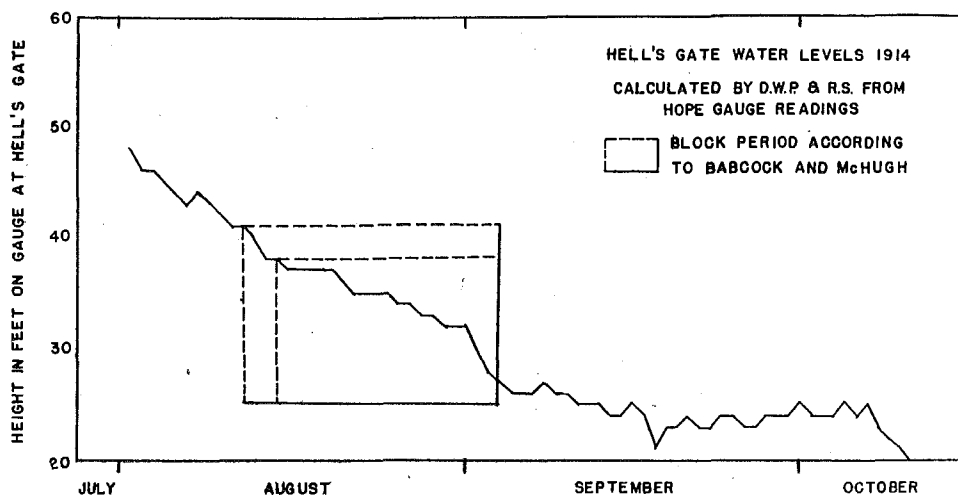


Fig. 19

COMPARISON OF WATER LEVELS AND PERIODS OF DIFFICULT PASSAGE AT HELL'S GATE IN 1914.
(According to McHugh and Babcock)

B. RECURRENCE OF OBSTRUCTION, 1915 TO 1940

The story of the blocks in 1913 and 1914, considered in the light of subsequent observations between 1938 and 1942, indicates their characteristic features. With these in mind clear evidence can be found in the literature of difficulties in passage through the canyon. This was not coupled with discovery or even suspicion that they caused mortality sufficiently heavy to be responsible for the present condition of the river. The characteristics are in the main: 1. Presence of active fish in large numbers in the eddies below Hell's Gate at any time during the season; 2. Presence of maturing sockeye in the creeks below the Gate late in the season, especially as late as November; 3. Abnormal quiescent behavior indicating lack of desire to pass; 4. A tendency of the schools to disappear progressively in late October or November; 5. Presence of dead or dying fish on the shore or drifting with the current from October to December.

With regard to the first point, it may be said that recent investigations have shown that when delays occur they are prolonged in time and cannot be said to be as brief as a day or two except occasionally in the latter part of the season. At that time the water may have fallen below 27 feet and will occasionally rise above that level again for brief periods. The levels which are blocked are so extensive that periods of a month or more usually lapse between water levels which allow passage. Consequently any statement as to temporary delays at the Gate, except late in the season, must be regarded as evidence of blockade.

Observations as to the very early conditions are hard to find. For the years before 1913, it should be noted that obstructions might possibly have occurred during the construction of the Canadian Pacific Railway through

the canyon prior to 1885, the year of its completion. On October 15, 1880, a great slide took place above Spences Bridge on the Thompson River, interfering, at least temporarily, with the run of salmon.⁴⁴ Indians interviewed by Babcock⁴⁵ in 1913 stated that great schools similar to those of 1913 had been seen in the canyon "fifteen or twenty" years earlier. During every big year the eddies below Hell's Gate were full. If true, this indicates either a natural block to passage, or one produced by early construction activities. The dates are naturally vague.

The first disquieting report after 1913 as to the continued presence of an obstruction at Hell's Gate is found in the report of the resident engineer, J. McHugh. His excellent report is as follows:

"(i) Fraser river at Hell's Gate: During the course of the year many inspections and reports have been made and prepared, showing the condition of the Fraser river at Hell's Gate since the work here was completed one year ago. Observations made by the special fishery guardian at this point during the run of 1915 showed undoubtedly that the work was successfully performed. Personally, however, I am not assured that salmon can pass as freely up the river as they did prior to the time when railroad construction on the Canadian Northern railway was commenced. Up to this time no difficulties had been experienced on the Fraser river, and in consequence it was never considered necessary in the interests of conservation to keep close watch on the movement of salmon through the canyon. In view, however, of the troubles which have since occurred, it often appears to me regrettable that some data concerning the flow of the river at Hell's Gate, and the action of the salmon in passing through before the trouble occurred should never have been obtained. Had such information been available a comparison of the conditions of to-day with those of the past would have shown just how the run to-day is affected. At certain stages of the water, salmon are now undoubtedly delayed in their passage up the river. That they get through eventually, however, is certain, but whether the greater delay and the greater physical exertion which is now undoubtedly required to get through has any effect upon the parent salmon, only the future can tell . . . In a recent report I have suggested that it may be yet necessary to do further work here. Such work, however, should not be performed until the data collected are sufficiently great to warrant the laying down of a further scheme of improvement."⁴⁶

Subsequent reports by the Dominion and Provincial departments of fisheries through the years between 1915 and 1937 have been carefully examined. Babcock's report for 1917 presents the situation as he saw it in a normal year and as he consistently viewed it until his death, in common with the majority of experienced observers.

"... The average water conditions throughout the summer and fall were favourable for the passage of salmon through the rapids in the canyon.

⁴⁴ Howay, F. W. *The Canadian Pacific railway and how it was built.* (In Scholfield, E. O. S. *British Columbia from the earliest times.* v. 2, p. 417-28. Vancouver, Chicago, etc. The S. J. Clarke Publishing Company, 1914). *Dominion Pacific Herald.* October 20, 1880.

⁴⁵ B. C. Fish. Dept. Rept. 1913, p. R 23.

⁴⁶ Report of the Department's resident engineer. (Canada. Dept. Naval Service. Fisheries Branch. Report, v. 49, 1915/16, p. 266-67).

There were short periods this year, as in former seasons previous to the slide in 1913, during which the salmon had considerable difficulty in getting through the rapids at Hell's Gate, but all eventually passed through en route to the spawning area above. They experienced no difficulty at the Scuzzy . . . The channel of the river at this point [Hell's Gate] has been fully restored."⁴⁷

But minor delays "for days at a time", or "a day or so", or "a few hours", are recorded in Provincial or Dominion reports for 1915, 1917, 1919, 1922, 1923, 1924, 1925, etc. As has already been stated, the brevity of these delays is not characteristic of Hell's Gate, and the fact that they are mentioned at all is good evidence that the difficult situation found since 1938 has prevailed from at least 1915.

There were, however, certain years in which greater difficulties were met.

In 1915, Babcock's report stated that the fish which reached Hell's Gate in August and September were "considerably delayed, and for days at a time were unable to pass to the waters above". He cites the report of an observer, Newcombe, that no fish could be taken above Hell's Gate during these delays.

In 1919, Babcock cites two occasions when the run was delayed for "several days" and Cunningham⁴⁸ states that there were large numbers of sockeye in October in Coquihalla River and Kawkawa Lake.

There were complaints of conditions at Hell's Gate in 1919 and 1921. There were also observations in 1922 by W. H. Pugsley⁴⁹. He raised questions as to possible difficulties leading to delays in passage, but did not prove mortality. These were answered by Babcock⁵⁰ with the declaration that the river was as satisfactory as it was before the slide and that no blockade had occurred since 1913.

In 1926 and 1927 there were evidently difficulties which were hard to explain. It will be shown later in this report that conditions were unusually difficult in 1927. Motherwell's report is instructive and informative.

"At Hell's Gate canyon in the Fraser river conditions since the clearing away of the slide which occurred in 1913 have remained unchanged and those who have been in the best position to know, have felt that the salmon runs have all succeeded in passing up to their spawning grounds, although, due to unfavourable stages of the water, there may have been hours or even days when they were delayed. In spite of several reports to the effect that the fish were permanently blocked, or were so badly damaged at the Gate as to prevent their reaching the spawning grounds in fit condition there would appear to be no doubt but that the salmon did get through this obstruction, at least, until the very last runs of the seasons 1926 and 1927. In fact, there is

⁴⁷ B. C. Fish. Dept. Rept. 1917, p. Q 21-22.

⁴⁸ Cunningham, F. H. Report . . . western fisheries division (British Columbia) 1919. (Canada. Dept. Naval Service. Fisheries Branch. Annual Report, v. 53, 1919, p. 43).

⁴⁹ Pugsley, W. H. Obstructions in Hell's Gate canyon. (Washington (State). Dept. of Fisheries and Game. Fisheries Div. Annual Reports, v. 32-33, 1921/23, p. 14-15).

⁵⁰ Conditions in Fraser river canyon. (Pacific Fisherman, December 1922, p. 13).

every reason to believe that all of the 1926 run succeeded in passing this point. However, during the last two seasons there has developed an unusually late run of sockeye which has arrived at Hell's Gate in a very advanced stage towards spawning. The condition of this run in the fall of 1927 was found to be even worse than that of the preceding season and whilst there was no unassailable evidence to justify the conclusion that any run was permanently prevented from ascending, there is very considerable doubt as to whether the latest run of 1927 did actually succeed. It has been suggested that the lack of male fish in the Kawkawa lake spawning area for instance, which is tributary to the Coquihalla system, is evidence that they were probably able to pass Hell's Gate, but that the female, being weaker, were obliged to turn back and passed up to the Kawkawa lake spawning grounds. It is hoped that investigations will divulge the facts in this matter in the very near future."⁵¹

Babcock's report for this year, 1927, is somewhat more detailed. A considerable number of salmon reached Hell's Gate early in October and passed with "no delay". They were later noted in Adams and Little Rivers. On October 25 a "very large run" reached Hell's Gate, but water stages were unfavorable and "... many of the fish were not seen passing through. Either the fish had no inclination to do so or they were not strong enough." However, some did pass and were seen above Lytton in both the Fraser and Thompson. But what became of these fish was problematic, as no dead were observed at the Gate or below it, and no dead or living fish were seen dropping downstream. Some thousands spawned in Kawkawa Lake (below Hell's Gate) at the end of November and until December 10, later than had ever been known, and the females greatly outnumbered the males. It proved impossible to locate the spawning grounds of the delayed fish which "passed" during October and November.

As the result of the experiences in 1926 and 1927 the Dominion Department of Fisheries arranged for a board of engineers to consider possible correction of the difficult currents. It reported in 1928. But no further evidence as to a blockade, and certainly none as to actual mortalities, was presented. In 1928 Babcock could state without denying the existence of delays: "Since 1914 the Fraser River canyon has not been blocked to sockeye salmon." Others suggested that the blocked fish of 1927 were actually lower river fish which had been transplanted to the upper river and were physically unable to proceed thereto.

In 1930, during the large run to the Shuswap area, some doubt was expressed that all were able to get there.

"... It is not conceivable that all reached the Shuswap area, though a considerable part of the run may have spawned in the South Thompson River. Sockeye were observed passing Hell's Gate well into December, and under date of Nov. 29 it was reported that every stream for 65 miles below this point had large numbers of spawning Sockeye."⁵²

⁵¹ Motherwell, J. A. Report ... western fisheries division (British Columbia) 1927. (Canada. Dept. of Marine and Fisheries. Fisheries Branch. Annual Report, v. 61, 1927/28, p. 77).

⁵² Motherwell, J. A. Great run in British Columbia results in heavy spawning. (Pacific Fisherman Statistical Number, 1931, p. 112).

And again for the same year:

"... It is a fact that quantities of sockeye were observed spawning in streams below Hell's Gate which was quite an unusual occurrence, but there was no reason to believe that these could not have passed Hell's Gate had they so desired."⁵³

In the report of the same department for 1941, the similarity of conditions in that year to those in 1930 is noted. In the report of the British Columbia Commissioner of Fisheries⁵⁴, it is stated that in 1934 fish were found in numbers in the smaller streams between Hope and Lytton.

In 1934 the conditions found in the streams of the canyon in 1930 were duplicated.

To summarize this review, it seems, as far as can be deduced from reports, that conditions similar in varying degrees to those in 1913 (although less spectacular) and in 1941 have occurred in the Fraser at Hell's Gate in many years. There seems to be some evidence that difficulties were encountered prior to 1913.

Had such significant evidence been lacking in the literature the seriousness of the present findings might well have been doubted, as indicating merely unusual conditions. But the records are what might have been expected as the result of continuing conditions difficult to recognize or prove. In such years as 1927, and as will be seen later in 1939 and 1941, conditions were very bad. There was lacking only general recognition that they meant serious mortality. Had this been known, as in 1913, there is little question but that the obstruction would have been given immediate attention.

It would be a serious injustice to the many sincere men who have been concerned with the problem in the past, to assume that they should have known what now seems so readily accepted. It is simply a fact that action has awaited definite proof, a difficult and expensive thing to obtain.

The crucial problem in this report, therefore, is to prove that extensive mortality occurs. Without such proof, difficult as it is, there is no basis for action.

C. THE BLOCKADE IN 1941

The staff of the Commission had observed the delay in sockeye salmon runs at Hell's Gate in each year that tagging operations were carried on, commencing with 1938. Sockeye tagged at the Gate were recovered downstream and at the Gate itself after a lapse of considerable periods of time. During certain intervals, the percentage of tags recaptured at the point of tagging increased sharply, indicating the continued delay in passage. At other levels of the river the accumulated schools of tagged fish disappeared

⁵³ Motherwell, J. A. Annual report . . . western division (British Columbia) 1930. (Canada. Dept. of Fisheries. Annual Report, v. 1, 1930-31, p. 95).

⁵⁴ Motherwell, B. C. Fish. Dept. Rept. 1934, p. K 62.

and apparently passed through the canyon. This was in accord with the generally expressed opinion that the sockeye were delayed in passage but finally passed. But in 1941 the river remained at difficult levels practically all fall. The similarity of events in this year of blockade to the catastrophe of 1913 is striking. The mere correspondence of the two events is one of the major proofs that some of the conditions which destroyed the run in 1913 are still present.

On July 14, 1941, the writer saw, in company with members of the staff, large numbers of sockeye congregated below Hell's Gate. By September 1, the eddies on both sides of the river were filled with fish for a distance of six or seven miles down-stream. These fish were for the most part active, fighting the rapid currents, and jumping continuously at points difficult of passage on both sides of the stream. On September 1 to 3 the water fell to and below a level of 26 feet on the gauge and in those three days a continual stream of fish passed Hell's Gate on the left bank. It is not clear that any fish passed the right bank unless they were thrown across the stream by the force of the current.

The water rose again and from then until the end of the season there was no evidence from return of tags that any fish passed, although for a brief period in October the water rose above 40 feet.

Conditions below the Gate were strikingly similar to those in 1913. At first the fish were active and continually jumped at the difficult points of passage opposite the jutting rocks on each bank. As the season progressed in October and November, the fish left the more active eddies and tended to lie closer inshore where the water was more nearly stationary.

An observer⁵⁵ daily counted the number of fish in each of the eddies for a distance of four to five miles downstream. The results of his count are shown in Figure 20. It will be noted that the schools of fish gradually disappeared after lying in the quiet waters for some time; they apparently left the surface and were to be found near the bottom attempting to spawn, wherever riffles were available. This caused the gradual disappearance of the massed schools in the river since the waters of the Fraser were so turbid as to hide them. This disappearance has been regarded in the past as evidence of passage up-stream. But it came after the fish had ceased to seek passage up-stream and it proved possible to find them by feeling with gaff-poles at various points below Hell's Gate.⁵⁶

During this period of disappearance, the creeks and streams from Hell's Gate to Hope became full of sockeye. Even those which later dried up were filled. They appeared when the water in the creeks became sufficiently low and clear. Observation in the mouth of each stream showed a rapid passage in and out while little spawning occurred. The great mass of fish disappeared without spawning. It is apparent that there was a rapid turnover of sockeye

⁵⁵ Ernest Kennedy.

⁵⁶ J. L. Kask.

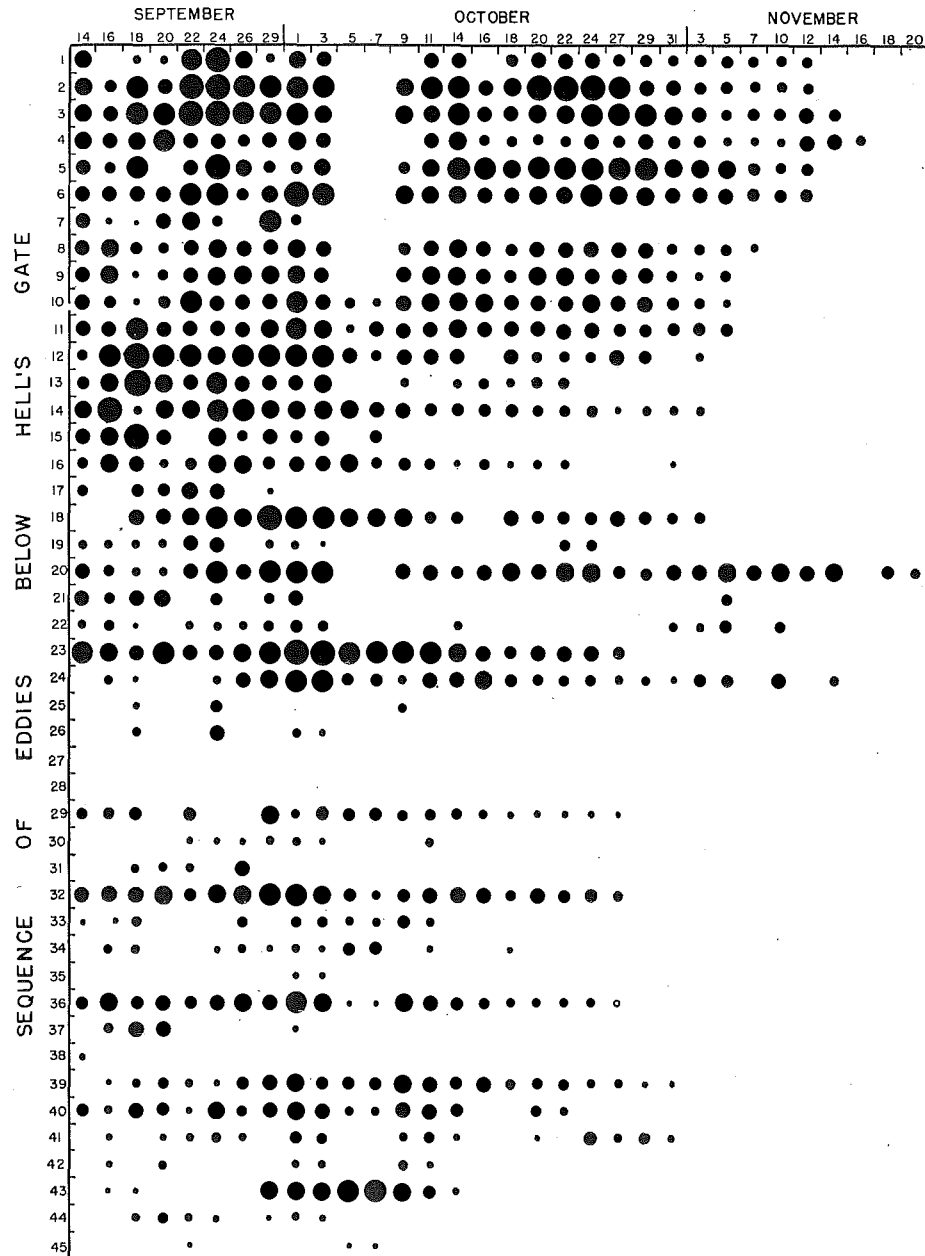


Fig. 20

RELATIVE ABUNDANCE OF FISH IN EDDIES BELOW HELL'S GATE FROM SEPTEMBER 14 TO NOVEMBER 20, 1941, AS SHOWN BY AREA OF CIRCLES. NO EXACT COUNT IS GIVEN FOR THE EDDIES. THEY ARE CONSECUTIVELY NUMBERED FOR A DISTANCE OF FOUR MILES DOWNSTREAM.

in each creek. The population was not resident but was composed of fish looking for spawning grounds.

Towards the end of the season, an examination was made of the gravel in these creeks. The area available for spawning was in no case sufficient to accommodate the fish known to have been present. The gravel proved to have been repeatedly dug up by the spawning fish, including coho, sockeye, steelhead, dog salmon, etc. The eggs removed from the fish or recovered from the gravel were placed in a hatchery and hatched with difficulty, apparently having excessively heavy egg cases, perhaps due to long retention. They had a heavier than normal mortality.⁵⁷

It is evident that the fish below Hell's Gate had passed through the same physiological changes which accompany their passage to the spawning grounds. They had become progressively less active in fighting the current. At the same time, they had assumed their nuptial colors of red bodies, green heads, and green tails, although these were not as vivid as on their proper spawning grounds. Their retirement to quieter eddies seemed to correspond physiologically and in time to their arrival in quieter tributaries near their spawning grounds. Their disappearance from the surface obviously corresponded to normal dispersion over the bottom on the spawning grounds preparatory to the deposition of their eggs. Their appearance in the creeks was actually their search for gravel spawning areas. These changes occurred well into December.

During all of this time it was apparent that fish were becoming too feeble to maintain their position in the rapid currents and when forced out into them, they were washed helplessly down-stream. As the season progressed, these drifting fish were often in the last stages, comparable to those preceding death on the spawning grounds. The writer's own observation was sufficient to lead to the conclusion that large numbers of sockeye died thus. A quantitative study of these mortalities presented much difficulty and is not reported on here.

It was possible to find some numbers of sockeye, pink salmon, and occasionally other species dead on the shore or on the bars in the river, but there was no evidence of the "vast" number described by Babcock for 1913. Many dead fish were found in the creeks and also along the main river, but not in such numbers as to justify the terms used by Babcock. This lack may have been due in part to the tremendous disparity in numbers, for in 1913 the catch was nearly ten times as great as in 1941. In all other respects the two years presented strikingly similar conditions.

This exception is not difficult to understand because on the spawning grounds salmon will sink into the deeper parts of the stream, and by far the

⁵⁷ Eggs from the eddies below Hell's Gate were taken by George Esveltdt and hatched at the University of Washington under the supervision of Dr. Lauren Donaldson. Eggs from the creek beds below Hell's Gate were dug by Stever Tremper, Don Johnson, and Alvin Peterson and hatched at the University of Washington's experimental hatchery under Don Johnson's supervision.

greater proportion will disappear unless the stream is very small and shallow. Only by a rather rapid fall of the river levels could very many of these dying fish be exposed to view.

It could be said that numbers of them were observed approaching death, having reached a condition which obviously precluded their passage through any difficult currents; yet simple observation could not prove that death actually occurred nor that the percentage dying was very high. To find even hundreds of fish near death along the riffles in the river, or in the creeks did not necessarily prove that a great part of the run perished below. Some form of evidence more conclusive was necessary.

The evidence from above Hell's Gate was strikingly similar to that of 1913. Very few fish were taken by Indians above the Gate prior to the time at which the river fell below 26 feet on the gauge at Hell's Gate on September 1 to 3. At that time quantities of fish were observed above and captures persisted for some short time afterwards. As the result of passage through the Gate on these dates, heavy catches were made at Bridge River Rapids and fish were later observed en route to their spawning grounds.

There can be no question but that the water levels in 1941 were most unusual. It was a rational expectation that had the Gate been open for a long period early in September instead of the actual two days, the great majority of fish blocked below the Gate might have passed up the river to their spawning grounds. The usual year of short blockade not exceeding 30 to 35 days might, as far as visual observation showed, have been harmless to the runs. No good evidence of serious delay, certainly none of heavy mortality, has been shown for the 30 years since 1913 until the present observations began.

Facts from scattered references in the literature show that the obstruction is partial and occurs at certain levels. But they are not enough to prove what these levels are or what damage is done by the obstruction, or to define remedial action. It is necessary to show more exactly (a) the existence and duration of the obstruction, (b) its nature, and (c) its effect on the salmon.

The most serious problem faced by the Commission in analyzing the block to passage, is not only the occasional unusual year such as 1941, but the ordinary year with its short period of delay.

SECTION III

EXPERIMENTAL INVESTIGATION OF WATER LEVELS
AT WHICH PASSAGE IS OBSTRUCTED

A. METHOD OF TAGGING

The migration and mortalities of adult fish can be successfully studied only by extensive marking experiments. The Commission has carried these on in salt water annually since 1938. But such high percentages of the tags have been returned or lost that very few were left to enter fresh water. It was therefore necessary to tag additional fish somewhere on the lower river.

Such added tagging was also necessary because a new group of problems as to migration and mortality were encountered in fresh water. Returns were difficult to interpret when made in the river after being subjected to the varying vicissitudes of passage through the commercial fishery.

Tagging was begun in 1938 at various places below Yale, but the most favorable fishing spot was found to be below Hell's Gate and subsequent work became centered there, most fortunately as it developed. The numbers tagged and recovered are shown in Table 12.

Fish were captured by gill-nets during the first three years. But the nets proved selective as to size and sex and care had to be used to alternate nets of various mesh. In 1940 and 1941 dip-nets were used part of the time and found to be as satisfactory as gill-nets. In 1942 dip-nets only were used.

The fish were caught below Hell's Gate on the eastern side only during 1938, 1939, and 1940, and not on the western side as sufficient money was not available

TABLE 12
TAGGING AT HELL'S GATE AND RECOVERIES
ABOVE AND BELOW

<i>Year</i>	<i>Location</i>	<i>Number Tagged</i>	<i>Number Recovered Above</i>	<i>Number Recovered Below</i>	<i>Percent Recovered</i>
1939	Below	4,344	1,750	612	54.6
1940	Below	5,194	1,616	161	34.2
1941	Below	12,023	368	2,671	25.2
	Above	971	280	9	29.7
1942	Below	6,847	1,590	195	26.1
	Above	1,359	532	9	39.8
	In flume	752	305		40.6
	Totals	31,490	6,441	3,657	32.1

for duplicate crews which would have been necessary because there was no bridge within reasonable distance. In 1941 some fish were tagged above the obstruction in addition to the majority caught below. In 1942 a bridge had been built across the river and tagging was done at four stations, two on each side of the river, above and below the narrows. A flume had been built in that year to carry fish over the obstruction, and in it 752 fish were tagged and passed upstream. Fishing stations were necessarily varied as the river rose and fell.

Careful records were kept as to size and condition of the fish. Scales were taken for age determination and preserved. This material is not reported upon here.

The tags used were white celluloid disks 13.5 mm. in diameter. One of each pair was serially numbered, with the name of the Commission, its address, and offer of a reward. Various patterns were used. Those placed in salt water had a red spot in the center 7 mm. in diameter. Those used at Hell's Gate had a black cross or were without a sign. The other of each pair was blank. The tags were attached to the fish on opposite sides by a nickel pin run through the upper edge of the body immediately below the dorsal fin.⁵⁸

Recovery of tags was through Indian fishermen and through members of the Commission staff on the spawning grounds. As a reward was offered, a great many tags were received through storekeepers who accepted them subject to redemption by the Commission. This led to occasional difficulty in securing accurate dates of recovery and it became necessary to collect tags as frequently as possible since the longer the delay the more error. Observers were charged with this duty in 1941 and 1942. Nevertheless, in the upriver recoveries, a certain amount of inaccuracy must be accepted as contributing to the apparent period of time between tagging and recovery.

The observers on the spawning grounds recovered tags whenever they were seen on either dead or live fish. Here again, some delay in recapture was inevitable because the fish would frequently be some time on the spawning ground before being observed. Where tags were not readily found until the fish died the delay was greater than where they were taken at a weir or while spawning. These delays in reporting the recaptured tags necessitated special care in analyzing results.

The completeness of the returns was dependent largely upon two factors: 1, the ability of the observers and Indian fishermen to see every fish; 2, the loss of tags from the fish. All sections of the river were covered by observers, and each spawning ground of any importance was inspected repeatedly while the fish were present. Where the numbers were greatest observers were present from beginning to end of the season. This was true of Chilko, Adams River, Middle River in the Stuart district, and Seton Lake. A relatively high percentage of scars was observed. Symmetrically placed scars on opposite sides of the fish were peculiarly distinctive. No explanation for these tag scars seems possible except defective methods of attachment, or more probably entanglement in Indian gill-nets en route up the Fraser.

⁵⁸ The Commission originally received samples of tags and assistance in finding a maker from Dr. Daniel Merriman, now Director of the Bingham Oceanographic Laboratory of Yale University.

Increasing stress has been placed upon prompt contact with the finders as contributing to the accuracy of the returns. An observer especially charged with contacting the Indians has reduced the number passing through the hands of third persons since 1941.

B. THE RACES OF SOCKEYE AND EVIDENCE OF MORTALITY IN DIFFERENT DISTRICTS

Each spawning ground has a race which migrates through the canyon of the lower Fraser at definite times. The effect of the obstruction can only be understood when these times are known (*see* page 16 for discussion of the term "race").

In Figure 21 the numbers of sockeye tagged at Hell's Gate and recovered in various districts of the Fraser are shown as frequencies according to the date on which they were tagged. In this figure all data for the years 1939, 1940, 1941, and 1942 are included, as completing one four-year cycle of runs. The migration of the races may be readily followed up the Fraser River and its principal tributaries, the time of tagging at Hell's Gate being shown in each case. The graphs have been lettered in succession up the Fraser. The number tagged each day below Hell's Gate is shown as A. The recoveries from each day's tagging are listed as follows:

B. Between Hell's Gate and the junction of the Fraser with the Thompson at Lytton. This carries all the races which passed Hell's Gate.

C. (1) The Thompson between Lytton and the junction of the North and South Thompson.

C. (2) The North Thompson spawning grounds at the Raft River.

C. (3) The Seymour River, flowing into Shuswap Lake.

C. (4) Adams and Little Rivers and the Shuswap Lakes.

D. The main Fraser between Lytton and Seton Creek. This is the outlet of Seton and Anderson Lakes, and between these lakes lies Portage Creek, a spawning ground.

D. (1) Portage Creek.

D. (2) Seton Creek.

E. Between Seton Creek and the mouth of the Chilcotin River, a stretch which carries all the races bound for the upper Fraser.

E. (1) The Chilcotin River, leading to

E. (2) The Chilko spawning grounds.

F. The Fraser between the Chilcotin and the junction of the Fraser and the Nechako at Prince George, through which Bowron, Stuart, and Nechako fish pass as shown under G, H, and I.

G. The Fraser above the Nechako, leading to

G. (1) The Bowron and the spawning grounds above Lake Bowron.

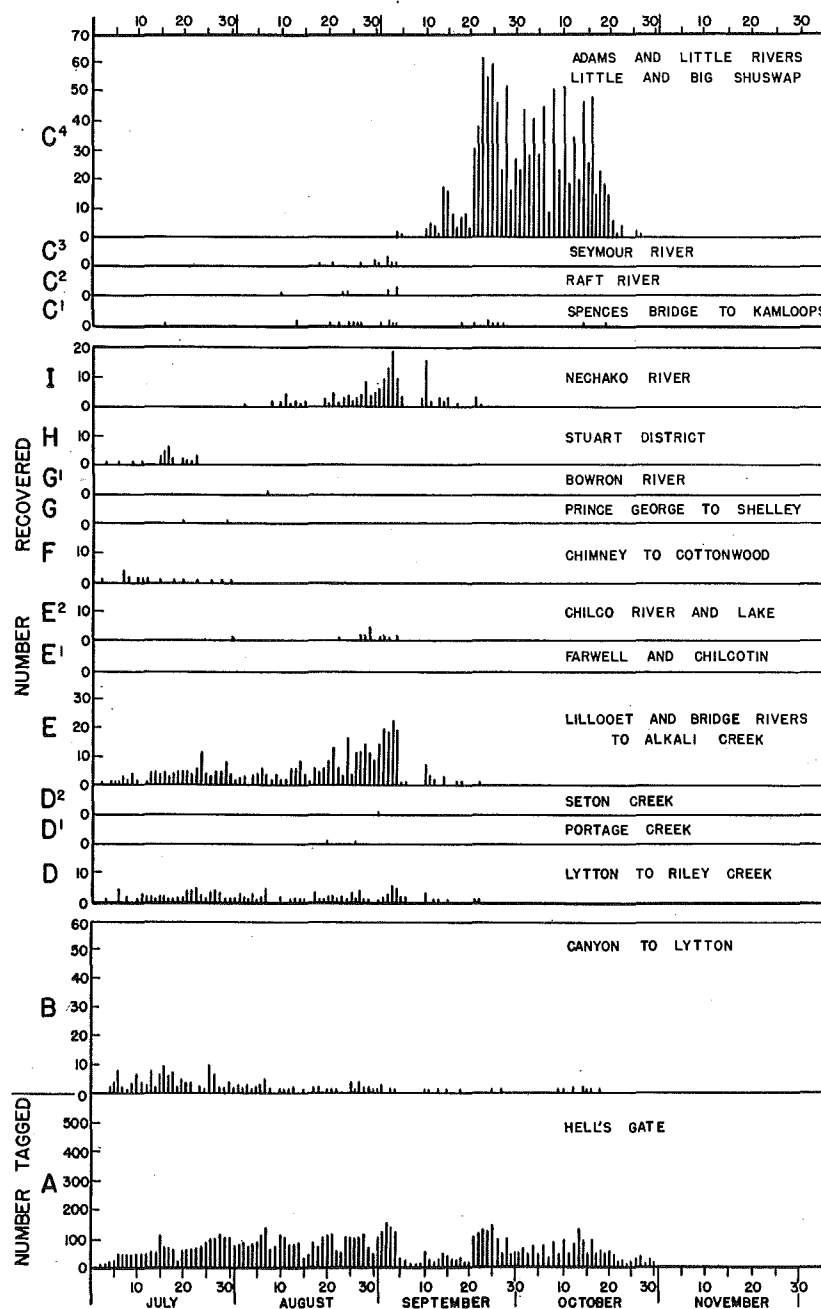


Fig. 21

NUMBERS OF SOCKEYE TAGGED AT HELL'S GATE (A) AND NUMBERS RECOVERED IN VARIOUS DISTRICTS OF THE FRASER RIVER BY DATE OF TAGGING IN THE YEARS 1939 TO 1942, INCLUSIVE.

H. The Stuart River and its tributaries, with spawning grounds in Middle River, Kynoch, and Forfar Creeks.

I. The Nechako, including Nautley, Stellako, Endako, Francois Lake, Fraser Lake, etc.

It is not possible to set accurate dates on which these various races passed Hell's Gate. There were a few extremely early and late individuals which may not have been typical of the race. Even at Adams River, where great numbers of tags were recovered, the beginnings and endings of the runs were not definite. The graph (Figure 21) gives a better picture of the times at which the runs passed Hell's Gate than a table of dates of beginnings and endings. However, in Table 13, the dates defining what might be called the main runs through Hell's Gate are given, together with those of the extremely early and late migrants.

The distribution of sockeye salmon throughout the Fraser system does not show a uniform season in each district. The run to each district has its own time of migration past Hell's Gate, its own particular year or years of the cycle in which it appears, and its own history of depletion and rebuilding. In this the findings from the tagging are consistent with the history of the runs (page 50). The runs of sockeye to the Fraser have therefore behaved as a series of units, largely independent.

At present there are two main divisions of the runs, one before September 18 to the Fraser above its junction with the Thompson, the other after September 18 to the Thompson. This suggests that there is some form of change about that time in the water of the two rivers, in temperature, or substances in solution, which affects all sockeye and accordingly shifts the migration route.

But the history of the Thompson (*see* page 62) shows that there was once a very large early run there, before September 15, and remnants of such early runs still exist, to the Raft and Seymour Rivers (*see* Figure 21). Furthermore, the late run was destroyed and was rebuilt on a different year of the cycle (*see* Fig. 13, showing the effect of Adams River dam). There is sound reason to believe that some still persistent factor has nearly destroyed the early runs, leaving one late run

TABLE 13
TIMES OF PASSAGE THROUGH HELL'S GATE OF PRINCIPAL
RACES SPAWNING IN FRASER RIVER DISTRICTS

<i>District</i>	<i>Main Run</i>	<i>Extremes</i>
Stuart Lake.....	to July 29	to Aug. 25
Bowron.....	July 15 to Aug. 15	July 11 to Aug. 28
Chilko.....	July 30 to Sept. 11	July 26 to Sept. 21
Nechako.....	Aug. 2 to Sept. 21	July 24 to Sept. 21
Shuswap.....	Sept. 9 to Oct. 27	Sept. 3 to Nov. 2
Seton-Anderson....	Aug. 20 to Sept. 27	July 2 to Sept. 27
Raft River.....	July 23 to Sept. 5	

in real abundance. The runs to the Thompson should, then, occur naturally the full length of the sockeye season at Hell's Gate; and as far as it is concerned the present diversion of the greatest numbers of sockeye up the Thompson after September 18 is the result of differences between the several races and the history of the mortalities to which they have been subjected, and not the result of a chemical or physical change at that time affecting all sockeye alike.

The history of the runs and the present study show the same type of facts regarding the runs up the main Fraser River beyond its junction with the Thompson. The runs cease about September 18, but in the only case when tags were found in the Fraser after that date, in 1940, they could not be followed beyond the Bridge River section. The history of the Seton district (page 59) indicates that erratic late runs have occurred before and since 1913, apparently runs which have failed to pass Bridge River and have found refuge in Seton Creek, which is just below Bridge River rapids. If this is due to an obstruction at the latter place, beginning at low water levels, which follow shortly the release by low water of fish from Hell's Gate, the absence of late runs to the main Fraser may be explained. If so, the separation of runs at the junction of the Fraser and the Thompson is a result of the timing of obstructions, acting upon distinct races which have a different season of migration. The possible obstruction at Bridge River needs careful examination from this standpoint as perhaps the cause of the absence of late runs to the Fraser above Lytton.

The particular levels of abundance at which the various races in the Fraser above Lytton find themselves results from the mode of action of the Hell's Gate obstruction as will be shown in the following sections of the report.

These facts lead to important conclusions. The piecemeal destruction and rebuilding of these runs could only take place if they were composed of independent units, which we can call races. The character by which we know them in this report is their time of migration past Hell's Gate. It is a character which cannot be a memory acquired while young because it is shown by the adults only, and shown at a time when the young are either in the lakes or in the sea, and in response to an environment the individual has not met before. It must be embedded in the inherited structure of the race as the net result of changes in the functioning of its nervous system, in its physiology, or otherwise. This would be true whether the segregation is on a basis of some particular phase of the constantly shifting temperature or the chemical characteristics of the water from the two streams, or of time in relation to the internal reproductive processes of the maturing adult.

It is a necessary consequence of the existence of these races and the difference in time of their migration, that during the early years of obstruction, those races most subject to injury should disappear, or be diminished greatly. This is evident as reduction of the catch, in the first section of the Fraser run. There seems to have been left a group of races capable of passage in sufficient numbers because of the timing of their migratory habits. This means that the most visible damage and great depletion occurred during the early years after 1911 and have left behind certain stocks, or a group of relatively stable races, now subject to no greater mortality than they can support.

Some of these races, such as the late run to Adams River, have escaped damage and have increased in abundance. Others must have encountered a maximum of difficulty at the obstruction and may have disappeared. Between these extremes there may remain races which still survive in small numbers, and which increase and decrease as the obstruction varies in effect. However, in general the runs must have adjusted themselves to the average mortality, and no great runs can now be expected to take place during the period of time each season when passage is usually difficult.

For this reason no great annual mortality, such as happened in 1913 and adjacent years, can be expected except in a year of long closure such as 1941 when the levels difficult of passage persisted into relatively untouched migration periods. But even in an ordinary year, due to natural variability in habit, or to a degree of survival of certain races, some fish could be expected to arrive during the period of block. It is in the effect of the obstruction on this small stock of fish in the ordinary year that its destructiveness can be gauged.

Whatever heavy mortality rate occurs in these limited numbers thus affected by the block cannot usually be seen easily, because the dead sink in the water. But if we apply efficient tests, we must be prepared for a mortality proportionate to their small numbers. An efficient test requires an adequate sample, and this has been obtained whenever possible.

Since in doing this as many fish were tagged daily as could be taken and handled, the numbers tagged by no means represent the abundance of fish. They tend to give equal representation to depleted and to abundant races, whenever such races are present at different times. But when a depleted race is passing at the same time as one more abundantly represented, there is as yet no way whereby the two can be distinguished. Thus there are still many of the races inadequately represented in the tagging. In this lack lies one of the main reasons why the tagging experiments have been continued over a four year cycle.

Sockeye were tagged at Hell's Gate as consistently as possible throughout the season. It was hoped that this would give sufficient numbers for each day to indicate any unusual mortalities at any part of the season. The returns have been classified by the date of tagging, since the evidence thus bears most closely on the time of damage done to the runs while they were in the canyon near Hell's Gate. The date of recapture could not be used because the returns of each day's tags from the spawning grounds, and en route, were necessarily scattered over a period of time. It was also expected that returns from all parts of the season for any one race at Hell's Gate would be present together on the spawning grounds of that race, and could be searched for with thoroughness at some time during the spawning period. All spawning grounds and all fishing grounds en route were watched by the observers.

The evidence shows very marked inequalities in the percentage recovered of fish tagged at different parts of the season at Hell's Gate. Each of these inequalities must be examined with care and explanations sought. They are of three different types.

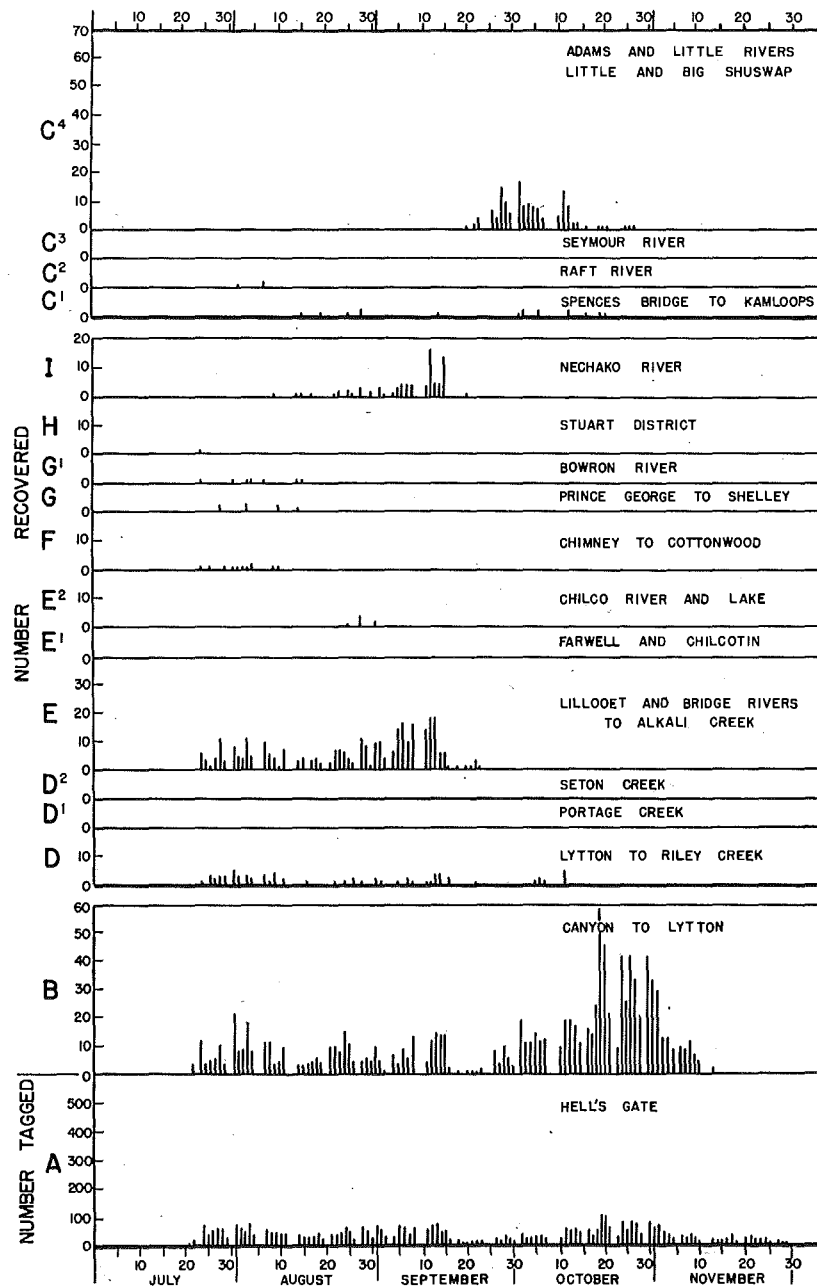


Fig. 22

NUMBERS OF SOCKEYE TAGGED AT HELL'S GATE (A) AND NUMBERS RECOVERED IN VARIOUS DISTRICTS OF THE FRASER RIVER BY DATE OF TAGGING IN THE YEAR 1939.

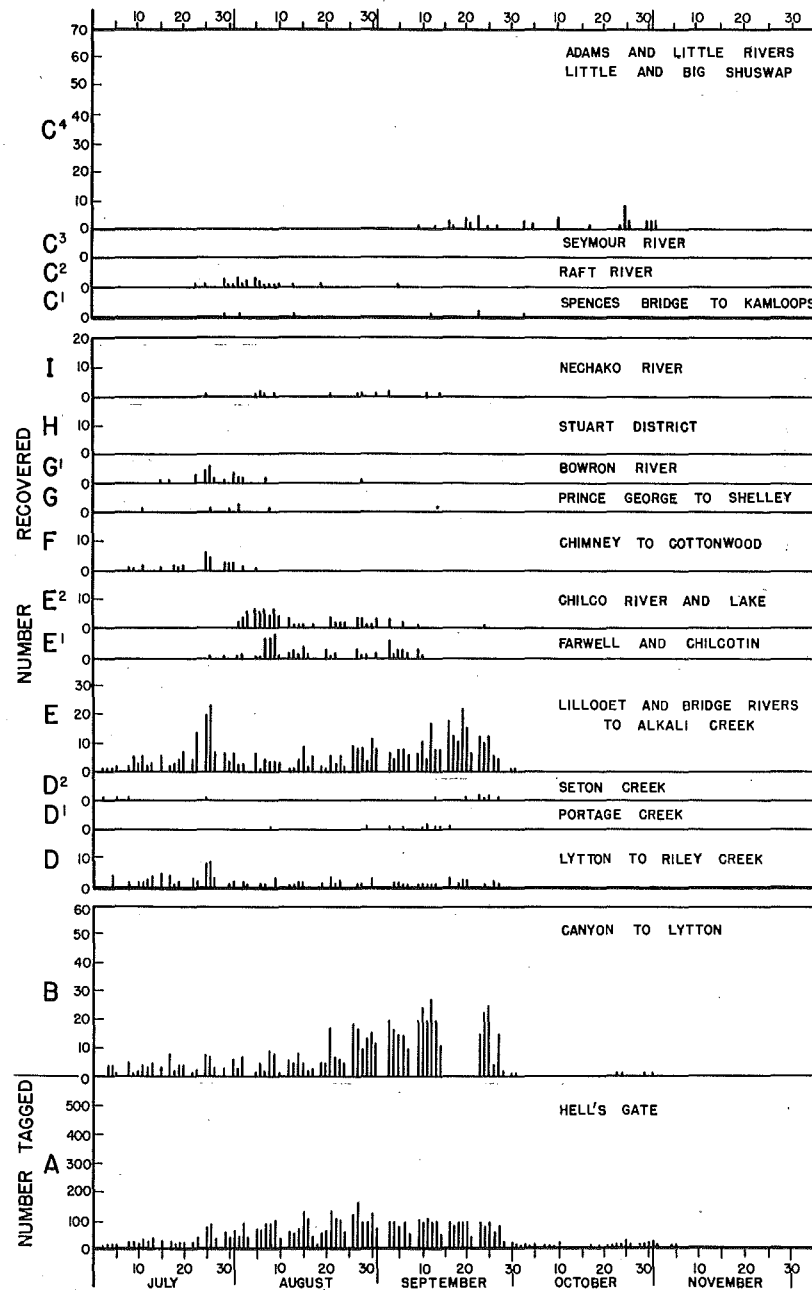


Fig. 23

NUMBERS OF SOCKEYE TAGGED AT HELL'S GATE (A) AND NUMBERS RECOVERED IN VARIOUS DISTRICTS OF THE FRASER RIVER BY DATE OF TAGGING IN THE YEAR 1940.

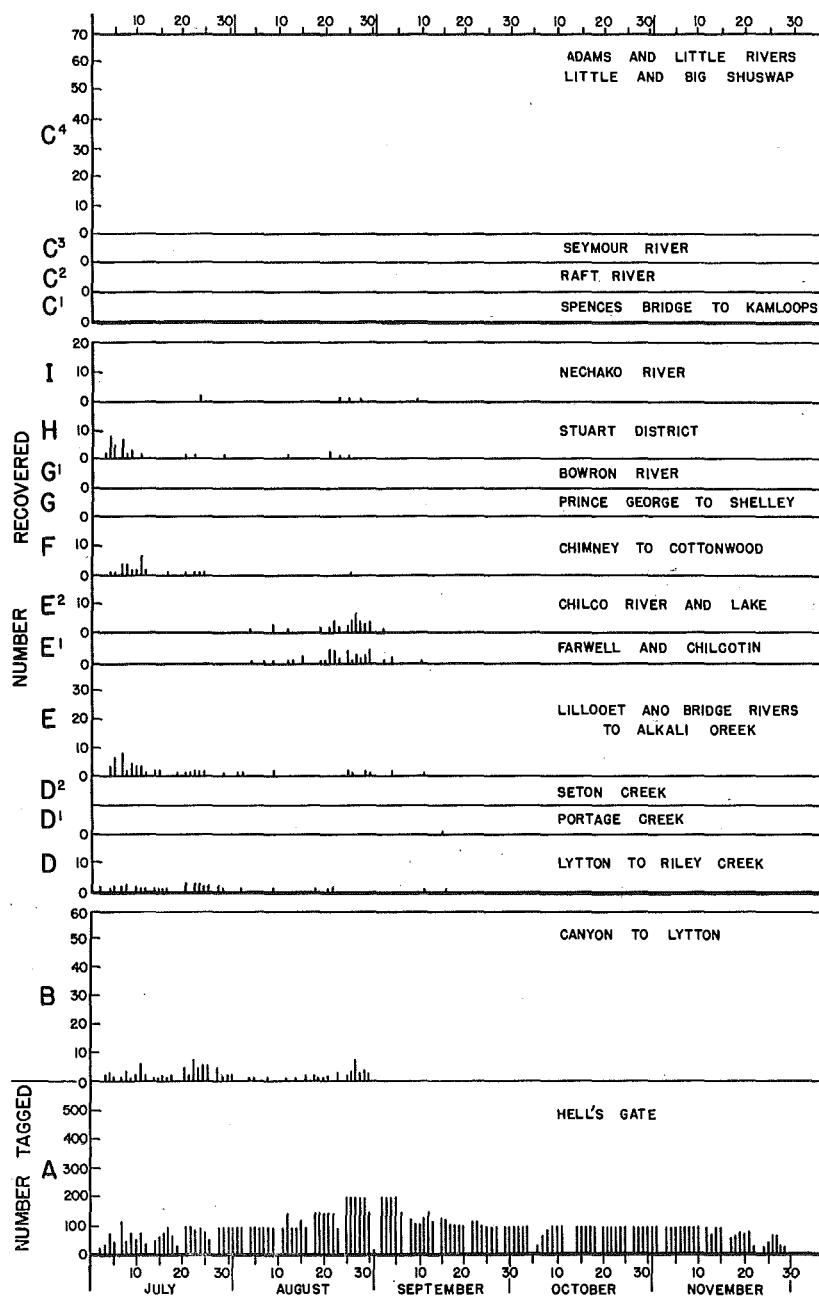


Fig. 24

NUMBERS OF SOCKEYE TAGGED AT HELL'S GATE (A) AND NUMBERS RECOVERED IN VARIOUS DISTRICTS OF THE FRASER RIVER BY DATE OF TAGGING IN THE YEAR 1941.

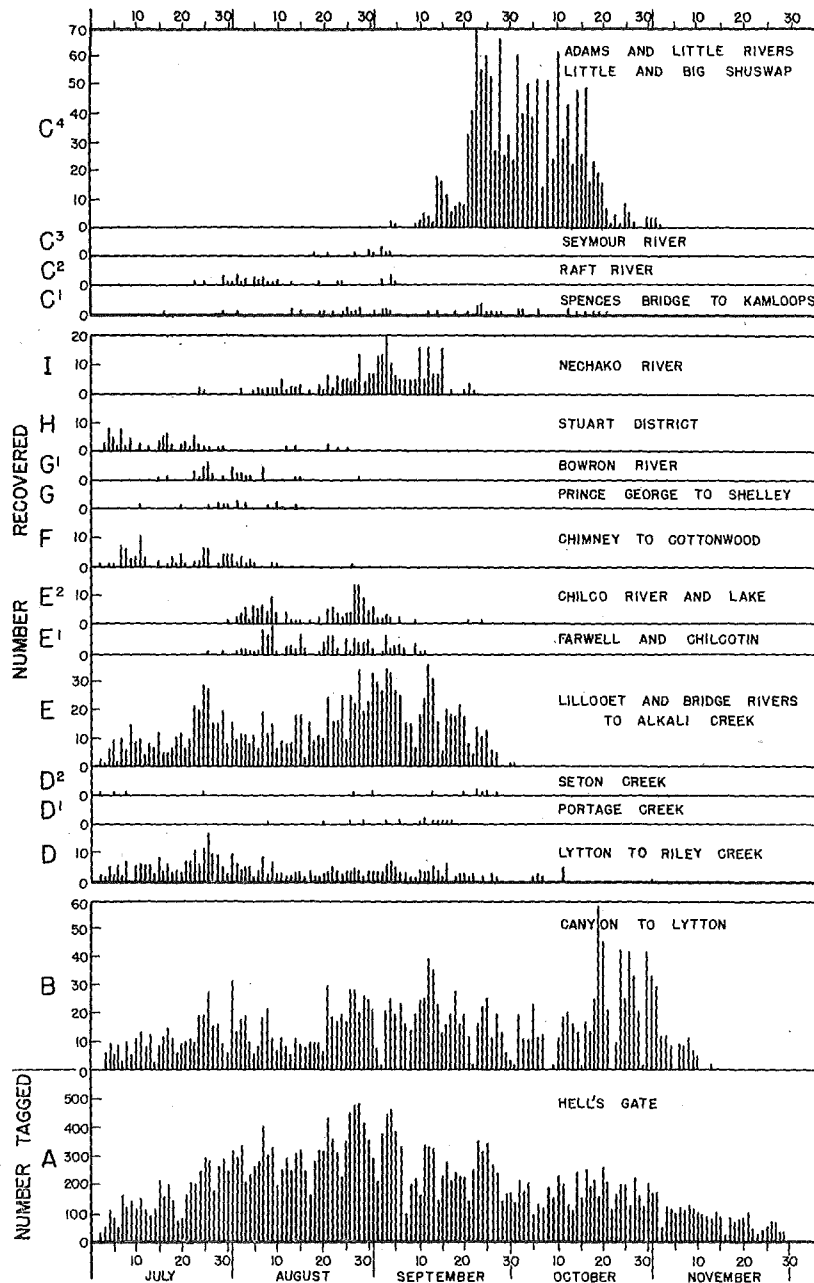


Fig. 25

NUMBERS OF SOCKEYE TAGGED AT HELL'S GATE (A) AND NUMBERS RECOVERED IN VARIOUS DISTRICTS OF THE FRASER RIVER BY DATE OF TAGGING IN THE YEAR 1942.

(1) Recoveries were much higher in proportion from the Adams and Little Rivers of the Thompson, shown in graph C4 of Figures 21 and 25 than elsewhere. The loss at Hell's Gate was less for those races than it was for the races passing earlier. As will be shown later, there were many recoveries downstream during the season before the beginning of the run to the Thompson; and the explanation of the resultant lack of recoveries upstream is to be found in the effect of the barrier at Hell's Gate in reducing the numbers passing that point. The Adams and Little River races passed after this barrier lifted. This will be brought out more clearly later.

The run to the Thompson began to pass Hell's Gate in numbers about the middle of September and was readily separated from the run to the main Fraser River above Lytton which ended at that time. The run to the Thompson was an unobstructed run in 1942 and the variation in percentage returns is shown in Figure 12. They were in excess of 50 per cent at times. The decline in these toward the end of the season must be due largely to natural mortality, or to some unexplained variation in efficiency of recovery.

(2) However, the failure of recoveries at the end of the season goes much farther than any possible minor variation in the efficiency of the search for them could explain. In Figure 21, showing the combined returns for the four-year cycle 1939-42, tagging persisted at Hell's Gate well after November 10, but no fish tagged after that date (with one exception) were found elsewhere in the Fraser system above that point. In Figure 22, for the year 1939, this is shown to be true of returns for that year. The stock of fish present below Hell's Gate after October 15, 1939, got no farther than the canyon below Lytton in any numbers. A closer study of returns for that year has suggested the cause (*see* page 123). In contrast, there were recoveries from the spawning ground at Adams and Little Rivers in the Shuswap district, shown in graph C4 of Figure 25, for all parts of the season after September 18, 1942, although in diminishing proportion toward the end. The unusual returns in 1939 were caused by the barrier in the canyon at or near Hell's Gate. The same was true in 1941.

A similar type of loss is shown by recoveries in the main Fraser. In Figure 21, showing the years of the cycle in combination, the returns for Bridge River, given in graph E, included many tagged at Hell's Gate after September 15. But this group of tardy migrants was not seen again in numbers on any spawning ground above Bridge River on the main Fraser. Observation of the spawning grounds should have been complete enough for months thereafter to assure the finding of more of them had they passed, as the observers were required not to leave until new fish ceased arriving. By reference to Figure 23, it will be seen that this loss occurred in 1940. It did not occur in the other three years, as shown in Figures 22, 24, and 25, when most of the late spawning ground recoveries shown after September 15 were made.

Moreover, the recovery of tags above Bridge River for the period just preceding September 18, 1940, was unexpectedly light in view of the many recovered at or below Bridge River.

The loss of the last section of the run is therefore an irregular occurrence, having happened at Hell's Gate in 1939 and Bridge River in 1940.

It is apparent that, with the exception of this loss of late migrants, the runs through the rivers leading to each spawning ground are of the same fish which are later taken on that spawning ground. For instance, in Figure 21, the graph E1, showing the recoveries at the fishing stations of Farwell and Chilcotin, resembles graph E2, for the Chilko spawning grounds, both as to season and as to distribution of returns. So also, are the returns from Prince George and Shelley similar to those from Bowron. The returns from the Chimney to Cottonwood section are an apparent exception, because fishing ceased too early to reflect the Nechako run. But the fish lacking there were present in the main river below Chimney. The conclusion seems justified that in no case has a run been detected en route which has not been found on a spawning ground, except in the two instances cited for parts of runs at Hell's Gate in 1939 and Bridge River in 1940. For these, explanations are available in the changing water levels at Hell's Gate.

(3) Recoveries above the canyon of sockeye passing Hell's Gate in August were not in proportion each day to the number tagged.

The fish tagged before September 18 passed nearly invariably up the main Fraser, beyond the junction with the Thompson. Returns in the main Fraser

TABLE 14
TAG RETURNS IN 1939, 1940, 1941, AND 1942, ACCORDING TO
SECTIONS OF THE RIVER AS SHOWN IN FIGURE 21,
BY DATE OF TAGGING

Date	Number Tagged	Percentage Returned Sections		
		B	D	E
July 3 - 9	738	6.5	2.9	6.8
10 - 16	973	7.4	3.7	5.6
17 - 23	1105	6.4	3.4	6.6
24 - 30	1872	6.2	3.1	7.2
July 31 - Aug. 6	1960	5.5	1.3	3.0
Aug. 7 - 13	2010	4.2	1.3	3.7
14 - 20	1986	3.3	.7	4.1
21 - 27	2636	6.1	1.1	5.1
Aug. 28 - Sept. 3	2634	4.9	.8	7.2
Sept. 4 - 10	1861	7.7	1.3	7.4
11 - 17	1858	8.9	1.1	7.7
18 - 24	1762	6.7	.5	4.5
Sept. 25 - Oct. 1	1599	5.1	.2	1.6
Oct. 2 - 8	1546	5.2	.3	
9 - 15	1368	6.1	.4	

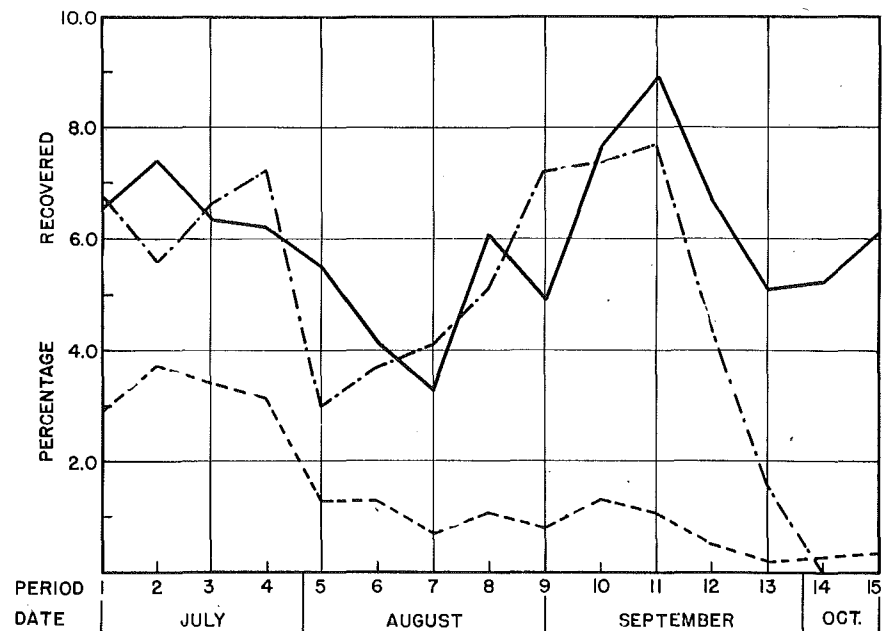


Fig. 26

PERCENTAGE RETURNED OF ALL SOCKEYE TAGGED AT HELL'S GATE IN THE YEARS 1939 TO 1942 INCLUSIVE BY DATE OF TAGGING AND DISTRICT OF RETURN AS SHOWN IN FIG. 21.

Section B, Fraser Canyon to Lytton _____
 Section D, Fraser River, Lytton to Riley Creek _____
 Section E, Fraser River, near Bridge River _____

above Lytton are shown in the central part of the figure, in graphs D to I, of Figures 21 to 25. The most numerous returns are shown at or near Bridge River Rapids, in graph E. Above this section of the river, the runs broke into their constituent parts, each bound for a spawning ground, from which returns were relatively few. Graphs B, D, E, E1, F, and G represent sections of the river through which fish pass. D1, D2, E2, G1, H, and I represent spawning grounds. The runs passed through sections of the main Fraser, from which returns are shown in graphs B, D, and E, before diversions into any main spawning ground. In these three graphs there are enough returns to support analysis for the period prior to September 18, when the migrations shifted to the Thompson. In all these the returns during August are not in as high proportion to the numbers tagged, as during July and September. In general the distribution of returns in graphs D and E resembles that of graph B for the canyon immediately above Hell's Gate. It follows that whatever produced the difference, was effective at or immediately above Hell's Gate. The unaccounted for percentages were lost at Hell's Gate.

In Table 14 and Figure 26, the returns from these districts during the four-year cycle combined are shown by seven day periods, as percentages of the fish tagged. This grouping is necessary because the recovery of tags is strongly affected by weekly closed seasons. The returns are fairly uniform throughout July, but fall abruptly to a minimum the first week in August. Thereafter graphs B

and E rise to a second maximum in September, only to disappear as the run shifts into the Thompson. This deficiency during August is evident in both the recoveries in the canyon from Hell's Gate to Lytton and those from the main Fraser above Lytton. The graphs, B and E, are very similar, so similar in fact as to suggest that the sampling done by the Indians in the two districts was very much alike and upon the same body of fish. But the similarity could only be fortuitous, if it depended upon the character of Indian operations. The presence in two distinct districts of the Fraser of a similar deficiency, one which was greatest in the period when it made its first appearance and which gradually disappeared to cease in early September, is a most significant fact from the viewpoint both of the cause of the deficiency and of the circumstances which made recovery percentages so similar in the two districts.

The similarity in percentage returns during August from the three sections of the Fraser will be given an explanation when it is later shown that the fish tagged in August below Hell's Gate were held there and the accumulation was passed upstream at nearly the same time, in early September. It was, consequently, subjected in each fishing station to the fishing intensity prevailing at the time of passage; and because the time of passage was short, the intensity existing was uniform in its application to all fish forming parts of this accumulated body of migrants, regardless of the date of tagging. In fact, there might have been a still closer correspondence in the distribution of percentage returns, had not the period of delay and the proportion of recoveries been different in the different years of the cycle represented in Figure 26. A correspondence, suitable for exact mathematical analysis to show the probabilities of origin of the catches from the same body of fish, could not in the nature of the case, have been expected.

Examination of the spawning grounds for these deficiencies in return requires reference to the returns of individual years, since the run to each ground usually occurs but once in the four year cycle. These three types of variation in tag returns are found in the individual years of the four-year cycle.

The returns for each of the four years, 1939 to 1942, have been graphed separately, and are shown in Figures 22, 23, 24, and 25. In each the divisions of the river used in Figure 21 for the combination of years, are retained.

In comparing these figures, it is at once plain that the returns from different spawning grounds differ widely between the years. This variation is in accord with the evidence from historical sources (*see* page 50), and from stream observations. It is consistent from cycle to cycle, as already stated, and forms part of the proof of a high degree of independence of the units or races of which the sockeye run is composed. Wherever a sufficient number of tags were returned, a closer examination can be made. This can only be done in a limited number of cases.

The run at Adams River and vicinity, graph C4, was present in numbers only in 1939 and 1942. In 1939 the number of recoveries was small, and only the first section of the run which appeared at Hell's Gate and in the canyon above Hell's Gate reached Adams River (*see* page 150). In contrast the recoveries in 1942 at Adams River reflected with some degree of faithfulness the season of tagging at

Hell's Gate, even though the percentage recovered decreased toward the end of the run.

Returns from the Nechako River, graph I, were present in some numbers in 1939 and 1942. In each case the returns showed a highly skewed curve, with a long gradual increase in numbers of returns to a late peak. In this it reflects the distribution of returns in August in graphs B, D, and E of Figure 21, showing the combination of the four years in the cycle. The same distribution is found in the two years, 1939 and 1942, but with a significant difference (Figures 22, 25). In 1939 the peak ended September 15; in 1942 between September 2 and 4. These dates may be compared to those on which the water first fell below a level of 26 feet at Hell's Gate, namely, September 15 in 1939 and September 3 in 1942. Allowing a day or two for an accumulated stock of fish to pass, this timing is very suggestive of a stock which had been held until water levels had fallen to those which were suitable for passage (*see also* pages 121 and 131).

Returns from Chilco (graphs E1 and E2) were best in 1940 and 1941, the years of the best runs to that district, shown in Figures 23 and 24 (*see* page 56).

In 1940 there were two groups of returns, the first of fish tagged between August 1 and 12, the second a diffuse, long drawn out series of returns, few in number for any one day. Unfortunately, no tagging had been done at Hell's Gate on August 11, and very little on August 10. The first group was therefore tagged at Hell's Gate at water levels above 40 feet (*see* page 125, where it is regarded as a doubtful block). If the run to Chilco begins about July 30 and ends September 11, the returns suggest, but do not prove, better passage midway of the run, on August 12, with a mere dribble of tagged fish passing thereafter until the run ended. A few were either able to pass during the obstruction or were able to survive until the river became passable between September 13 and 28 (*see* page 125).

In 1941, Figure 24, there was at Chilco but one group of returns in graphs E1 and E2, ending between August 30 and September 2 (*see* page 127). The exact date was lost because of a lack of tagging on the intermediate days. The same grouping of returns is shown in the canyon above Hell's Gate, by graph B, and it consequently must have originated at Hell's Gate. The water level at Hell's Gate was 26 feet on September 1, the same level found to be significant in considering the Nechako run. Evidently, in this year, in contrast to 1940, the obstruction above 26 feet was over early enough so that some of the Chilco run still survived, since that run ended about September 11.

In this year, 1941, water levels at 40 feet came July 27 instead of August 12, as in 1940. It was at that level that fish passed in 1940, but in 1941 this level came before the Chilco run began. As a result no group of fish passed at that level in 1941, in contrast to 1940. It is evident that the Chilco runs reflect the conditions at Hell's Gate in the same way as do the Nechako runs.

Other groups can be seen in other sections of the run. There was a noticeable group which passed before July 27, 1941, shown in graphs B, E, F, and G1 of Figure 24, when water levels were near 40 feet, but elsewhere than in the Chilco run (*see* page 128). One earlier in July, 1941, reached the Stuart district, possibly

passing at 40 foot levels (*see* page 128, top). A passage about July 26, 1940, of fish which reached the Bowron, was at levels above 48 feet (*see* page 124). These indications are not precise, owing to the relatively few fish which were tagged. Had weirs been installed in each district and the migrants counted, the evidence would have been clearer. But there was partial passage at 40 and 48 feet and complete passage below 26 feet, these levels in each case being approximate, and being understood as the end of an accumulation at Hell's Gate.

If it is true that fish pass up-stream as a body, from an accumulation at Hell's Gate, to give a distribution of returns such as those from the Nechako, it should be possible to corroborate the fact best by examination of returns from points en route rather than of those from the spawning grounds. The returns from points en route would be concentrated, whereas those taken while spawning would be scattered over a considerable period regardless of how the fish arrived. The returns from the Nechako run in 1939 and 1942 would be best for use in this regard, because these runs were not mixed with those to other areas, and they occurred at the final decisive opening at the 26 foot level. In a following section of the report, the accumulations below Hell's Gate, their release, and their progress up the river will be shown thus (*see* pages 113, 134 and 140).

It can be concluded from the examination of tags returned from above Hell's Gate that the obstruction there has modified all parts of the run during the time the barrier has been effective. The fish on each spawning ground, and the recaptures made en route, reflect the incidence of the block, insofar as the tagged fish reflect the total run of sockeye. The numbers reaching the Fraser above Lytton during the season from its beginning to the middle of September are thereby reduced, and those which pass thereafter are affected by conditions at Bridge River.

This conclusion will be found to be confirmed by the results at Hell's Gate, stated in the following section. As might be expected, the periods of difficult passage did not always affect sufficient fish to be shown in the returns from the river above Hell's Gate. Consequently, these periods are much more accurately studied by examination of the recoveries at Hell's Gate.

C. RECAPTURES OF TAGS AT HELL'S GATE TO SHOW PERIODS OF DIFFICULT PASSAGE

A varying number of tagged fish were recovered by the taggers themselves at Hell's Gate. In years of heavy runs the numbers recaptured were small because the tagged fish were few, the number of fish caught and tagged being limited to what the tagging crew could handle. In poor years, as 1939, the ratio was high and recaptures many. The relationship between the recaptures and the catch of each year is as follows:

<i>Year</i>	<i>No. Tagged</i>	<i>No. Recaptured at Hell's Gate</i>	<i>% Recaptured at Hell's Gate</i>	<i>Commercial Catch</i>
1939	4,344	266	6.1	116,777 cases
1940	5,194	147	2.9	148,963 cases
1941	12,994	131	1.0	260,477 cases
1942	8,958	112	1.3	731,095 cases

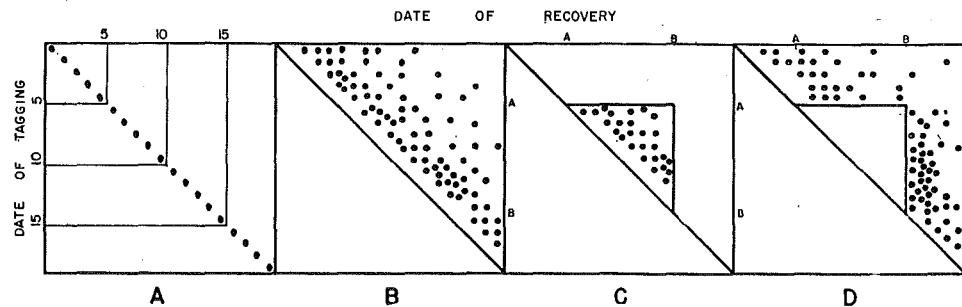


Fig. 27

DIAGRAM OF METHOD OF PRESENTATION OF RETURNS BY DATES OF TAGGING AND RECOVERY
(See Text)

If 1941, the year of a long blockade, is omitted, there is an inverse relationship between the catch and the percentage recaptured at the tagging locality. The escapement is larger in years of good catches.

In each case while the block was complete, the stock of tagged fish held below the obstruction increased daily. The number of recaptures per day and the average elapsed time since tagging also increased with the period of delay. Thus in 1939, toward the end of the period of block, one fish in 20 captured was found to have been tagged previously. And of the tagged fish reliberated approximately one in 20 was caught a second time by the taggers.

These circumstances led to a characteristic and interesting sequence of changes in the number and character of recaptures *during* the period of block. To bring this out clearly, a form of graph was chosen which showed the time of recapture, the time of tagging, and the number of recaptures on each date. These are shown for each year in Figures 28, 29, 33, 35, 37, and 38. Figure 29 is a good example.

The recaptures each day are shown above dates along the base line of each graph. Above each date, starting at the bottom with the earliest, each recapture is represented by the end of a line. This line is projected left to a point above the date on which it was tagged. The length of the line indicates the time elapsed between tagging and recapture. The number of lines ending above each date indicates the number of recaptures on that date. Thus in Figure 29 on August 18, *two* fish were recaptured; one of them had been free 12 days, the other 8 days. The lines are superimposed in chronological order.

The graph shows clearly the number of the recaptures on each day of the block, and the length of time they have been delayed. As the accumulation proceeds the number of recaptures increases and the whole graph rises more rapidly and shifts less to the right. The pattern made by the lines increases in breadth to correspond with the length of the delay. The left hand margin formed by the lines shows the dates on which the recaptured fish were tagged, hence the date on which the accumulation began can be estimated.

For comparison, the water levels of the river at Hell's Gate on the gauge established there are shown on the same time scale. The pattern formed shows

either that the tagged fish were accumulated faster than the untagged, or that the susceptibility to recapture increased with the length of time the fish were delayed until they began to drift down-stream. That the latter is true is shown on page 119. Where there was good reason to believe that the accumulation grew faster than the tagged stock, as in October of 1941, the number of recaptures was small.

This form of graph shows well the progressive accumulation of fish and the increasing number of recaptures as the period of block lengthens. It also summarizes the events of the season in a concise and vivid form. But a different type of graph can be used to show more clearly the date on which periods began and ended. It will be found to be more difficult of interpretation and more precise in its meanings.

In Figures 30, 34, 36, 39, the tagged fish recaptured by the tagging party are arranged on a system of coordinates, the dates of tagging along the vertical and the dates of recovery along the horizontal. In the accompanying diagram, Figure 27, this is illustrated. In the first part (A) of the diagram, a series of tag recoveries are shown as though they were recovered on the same day on which they were tagged. The result is a diagonal of dots across the graph, each dot representing a fish.

In the second part (B) this diagonal is shown as a line. The recoveries are delayed and each day's tagging is scattered over several recovery days. In the third part (C) only those recoveries are shown which were tagged after date (a) and recovered before date (b). This is what would be shown in the case of recaptures from an accumulation of delayed fish caught behind a barrier which became effective on date (a), and which was removed on date (b). In the fourth part (D) the recoveries are shown at a point above the barrier. The graph resembles B

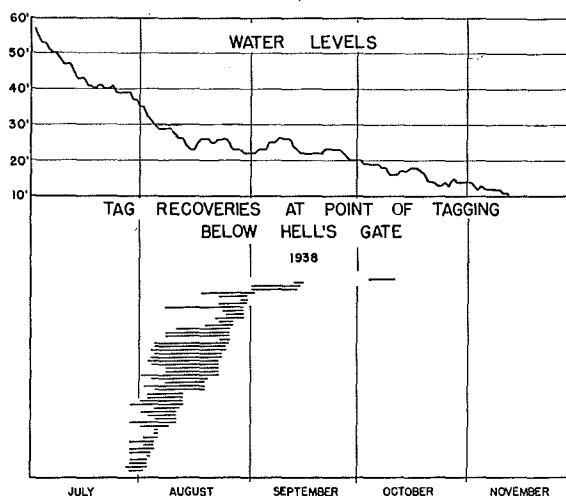


Fig. 28

PERIODS OF DELAY AS SHOWN BY TAGGED FISH RECAPTURED AT POINT OF TAGGING, HELL'S GATE, GIVING NUMBER EACH DAY, LENGTH OF TIME SINCE TAGGING, AND COMPARISON WITH WATER LEVELS, 1938.

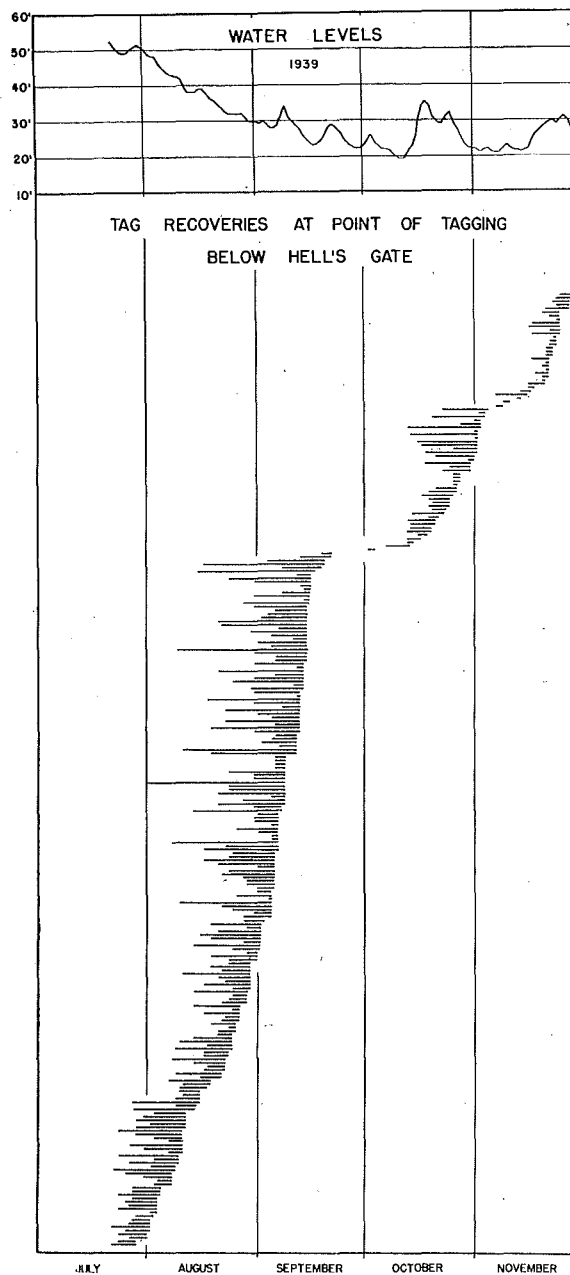


Fig. 29

PERIODS OF DELAY AS SHOWN BY TAGGED FISH RECAPTURED AT POINT OF TAGGING, HELL'S GATE,
 GIVING NUMBER EACH DAY, LENGTH OF TIME SINCE TAGGING, AND
 COMPARISON WITH WATER LEVELS, 1939.

except for the withholding by the barrier as in C of the fish tagged after date (a) and before the release on date (b). Such withheld fish are released on date (b) and arrive in numbers, in D, as an accumulation of those which should have previously passed. The contrasting triangles in C and D illustrate the form which the graphed returns take below and above a barrier when the barrier is effective between two given dates. Since a more or less equal number of fish were tagged daily, the composition of the accumulated stock of fish according to date of tagging is shown by the recaptures just prior to date (b) in C and just after date (b) in D.

A detailed description of the results in each year is given.

1. 1938. The water levels for 1938 are calculated from those at Hope, some miles downriver, hence are not to be relied upon in detail. For subsequent years those at Hell's Gate are given.

In 1938 (Figure 28) tagging commenced after accumulation below the obstruction had already begun. It is not possible to show the upper levels of the period of block, but the accumulation is shown clearly by the grouped lines in the lower graph. On August 12 the water levels on the gauge fell briefly below 25 feet (Hope gauge). Tagging and recaptures ceased for the time being, but when resumed on August 18, the stock of tagged fish below the obstruction still remained and consisted of fish tagged before the 12th. It was not until August 25 when the water fell below 25 feet and remained so for some time that the fish tagged earlier began to disappear. By August 29 and 30, four days later, the accumulated stock had largely disappeared and from then to the end of the season only occasional tagged fish were delayed in passage. Although the upper levels of the block were not evident because of a late beginning of operations, the lower level seems to be distinct.

The tagging during 1938 was irregular. While the general fact of a period of blockade above 25 feet is plain, the data will hardly bear precise interpretation.

However, the approximate length of closure was between July 21 and August 25, about 33 days.

2. 1939. The run of fish was much smaller, the recaptures more numerous, and over the whole season in 1939 (Figures 29 and 30). For this reason an attempt can be made to interpret the returns more closely.

The most striking fact is the presence of three distinct periods of accumulation, one ending approximately September 15, another November 3, and the last at the end of the season, before December 1. These correspond to three periods when the water was above 25 feet (Hell's Gate gauge). The delays are shown so well as to be undeniable.

Within the first period as shown on the lower graph of Figure 29 and in Figure 30, there is a transition on August 10 and 11, at about 45 feet on the gauge, which will bear further study. The fish tagged above the 45-foot level in July had accumulated and had disappeared nearly completely by August 11, and probably belonged to a separate accumulation. Tags placed below the 45-foot level, hence

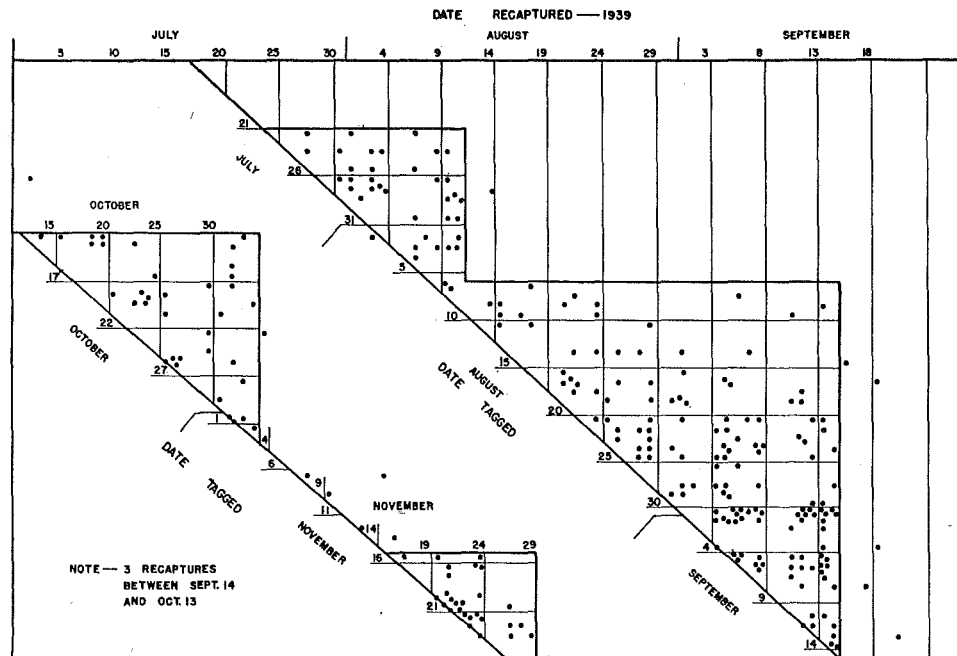


Fig. 30

RECOVERIES OF TAGGED SOCKEYE AT THE POINT OF TAGGING BELOW HELL'S GATE ACCORDING TO DATES OF TAGGING AND RECOVERY, FOR THE YEAR 1939.

on and after August 8, began to accumulate and were found in the recaptures as late as September 15, forming a second and distinct accumulation.

To aid interpretation of the season's returns the recaptures are plotted in Figure 30 by the date of tagging and the date of recovery. The discussion can be followed on this as well as on Figure 29. The accumulations of tagged fish are enclosed in triangles in Figure 30. Delays in recapture are shown by the position of the dots to the right of the diagonal. It will be noted that at the beginning of the season the minimum delay was four days. Toward the last of August a few fish were retaken the next day after tagging. In September the minimum was one day, and by November it was the day of tagging.

TABLE 15

SUMMARY OF RECAPTURES AT HELL'S GATE DURING THE
LONG PERIODS OF BLOCK IN 1939 AND 1940 COMBINED

	PERIODS OF TEN DAYS			
	1	2	3	4
Number Tagged	1,313	1,014	1,277	1,161
Number Recaptured	59	66	74	28
Fraction Recaptured045	.065	.058	.025
Average No. Days in Period.....	35	25	15	5
Fraction Recaptured per Day....	.0013	.0026	.0039	.0050
Number Recaptured within 2 Days	0	2	9	13

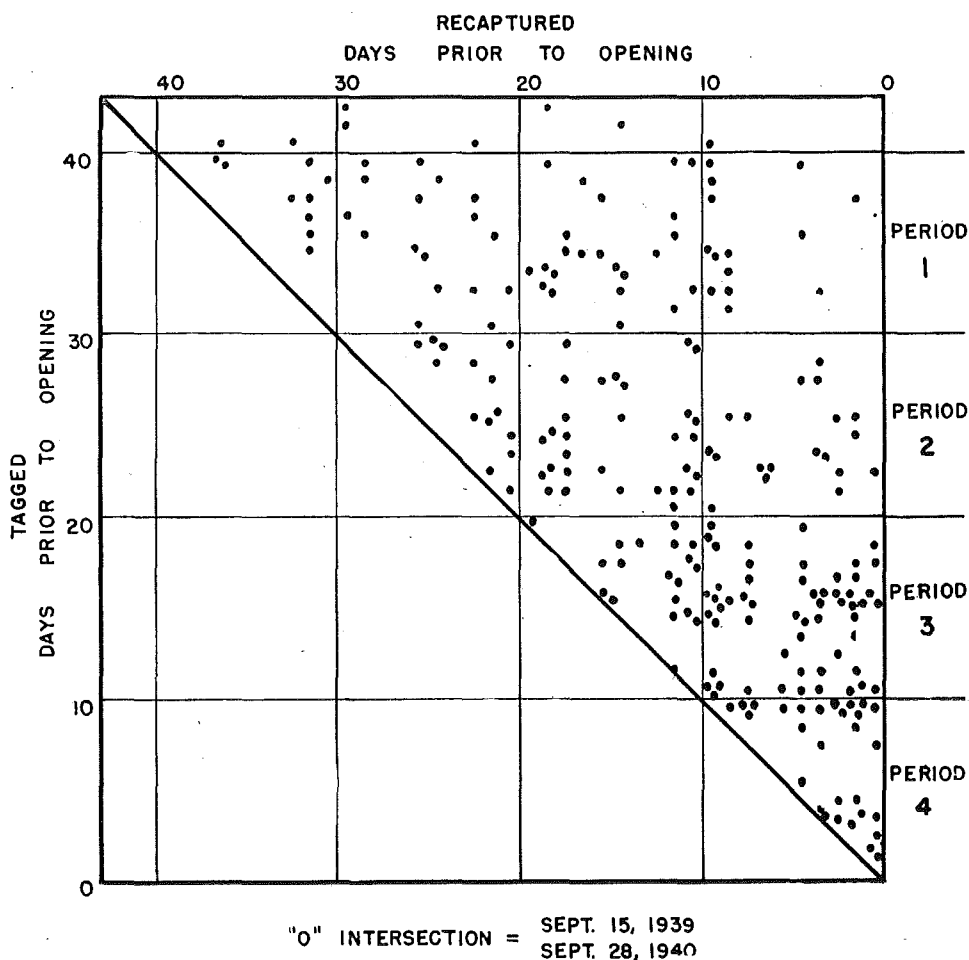


Fig. 31

RECOVERIES OF TAGGED SOCKEYE AT PLACE OF TAGGING BELOW HELL'S GATE, ACCORDING TO DATES OF TAGGING AND RECOVERY FOR TWO PERIODS OF BLOCK, SUPERIMPOSED ACCORDING TO DATES OF RELEASE, SEPTEMBER 15, 1939, AND SEPTEMBER 28, 1940.

The fish presenting themselves early in the season were slower in returning to the point of tagging. It would seem likely that this period of delay would vary with the part of each race which happened to be passing, the latest and ripest migrants delaying least. It should be determined from returns as near as possible to whatever date is being considered.

It is desirable to determine some of the characteristics of these accumulations. To this end, in Figure 31, the triangles including the two large accumulations of 1939 and 1940 are added, with the dates of clearance superimposed, as shown by the right hand margin of the graph (*see* Figures 30 and 34). These dates were September 15, 1939 and September 28, 1940. An oblique line is drawn to show the position of recoveries made on the day of tagging. The graph shows that the delay before the first recaptures from any given day's tagging was 3 or 4 days at

the beginning, and none at the end, which is shown in the lower right hand corner of the triangle. It is also apparent that the number of recaptures is actually less for the fish tagged at the beginning of the block than later. The period of block can be divided into ten day intervals, the first shown along the broad upper limb of the triangle, the fourth at the lower angle. The number tagged in the first period was 1,313, the number recaptured 59, which was .045 of the number tagged. In the four periods, in order, there were recaptured .045, .065, .058, and .025 of the number tagged. But the average length of these periods, as measured from the oblique line to the vertical at the right, was approximately 35 days for the first period, 25 for the second, 15 for the third, and 5 for the fourth. Consequently the fraction recaptured per day of delay was, again in order, .0013, .0026, .0039, and .0050. This greater rate of recapture toward the end of the block accompanies the lesser delay between the time of tagging and the first recoveries already noted. It appears from this that during the early days of the blocks the tagged fish leave and return after several days and that not as many of them remain in the tagging locality as later. At the end of the period the fish remain closer and are retaken more quickly and in greater numbers as the block lengthens. The fish taken for tagging probably consist of a greater and greater percentage of fish which have been blocked for some time. They become less sensitive to disturbance, perhaps as their approaching ripeness renders haste in migration necessary if they are to reach their redds.

It is not necessarily true that the recaptures during the last few days of the blockade represent equally all the fish waiting to pass. Nevertheless, the recaptures during the last ten days show a diminishing number of the fish which have been tagged for the longest time. During the last ten days shown in Figure 31, hence along the vertical right hand limb of the triangle, those fish which had been held by the block between 11 and 20 days and then recovered numbered 55; between 21 and 30 days, 20; and between 31 and 40 days, 14. It will be shown that this decrease in numbers of fish tagged longest is reflected in the composition of the schools which reach the next point of convenient observation 75 miles upriver, at Bridge River Rapids.

The second accumulation in 1939 can be used to show the assumptions which have to be made in order to choose a date for the beginning and ending of a period of block. Reference can be made to Figure 30.

The vertical limb of the triangle enclosing the accumulation indicates the day on which passage becomes possible. Recaptures show in numbers only when they are held in the tagging pool below the obstruction. When the river is open the tagged fish go through with but a very occasional recapture, as can be seen by the part of Figure 30 which lies between September 16 and October 12. It is typical of periods of free passage which occurred in three of the four years. There were 468 fish tagged and but three recaptured. If this is true, recaptures in any number indicate that the passage is closed. Thus in Figure 30 the last day on which this occurred for the second and largest block was September 15, and this was the day on which the river opened. The water fell below 25 feet for the first time during the season. But thereafter, fish could pass the tagging station without delay and with few recaptures, and doubtless that is what most of them did.

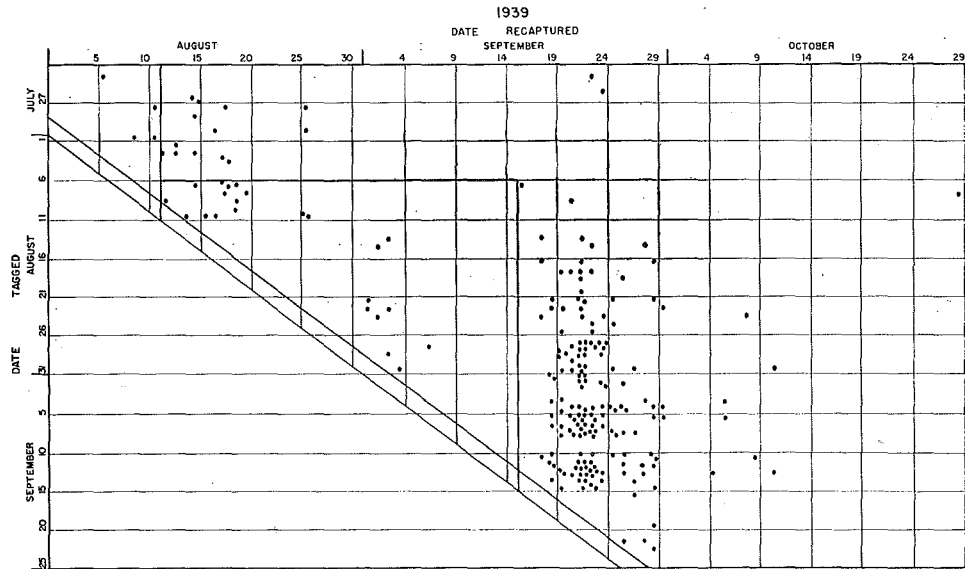


Fig. 32

RECOVERIES AT BRIDGE RIVER OF SOCKEYE TAGGED AT HELL'S GATE IN 1939, ACCORDING TO DATE OF TAGGING AND RECOVERY, SHOWING MINIMUM TIME OF PASSAGE BY PARALLEL OBLIQUE LINES AND BY DELAYED RECOVERIES AFTER TIME OF RELEASE AT HELL'S GATE.
TRIANGLES IDENTICAL WITH THOSE IN FIG. 30.

The beginning of a block is shown by the upper horizontal limb of the triangle. This shows the first day of block corrected for the amount of delay between tagging of a day's sample and first recoveries. At the beginning of a block the first possibility of accumulation would be found in fish which were returning to the tagging place after recovering from tagging, and which then found passage impossible. The delay in returning would determine whether fish from a given day's tagging were caught in the accumulation. The normal amount of delay between tagging and first recovery was four days in early August of 1939. Hence if the first of the accumulations included fish tagged on August 7, then the block must have begun on August 11 to retain any of them. But no fishing was done on August 5 and 6 and there is a possibility that recoveries would have begun earlier. The best that can be done is to assume that August 7 was the correct date. Although the date of the commencement of the accumulation is not a definite one, as shown in the figure, the block can then be said to have begun August 11, when the water levels were below 40 feet on the gauge for the first time in the season. The determination is plainly an approximation.

The second and longest period of block in 1939 was thus from August 11 to September 15, inclusive, between water levels of 40 and 25 feet.

These dates can be checked by comparison with the returns from Bridge River fishing grounds above Lillooet, where recaptures were made in number. In Figure 32 the recaptures are graphed in the same manner as in Figure 30.

The second period of block which we are examining for comparison is shown clearly. The triangle is blank, where it was full at Hell's Gate. The delayed migrants are grouped along the right arm of the triangle. Recaptures began on September 18 and were in numbers on 19 and 20. Since the block at Hell's Gate lasted until September 15, there were allowed three and four days for the period of migration. The graph can be examined elsewhere than during the block for the time elapsed between tagging and recovery at Bridge River. As in Figure 30 the diagonal line indicates the time of tagging; and if recovery were in each case on the day of tagging, the dots would be on this line. The distance between it and the first recoveries to the right is thus the time required for migration. Three days is the very minimum, and the fish making the distance in that time are very few. They would be fish which had recovered from tagging and which were ready to pass, as were those of September 15 at Hell's Gate. Many more required six or seven days. Fish retaken at Hell's Gate on September 15 were definitely bound upstream, and the first of them would be due at Bridge River September 18, the greater mass on September 21 or 22.

On this basis, the four periods of block at Hell's Gate in 1939 may be examined, using Figure 30.

The first period of block is shown by recoveries of fish tagged July 22. But this was the first day of tagging in 1939, hence the most that can be said is that the block began prior to July 25, allowing three days delay in the return of tagged fish to the tagging station. The block ended August 11 when water levels fell to 39 feet. The period is not shown clearly at Bridge River (Figure 32), probably due to inaccuracy of returns from Indian fishermen at that season of the year, as they were not as active then as later, or to passage of many fish through the block. The block above 40 does not seem to be as complete as that below, or the fish are more capable of passing. The most that can be said is that water levels in the vicinity of 40 feet are open to passage to a greater extent than those between 40 and 45 feet.

TABLE 16
1939 BLOCKS

<i>Block</i>	BEGINNING		<i>Maximum Level During Rise</i>	ENDING	
	<i>Date</i>	<i>Water Levels</i>		<i>Date</i>	<i>Water Levels</i>
1	Before July 25	?		Aug. 11	40-50 feet
2	Aug. 11	Falling 40 feet		Sept. 15	25 feet
3	Oct. 14-15	Rising 23-30	30	Nov. 3-4	Below 22 feet
4	Nov. 17	Rising 24-26	31	?	Below 22 feet

The second period began the same day, August 11, effective on some fish tagged August 7 to 10, ostensibly leaving but a single day for passage. But the manner of determination is not sufficiently precise to warrant such a conclusion. Passage may well have been partial on days before and after August 11, sufficiently so to allow clearance of the prior accumulation. The period ended September 15, when water levels were below 25 feet.

Very brief rises in water levels above 25 feet on September 19-23 and October 2, produced no accumulation.

The third period began with an accumulation of fish tagged on October 13. The delay at that time was one or two days between tagging and first recoveries, with but few records to support this statement. If so, the block began October 14 or 15, but between the latter two days it rose from 23 to 30 feet, and the level at which difficulty began is therefore not to be determined. It ended November 3 or 4, some time after the river was known to be passable and when it was the lowest it would be for the remainder of the season. The fish were plainly too far advanced to go far upriver. With the exception of 8 fish tagged at the beginning of the block and which later appeared in Adams and Little Rivers, a total of 1,486 fish tagged between October 15 and the end of the season failed to be retaken elsewhere than in the canyon just above or below Hell's Gate, or in the lower Thompson. The conclusion must be drawn that the fish tagged during this block were so nearly ripe and so delayed as to be unable to continue their migrations.

The final block, which began by an accumulation of fish tagged on November 16, was caused by a block on November 17, since the delay between tagging and recovery was one day or less at that part of the season. If so, the block began at water levels between 24 feet on the 16th and 26 feet on the 17th. The water rose above 30 feet. Operations stopped on November 29, at which time the water was again at 26 feet. In the figure the vertical line of the triangle is shown, but no attempt to complete the record was made. As in the preceding block, the fish were very ripe, and none of them were later taken above the obstruction. Many returns came from downstream.

This is consistent with what was found to be true of the Adams River race (see Figure 11, page 45). The last migrants of that race to pass Hell's Gate had less time to reach the spawning grounds and died quickly after reaching there. They were nearer ripe than earlier migrants and could stand less delay. This explains the fate of the November fish in 1939. They were retaken downstream from the obstruction, as shown in Figure 26.

There were, therefore, four distinct accumulations below Hell's Gate in 1939, corresponding to levels between 25 and 40 feet, and above 40 feet on the gauge at that point. The levels are not exact, and are obscured at the end of the season by the failure of nearly ripe fish to migrate. The three last accumulations correspond to periods of time when the water levels were above 25 feet at their beginning, and the striking coincidence is good evidence of the reality of the block. The close correspondence of the evidence from recaptures at Bridge River strengthens this evidence and the conclusions as to the time the blocks end. The complementary character of the graphs for Hell's Gate and Bridge River is striking.

It follows that the recaptures grouped along the vertical limb of the triangle in the graph for Bridge River returns, represent the survivors of those tagged fish whose recoveries are shown in the graph for Hell's Gate. From the Bridge River returns it should be possible to determine the fraction of each day's tagging which survived to migrate that far at least.

3. 1940. There are three blocks, resembling those of 1939 as they changed with the season in 1940. Fewer recaptures are available for analysis. Tagging began June 27, but the first recaptures were from tagging on July 4. The same method of study can be used as in 1939. Figures 33 and 34 present the data.

The first accumulation occurred in July. The first delayed recapture was from fish tagged on July 8, but no fish were tagged on July 6 and 7. The delay between tagging and first recoveries was three or four days at that time, so that the block might have commenced any day between July 9 and 11. It ended July 26. The water levels were between 48 and 50 feet at the start and 48 feet at the end, with

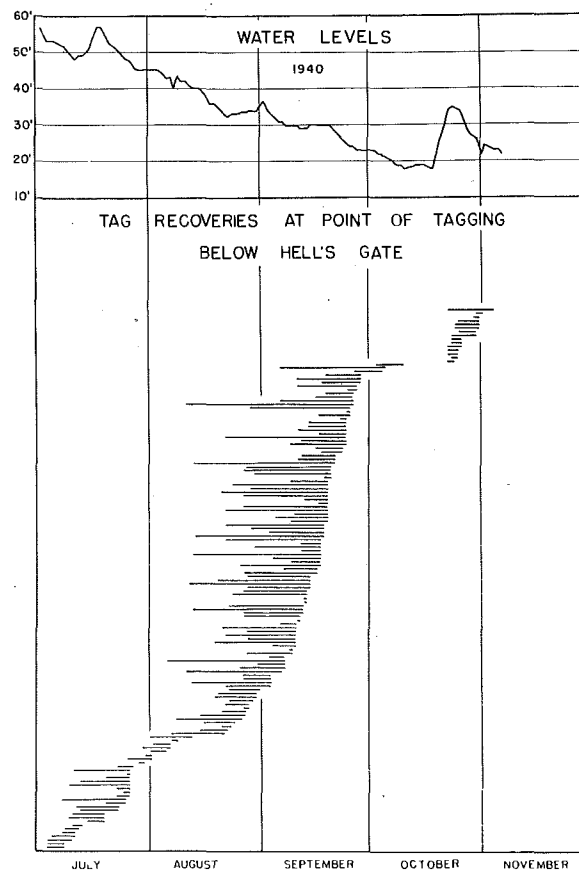


Fig. 33

PERIODS OF DELAY AS SHOWN BY TAGGED FISH RECAPTURED AT POINT OF TAGGING, HELL'S GATE, GIVING NUMBER EACH DAY, LENGTH OF TIME SINCE TAGGING, AND COMPARISON WITH WATER LEVELS, 1940.



an intermediate rise to 57 feet on July 17 and 18. The number of recaptures was so few as to render the dates doubtful, but the block at these high levels is obvious and confirms the evidence from 1939.

Between July 26 and August 8 there was no clear evidence of a block, but there were so few recoveries that it is unsafe to conclude as to this. A triangle could be drawn as shown by the lines, but with some doubt, indicating a block from July 27 to August 12, at water levels between 40 and 48 feet. It would correspond to the last of the first accumulation in 1939, between water levels of 40 and 50 feet. During this period recaptures were made on the day of tagging and one and two days later, contrasting with the longer and distinctly indicated delay shown during the second accumulation. It must be concluded that the recoveries at this time in 1940 are hardly enough to encourage any elaborate analysis, or even to say there was a block at the levels mentioned, except that experience in 1939 indicates there should be one. For that reason it is not called a second block in 1940. However, the returns at Chilko indicate that it occurred (*see* page 112).

The second distinct accumulation began with delayed recaptures from the tagging of August 6. There are few recaptures to show the minimum delay between tagging and recovery, but the majority indicate from four to six days. If so, the block began between August 10 and 12 between water levels of 40 and 42 feet. The block was passable on September 13 but ended September 28 at a water level of 23 feet. This is below the 25-foot level at which the second accumulation of 1939 was cleared. The fish must have been in poor condition.

TABLE 17
1940 BLOCKS

Block	BEGINNING		Maximum Level During Rise	ENDING	
	Date	Water Levels		Date	Levels Water
1	July 9-11	Rising 48-50	57	July 26	48 feet
1a	July 26	48		Aug. 12	40 feet
2	Aug. 10-12	40-42		Sept. 28	23 feet
3	Oct. 20-23	Rising 23-35	35	Oct. 31	22 feet

However, the recaptures of this block in 1940 presented a picture in certain respects intermediate between that of the second and third blocks of 1939. It was two weeks later in ending than was the second in 1939, mid-way between that and the third, in fact. The last day on which frequent recaptures of fish tagged prior to September 5 of 1940 were made, was September 20, and the delay after tagging was in the majority of cases long, about six days. But of fish tagged after September 5, many recaptures were made on the day of tagging or shortly thereafter, while recaptures in numbers persisted until September 28. As in 1939 this meant that many fish remained at the tagging station, neither going downstream to escape recapture, nor moving upstream promptly when released, indicating their ripeness and lack of vigor. The fish tagged after September 5 were represented also at Bridge River, 75 miles farther, in numbers, (Figure 23) *but very few reached any spawning ground known to the Commission observers*, and but three did so that were tagged after September 9. It is apparent that the fish tagged after September 5 were too mature to complete their migration after the delay they had suffered.

Since tagged fish were taken at Chilko and Stellako redds that had been tagged before this change in behavior took place at Hell's Gate, it is probable that these last fish were the last of the runs to those districts for 1940. The disappearance of fish between Bridge River and the spawning grounds that was noted in connection with the timing of the runs (Figure 23, page 108), finds an explanation in the delays at Hell's Gate in 1940.

The third accumulation, during the last days of October, was in response to a brief rise in water levels reaching 35 feet. It is not possible to say when the brief block began, as no tags were placed to indicate it. Only scattered fish were taken for tagging until October 23, when 9 were secured. Of these, 5 were recaptured by the taggers. The number of fish taken for tagging was a result of a brief accumulation from what must have been a very small run of ripe fish, which ceased on October 31, when the water levels had reached 22 feet. The delay in passage until after the low level of 22 feet had been reached was characteristic of the other

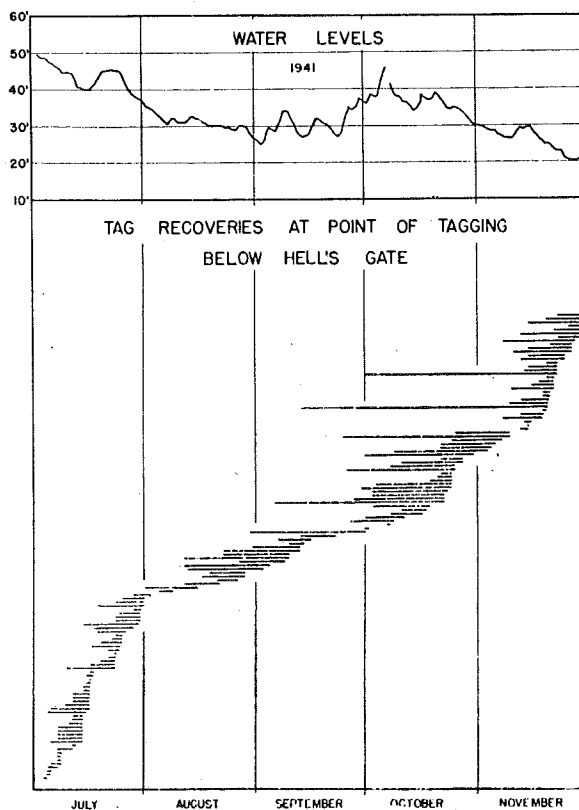


Fig. 35

PERIODS OF DELAY AS SHOWN BY TAGGED FISH RECAPTURED AT POINT OF TAGGING, HELL'S GATE, GIVING NUMBER EACH DAY, LENGTH OF TIME SINCE TAGGING, AND COMPARISON WITH WATER LEVELS, 1941.

late season block, in 1939. So, too, was the recapture of fish the same day that they were tagged. A few of these fish, and others tagged later were taken in Adams and Little Rivers, at the last of a scattered run to those grounds.

4. 1941. The year 1941 (*see* Figures 35 and 36) was a remarkable one because of the length of time the unfavorable water levels persisted. The result has already been described on page 92. The writer saw many fish in the eddies below Hell's Gate on July 14. By August 1, the fish tagged were lost in the dense masses of delayed fish. The cessation of recoveries shown by the graph after July 14 was not due to reduction of the schools below the obstruction by migration upstream, but to their vast increase by new arrivals. From that date to the end of the season the lack of recoveries was significant of a continued huge accumulation. About September 1 and 2 the water fell briefly below 25 feet, and considerable numbers of fish passed upstream before the water rose again. But so great were the schools that these successful migrants did not much reduce the accumulation, certainly not to the point where the numbers of recaptures at the tagging station could increase. In Figure 47 the relatively small numbers retaken upstream from

tags placed before the escapement on September 1 and 2 contrast sharply with the numbers retaken there in other years. Reference to Figure 35 will show the irregularity of the recaptures, and the prolonged presence of fish tagged early in the blocked period.

The first block was already effective on July 2 when tagging began with water at 50 feet. Of 547 fish tagged from July 2 to 11, recoveries at Hell's Gate totalled 28, a high rate of recovery, indicating few migrants. It ended July 16, at a water level of 40 feet. It was comparable to the first block in 1939, and the minor block which followed the first in 1940, both having the same water level at the end of the block. In each case the next block began almost at once.

Unlike the other years the water levels in 1941 rose again from 40 to 45 feet, and then fell once more to 40 feet on July 28. The recaptures indicate a second accumulation which is shown in the graph of Figure 36 as commencing on July 16. There was a delay of one day or none in recaptures after tagging, so that the second block must have begun, as in other cases, almost at once, probably on July 16, at a 40-foot level. The data do not lend precision to such a calculation.

The end of this second accumulation is difficult to determine. In Figure 47, showing the recovered tags from above the obstruction, the last day's tagging from which any number of recoveries was made was that of July 26. The water levels were at 40 feet the next day when no tagging was done. But these upriver

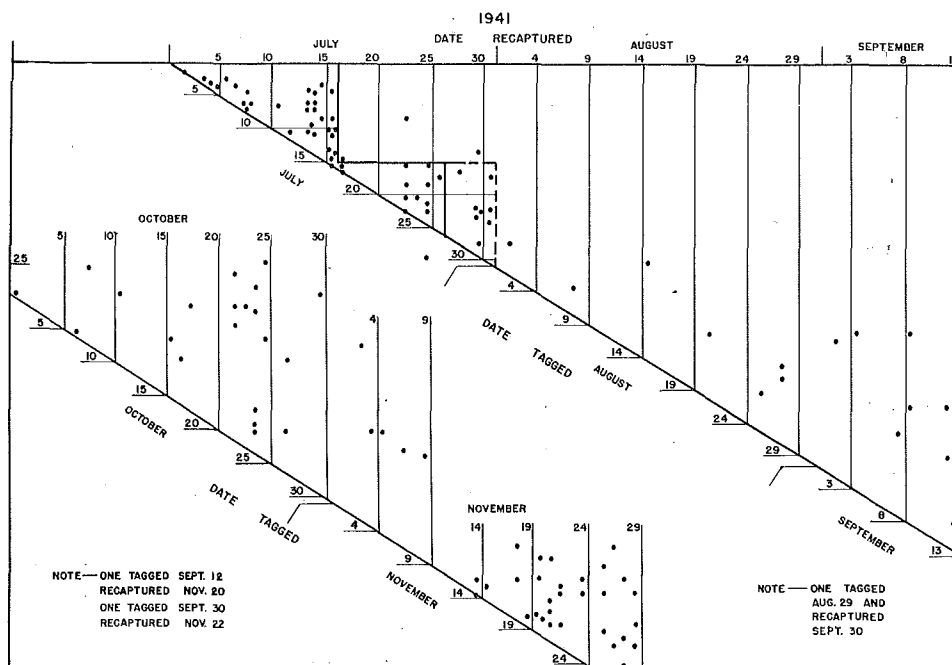


Fig. 36

RECOVERIES OF TAGGED SOCKEYE AT THE POINT OF TAGGING BELOW HELL'S GATE ACCORDING TO DATE OF TAGGING AND DATE OF RECOVERY, FOR THE YEAR 1941.

recoveries were few in number, averaging less than 10 per cent of those tagged, compared to 40 per cent or more in some other years at the same season. Moreover, recaptures continued to be made at the tagging station from this accumulation until July 31. At that time the great numbers of fish held by the block began to be apparent, and the recaptures were few and very scattered from then until much later in the season. The conclusion is inescapable that the water must have fallen so quickly through the passable stages as to hold most of the fish below, to join and increase the great numbers in the third and longest accumulation. Without direct proof, the ending of the second block may be set as July 27, at a water level near 40 feet.

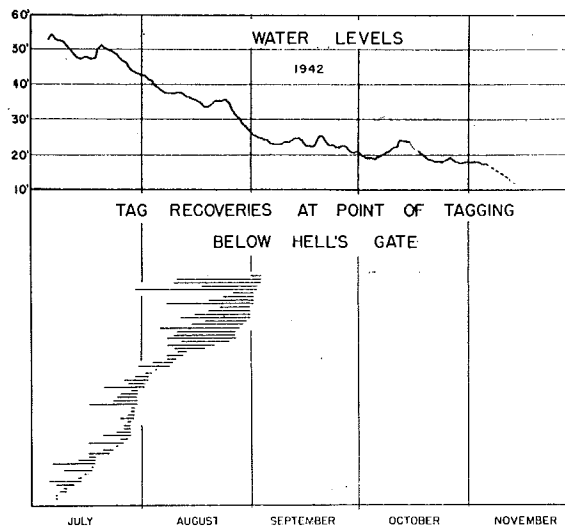
The third, and main period of block began about that time. But so great were the numbers in the eddies that tagged fish were very rarely recaptured by the tagging party. There is no way of determining its beginning from Figure 36. From other evidence, particularly visual observation and the record of recoveries upstream shown in Figure 47, it is known that Hell's Gate was open September 1 and 2, allowing fish tagged August 30 and earlier to pass in numbers. But again, as at the end of the previous block, the opening was so brief that only a small proportion passed, being 7 or 8 per cent of each day's tagging as compared to 30 to 50 per cent in other years. The accumulation lasted to the end of the season, a brief rise in early October to levels above 40 feet passing no fish so far as is known.

TABLE 18
1941 BLOCKS

Block	BEGINNING		Maximum Level During Rise	ENDING	
	Date	Water Levels		Date	Water Levels
1	Before July 2	50+	45	July 16	40 feet
2	July 16	Rising 40		July 26	40 feet
3	July 27	40		End of season	25 feet

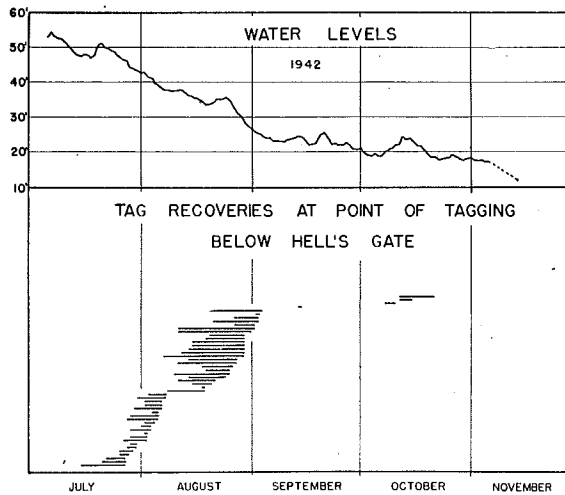
During this long block, the most important factor influencing the number of recaptures at Hell's Gate was, as has been stated, the arrival of great numbers of fish to join the schools in the eddies.

The recaptures decreased, from this cause, to a minimum toward the last of September. In October great numbers of fish began to be retaken downstream, in the riffles and up the creeks, and with them were the tags placed daily. It is apparent that the fish tagged each day were dropping downstream (*see* Figures 20 and 47). Toward the end of October the schools were greatly reduced by this movement, so that recaptures again were made in some numbers. In November,

*Fig. 37*

PERIODS OF DELAY AS SHOWN BY TAGGED FISH RECAPTURED AT POINT OF TAGGING, HELL'S GATE,
GIVING NUMBER EACH DAY, LENGTH OF TIME SINCE TAGGING, AND
COMPARISON WITH WATER LEVELS, 1942.

(For fish tagged on East Bank)

*Fig. 38*

PERIODS OF DELAY AS SHOWN BY TAGGED FISH RECAPTURED AT POINT OF TAGGING, HELL'S GATE,
GIVING NUMBER EACH DAY, LENGTH OF TIME SINCE TAGGING, AND
COMPARISON WITH WATER LEVELS, 1942.

(For fish tagged on West Bank)

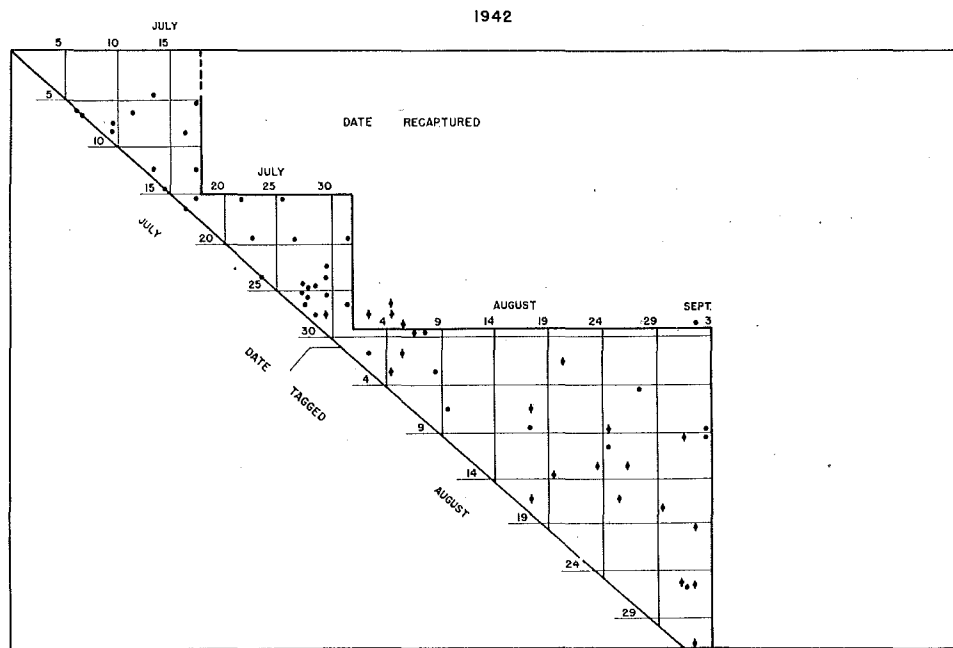


Fig. 39

RECOVERIES OF TAGGED SOCKEYE AT THE POINT OF TAGGING BELOW HELL'S GATE, ACCORDING TO DATE OF TAGGING AND DATE OF RECOVERY, FOR THE YEAR 1942.

Those tagged and recovered on the West Bank are shown by a bar through the dot.

at the end of the season, and as in 1939 and 1940, ripe fish were taken and provided a group of recaptures. The pseudo-blocks which were a part of the long block were caused by changes in the numbers of fish present, an increase in recaptures accompanying lessened fish in the eddies.

5. 1942. In this year tagging was done on both sides of the river, both above and below, as a bridge had been constructed at Hell's Gate. Recaptures by the tagging party from the tagging above were not sufficient to give a basis for analysis from recaptures by the taggers. The recaptures at Hell's Gate from the two sides below the obstruction are shown in Figures 37 and 38. They are combined for Figure 39, that of the east and west sides being shown by different symbols. Recaptures from fish which had crossed the stream were omitted, because of differences in behavior of fish on the two sides. The number of recaptures from tagging after September 4 were so few that they are omitted, being only two from each side.

The recaptures at the tagging station on the east side below the obstruction, of fish tagged there, may be considered first, as comparable to the data for previous years. The accumulation was already under way when tagging began July 2. The recoveries continued to July 18, when the water was 48 feet but might have persisted. It is difficult to be sure, so few are the recoveries on which the data are based.

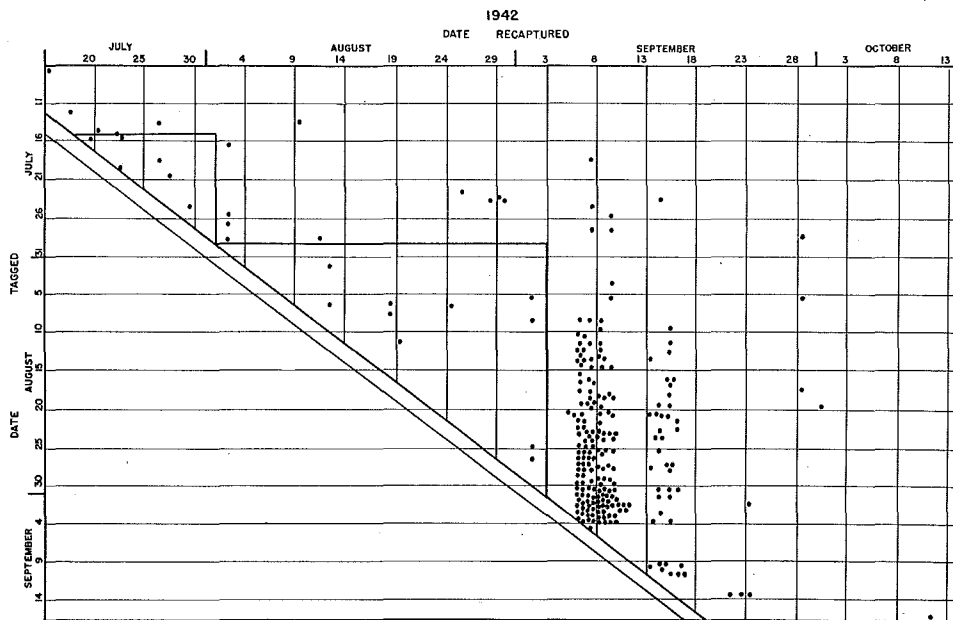


Fig. 40

RECOVERIES AT BRIDGE RIVER OF SOCKEYE TAGGED AT HELL'S GATE IN 1942, ACCORDING TO DATES OF TAGGING AND RECOVERY, SHOWING MINIMUM TIME OF PASSAGE BY PARALLEL OBLIQUE LINES AND BY DELAYED RECOVERIES AFTER TIME OF RELEASE AT HELL'S GATE.

Triangles identical with those in Figure 39.

The second block was between July 18 and August 1 or after, hence from water levels of 48 or 50 feet to 42 feet or below, the data again being very sparse.

The third and longest was from August 1 to September 3, between water levels of about 42 to 25 feet.

If Figure 40, showing the recoveries of tags at Bridge River according to dates of tagging and recovery is referred to, it will be seen that fish delayed in this long block arrived there on September 7, with a migration time of 4 days. This corresponds to that of other years. The date of termination of the block is therefore confirmed.

The same cannot be said of the earlier blocks of 1942. Recoveries were made at Bridge River and elsewhere, and as in other years fish either seem to have passed during the block or the data of recapture were inaccurate.

TABLE 19
1942 BLOCKS

Block	Beginning	Ending	Water Levels	Water Levels
1	Before July 2	?	July 18	48
2	July 18	48-50	After Aug. 1	42—
3	Aug. 1	42	Sept. 3	25

No further blocks developed. The great Adams River run went through Hell's Gate in September without hindrance. The lack of a block and the great numbers of fish combined to eliminate recaptures at Hell's Gate.

If Figures 37, 38, and 39 are compared, it will be seen that the recaptures made between August 3 and 7, of fish tagged July 27 to August 3, on the west bank of the river behaved differently from those tagged and recovered on the east bank. The second accumulation, to which these belong, was cleared on the east bank by August 1, but not until August 7 on the west. The east bank is where the water is thought to become passable, and the delay may have been due to this difference in behavior of the water on the two banks. Tagging did not start on the west bank until July 25, which explains the lack of early recoveries on that side.

TABLE 20
PERIODS OF BLOCKED PASSAGE AT HELL'S GATE

No.	1939 Water Levels	No.	1940 Water Levels	No.	1941 Water Levels	No.	1942 Water Levels
		1	Flood 48-57-48			1	?-48
1	50-40	1a	48-40	1	50-40	2	48/50-42—
				2	Flood 40-45-40		
2	40-25	2	40/42-23	3	40-25	3	42-25
3	Flood 23-30-22	3	Flood 23-35-22				
4	Flood 24-31-22						

Summary of Conclusions from Recaptures at Hell's Gate

1. Water levels at which conditions are difficult can be summarized in tabular form (*see* Table 20). Where a flood and recession occurred, it is shown as "23-35-22", meaning a rise to 35 feet and fall to 22. Like periods of blocked passage are on the same line. The blocks are numbered for each year to facilitate comparison with the text.

2. There are two ranges of difficult water levels which occurred in all four years, at levels between 25 and 40 feet, and between 40 and 50 feet. One range occurred above 48 feet in 1940 during a brief rise, and in 1942 during a continued fall from initial high water. The other periods of recorded block are, all of them, times when the water rose as a flood more or less briefly into one or the other of the three blocked levels. The river was therefore passable in the vicinity of 50, 40, and at 25 feet and below on the gauge at Hell's Gate. The major block is between 40 and 25 feet; that is, from 40 to 26 feet, inclusive.

3. These levels are approximations only, and the blocks may be graduated in effectiveness over levels near those stated. They vary in completeness; those above 40 feet being probably less so. Their effectiveness varies, being particularly great late in the season when fish must complete their migration at once because of their approaching ripeness.

4. At the end of each obstruction the surviving fish escaped upriver as a migrating school, bearing tags. These tags showed the survivors of each day's tagging.

5. There was a significant difference in the behavior after tagging of the fish which were tagged early and late during the obstruction. Those which were early were delayed in return to the point of tagging. Those late were more nearly ripe, remained in the tagging locality, were retaken in greater proportion, and toward the end of the season failed to pass at any water level. This explains the 22 and 23 foot levels shown by the last two blocks of 1939 and 1940.

6. Experiments on the two sides of the river below the obstruction differed in results at the 40-foot level, indicating the possibility that the west side did not become passable when the east side did.

7. The recaptures of tagged fish at Hell's Gate formed a characteristic pattern in the graphs, which was complementary to that of recoveries at Bridge River. This confirmed the existence of the blocks, and provided an opportunity for investigation of the mortality shown by the Bridge River recoveries.

D. EFFECT OF OBSTRUCTION UPON ESCAPEMENT UPRIVER

In the preceding pages it was shown that the blockade at Hell's Gate exists at all water levels above 25 feet, with brief openings at or near 40 and 50. The fish are delayed for periods of varying length.

The effect of this delay in reducing the number reaching the spawning grounds is a matter of greatest importance. It can best be studied during the period when water levels are between 25 and 40 feet, as these water levels occur well after the run has begun and the block is longest and seems most complete. It is not complicated by subsequent difficult water levels below 25 feet, which might retain part of this accumulation. Accordingly, we have considered this period alone, leaving the remainder of each season for further study.

Returns from above the obstruction were usually reliable. But the tagging in 1938 was too fragmentary. In 1939 the Indians carried on a very intensive fishery for tags in the canyon during the block and it was not always possible to distinguish those taken by them immediately above and below the obstruction. The percentage returns from each day's tagging in that year are extremely high, reaching 90 per cent for some days. In 1940 there was still trouble with the Indian returns from the canyon, but they formed a much smaller share of the total returns.

The returns in these two years are used with some caution, and are commented upon accordingly, where necessary, in what follows. In 1941 the sequence of events was remarkable because of a closure during nearly the whole season, which allowed very few returns from upstream. It requires separate discussion. In 1942 returns were carefully checked, and much more reliance can be placed on them. It was the most satisfactory year of the four.

Tagging at Hell's Gate continued throughout each season with some interruptions. An attempt was made to tag an equal number of fish daily, but this could not be done because they could not always be caught. To overcome the inequality in the numbers tagged from day to day the returns have been calculated as percentages of these numbers. This was done for the recoveries upstream and downstream, and for each separate experiment as for the left and right banks in 1942. The resultant graphs are given in Figures 41, 42, 43, and 44 for 1939, 1940, and 1942 and including the periods when water levels were between 25 and 40 feet.

Returns from Upstream

It is evident from these that the percentage returns from upstream are very much less for the samples tagged at the beginning of a period of blockade than they

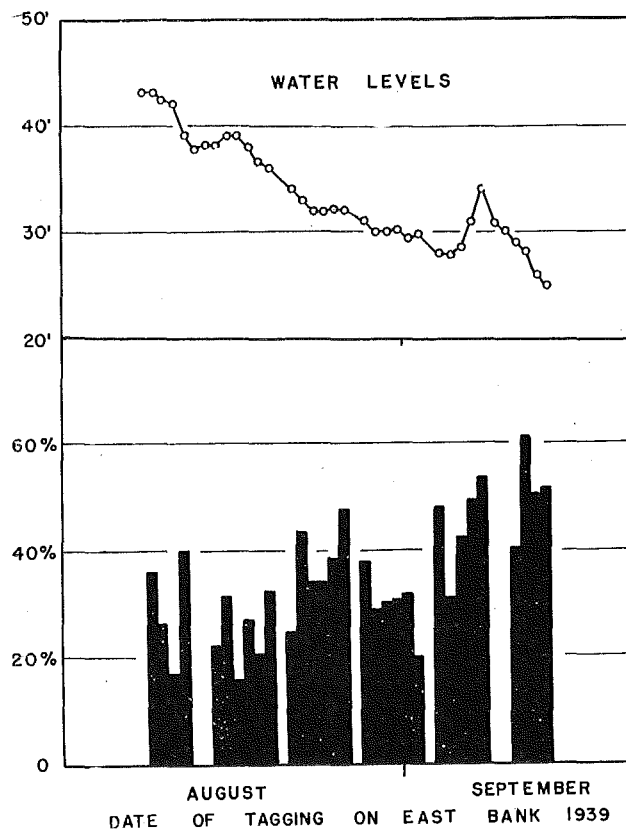


Fig. 41

RECOVERIES OF TAGS ABOVE HELL'S GATE IN 1939. PERCENTAGE RETURNED FROM FISH TAGGED BELOW DURING A PERIOD OF DIFFICULT PASSAGE COMPARED WITH WATER LEVELS AT HELL'S GATE.

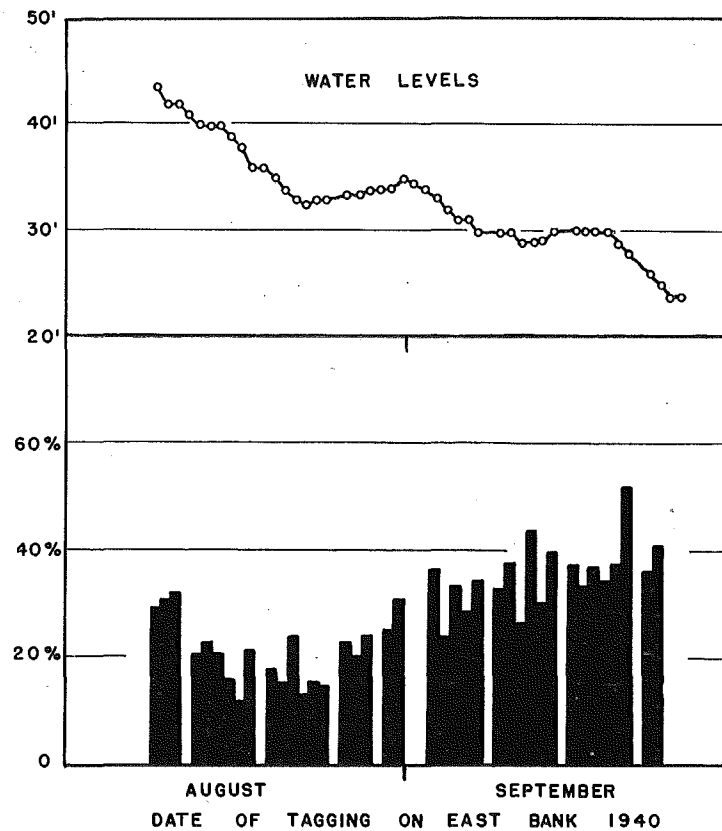


Fig. 42

RECOVERIES OF TAGS ABOVE HELL'S GATE IN 1940. PERCENTAGE RETURNED FROM FISH TAGGED BELOW DURING A PERIOD OF DIFFICULT PASSAGE COMPARED WITH WATER LEVELS AT HELL'S GATE.

are for those tagged near the end. The percentages for intermediate days during the respective periods were graduated somewhat irregularly between the extremes. A comparison may be made for each year in an approximate way.

In 1939 the return was about 20 per cent for fish tagged at the beginning of a 30-day delay and 50 per cent at the end. The returns by Indians in the canyon for this year were unusually heavy and many caught during August were said to have been recovered above, but were doubtless taken below in Spuzzum Creek and elsewhere. As a result, the percentage return from above should be reduced, especially for those taken from tags placed early in the block.

In 1940 the percentages were 15 and 40 for a 40-day delay. The returns from Indians in the canyon were so few as not to distort the percentages appreciably.

In 1942, they were 8 per cent and 30 per cent for a 27-day delay, using the left or east bank as in the earlier years. The returns from the west bank were similar. Because they were relatively accurate, these percentages seem to be the most acceptable.

When the time of recovery is studied, it is found that a number of fish are able to pass the obstruction while it is still effective (*see* Figures 32 and 40 showing recoveries at Bridge River for 1939 and 1942 by time of tagging and time of recovery). The exact estimation of their numbers is hindered by inaccuracies in the date of recapture of tags as given by Indians and others, and by the fact that a variable time is required for the migration between Hell's Gate and the recovery area. They are shown as records falling within the triangular area in the graphs, which should be blank if the blocks were complete. Those tagged fish which seemed to have passed in advance of the majority and to have been recovered within a shorter time than was possible had they awaited passable stages are estimated to constitute 4 per cent of the total recoveries upstream in 1939, 20 per cent in 1940, 9 per cent in 1941, and 20 per cent in 1942. A disproportionate number of these were retaken in the canyon by Indians and there is naturally doubt as to the accuracy of the data. Where data are obtained as soon as possible after recapture, as at Bridge River in 1942, few such records appear. It may be possible, however, that some of the most vigorous of the early migrants were able to pass at the higher water stages.

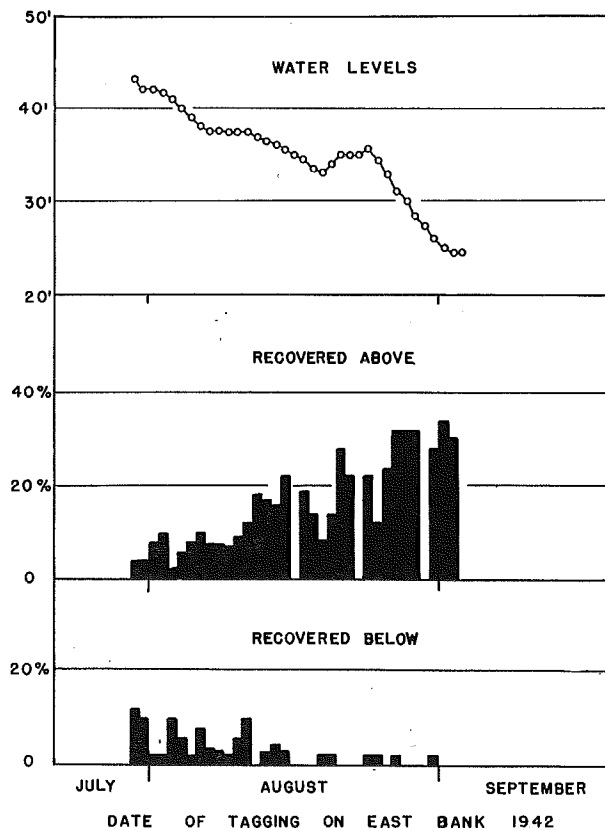


Fig. 43

RECOVERIES OF TAGS ABOVE AND BELOW HELL'S GATE IN 1942. PERCENTAGE RETURNED FROM FISH TAGGED BELOW ON THE EAST BANK DURING A PERIOD OF DIFFICULT PASSAGE COMPARED WITH WATER LEVELS AT HELL'S GATE.

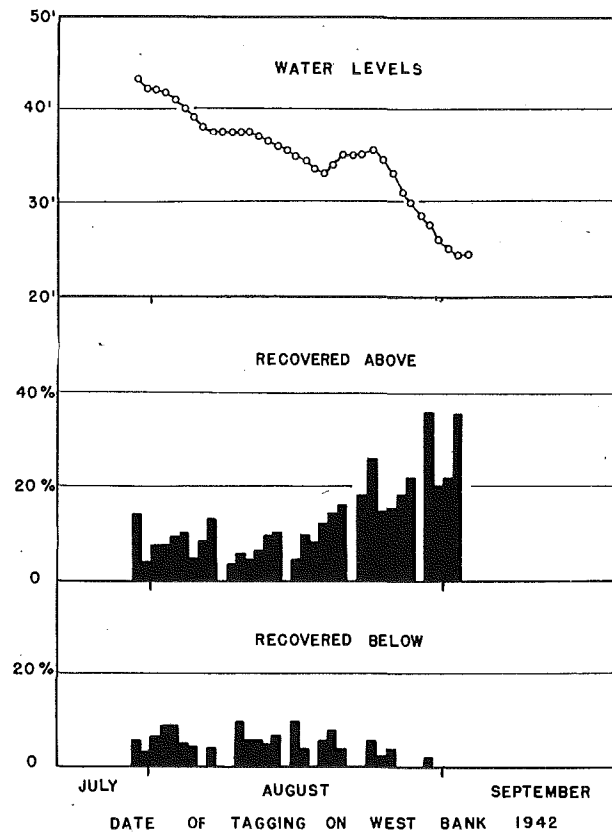


Fig. 44

RECOVERIES OF TAGS ABOVE AND BELOW HELL'S GATE IN 1942. PERCENTAGE RETURNED FROM FISH TAGGED BELOW ON THE WEST BANK DURING A PERIOD OF DIFFICULT PASSAGE COMPARED WITH WATER LEVELS AT HELL'S GATE.

When Figures 41, 42, 43, and 44 are examined more closely, it will be observed that while the percentage recovered upstream increased from the beginning to the end of the block, the recoveries were somewhat more for a date midway of the period than a steady increase would produce. This corroborates the evidence above as to passage of some fish during the block.

On the other hand, when the canyon was impassable for a prolonged period in 1941 (Figure 47) there were virtually no recoveries whatever from upstream after the brief open period in the first days of September. There is no room for erroneous returns in such a case and it shows that fish were not able to pass the obstruction in detectable numbers that late in the season whatever might have been true earlier.

At most, these fish which passed during the closure constituted one-fifth of the number which passed at its end (not of the number tagged). They do not change the evidence of heavy losses in the number of migrants reaching their destinations because they were included in the totals shown as recovered above the

TABLE 21
RECOVERIES IN 1939 AND 1942 OF TAGS PLACED DURING
WATER LEVELS BETWEEN 25 AND 40 FEET

1939					1942				
Date	No. Tagged	Bridge River	Ne- chako	Total Above	Date	No. Tagged	Bridge River	Ne- chako	Total Above
Aug. 13					Aug. 1	78			8
" 14	40	3	1	9	" 2	77	1	1	8
" 15	30	3	1	10	" 3	72			4
" 16	33			5	" 4	78	1		7
" 17	34	3	1	9	" 5	79			6
" 18	50	4		10	" 6	99	3		10
" 19	21	2		7	" 7	113	3		13
" 20					" 8	64	1	2	5
" 21	47	1		12	" 9	66	4		4
" 22	43	6		19	" 10	89	2	2	8
" 23	50	6	1	17	" 11	64	2	5	8
" 24	65	5		22	" 12	61	5	1	9
" 25	51	2	2	19	" 13	65	5	2	12
" 26	21	2	1	10	" 14	64	7	1	12
" 27					" 15	37	3	2	7
" 28	68	11	3	26	" 16	23	1		1
" 29	51	7		14	" 17	55	6		12
" 30	27	1	1	8	" 18	41	3		8
" 31	74	9		23	" 19	70	6	3	10
Sept. 1	60	6	2	19	" 20	80	8	1	14
" 2	30	4	1	6	" 21	79	10	5	21
" 3					" 22	50	6	1	10
" 4	31	6		15	" 23	15	3	3	9
" 5	71	13		22	" 24	68	14	4	23
" 6	68	15	3	29	" 25	61	4	2	13
" 7	44	10	3	22	" 26	73	8	3	18
" 8	63	15	4	35	" 27	73	9	4	25
" 9					" 28	67	12	9	27
" 10					" 29	50	5	4	16
" 11	57	14	2	23	" 30	28	8	5	17
" 12	75	14	13	47	" 31	63	11	6	24
" 13	78	16	2	40	Sept. 1	100	16	5	28
" 14	50	6	3	26	" 2	100	14	10	33
" 15	54	6	8	34	" 3	95	12	13	35
" 16	18	1		5	" 4	99	14	8	34
" 17					" 5	36	1	3	7
" 18	7			2	" 6	13			1
" 19	4				" 7	5			
" 20	5	1	1	4	" 8	3			
" 21	6			2	" 9	10		3	3
" 22	11	2		7	" 10	48	5	12	22
" 23	11	1		7	" 11	18	3	1	7
" 24					" 12	1			
" 25					" 13	24		3	6
" 26	22			15	" 14	24		1	7
" 27	12			9	" 15	19		1	4
" 28	37			26	" 16	5			1
" 29	21			16	" 17	6		1	3
" 30	10			9	" 18				

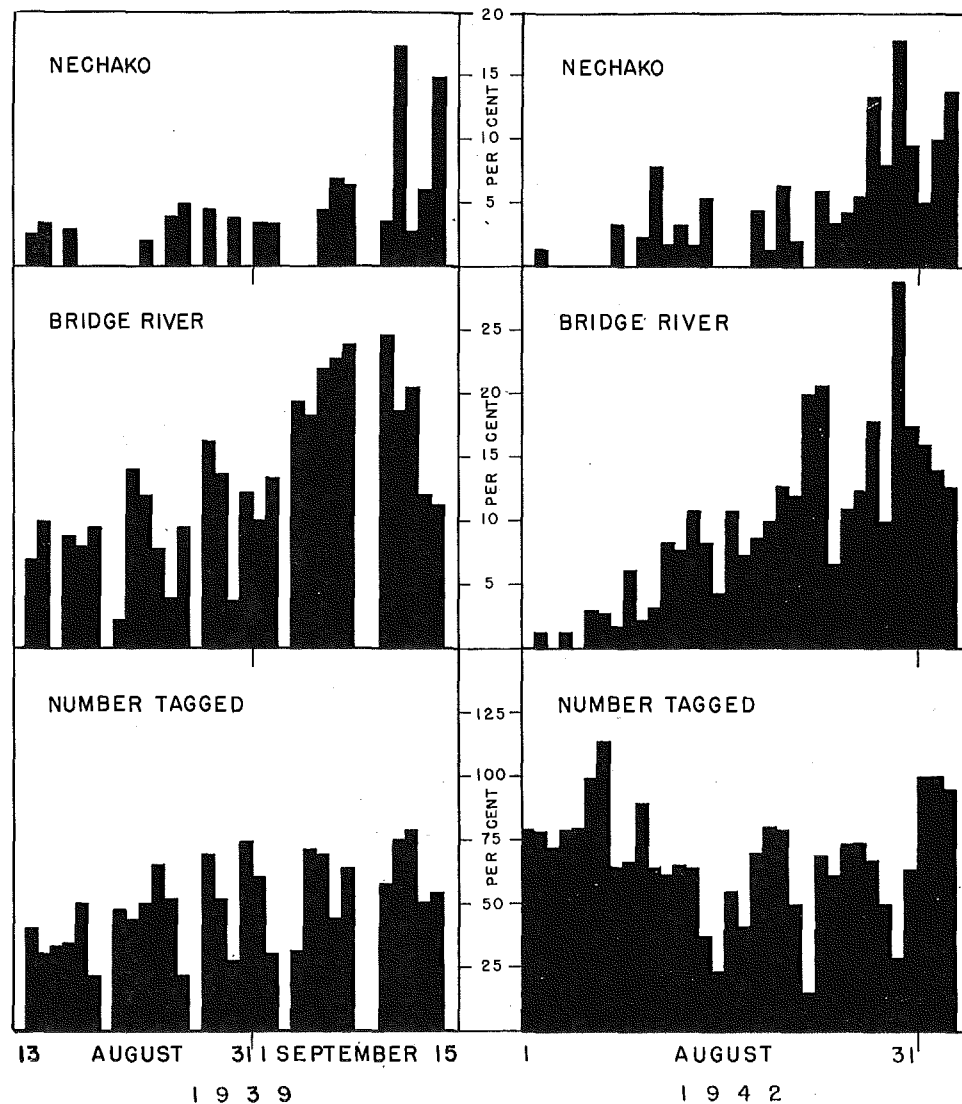


Fig. 45

RECOVERIES AT BRIDGE RIVER RAPIDS AND IN THE NECHAKO RIVER BY PERCENTAGE OF SOCKEYE TAGGED IN 1939 AND 1942 DURING THE PERIOD OF BLOCK BETWEEN WATER LEVELS OF 25 AND 40 FEET TO SHOW THE DECREASE IN RETURNS FROM FISH DELAYED LONGEST.

obstruction. Whether they passed the obstruction while it was effective or after it became passable is immaterial in calculating the losses.

The results indicate that the proportion of the run which fails to pass varies with the length of the delay, but the proof cannot be regarded as complete until it can be shown that the missing fish do not reach the spawning grounds. When the water fell to a level between 25 and 26 feet, the major escapement upstream took place. The migration occurred as a wave passing successive fishing points en route to the

spawning grounds. This wave contained the tagged fish from which recaptures were made during the last days of the blockade, and it has already been shown, on page 120 and Figure 31, that those fish tagged during the early days of the block were much diminished in number even before passage. At Bridge River Rapids, 75 miles upstream, the most important of these points, there is an active Indian fishery. Here the tagged fish were caught in numbers beginning with the third or fourth day after Hell's Gate became passable. The percentage composition according to date of tagging was much the same as that of the total recoveries upstream for the season from the fish tagged during the blockade. The similarity in composition indicates that the apparent mortality occurred before passage, certainly before reaching Bridge River Rapids, and was the result of the blockade. It was not due to failure to recover the early tags from the spawning grounds or elsewhere.

The wave of migrating fish is shown according to date of tagging in 1942, in the right hand graphs of Figure 45. The recoveries from Bridge River Rapids are compared with those returned from the Nechako River, from fish in this same wave as it reached those spawning grounds. The general picture of lowered percentage returns from fish tagged early in the period of blocked passage is the same, with some tendency perhaps for those most delayed to fail in the last part of the migration.

The wave left Hell's Gate about September 2, 1942, reached Bridge River by September 7, and the Nechako on September 22.

The same sequence occurred in 1939, at different dates, leaving Hell's Gate September 15. The two weeks' delay may have altered the relative composition of the recoveries from fish tagged early and those tagged late. In the left hand

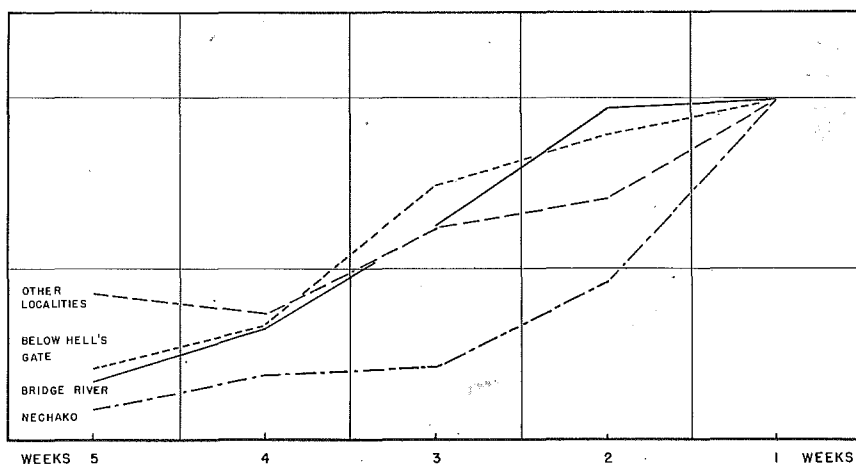


Fig. 46

COMPARISON OF RECOVERIES DURING 1939 AND 1942 OF SOCKEYE BLOCKED AT HELL'S GATE. THE RECOVERIES ARE COMBINED ACCORDING TO SEVEN-DAY PERIODS WHICH ARE NUMBERED ACCORDING TO LAPSE OF TIME BEFORE RELEASE OF THE ACCUMULATION. THE RECOVERIES DURING THE FIRST WEEK ARE EQUATED AND SHOW THE GREATER PROPORTIONATE LOSS AT NECHAKO OF FISH DELAYED LONGEST.

graphs of Figure 45 the percentage recoveries during 1939 are compared for the same districts as in 1942, including again the spawning grounds on the Nechako. There is evident again a low rate of return for fish delayed longest, and this low rate is most pronounced farther upriver. There is again a contrast between Bridge River Rapids and Stellako (Nechako). This must be due to a greater loss en route of the more delayed fish, a fact already noted on pages 108 and 109.

The chance irregularities of the data do not permit a clear picture of the graduated mortality. The number of fish tagged in 1939 and 1942 and the corresponding recoveries have therefore been combined. This has been done so as to combine those days of equal length of time prior to the dates of opening, which were September 15 in 1939 and September 3 in 1942. Thus September 13, 1939, and September 1, 1942, were added. The results were then grouped by weeks, since the weekly closed seasons and the week end cessation of tagging necessitated smoothing the data by such a procedure. The number of recoveries for each place for each week was then expressed as a percentage of the total tagged in that week. The resultant percentages for five of these week periods are given in Table 22. In order to compare them graphically, the returns for each locality have been multiplied by factors which have brought the values for the first week to equality, thus allowing the slope of the curves to be compared. The result is shown in Figure 46.

The same procedure has been applied to the recaptures of tags below Hell's Gate by the tagging party, in 1939 and 1942 as combined in Figure 31. The recaptures during the last ten days of the block should reflect the composition of the accumulation, not as well as those on the last day, but as well as could be expected in view of the need for sufficient numbers to give usable totals. They showed a reduction of those tagged earliest in the period. This has already been noted on page 120. The opportunity for recapture of those tagged during the last ten days of the period was, however, reduced. For instance, fish tagged one day prior to the opening were subject to but one day's fishing during which recoveries were possible, whereas those tagged ten days prior, had ten days. An approximate correction for this yielded the percentages shown in Table 15 for the recaptures below Hell's Gate by the tagging party. These are shown in Figure 46.

Of the three resultant curves, all decline sharply with the period of delay. The recoveries for Hell's Gate and Bridge River are not very different, but that for Nechako seems to indicate that only those fish delayed the shortest time were able to reach that locality in numbers.

For comparison, the recoveries from the other localities above Lytton—that is, above the main canyon in which Hell's Gate is situated—are shown in a similar manner. The decrease in returns with delay is not as great as for the recoveries from the Nechako and Bridge River, but is certainly present. Because of this, it cannot be said that the decrease is shown by the remaining three curves because of the diversion of tagged fish to some other district than those to which they apply.

It has therefore been possible to trace the mortality of fish held by the difficult water levels at Hell's Gate through the entire migration. The mortality is to be seen in the pool below Hell's Gate from which the tagged fish were taken, at Bridge

River, and at the spawning ground. It has been shown that after a long delay fish are less able to traverse the distance still remaining to the spawning grounds, and that when delay is too great fish do not pass Hell's Gate. Others fail on the way up the river.

Returns from Downstream

The returns from downstream during the period of difficult passage should have been greatest when returns from upstream were least. They must, however, be interpreted with care. As has already been said, the tagging in 1938 was too intermittent and experimental to yield good evidence. During 1939 there was a great deal of trouble with data given by Indians as to their recoveries in the canyon. It was necessary to prohibit their operation immediately below and above the tagging site except under strict control. Even in 1940 numerous returns of tags through storekeepers who obtained them from Indians had to be questioned as to time and place of recovery. Recoveries in 1941 and 1942 were made by, or under more direct supervision of, employees of the Commission. These two latter years yielded much more satisfactory evidence than 1939 and 1940. However, there were very few recoveries from above in 1941, so that the year 1942 only can be used for comparison of returns from below and above Hell's Gate.

To contrast with the recoveries above the obstruction during the period when water levels were between 40 and 26 feet, inclusive, those from below were tabulated in the same way as those above, by date of tagging.

Those for 1942 are shown separately for the two sides of the river on the same graphs as the returns from upstream. The returns from downstream are very much fewer in number through the whole period of the block than those from upstream. But they show that the percentage returned from downstream of those fish tagged during the early days of the blockade is greater than of those tagged in the last days, the reverse of that shown by the upstream recoveries. (See Figures 43 and 44).

TABLE 22
PERCENTAGE RECOVERED AT VARIOUS LOCALITIES OF SOCKEYE
TAGGED, BY PERIODS OF SEVEN DAYS, ACCORDING TO
TIME PRIOR TO DATE WHEN WATER FELL BELOW
26 FEET AT HELL'S GATE

<i>Days Prior to Opening</i>	<i>Below Hell's Gate</i>	RECOVERED		
		<i>Bridge River</i>	<i>Nechako</i>	<i>Other Places Above Lytton</i>
1 - 7	6.1	16.4	9.8	9.1
8 - 14	5.5	16.1	4.6	6.5
15 - 21	4.6	10.4	2.1	5.7
22 - 28	2.1	5.5	1.9	3.4
29 - 35	1.3	2.7	.9	4.0

The recoveries in 1941 for the period prior to September 1 can be seen in Figure 47. The increase in downstream recoveries with duration of the obstruction is very plain.

In 1942, even during the first part of the period, for the fish delayed longest, their numbers are still much less than the recoveries upstream. But the difficulties of recovery are much greater. The fish are not taken in numbers until the water in the creeks and streams in the canyon is lower and clearer. This does not occur until late September and October, nor do the Indians fish as much for them during August and early September as later. This difference in availability of tags will be shown best in considering the returns for 1941, when the blockade was complete for almost the whole season.

The recoveries for the whole season of 1941 are shown in Figure 47. It will be noted that the short opening period of September 1, 2, and 3, when the water fell below 27 feet, allowed but a very small escapement. Practically no fish which had been delayed longer than 12 days were later recovered upstream. The recoveries upstream were almost completely lacking after the water rose again into the blocked levels. This would indicate that but few fish were able to pass the obstruction

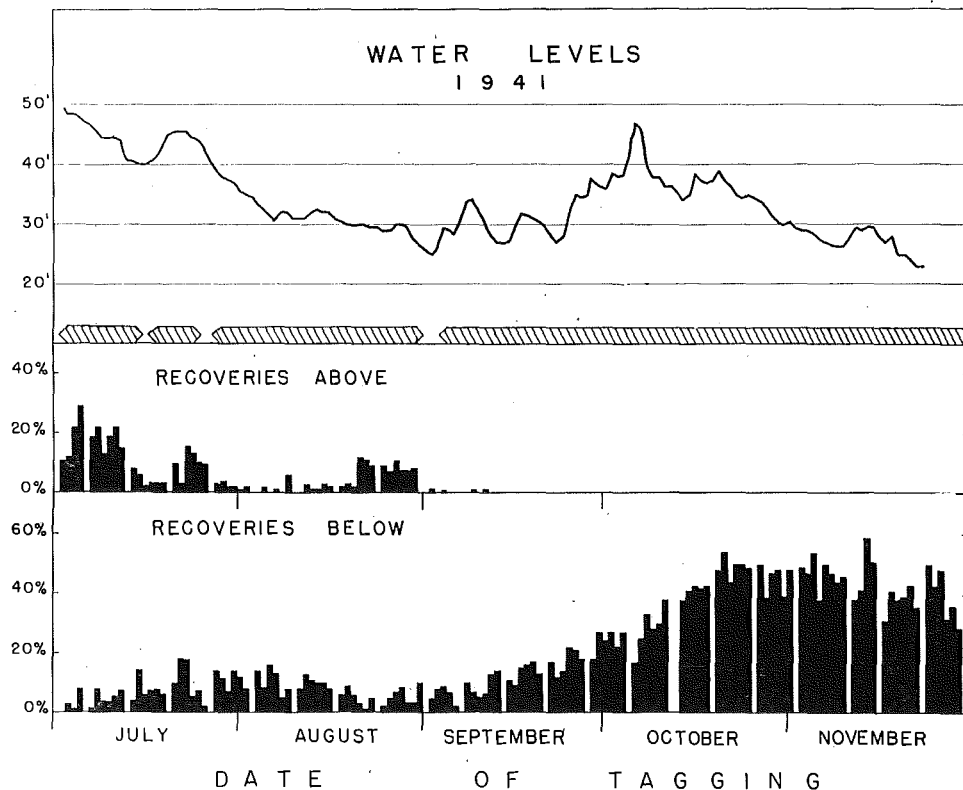


Fig. 47

RECOVERIES OF TAGGED FISH ABOVE AND BELOW HELL'S GATE IN 1941, EXPRESSED AS PERCENTAGES OF THE NUMBER TAGGED EACH DAY AT HELL'S GATE AND COMPARED WITH WATER LEVELS. THE DIFFICULT LEVELS ARE INDICATED BY A HORIZONTAL BAR.

after September 1, and that downstream recoveries should include all the tags placed thereafter. The percentage recovered of fish tagged each day after that date in 1941 should therefore provide an acceptable record of the availability of the tagged samples according to season.

But the recoveries downstream were in low percentage until early October, even for those days for which no recoveries whatever were made upstream. It can be roughly estimated from Figure 47 that the recoveries in early September were less than a fifth those in late October, when the tagged fish could be taken in the small streams below Hell's Gate. These high October percentages in 1941 seem to correspond to those from upstream during the same month of other years when the river was passable. The total percentage recovered seems to be approximately the same, whether taken upstream or downstream. In 1942 there were between 40 and 50 per cent from above; in 1941 nearly 50 per cent from below. It seems admissible therefore, to use a multiple of five in comparing July, August, or early September recoveries downstream with those taken upstream.

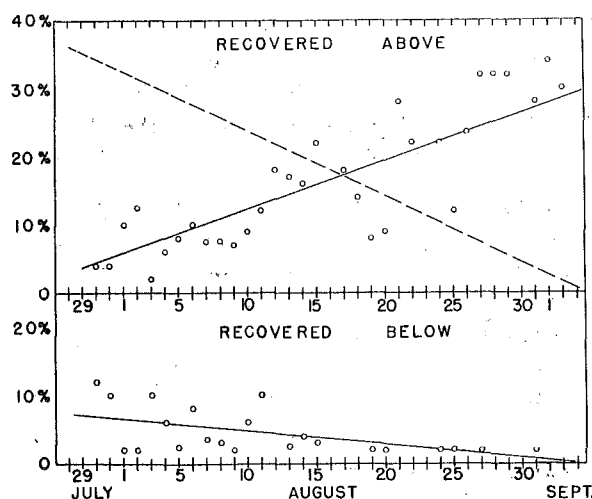


Fig. 48

COMPARISON OF RECOVERIES ABOVE HELL'S GATE (UPPER GRAPH); WITH THOSE BELOW (LOWER GRAPH), EXPRESSED AS PERCENTAGES OF THE NUMBERS TAGGED EACH DAY FOR 1942.

The broken line in the upper graph is the line of best fit in the lower graph, its values multiplied by five to correct for seasonal change in availability of tagged fish downstream from Hell's Gate.

In Figure 48, the actual recovery percentages in 1942 from upstream are compared with those from downstream, first, as to their original magnitude, and second, as multiplied by this factor. The result of using the multiple for recoveries downstream gives us two almost complementary graphs of returns, which added together make nearly all that could be expected, namely, over 40 per cent of each day's tagging. The calculation is admittedly a rough one, but appears to us acceptable in its implication that the two lots of returns account for all the tags.

If so, nearly 50 per cent of all tagged fish delayed by the obstruction failed to pass to their spawning grounds when the period of obstruction lasted as long as in 1940 or 1942.

On the same approximate basis, in the vicinity of 80 to 90 per cent of the fish blockaded between July 27 and August 30, 1941, may have failed to pass, as did practically 100 per cent of those after the brief opening in early September.

The increase during September and October in the proportion of tags recovered from those fish which had remained downstream, has been described for 1941. This *increase*, due to the greater accessibility of fish, is sufficient to obscure the *decrease* due to the lessened delay as the end of a period of block approaches. When such a period lasts to mid-September or later, the two trends should be expected to cancel one another. In 1942 the river became passable at 26 feet on September 3, in 1939 on September 15, and in 1940 on September 28. Whereas the effect of the delay upon the numbers of fish remaining downstream is clearly seen in 1942, it is barely visible in 1939 and not at all in 1940. Figures 49 and 50 may be consulted for the last named years.

The fact that seasonal changes in the facility of recovery may affect the recoveries, leaves any evidence from downstream subject to some question unless the seasonal changes can be thoroughly determined. But it can be hardly a coincidence that 1941 and 1942, with early cessation of the block, show the expected effect of delay, while 1939 and 1940, with late cessation do not show it.

The results may be summarized. It has been shown that those sockeye delayed at Hell's Gate fail to pass in greater numbers the longer the delay. A small proportion is able to pass, but the greater part accumulate below until the water falls below 26 feet. This accumulation passes upstream as a wave, apparently losing some of its more delayed members en route. It can be traced to Bridge River and to the spawning grounds. There is some ground for believing that only those which were tagged shortly before passage, hence were but slightly delayed, reached their destination in numbers. The returns of tags carried downstream corroborated these conclusions, as far as their evidence could be used. A rough calculation indicates that the expected quota of recoveries was thus accounted for.

E. EFFECT OF OBSTRUCTION UPON THE SUCCESSIVE SEASONS OBSERVED

It is now possible to review the results of the tagging for the whole of each of the seasons 1938 to 1942. Graphs of returns from tagging above and below the obstruction are given in Figures 47, 49, 50, 51, and 52.

In the preceding section various characteristics in the behavior of sockeye below an obstruction have been brought to light. To do this the returned tags from the long period of delay in passage, between water levels of 26 and 40 feet, have been studied. (Pages 135 to 146). It would be expected that the same characteristics would be found in the case of other periods, perhaps in modified form, and that they would help to explain features of the

experimental tagging that are not clear in themselves. To this end several points need to be borne in mind when interpreting the returns of tags for the whole of each of the several seasons. These are as follows:

(a) The survivors among the accumulated fish tend to pass as a mass, at the end of a period of delay, but are not recovered until months later. In making the analysis, the returned tags have been listed according to the day on which they were placed on the fish. There are usually representatives in this mass for every day's tagging during the period of delay and these are recovered upstream in due percentage. The effect of the delay is shown, not by entire absence of such recoveries upstream, but by their reduction in numbers according to the length of the delay to which they have been subjected.

(b) The recoveries of fish tagged during a short period of delay would in consequence be reduced but little and would have a high average. Since those delays above 40 feet on the gauge ended early in the season, soon after tagging began, they were short. The correspondingly high rate of recovery upstream during the time they existed, in the early part of each season, presents a strong contrast with the low rate that followed as soon as the period of the main block below 40 feet was entered. The recoveries for the first days of this block were of fish which had been subjected to a long period of delay during water levels between 25 and 40 feet and which passed in small part only. This contrast has already been described in commenting upon the low percentage of recoveries upstream during August on pages 109 to 111.

This will explain the contrast between the rate of recovery in late July and early August of 1939 and the following August 12-15 as shown in Figure 49; between July 10-25 and August 12-15, 1940, of Figure 50; and between July 1-20 and August 1-10, 1942, of Figure 51. This difference reflects in each case the lengths of the periods of delay to which the tagged fish had been subjected.

(c) From observation, we believe that as a period of delay by a block lengthens, the daily samples tagged include a greater and greater proportion of fish which have been delayed too long and which will not pass at once even though they have abundant time to do so. The returns from upstream tend therefore to be less even for the last days of such a period than they do for fish newly arrived and tagged below the obstruction after the accumulation has had time to vanish by passing either up or downstream. For example, recoveries for the first week in October 1939 when the river was open to passage were in higher percentage than for the week of September 5-12, the end of a long period of delay.

(d) Toward the end of the season the fish at the obstruction are so nearly ready for spawning that a large proportion of all fail to pass if delayed even for a short period. This happened in 1939, after the closure of October 15-27 (Figure 49). While many fish did pass, many did not. It also happened in

1941, no tagged fish passing when the river opened on October 6 and November 5 (Figure 47). But in the latter cases the mass of fish accumulated was so great that the relatively few tagged fish could hardly have included any of the fresh and strong individuals even had they been present in normal numbers. The effect is also to be seen in the water levels which are shown on page 133 and Table 20 for the end of obstructions. These are 22 and 23 feet for September and October of 1939 and 1940, whereas earlier in the season fish passed at levels below 26 feet.

(e) The short periods of delay, following closely in succession, which occur at levels above 40 feet, hence early in the season, tend to produce short humps in the graph of recoveries, corresponding roughly with the fluctuations in water level. No attempt is made to analyse these in detail, there being too many variable factors to permit precision. Some of these factors may be discussed. In no case do they do otherwise than provide a gradual transition between periods which are opened or closed to passage, or between one period of closure and another. They do not invalidate any conclusions reached thus far.

During a short opening only a part of the accumulation passes. It is evident that there is always a delay in clearing an accumulation after favorable water levels have been reached, although it is true that recaptures at the tagging station nearly cease when passage begins. The fish tagged during the period of block do not all present themselves at the obstruction at once but over a period of time. Those delayed in doing so fail to pass if the block begins again soon. Those doing so first, and passing upstream without delay, reach Bridge River Rapids in three or four days, but recoveries there may be spread over a week or more, due to tardy migrants.

A good example of this is the accumulation which was released September 1, 1941 when water levels fell below 26 feet. (Figure 47.) The period of open water was but two or three days in length, the water rising quickly again, and as a result only those fish passed which had been tagged within 12 days. They were no doubt the freshest and strongest, and were able to pass first as conditions ameliorated.

But the percentage of tags returned from fish which had been marked 10 or 12 days before the river opened was as great or greater than it was from fish marked immediately prior. The percentage returned from upstream decreased for the days just preceding the opening. This is evident in all three of the groups which passed upstream in 1941, as shown in Figure 47. It is evident, at least to some extent, in all other cases where the passage remained open but a few days, namely the openings of August 11, 1939, July 26, 1940, and August 1, 1942. (Figures 49, 50, 51, and 52) But it is not true of those cases where the passage remained open for a long period, as shown in Figures 41 and 45, after the prevalence of water levels between 26 and 40 feet. The best explanation seems to be that the probability of fish being at the barrier ready to pass is greater for fish tagged ten days earlier, and thereafter decreases sharply with time of delay. When but a few days

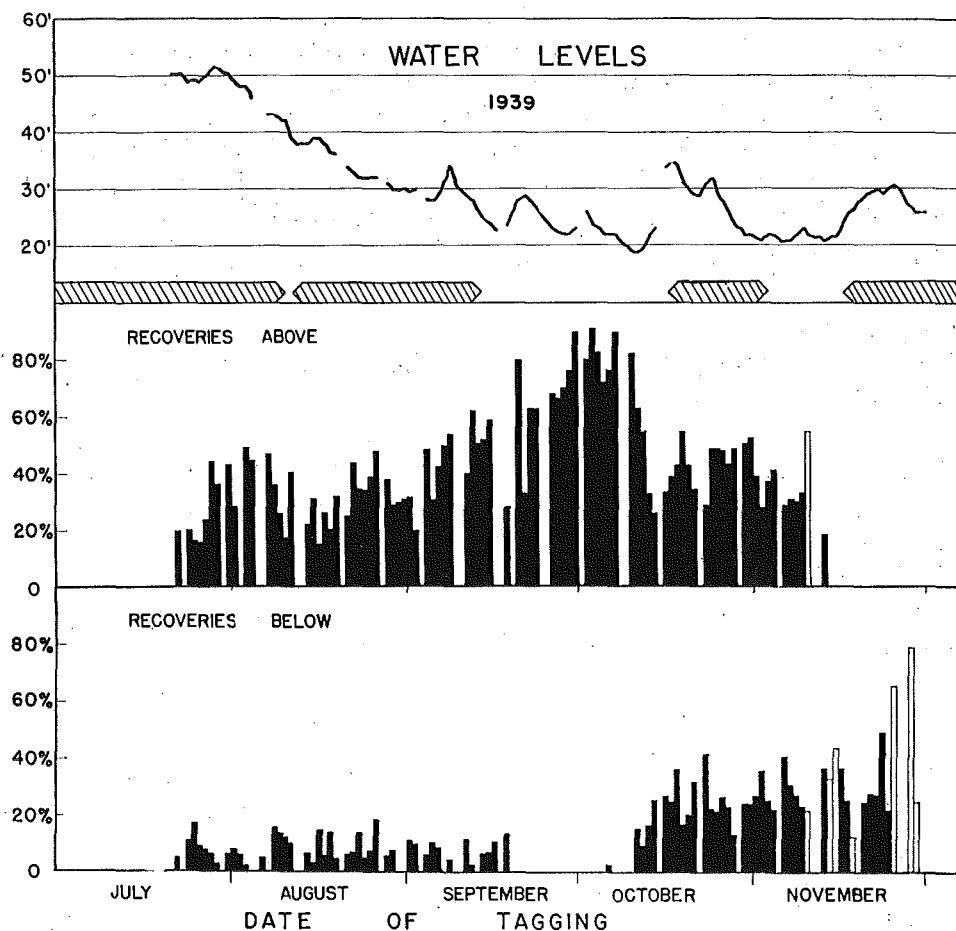


Fig. 49

RECOVERIES OF TAGGED FISH ABOVE AND BELOW HELL'S GATE DURING SEASON OF 1939, EXPRESSED AS PERCENTAGES OF THE NUMBER TAGGED EACH DAY AT HELL'S GATE, COMPARED WITH WATER LEVELS.

Returns for days on which fewer than ten fish were tagged are shown in open bars.
Periods of block are shown by cross-hatched bars.

are available for passage, those readiest go through, but when a prolonged open period follows, all those capable of doing so, ultimately pass upstream.

Fish tagged before closure may be caught below because of their failure to pass at once after being tagged. Hence the delay also affects the returns from fish tagged before the beginning of a period of impassable water. Tags placed shortly before the closure of about October 13 of 1939, failed to attempt passage at once and were caught downstream by the closure (see lower graph of Figure 49 for period immediately preceding date). The recoveries downstream increased, and those upstream decreased for the five or six days preceding the abrupt closure by the rise of water.

It was noted⁵⁹ in 1941 that the numbers of fish present in the eddies above Hell's Gate increased gradually as water levels fell from 30 feet to 26 feet, and that the eddies were not entirely clear after they rose again for nearly two weeks. This points strongly to the possibility that the reach becomes passable to some fish at water levels somewhat above 26 feet. There is, then, a gradual change between conditions permitting free passage and those of maximum difficulty, not an abrupt opening at 26 feet.

There is thus a transition between the rates of recovery upstream for any two successive periods, whenever they follow closely. It is due to delay in clearing an accumulation after favorable water levels have been reached and to delay of the fish which have been tagged in presenting themselves for passage.

We have marked Figures 47, 49, 50, 51, and 52 with bars along the base of the graph showing water levels. Each bar extends the length of a period of difficulty. It will be seen that these are consistent with the periods of delay shown by the recaptures made by the taggers at Hell's Gate themselves, as shown in Figures 30, 34, 36, and 39.

The returns in the successive years may be briefly reviewed, and will be seen to be consistent with the observations already made.

1. 1938. Tagging was too interrupted and scattered to give usable results.
2. 1939. (Figure 49). Tagging began July 22, and was continuous until the last of November.

A period of blocked passage had already begun and was not ended until August 11. The returns were low for the tagging done early in this block, about 20 per cent, but rose to 40 per cent and fell again as the end of the block approached. The lower returns from the early tagging were consistent with the mortality expected from the delay and were reflected in recoveries downstream. The lower returns as August 11 approached were also consistent with the discussion under (e) on page 148, as due to the failure of tagged fish to pass immediately, so that they were caught by the following period of block. But as a whole the recoveries from fish tagged during the early short blocks provided the expected contrast with those of the long block following. A long period of block began August 11 and continued until September 15. Within this period the fish tagged earliest showed the expected mortality, and few recoveries upstream, with increased passage as September 15 approached. There were somewhat higher returns midway of the period, also expected, as discussed on page 138. Recoveries downstream ceased for fish tagged after September 18 by which time the last of the over-tardy fish had disappeared. Thereafter the percentage recaptured upstream rose to unusual heights, without any recoveries downstream, the tagging evidently having been on fresh run fish. But a sharp rise in water level reaching and passing 26 feet on or about October 15, held fish below

⁵⁹ R. I. Jackson.

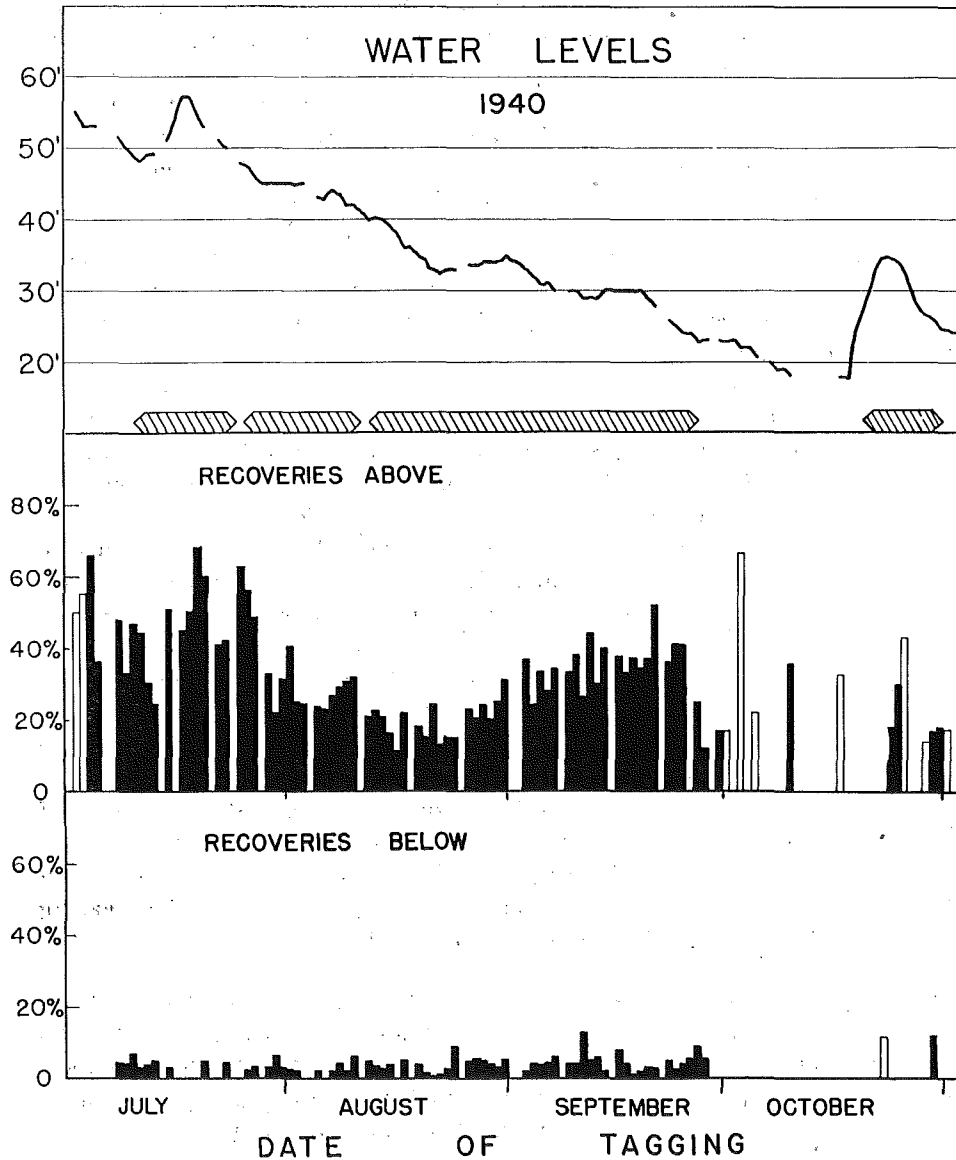


Fig. 50

RECOVERIES OF TAGGED FISH ABOVE AND BELOW HELL'S GATE DURING SEASON OF 1940 EXPRESSED AS PERCENTAGES OF THE NUMBER TAGGED EACH DAY AT HELL'S GATE COMPARED WITH WATER LEVELS.

Returns for days on which fewer than ten fish were tagged are shown in open bars.

Periods of block are shown by cross-hatched bars.

which had been tagged on October 12; and the recoveries upstream dropped sharply to half what had prevailed for fish taken before the rise. The recoveries below increased, and despite the recession of the water almost to 20 feet, they continued high until the end of the season. Recoveries upstream ceased completely early in November. It was evident that a large number of fish had not been able to endure the delay of the October rise and were unable to pass even the subsequent levels just above 20 feet. Those tagged fish recovered above may well have been the fresh run vigorous fish which the tagging party caught with the delayed individuals.

The downstream recoveries of October and November were unusually high, in contrast to those of August and September. This excess in October and November was seen again in 1941, and was due to the greater accessibility of tags in those months.

3. 1940. (Figure 50). In this year, as in 1939, there were recoveries downstream throughout the season from its beginning July 2, at a water level of 57 feet, until the water fell below 26 feet late in September, indicating failure to pass in varying proportion. As in 1939, these downstream recoveries did not reflect the changes in the numbers which passed upstream and must be regarded with caution until the Indian catch in the canyon can be corrected, if this is possible, not only for the relative accessibility of tags in the several months, but for accuracy of returns. However, as in 1939, the recoveries downstream in July, while the water was above 45 feet on the gauge, contrast with the nearly total lack of recoveries downstream after the water fell below 26 feet in late September and indicate that passage is difficult throughout the higher levels. Recoveries upstream were high during the short periods of difficult water levels in July and early August and contrast with those of mid-August, when the long period of delay had begun, as already noted on page 147, under (b). The graduated curve of returns through this long period of delay ending in September is obvious. Tagging ceased with the clearing of the accumulation made during this long period.

4. 1941. (Figure 47). The events in this year have already been described. The river was obstructed throughout the season except for the levels at 40 and 50 feet, and a short drop below 26 feet in the first days of September. A rise above 45 feet in October allowed no passage of fish, at that time too far advanced in physiological change to proceed.

Recoveries upstream fluctuated with the river levels as they varied between 40 and 45 feet in mid-July. Each time that the levels fell to 40 feet, which they did on July 13 and July 27, a small group of fish which had been tagged in the preceding period of water above 45 feet succeeded in passing.

Early in September, passage occurred over a period of two or three days. Fish tagged ten or less days previously succeeded in passing, but in much lower percentage than in other years when the opening was prolonged or final for the season. After reclosure, recoveries were almost nil above, but

rose to 50 per cent below as soon as the tagged fish could be taken in the smaller streams.

The three groups of fish which passed upstream from those tagged in July and August have each the same characteristics. They had accumulated from previous days and had been released by the water when it fell into levels which were passable below 26 or at 40 feet. The last group, passing upstream in early September, was notable because it released a great mass of fish, and

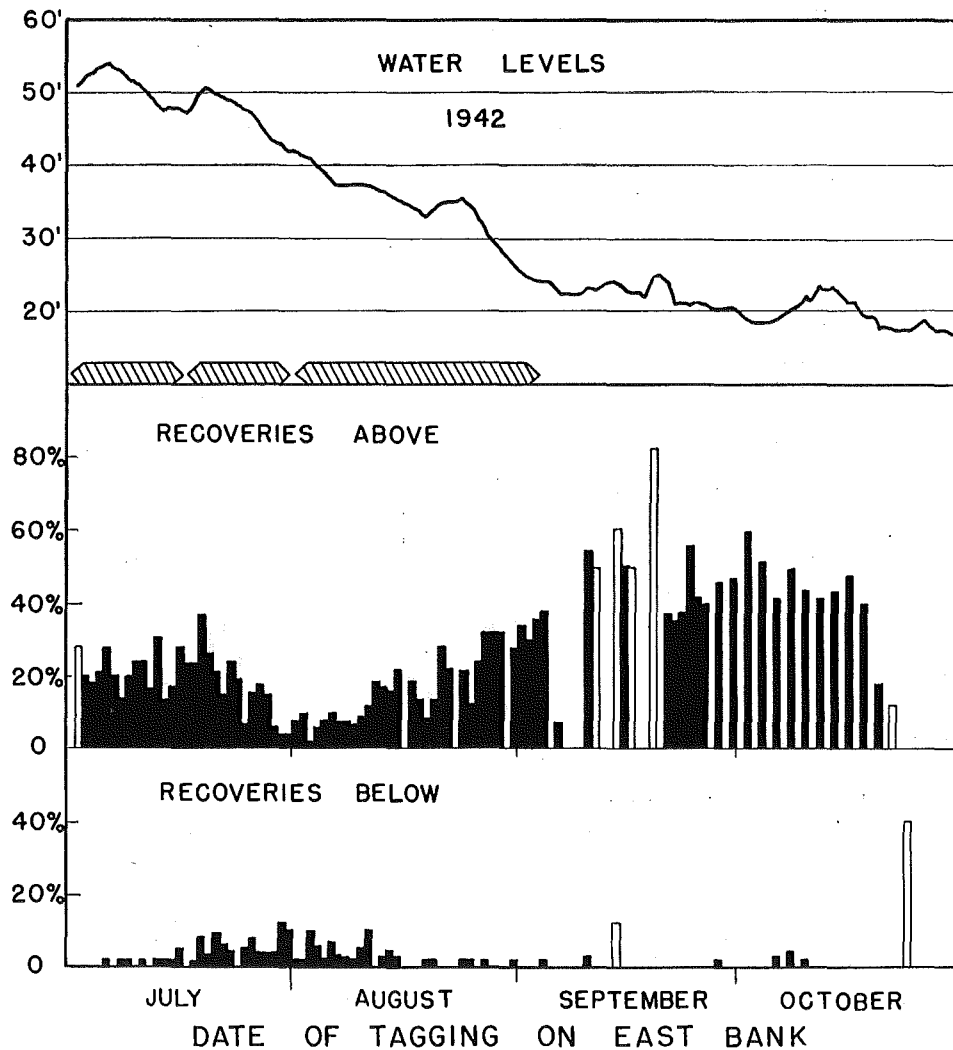


Fig. 51

RECOVERIES OF TAGGED FISH ABOVE AND BELOW HELL'S GATE DURING SEASON OF 1942, EXPRESSED AS PERCENTAGES OF THE NUMBER TAGGED EACH DAY ON THE EAST BANK BELOW AT HELL'S GATE, COMPARED WITH WATER LEVELS.

Returns for days on which fewer than ten fish were tagged are shown in open bars.
Periods of block are shown by cross-hatched bars.

could be followed in transit. - The two earlier escapements were as pronounced but occurred during a much smaller run of fish.

Recoveries were made downstream in high percentage throughout the year, the early September escapement being too small to alter their proportion greatly. These recoveries were checked with care and show what we regard as typical distribution through the season, its characteristics determined by the conditions in the small streams where tagged fish could be taken.

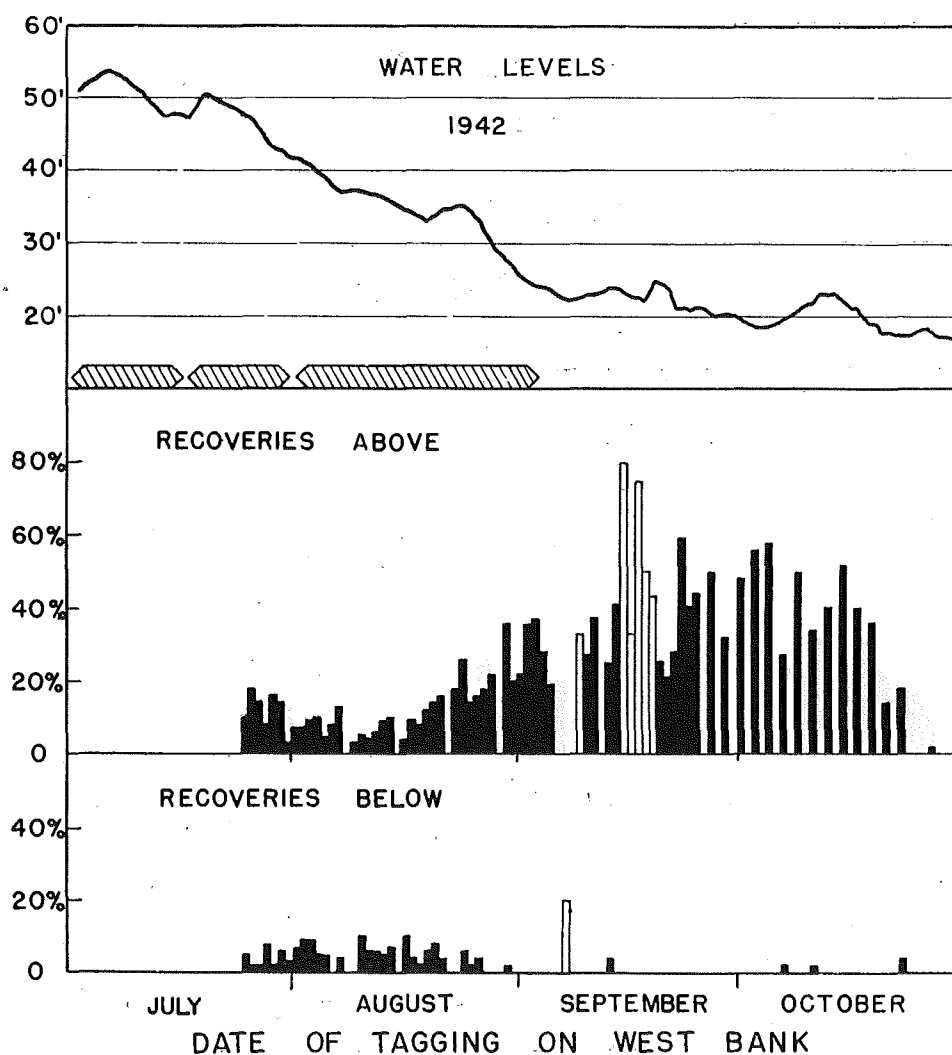


Fig. 52

RECOVERIES OF TAGGED FISH ABOVE AND BELOW HELL'S GATE DURING SEASON OF 1942, EXPRESSED AS PERCENTAGES OF THE NUMBER TAGGED EACH DAY ON THE WEST BANK AT HELL'S GATE, COMPARED WITH WATER LEVELS.

Returns for days on which fewer than ten fish were tagged are shown in open bars.
Periods of block are shown by cross-hatched bars.

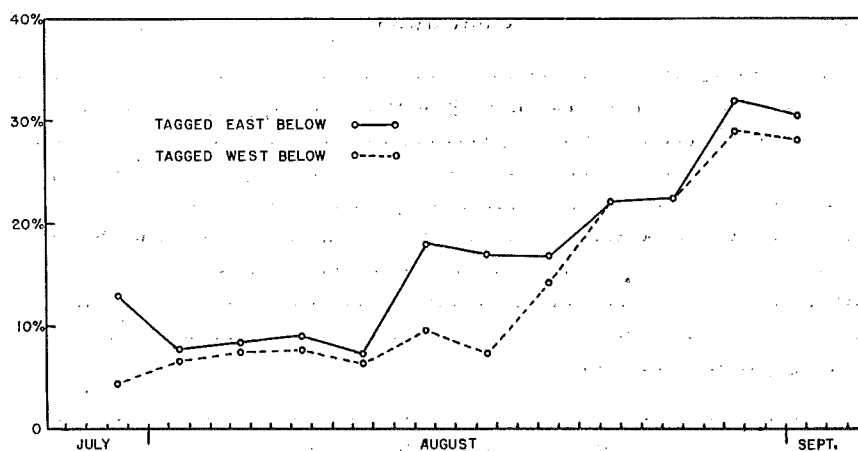


Fig. 53

COMPARISON OF RECOVERIES ABOVE HELL'S GATE OF FISH TAGGED ON EAST BANK AND ON WEST BANK DURING A PERIOD OF DIFFICULT PASSAGE IN 1942 BY THREE-DAY INTERVALS.

5. 1942. (Figures 51 and 52). Tagging was done at two stations on opposite sides of the river below Hell's Gate. That on the right, or west bank was not begun until July 25. That on the left bank was begun July 2, at water levels below 55 feet. After September 25, operations were alternated on the two banks. There is nothing unusual about the distribution of returns, which was of acceptable accuracy from below the obstruction as in 1941. Until the final opening at 26 feet, the distribution of the percentage returns from below was much the same as in 1941. (Compare Figure 47). The subsequent histories of the two years present a sharp contrast in accordance with the water levels prevailing, nearly all recoveries being upstream in 1942, all downstream in 1941. This in itself is proof of the obstruction. Both years indicated failure to pass at high water levels, above 40 feet, as well as between 25 and 40.

Again, as in 1941, a mass of fish was released from previous tagging when the water approached 40 feet late in July.

The returns from the two sides of the river differed somewhat. In Figure 53, the summed percentage returns for each three days for the two sides during the period of block are superimposed as line graphs. It will be noted that between August 13 and 21 returns were higher from the left, or east bank, along which fish are thought to pass when the river opens below 26 feet. This difference can possibly be interpreted as showing that the fish tagged on those days had at the time of opening not yet distributed themselves uniformly on both sides of the river, and that those on the right bank were delayed in reaching the point of passage on the left bank. The explanation is difficult to prove, but is an effect parallel to that observed at Hell's Gate at 40 feet in the recaptures by the taggers.

Conclusion

In concluding this interpretation of the periods of delay it should be pointed out that in every year during which the tagging experiments were carried on there were downstream recoveries for nearly all days at which the water was at or above 26 feet, including all above 40 feet. This is due to the fact that clearance is not complete during brief periods of open passage at such levels as 40 and 50 feet. The graphs should be examined with this point particularly in mind. It means that the short periods of passage are no substitute for long periods of obstruction-free water levels. It means that the early season passage of fish is limited to a percentage of the total, the block being partial, not total.

That the fish which present themselves at the obstruction can and will pass is plain from the failure of recoveries below when the water is below 26 feet on the gauge *for any length of time*. In 1939, from September 19 to October 10, there were no recoveries downstream. The recoveries between October 13 and November 29 were of fish too mature to pass, regardless of whether the river was open or not, and thereafter a large percentage of fish which were taken for tagging had been delayed too long. In 1940 the open period fell after September 23 and, while very little tagging was done because the fish passed rapidly, no recoveries were made from what was tagged until a new closure, October 19. The delay in clearing the accumulated fish must, of course, be discounted. There were no long open periods in 1941, and recoveries from below were made for all days on which tagging was done (*see Figure 47*).

In 1942 very few fish were retaken after September 1, contrasting with high percentages above, in accord with the low levels of water.

The evidence seems, therefore, to substantiate the findings of Section C, that the water levels are passable below 26 feet and at levels near 40 and 50 feet. The latter clearances are so short that it does not at any time completely terminate returns of tags from downstream. It can, furthermore, be concluded that when the river is passable for a sufficient length of time there are few or no returns from downstream from tagging done during that time. The continued recovery of tags from downstream throughout the early season is good evidence of delay. As we have already seen, delay means mortality in proportion to its length. This is particularly evident late in the season, when fish are near spawning and any delay of consequence seems to be decisive.

TABLE 23
OBSERVED WATER LEVELS AT HELL'S GATE

	1939					1940					1941						1942				
	July	Aug.	Sept.	Oct.	Nov.	June	July	Aug.	Sept.	Oct.	Nov.	July	Aug.	Sept.	Oct.	Nov.	Dec.	July	Aug.	Sept.	Oct.
1		49	30		22		57	45	35	23	25		35	26	36	30	24	50	42	25	19
2		48	30	26	21		55	45	34	23	24	49	35	25	38	29	28	51	41	24	19
3		48		24	22		53	45	33	22		48	34	25	38	29	27	52	41	24	18
4		46	28	23	22		53		32	22	23	48	33	29	38	28	25	52	40	24	18
5			28	22	21		53	43	31	21	23	48	32	29	42	28	25	53	39	24	18
6			28	22	21			43	31		22	47	31	28	46	27	26	54	38	22	19
7		43	31	22	21			44	30	20	20	46	30	31	45	27	26	53	37	22	19
8		43	34	21	22		51	44		19	20	45	32	34	40	26	25	53	37	22	20
9		42	31	20	23		50	42	30	19		44	32	34	38	26	24	52	37	22	20
10		42	30	19	22		49	42	30	18		44	31	32	38	26		51	37	23	22
11		39	29	19	22		48	41	29			44	31	30	36	28		50	37	23	21
12		38	28	20	22		49	40	29			44	31	28	35	29		49	37	23	23
13		38	26	22	21		49	40	29			41	32	27	35	29		48	36	24	23
14		38	25	23	22			40	30			40	32	27	34	29		47	36	24	23
15		39	24		22		51	39		19		40	32	27	35	29		48	35	23	22
16		39	23	34	24		54	38	30			40	32	30	38	28		48	35	22	21
17		38		35	26		57	36	30	18		40	31	32	38	28		47	34	22	21
18		36	24	34	27		57	36	30	18		41	30	31	37	26		48	33	22	19
19		36	26	31	28		55	35	30	23		43	30	31	37	25		50	33	25	19
20			28	30	29		53	34	29			45	30	30	39	25		51	34	25	18
21	53	34	29	29	30			33	28	30		45	30	29	37	24		50	35	24	18
22		33	28	29	30	57	51	33		34		46	30	28	36	23		49	35	22	17
23	50	32	27	31	29	58	50	33	26	35		45	29	27	35	23		49	35	22	17
24	49	32	25	32	30	60	49	33	25	35		45	29	28	34	21		48	35	22	17
25	49	32	24	30	31	59	48		24	34		44	29	32	35	20		48	34	22	18
26	49	32	23	28	30	58	47	34	24	32		42	29	35	34	20		47	32	22	19
27	50		22	26	28	56	46	34	23	29		40	30	34	34	20		46	31	21	18
28	51	31	22	24	27	57	45	34	23	28		39	30	35	33	21		44	30	20	17
29	51	30	22	23	26	59	45	34		27		38	29	37	31	22		43	28	20	17
30	51	30	23	22	26	60	45	34	23	26		37	27	36	30	24		43	27	20	17
31	50	30		22			45	35		25		37	26		30			42	26		17

Levels measured by Commission observers on gauge immediately below Hell's Gate.

F. EFFECT OF THE OBSTRUCTION ON THE COMMERCIAL CATCH SINCE 1912

It has been shown thus far in this report that the obstruction at Hell's Gate results in mortalities which are greater the longer the delay. They are suffered in varying degree by the different races, each of which has its characteristic time of migration past Hell's Gate, its own cycle of abundance, and its own history.

There is no reason to believe that each of these races requires a definite number of spawners to perpetuate itself. Presumably, as in other animals, the runs (populations) can be stabilized at a variety of levels by increases in survival rates which balance losses by obstructions, by fishing, etc. Nor is there reason to doubt that each race has its own environment and accordingly has its own natural death rate to overcome and its own limitations to an increase or decrease.

The question then arises whether the mortalities suffered at Hell's Gate, added to those due to fishing and to the natural losses, are too great to be compensated for by these races. Whatever opinions may exist as to the mechanism whereby this is done, the fact remains that there is no way to measure either the mortalities or the resilience of the species, hence the effect can only be proved by direct examination of the run or the catch.

There is an additional reason to require proof of an actual effect on the catch. This is the possibility that the salmon which have failed to pass have been able to spawn in streams below Hell's Gate.

This spawning is, however, unlikely to be of much importance. The sockeye salmon which fail to pass Hell's Gate and reach their spawning grounds have little chance to reproduce their kind. Very few sockeye tagged at Hell's Gate have found their way into other major tributaries below, such as the Harrison and the Pitt. The fish which are scarred and battered at the obstruction are not found on spawning grounds in these other rivers. The other streams on the main Fraser below Hell's Gate are small and the numbers of sockeye found in them do not account for the great numbers which have failed to pass. A large percentage of those found dead have died unspawned. Such streams as Yale and Spuzzum Creeks, the best available below Hell's Gate, have a quarter mile of gravel beds, not all suitable for spawning. There are no lakes within reach in which the young can live their first year and they must go to sea as fry if they survive.

In 1941 when passage through the canyon was blocked during the whole season, except for brief intervals, the salmon passed restlessly in and out of the creeks after they had fallen to the normal October levels. The population changed so rapidly that when the numerous tags present one day were removed, a new supply as great could be found the next. They filled creeks which later dried completely during the early winter. The eggs laid in the gravel were dug over repeatedly by other salmon. When they were raised in a hatchery they did not do well, many being deformed, apparently because the young could not escape through the toughened egg casing. Those laid in the riffles of the Fraser River itself were dried or were frozen when the water fell to low levels in the winter.

Either as the result of these unfavorable conditions, or the failure of races to transplant, no runs of worthwhile magnitude have been built up in these small streams. It would be expected from past experience that fish hatched and raised in a stream would return to it, and if they did so successfully would return year after year. There has been nothing of this sort in the Fraser Canyon. The destruction of the permanent runs to upriver spawning grounds has not been accompanied by development of corresponding runs below the canyon or anywhere else.

From a biological standpoint, there has probably always been opportunity for upriver races to seed streams which they pass en route. Had the species possessed the ability to transplant itself readily, and into such seemingly unfavorable environments as these creeks below Hell's Gate, there would surely have been self-perpetuating stocks there already, and also in many other places now barren. But the sockeye is known to have highly specialized migratory habits which could only have been developed if they were necessary to its survival. Even had strays into these streams produced offspring which returned, they would not be expected in such numbers as to perpetuate or increase the stocks there. If this did not happen before the fishery began, it does not seem logical to expect it after the heavy catch mortality has been added to that of an unaccustomed environment. Therefore there is no good biological reason to expect a permanent colony to result from the strays held below Hell's Gate unless it arises through a long slow process of selection and retrograde evolution of highly specialized habits.

To the extent that the fish whose migration has been blocked at Hell's Gate have failed to reproduce whether they died before or after spawning, they may be regarded as mortalities in so far as the return run four years later is concerned. But any conclusive proof that this is true to a serious extent can only be found in the demonstration of an effect on the runs as reflected in the index of return.

There also remains a question as to the effect of fishing. The opinion has been expressed in this report that overfishing does not explain the depletion of the Fraser River runs but may have contributed its share to the causes that brought this depletion. It may even be argued that fishing is still responsible for failure of the runs to recover. If so, not only must it be shown that some factor is preventing rehabilitation of the runs, but some means must be sought to show whether or not this factor is the obstruction at Hell's Gate.

An examination of the present runs must therefore be made. If the changes in the condition of Hell's Gate are reflected in the catch so that years of difficult passage are followed by poor catches and vice versa, then the effect of the changes at Hell's Gate can be identified. If, subsequent to the second and main period of depletion beginning in 1911, and after the races have had time to adjust themselves to the conditions as they were left, the effect of variations in these conditions still persists, they must surely have been sufficient to produce depletion of those races most affected by the blockade.

The depletion can possibly be regarded as a stabilization of the runs at a very low level of abundance. And if under present conditions the lessened mortality of

favorable years at Hell's Gate increases the yield, it will then be undeniable that the productivity of the runs is less than it could be were the obstruction removed.

A correspondence has already been shown to exist between the time of depletion and the period of railroad construction through the canyon. The catch since that time must now be examined to discover whatever correlation exists between its variations and those of the water levels at Hell's Gate. This must be done by use of the entire catch of Fraser River sockeye, since it is not possible to segregate that from the most injured races. If a correlation is present it must be found between two parallel series of records, one drawn from the obstruction, and one from the commercial catch.

For the first, the tagging experiments have given us a definition of those water levels which are for our present purpose regarded as obstructed. These are between 26 and 40 feet inclusive and above except for brief openings at 40 and 50 feet. The water records used are those kept and kindly furnished by the Canadian Water and Power Bureau for their station at Hope, British Columbia, since 1912. From these have been derived the water stages at Hell's Gate by a conversion based on a series of simultaneous observations at the two places in recent years.

A comparison of actual gauge readings at Hell's Gate shows that a level of 26 feet corresponds to one of 25 feet as derived from the records at Hope. In dealing with years prior to 1938, this correction has been used. Unless further comment is made, it can be understood that the water levels are thus corrected to correspond with those at Hell's Gate.

The brief periods of passage at levels of 40 and 50 feet are difficult to evaluate as to their effect on the catch. But they occur in every year, before September 1 as a rule, hence during the early run and without the extreme variability in occurrence which would alter the catch as a whole. For the purposes of the present section these brief open periods can be omitted from consideration.

The months of September and October are those in which the blocked period usually ends at a water level of 26 feet. The water levels of all years from 1912 to 1942 inclusive have been examined. In Figure 54 the days on which passage was difficult are shown each year by a horizontal bar. It will be noted that in no year is any considerable part of August free from obstruction, and that September 1 can be adopted as almost the earliest date in any year when the river is open for passage. On the other hand, but few tagged sockeye have passed Hell's Gate later than October 31 to reach a spawning ground. Therefore the variations in the numbers of days on which water levels are 26 feet or above (25 feet or above in records derived from Hope) in September and October should furnish an index to the relative year by year condition of the obstruction which would vary in such a way as to affect the runs. In Table 24 these counts are given. If they are subtracted from the total days in the two months, 61, the number of days on which passage is possible can be obtained. Data are available since 1912 only, as water records began in that year.

To compare with this there is available the index of success of return already defined. Since 1912, records of total catch of sockeye from the Fraser River are

obtainable and the ratio $\frac{C_4}{C_0}$ can be calculated. Total catches are given by Rounsefell and Kelez for years up to 1934, by Clemens up to 1937, and by the Pacific Fisherman up to the date of this report. For the sake of consistency, the data by Rounsefell and Kelez to 1934 and the Pacific Fisherman to date have been used.

Records of the amount of fishing are taken entirely from Rounsefell and Kelez in order that differences in method of collection may not destroy their comparative values. Their last records are for 1934, hence values of $\frac{C_4}{C_0} \cdot \frac{f_0}{f_4}$ and $\frac{C_4}{C_0} \cdot \frac{1-e^{-f_0 r}}{1-e^{-f_4 r}}$ are obtainable only for the period 1912 to 1934 inclusive.

The correction of the index values for the amount of fishing has been discussed from a theoretical standpoint. But the task of closely examining the data as to fishing has been too great for the present report. Until the number of licenses granted is corrected at least for the time each licensee operates, it is obvious that very great errors can arise in the values of $\frac{f_0}{f_4}$ and $\frac{1-e^{-f_0 r}}{1-e^{-f_4 r}}$. These errors, unless consistent in their direction from year to year and in their amount, would reduce any correlation existing even if the average values were closer to the truth.

As an illustration, the licenses granted in a year of poor catches, may be far more numerous than the number actually used, and in this respect the correction necessary might be very great as compared to that in a year of good catches. On the other hand the value of $\frac{C_4}{C_0}$ cannot be grossly in error. This ratio, as a limit is closer to the true value of $\frac{C_4}{C_0} \cdot \frac{1-e^{-f_0 r}}{1-e^{-f_4 r}}$ than is the ratio $\frac{C_4}{C_0} \cdot \frac{f_0}{f_4}$, when the escapement is less than 20 per cent (*see* Figure 9). It seems probable that the

TABLE 24
NUMBER OF DAYS ON WHICH WATER LEVELS WERE 26 FEET
OR ABOVE AT HELL'S GATE

Year	Days	Year	Days	Year	Days
1912	14	1922	36	1932	22
1913	34	1923	20	1933	31
1914	18	1924	37	1934	45
1915	10	1925	21	1935	21
1916	19	1926	0	1936	23
1917	20	1927	54	1937	27
1918	24	1928	9	1938	7
1919	25	1929	9	1939	30
1920	61	1930	21	1940	30
1921	58	1931	26	1941	58

escapement has usually been less than 20 per cent in recent years, but no proof of this can be offered here.

For these reasons, and because the value of $\frac{C_4}{C_0}$ is obtainable for a greater number of years, it is used throughout the correlations made in this section:

It should be understood, however, that these comments do not contradict the reasoning used earlier in this report when the limiting values of the index ratios were used to see if such extreme corrections would invalidate conclusions drawn as to the periods of depletion. Errors in the relative amount of fishing would be expected to increase the range between the limits and would merely apply a more

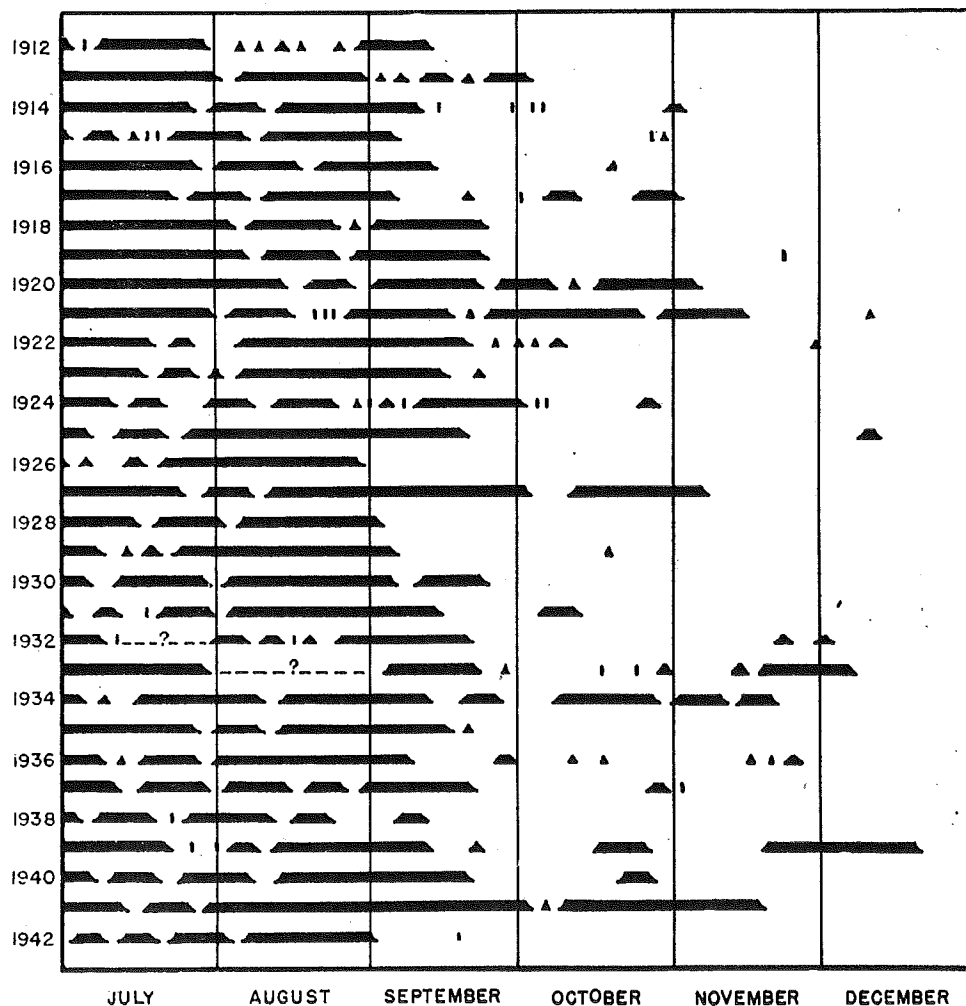


Fig. 54

PERIODS OF DIFFICULT PASSAGE AT HELL'S GATE FROM 1912 TO 1942. WATER LEVELS BELOW 26 FEET AND AT 40 AND 50 FEET ON THE GAUGE AT HELL'S GATE ARE SHOWN AS PASSABLE.

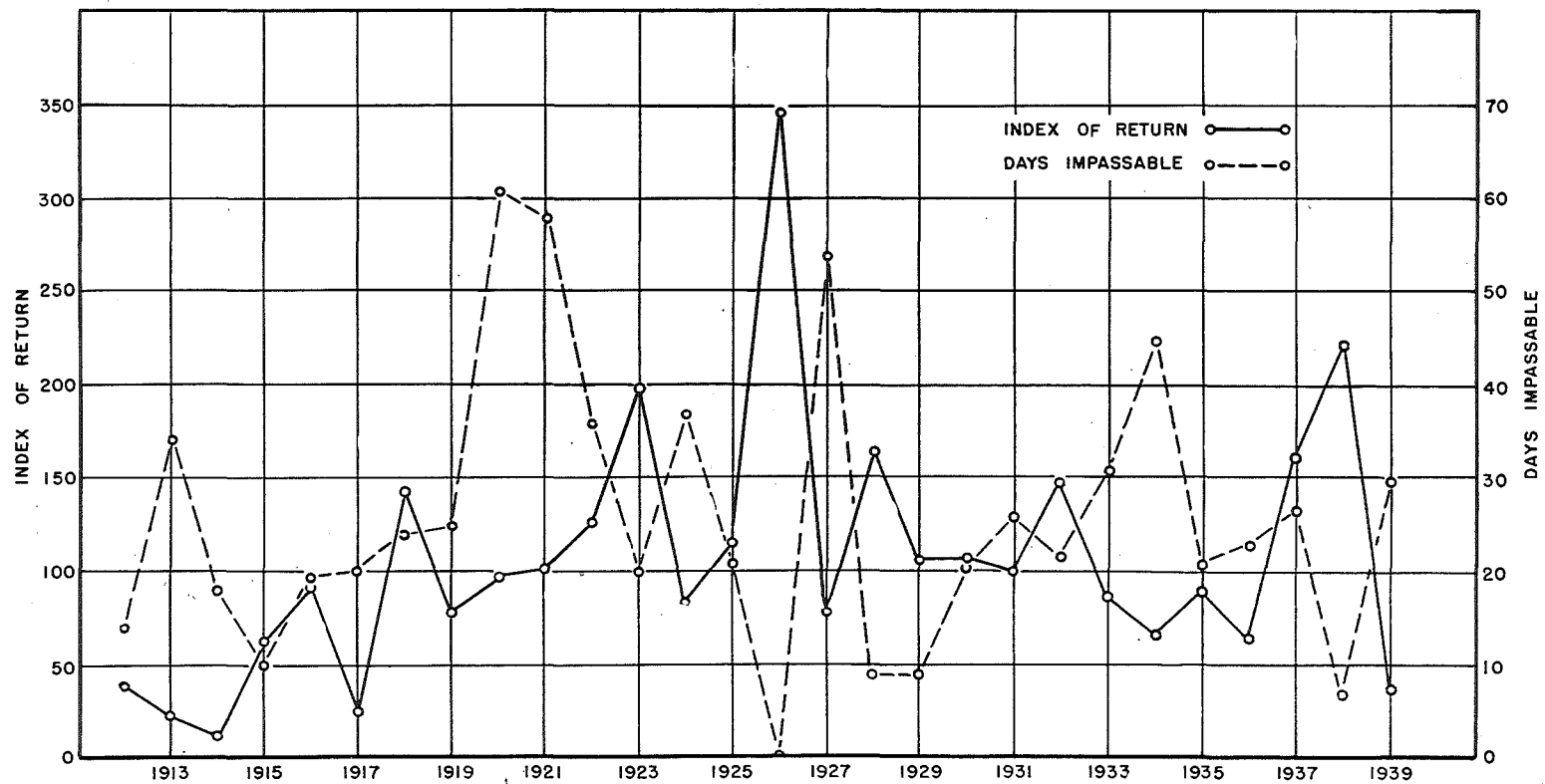


Fig. 55

COMPARISON OF ANNUAL VALUES OF THE INDEX OF SUCCESS OF RETURN $\left(\frac{C_s}{C_o}\right)$ AND OF THE
NUMBER OF DAYS IMPASSABLE IN SEPTEMBER AND OCTOBER, 1912 TO 1939.

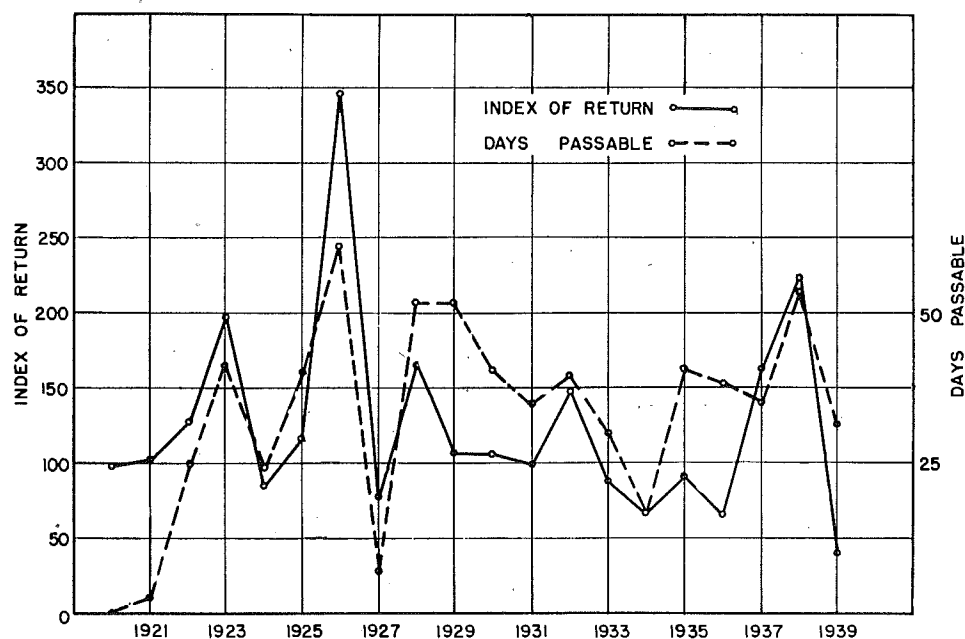


Fig. 56

COMPARISON OF ANNUAL VALUES OF THE INDEX OF SUCCESS OF RETURN $\left(\frac{C_4}{C_0}\right)$ AND OF THE NUMBER OF DAYS PASSABLE IN SEPTEMBER AND OCTOBER, 1920 TO 1939.

rigorous test to any such conclusions. The fact that the latter are not altered thereby remains an argument for their correctness.

In Figure 55 the two series of index values, $\frac{C_4}{C_0}$, and the number of days when Hell's Gate was above 26 feet, are shown on scales adjusted to give a roughly equal mean height on the graph. The deviations between each value and that of the following year should give an indication of the correlation existing. In Table 25 deviations in the same direction from the preceding year in the two indices are indicated by a plus sign, in the opposite direction by a minus.

TABLE 25

Year	Sign	Year	Sign	Year	Sign
1912	—	1920	—	1930	—
1913	+	1921	—	1931	—
1914	—	1922	—	1932	—
1915	+	1923	—	1933	—
1916	—	1924	—	1934	—
1917	+	1925	—	1935	—
1918	—	1926	—	1936	+
1919	+	1927	—	1937	—
		1928	—	1938	—
		1929	?		

The period 1912 to 1920 showed an equal number of positive and negative signs. But from 1920 on there were 17 negative and 1 positive signs if the questionable one for 1929 is ignored. The probability that this proportion or less would arise in two uncorrelated series of 18 events is given by the first two terms in the expansion of the binomial $(\frac{1}{2} \times \frac{1}{2})^{18}$, which would equal $19(\frac{1}{2})^{18}$. The probability would be .00007. If the questionable value for 1929 is regarded as positive this becomes .0004.

There is a good reason for the lack of a correlation prior to 1920. During the years after 1911 the runs up the main Fraser were disappearing. These passed Hell's Gate in July and August, and the varying length of the period of difficult passage could affect them very little. Yet they were of dominant importance in the catch. Thus the run of 1913 was greatly diminished on its return in 1917, and did not reach its new low level until 1921. This can easily be seen in Figure 1. The catch in 1921 was but 6 per cent of that in 1913. The other years in the four-year cycle had similar, if somewhat lesser, declines. Hence between 1911 and 1920 the runs were disappearing due to conditions in July and August, and any changes in September and October were subordinated. Therefore the correlation between conditions at Hell's Gate and the small fraction of the runs which were not in process of elimination was obscured.

The coefficient of correlation for the 28 pairs of values, of the indices to condition of the runs and of the obstruction, between 1912 and 1939 was $r = -.39 \pm .16$. This is a value greater than that which is given for the 5 per cent level of significance.⁶⁰

But the coefficient equals $-.59 \pm .15$ for the 20 pairs of items between 1920 and 1939. This value is greater than that given for the 1 per cent level of significance in the table cited. Using "Student's"⁶¹ t distribution, the probability that a value of this magnitude or greater would occur by chance is found to be .003.

The coefficient of correlation, r , thus calculated, depends for its value on both the trend and the deviations from the trend. But the nature of the ratio $\frac{C_4}{C_0}$ is such that its values tend over a period of time to return to 1.00. When the catch falls to a low level, and is held there either by continued adverse conditions at the obstruction or by elimination of sections of the runs, the ratio $\frac{C_4}{C_0}$ compares poor parent catch with poor return catch, and its value approaches 1.00. The same happens when good run is compared with good. It must also be expected that the relative importance of that component of the catch which is independent of Hell's Gate in September and October will vary. Races entering during July and August, or spawning in the lower Fraser, or entering very late in the season, must act to alter the degree of the effect of Hell's Gate from time to time upon the total catch.

⁶⁰ Fisher, R. A. Statistical methods for research workers. 8th ed. Edinburgh, Oliver and Boyd, 1941. Table V. A., p. 202.

⁶¹ "Student" (pseud.) New tables for testing the significance of observations. (Metron, v. 5, no. 3, p. 105-08, 113-20. Padova, Italy, 1925). Also Yule, G. U., and Kendall, M. G. An introduction to the theory of statistics. 12th ed., rev. London, Charles Griffin & Company, Ltd., 1940. p. 453, 536-37.

It must therefore be expected that correlation would be less between the trends than between short time variations from them.

This can be tested readily. The change in value of either series with time can be determined by fitting straight lines to the values. The coefficient of correlation between the deviations from these lines can then be calculated. Or the methods of partial correlation can be used to eliminate the correlation of the two variables with time. Thus calculated, the value of r between deviations becomes $-.70$ for the years 1920 to 1939.

However, the trend, due to the above mentioned characteristics of the index ratio, and the peculiarities of the runs, would obviously not be a straight line. An irregular trend such as would be expected can be better removed by using a "moving average" of each three items (*see* page 78). When this is done the value of r for

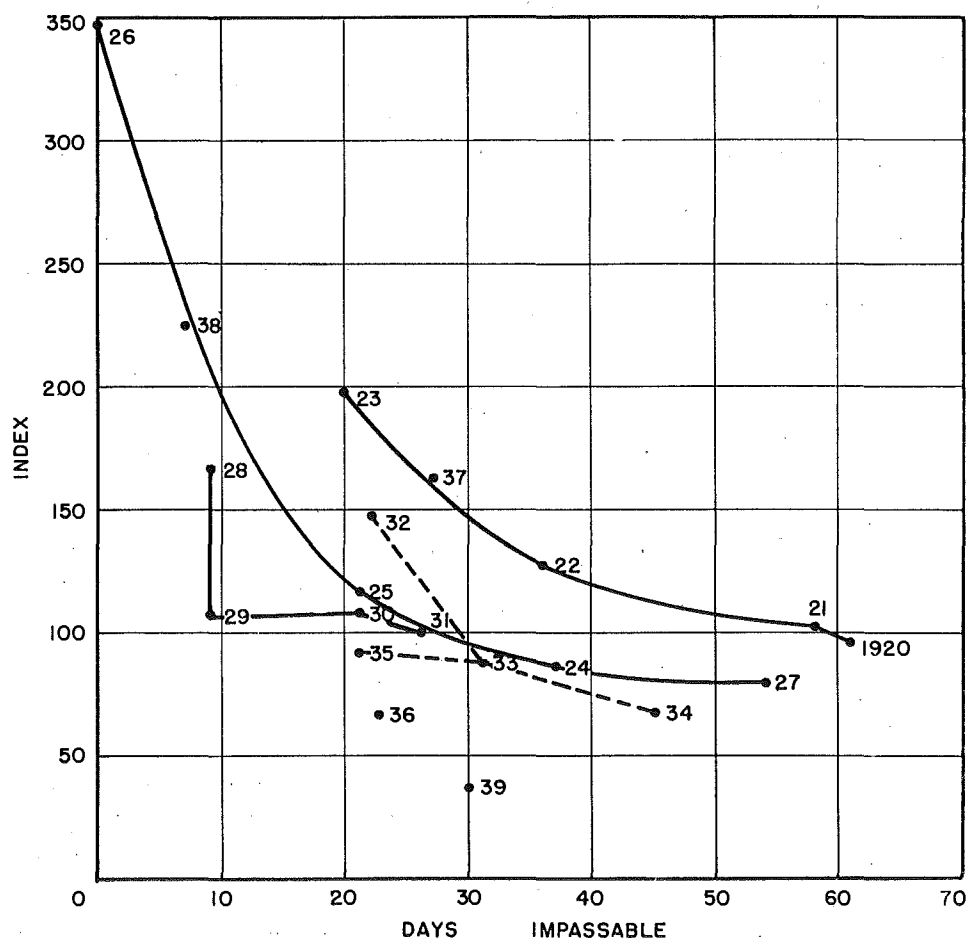


Fig. 57

COMPARISON OF INDEX OF SUCCESS OF RETURN OF CATCH AND OF NUMBER OF DAYS IN SEPTEMBER AND OCTOBER OPEN TO PASSAGE AT HELL'S GATE FROM 1920 TO 1939. Values are given on coordinates to show curvilinear regression, and are numbered to show years.

the deviations from the three-year means becomes $-.70 \pm .10$ for the years 1913 to 1938, inclusive, and $-.83 \pm .08$ for the years 1920 to 1938, inclusive. As an alternative the first difference between successive variates can be compared when $r = -.80 \pm .09$ for the years 1920 to 1938. The significance of these last two values of r is beyond any doubt. The probability that it could arise by chance between two non-correlated series of index values is virtually nil.

The trends are nevertheless correlated. For the period 1920 to 1938, inclusive, $r = -.39$. But it is obvious that between 1920 and 1927 the general levels of the two indices bear a different relationship than they do between 1928 and 1932, for example, despite the existence of high correlation between the deviations from the trends. This is seen more clearly if the comparison is made between the days passable and the index of return as in Figure 56, rather than between the days impassable and the index, as in Figure 55.

It follows from this relationship of trend and deviations from the trend, that the regression curves between the two variables approximate their true form only when observed within short periods of time. The index of return tends to assume a new level each four years. If the conditions at Hell's Gate vary widely within one cycle period of four years, the values of the index of return will cross the trend

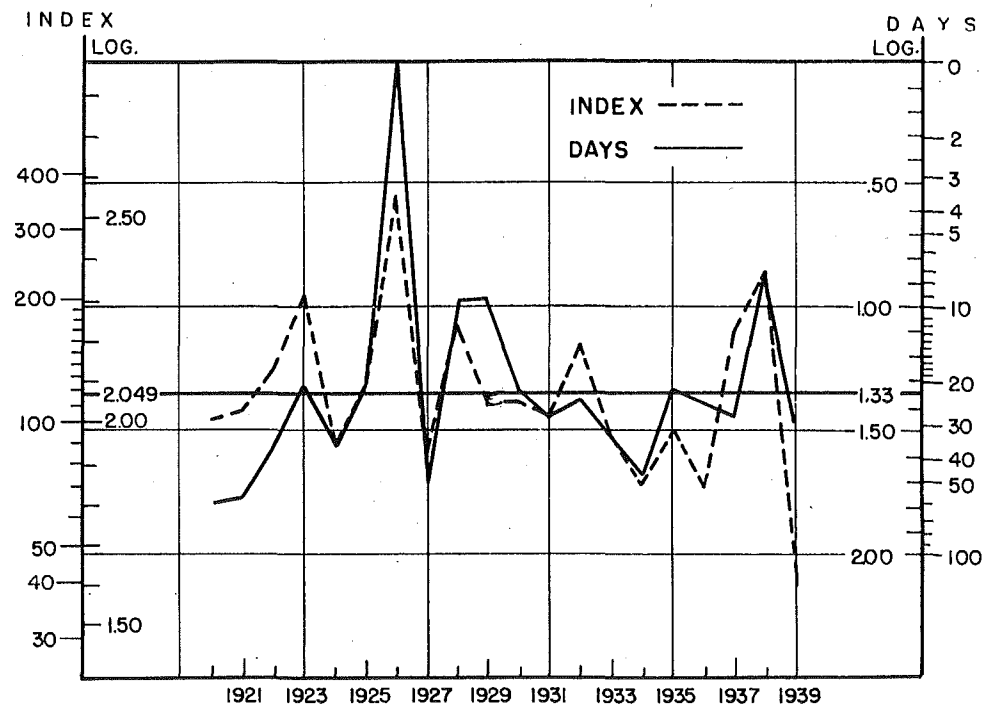


Fig. 58

COMPARISON OF INDEX OF SUCCESS OF RETURN OF CATCH AND OF NUMBER OF DAYS IN SEPTEMBER AND OCTOBER OPEN TO PASSAGE AT HELL'S GATE FROM 1920 TO 1939.

Values given in chronological order, after correction for non-linear regression by use of logarithmic scales.

at a sharp angle, and the regression curves will approach their true form insofar as they are free from the changing values of this trend. They will tend to repeat that form in the next four-year cycle, but with different values if the trend has altered in the meantime. The result is shown in Figure 57, as a series of regression curves of the same general character but differently placed in the system of coordinates.

Under the circumstances the degree to which the regression lines are influenced by the trend remains in doubt. It is possible that the curve shown is of the type $y = ax^b$, and that the regression curve for logarithms of the two indices should be linear. It does not seem, however, that the data are accurate enough, nor that the problem is sufficiently simple to justify further analysis at present. No further attempt has been made to measure with accuracy, or to determine the exact character of, the relationship between the two indices (*see* Figure 58). At all events, the values obtained for the coefficient of correlation are a minimum, and may be higher if corrected for the form of the regression curve.

The regression curves show, however, that for the period 1920 to 1939, the returns were very successful from parent runs which encountered short periods of difficult passage during September and October. This is the fact of greatest interest to us. It shows that the races affected by Hell's Gate will reproduce at a high rate when freed from the mortality caused by delay at that point.

It can be seen that the relationship is much less regular in the later years, as 1939 is approached. This may be due to the use of statistics of catch from a different source, the Pacific Fisherman, whose methods of collection may have differed from those of Rounsefell and Kelez. The records given by the latter extend only to 1934, consequently all index values after 1930 involve a comparison between catches collected and checked by other agencies. It has already been noted that the statistics of the amount of fishing should be examined more closely. It seems undesirable, therefore, to interpret too closely the exact meaning of the changing relationships of the regression curves.

This being so, further study is needed for the more recent years before it can be said that the high degree of correlation discovered still exists. That is equivalent to saying that while good results can be expected from removal of the obstruction because the correlation has probably continued, yet no close measurement can be made of the expected results.

It can be concluded that the effect of the water level conditions at Hell's Gate on the catch of sockeye has been definitely proved. The correlation is high, and particularly so between the year by year variations from the trend. It is sufficiently high to indicate that the major cause of the variations between 1920 and 1939 has been the varying extension of the periods of difficult passage into September and October. The returns from runs which occurred when Hell's Gate was entirely passable, or nearly so, during September and October shows that from 1920 to 1939 the races still had great resiliency. If this continues to be true, the removal of the obstruction at Hell's Gate should have good results.

SECTION IV

SUMMARY

1. The depletion of the Fraser River sockeye salmon run has deprived the United States and Canada of between a quarter and a third of a billion dollars, or an annual average of between 9 and 12 millions since its occurrence about 1913. This report is an analysis of the causes of this depletion based upon historical records and upon extensive experiments in which 34,000 migrating adult sockeye have been tagged within the river.

2. A historical index to the success of each annual run in reproducing itself can be derived from the percentage which the return four years later forms of the parent run. Limits to its value can be set to include maximum and minimum possibilities in the escapement from the catch and in competition between gear. The adoption of the limits does not alter the conclusions drawn in this report. The index can be modified to account for the effect of age at return and of incomplete statistics as to fishing in sections of the catch.

3. Depletion of the Fraser River sockeye occurred in two distinct periods, the first from 1899 to 1903, the second from 1911 to 1919, each constituting a distinct step downward in level of production. Hatchery and spawning ground records corroborate this. The outstanding loss was that of the cycle of the big run of 1913, recognized as due to conditions in the canyon. It was but one of a number of years of depletion in the period 1911 to 1919.

4. The character of this depletion and that of a degree of subsequent recovery indicated that the primary cause was not overfishing but a selective depletion. It applied to those races passing above the lower canyon of the Fraser River and in the case of the second period to those races of both the Thompson and the main Fraser. Recovery from the second period of depletion has been limited in extent and largely confined to late runs. This points to continuation of a cause of damage, situated in the canyon and affecting particularly the early runs. The timing of the runs to various spawning areas as they pass Hell's Gate has been determined.

5. The possibility of overfishing is not negated, but remains a serious problem for the future.

6. The first period of depletion was coincident with the existence of a dam without an adequate fishway at the outlet of Lake Quesnel and the near destruction of the run into that lake.

7. The second period was not due to a slide in 1913, since this occurred in 1914. It is thought to have been due to dumping of rock during the period of railroad construction through the canyon. Where passage was already difficult

it undoubtedly made existing difficulties much worse. Railroad construction began in May or June of 1911 and coincided with the period of damage to the runs. Passage may have been hindered at these points in earlier years. The damage was most obvious during the year 1913 because of the magnitude of the run of that year, affected by continuing high water and much dumped rock.

8. A review of the disaster of 1913 and of recorded difficulties in the canyon since that time, shows that they were similar to the events of 1941 when large numbers of fish failed to pass Hell's Gate. The obstruction has existed since 1913, if not since earlier years.

9. The tagging experiments showed that the runs during the usual period of blockade have been adapted to it by elimination, by reduction in numbers, or by time of arrival.

10. The obstruction occurs between levels of approximately 26 and 40 feet inclusive, measured on the gauge below Hell's Gate. The levels are not exact because fish tagged do not attempt passage at once, because water conditions are graduated in difficulty and because the condition of the fish varies. The obstruction is present above levels of 40 feet and fish may pass intermittently at 40 and 50 feet approximately. No tagging has been done above 57 feet.

11. The effect of the obstruction is shown by nearly complete absence of recoveries below Hell's Gate when the river is passable, and by a high percentage above. This contrasts sharply with no recoveries above and a high percentage below when the obstruction is present. October of 1941 and 1942 illustrate this contrast well.

12. During periods of obstruction fish fail of passage in proportion to the length of the delay. The percentage of each day's tagging which succeeds in passing falls from over 30 per cent for days just preceding the disappearance of the block, to eight per cent after 20 days delay.

13. Fish tagged during these periods are recovered downstream in proportion to the time of the delay. Of fish tagged immediately prior to and after the opening, virtually none are recovered downstream, but after 20 days delay the number increases to about 8 per cent of each day's tagging.

14. As was shown by the long block of 1941, the recovery of tags below depends upon the condition of the small streams and the habit of the fish in entering them when they are ready to spawn. In this year it was possible to recover but one-fifth as many tags during the ordinary season of blocked levels as are known to be recoverable. It is therefore necessary to regard the recoveries of 8 per cent downstream described in the previous paragraph as equivalent to 40 per cent upstream.

15. Added to the upstream recoveries, these corrected downstream recoveries account for as high a percentage recovery of tags as from experiments in a normal season when the river was known to be open.

16. From these data it is possible to estimate very approximately that during a period of block of 40 days half or more of all fish delayed thereby and tagged, failed to pass upstream even after the river had opened permanently.

17. During the year 1941, a brief opening of three days early in September did not allow complete passage. Only those tagged within 12 days passed in any number, and not more than 10 per cent of any day's tagging. The fish failing to pass approximated 90 per cent of those fish delayed and tagged below the obstruction. It is evident that brief opening of the river to passage is taken advantage of by only a portion of the tagged fish.

18. A small percentage of fish succeed in passing during difficult or blocked periods. The data are not sufficient to give a reliable estimate of their numbers, but the proportion is small.

19. The fish released by the arrival of passable water levels at Hell's Gate accordingly present a characteristic composition, according to the days on which they were tagged. These fish pass upriver as a well marked run, arriving at Bridge River four or five days and at the Stellako about 20 days later. In 1942 this was well illustrated by the fish released about September 1 and followed to Bridge River and the Stellako.

20. The prolonged period in 1941 during which the water was within the obstructed levels produced a very high mortality. The sequence of events was strikingly similar to those in 1913. Fish passed through the same physiological changes as they do en route to their spawning grounds. They became less active, fell back into quieter eddies, sought spawning grounds in the creeks below the obstruction, and died usually without spawning. While no quantitative determinations of the number dying were possible, the changes were followed by constant observation.

21. Few eggs were spawned in the creeks below and in the shallow places along the river, and those which were so spawned developed abnormally, or died before hatching. It is not thought possible that many could survive without lakes in which to dwell as young. There is no evidence of established runs in creeks below the canyon.

22. The periods of block were determined for each year since 1912, when water records were first taken by the Canadian government.

23. It was shown that the index values of success of each year's run in reproducing itself has since 1920 varied inversely to the number of days that passage was blocked at Hell's Gate during September and October of each year. The coefficient of correlation is high and is proved significant by rigorous mathematical tests. It is higher for the year by year variations than for the trends, due in part to the characteristics of the index of success of return.

24. The rate of reproduction shown for years in which there was no obstruction is very high and promises well for the future of the runs when the river is clear.

25. The effect of the blockade gives a rational and consistent explanation of the partial and selective depletion of important races of sockeye salmon. It explains the continued existence of late runs and depletion of the early. Certain races have been reduced, if not eliminated, to give a lower level of production which is permanent as long as an obstruction exists at the time of passage of these races.

26. The removal of the obstruction is necessary, because it is the principal cause of the present depleted condition of the Fraser River sockeye run, although heavy fishing may have contributed.

27. The effect of the removal of the obstruction will depend upon the number of races still existent in a depleted condition. No estimate of these can be given.

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