INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION *

APPOINTED UNDER A CONVENTION
BETWEEN CANADA AND THE UNITED STATES FOR THE
PROTECTION, PRESERVATION AND EXTENSION OF
THE SOCKEYE AND PINK SALMON FISHERIES
IN THE FRASER RIVER SYSTEM

BULLETIN XXVII

ESTIMATION OF FRASER RIVER SOCKEYE ESCAPEMENTS FROM COMMERCIAL HARVEST DATA, 1892-1944

PHILIP GILHOUSEN

VANCOUVER, B.C.
CANADA
1992

* Dissolved December 31, 1985 by agreement of the Governments of Canada and the United States in accordance with Article XV of the Pacific Salmon Treaty.

FRONTISPIECE. Gillnet boats of circa 1900 at the mouth of the Fraser River. Cloudy weather suggests southerly or southeasterly wind. Angle of sails and sunrays through clouds indicate afternoon view toward southwest, probably in July or early August shortly before the 6:00 p.m. starting time of the weekly fishing period, since no fishing activity is visible. Photo from Report of the British Columbia Commissioner of Fisheries for 1902.

ABSTRACT

Estimates were derived of sockeye salmon (*Oncorhynchus nerka*) escapements from the Fraser River gillnet fishery between 1892 and 1944 (years before reliable estimates of escapements based on survey programs). Based on the results of experimental fishing conducted by the International Pacific Salmon Fisheries Commission between 1947 and 1963, models were developed to relate exploitation rates of the gillnet fishery with durations of weekly fishing periods during the early and middle parts of the fishing season. The models were adjusted to account for differences in the vulnerability of sockeye of different sizes to the mesh sizes of gillnets used in the fishery. The models were then applied to records of harvest, annual variations in sizes of sockeye caught, mesh sizes in use and fishery openings to develop estimates of annual sockeye escapements from the commercial fishery during the early and middle portions of the fishing seasons. Adjustments were made to account for variations in exploitation rates due to landing restrictions during times of high abundance when cannery processing capacities were exceeded.

Because migration patterns of late-run sockeye were more erratic than those of early- and mid-season runs, the models could not be used to estimate escapements of late-run sockeye. However, approximate estimates of late-run escapements were developed from spawning ground records and surmises of likely rates of exploitation based on the early- and mid-season data.

The resulting estimates of total escapements were usually close to IPSFC estimates from direct observations for 1938 through 1944. For earlier years, estimates by Thompson (1945), Rounsefell (1949), and Killick and Clemens (1963) failed to account for dynamics of the fishery and effects of variations in fish size, and were generally substantially lower in years when sockeye runs were large and generally larger when runs were small. The present report suggests that escapements in the year of the largest recorded Fraser sockeye catch (about 6.7 million escapements in 1913) were substantially smaller than estimated by Ricker in 1987 (50 to 100 million).

TABLE OF CONTENTS

TABLE OF CONTENTS, CON'T

INTRODUCTION

BACKGROUND

The Fraser River, Canada's most abundant producer of salmon, was the cradle of Canada's commercial Pacific salmon fishery which began in the 1860s. Fraser-bound salmon also provided the resource base for development of the important Washington State fishery around Puget Sound, which began on a significant scale in the 1890s. Sockeye salmon (*Oncorhynchus nerka*) was the main target of the fisheries, but the other four species of Pacific salmon have been important as well.

The Fraser River gillnet fishery reached a stage of intensity in the 1890s almost as great as that of modern times (Rounsefell and Kelez, 1938). Tragically, the sockeye runs were devastated by a rock slide at Hells Gate in the mainstem of the River in 1913-14 (Thompson 1945). Few spawners reached the important upstream tributaries in 1913 and passage remained impeded for many years thereafter. Heavy fishing by fishermen of both countries kept the runs at low levels with the result that from a peak of over ten million sockeye annually around 1913, catches plummeted to average only about 1.4 million in the early 1920s (Figure 1). Since then, through cooperative international efforts by the International Pacific Salmon Fisheries Commission (IPSFC) during 1938-1985 and more recently by Canada, working with the United States through the Pacific Salmon Commission (PSC, established in 1985), the stocks have been rebuilt to a considerable extent.

As background for management to provide further increases in production, information on the magnitude of runs in earlier years and on the relationship between the extent of fishing and resultant production is of great importance. Key measurements in such assessments are the numbers of fish actually harvested and the numbers of salmon escaping the fishery, together comprising the total return of mature fish.

Complete statistics on the numbers of Fraser-bound sockeye harvested in the commercial fisheries in the estuary and lower mainstem of the Fraser are available from 1938 when the Salmon Commission began its scientific studies. Less complete statistics of numbers of sockeye caught are available for a few years prior to 1938. Annual records of commercial production (weights of canned product) of sockeye exist from the turn of the Century through 1937. For earlier years, data on total production of salmon (lumping all species) are available. As will be outlined later, these various sources of data can be used to provide reasonably reliable estimates of numbers of sockeye harvested for most years from the beginnings of the canning industry (the 1870s) to the present.

Reliable direct estimates of escapement have been made since 1938, and less comprehensive, less accurate data based on spawning ground observations are available for some earlier years (e.g., Babcock, 1902-1932; Motherwell, 1926-1945, Clemens and Clemens, 1933-1937 and Clemens, 1938). Due to lack of rigid quantitative methods (creating uncertainties regarding consistency between observers, lack of calibration, etc.), estimates for these early years are not considered to be reliable or even comparable between years. During 1938-1944, although comprehensive spawning ground enumerations were made, fish passage facilities at Hells Gate were not yet operating and losses of salmon occurred there. For this reason, spawning ground estimates in those years did not cover the entire escapement of salmon from the commercial fishery.[1]

---

[1] In addition to salmon reaching the spawning grounds, the escapement from the commercial fishery includes salmon later caught in Indian food fisheries throughout the system. Estimates of Indian catches are available from 1929 onward.

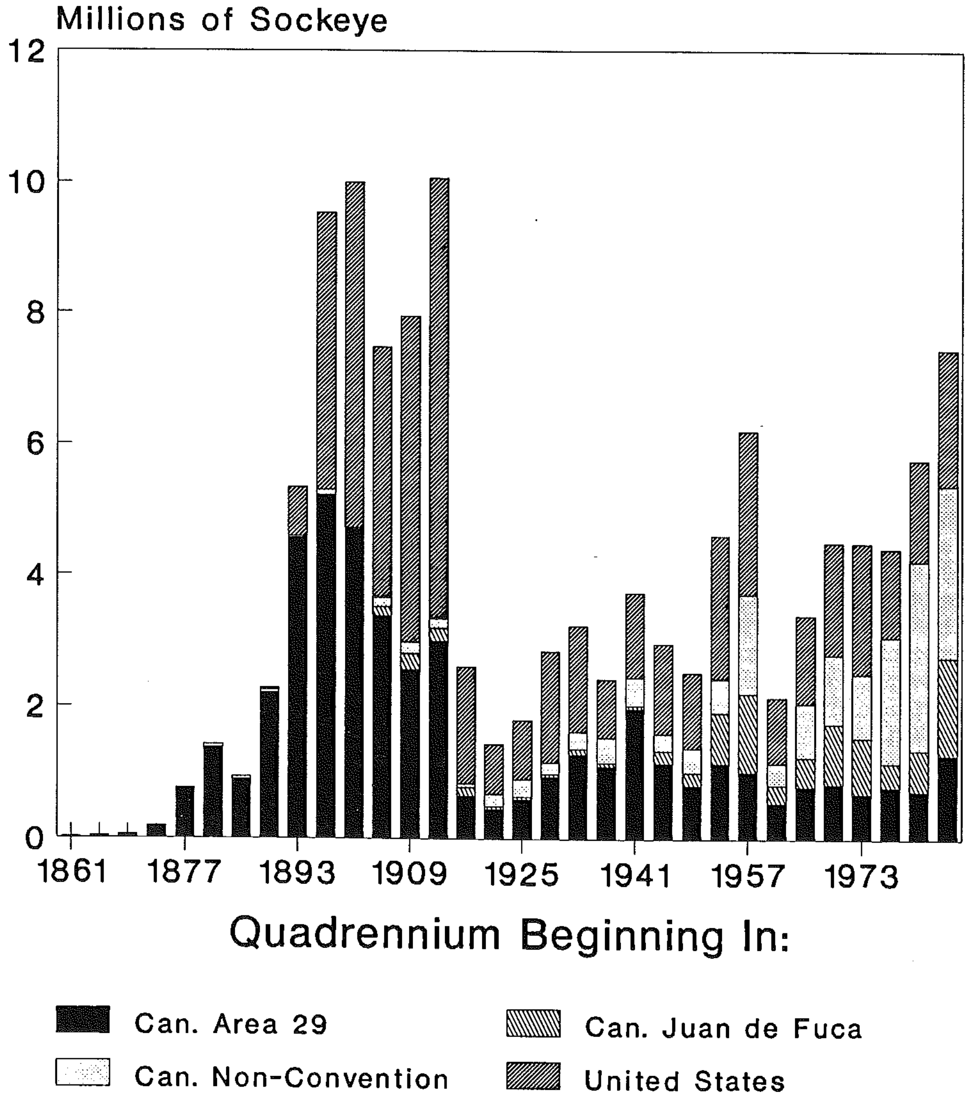

Figure 1A. Average annual sockeye catches in Puget Sound & Southern B.C., by quadrennium, 1861-1989.

Figure 1. Average annual sockeye catches in Puget Sound and Southern British Columbia, by quadrennium, 1861-1989.

APPROACH

The present paper develops estimates of escapement for the pre-1945 period derived from the reasonably complete and reliable data on commercial harvests in the Fraser River gillnet fishery in the estuary and lower mainstem of the Fraser River. The method involves applying estimates of Exploitation **R**ate to firm information on Catch to estimate the abundance of the total returning stock divided into its Catch and Escapement components:

$$R = C/(C+E)$$

Thus, $$E = C(1-R)/R$$

Several authors (Rounsefell, 1949; Killick and Clemens, 1963; and Ricker, 1950 and 1987) have attempted to review information on the fishery to develop estimates of escapements, but, as will be outlined later, the estimates failed to take into account a number of important sources of variability.

The analyses presented here involve an assessment of information collected since 1938 on exploitation of sockeye in the terminal Canadian gillnet fishery in the estuary and lower stretches of the Fraser River (related to information on escapements upstream). Such information is used to provide a basis for estimating total returns to the river from the early 1890s, when the fisheries became intense by modern standards, through 1944.

To provide perspective, the report first presents a brief review of the biology and history of the fisheries for Fraser River sockeye. It then reviews available data on the two key elements in the estimation of total return - the harvest in the Fraser River gillnet fishery and the rate of exploitation.

In respect of harvests, data on the size of fish are used to convert production data (mostly weights of salmon canned) into estimates of equivalent numbers of fish landed. The data are corrected to account for quantities of salmon shipped to the Fraser area for canning from areas outside the estuary and river, salmon caught in the Fraser gillnet fishery but processed elsewhere, and salmon caught by gillnets but discarded before processing or used for purposes other than canning.

In respect of rates of exploitation, the report analyzes data from experimental ("test") fisheries to develop indices of the abundance of sockeye escaping from the upper reaches of the commercial fishery related to variations in the length of weekly closures in the fishery. However, these estimates had to be adjusted to take account of the differences in the vulnerability of sockeye of different sizes to gillnets with different mesh sizes. Analyses of the data permitted the development of models relating exploitation rates to duration of weekly closed periods and fish/mesh size variations. Estimates derived from such models were then corrected for factors which limited the activities of fishermen (e.g., closures in addition to weekly closed times, and limits on landings imposed by canneries during periods when harvests exceeded cannery capacities).

Because of differences in migratory behaviour (late-running fish tend to spend variable lengths of time in the fishing area), the techniques developed could be applied only to estimates for portions of the runs migrating early in the season. More subjective analyses were applied to provide gross assessments of escapements for late season portions of the runs.

Finally, the estimates derived were compared with those developed by other authors and differences noted and discussed.

It is hoped that the information developed will provide further insight into the productivity of Fraser sockeye in the critically important years of the fishery when the stock was probably near its peak (1913 and earlier), when it was at its low ebb in the 1920s following the Hells Gate slide and in the post-slide era of intensive exploitation.

BIOLOGY OF FRASER RIVER SOCKEYE

Fraser sockeye, like most anadromous salmon, spend the beginning and end of their life in freshwater, and the intervening period in saltwater. From eggs laid in the autumn, fry emerge in the spring and spend a year or more as fingerlings feeding in a lake. They migrate as smolts to the northeastern Pacific Ocean to complete their growth, and return as adults to the river either through Juan de Fuca Strait or, usually in smaller proportions, through Johnstone Strait (Figure 2) to spawn in their home streams and die. Commercial fisheries of Canada and the United States harvest the maturing fish on their approach to, and, in Canada's case, in the lower reaches of, the Fraser River.

The sockeye returning to the Fraser River each year comprise a series of elements, each of which represents a self-perpetuating unit destined to spawn in a specific river or

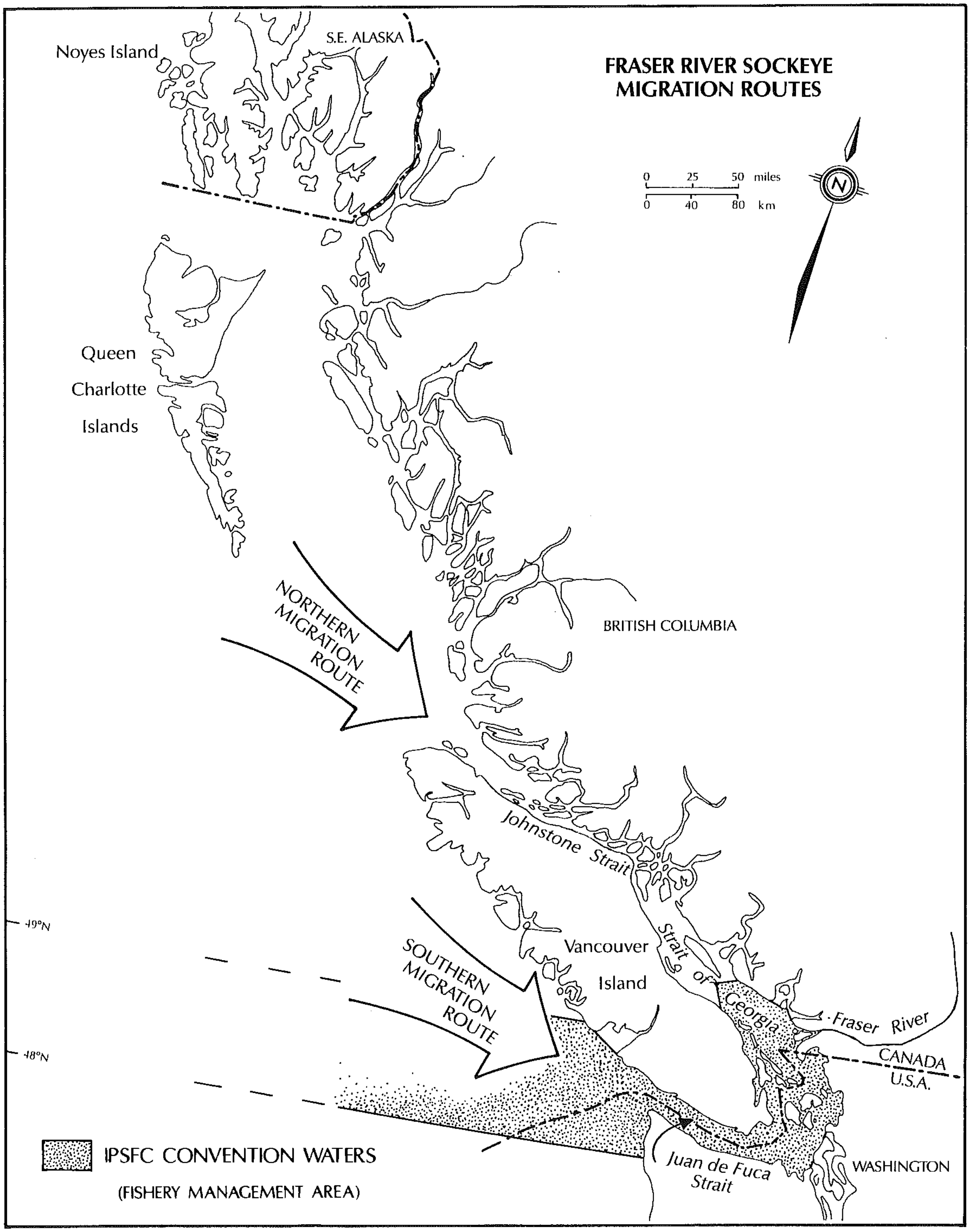

Figure 2. The waters of southern British Columbia and northern Washington State showing the principal routes of approach of sockeye to the Fraser River. Source: PSC 1988. Rept. Fraser River Panel. P.3

part of a river. Such "units" have variously been termed "stocks", "substocks", "races" or "runs". In the present report the aggregate of all sockeye units returning to the Fraser is called the Fraser River return. The various individual, self-perpetuating units within this total return are referred to as stocks.[2] Less technically, groups of salmon from one or more stocks migrating together are referred to as runs.

Fraser River sockeye migrate through coastal waters from late June to September. The duration of passage of individual Fraser sockeye stocks past any checkpoint along the migration path is typically about thirty days, although longer durations have been noted (Henry 1961). Normally, the abundance of a single stock as indicated by commercial fishing at one location will rise and fall in a bell-shaped pattern approximating a normal curve. Aggregate sockeye abundance at any point will be the sum of the abundances of the several stocks present at the time. Migration rate in saltwater is rapid, usually about 30 miles (48 km) per day (Henry, loc. cit.)

Fraser River sockeye largely cease feeding when they enter Juan de Fuca Strait (Gilbert 1913). Sockeye stomachs are empty in commercial catches made from this point riverward, and do not cause deterioration of the flesh as is the case when feeding fish are retained without being cleaned. Sockeye are therefore handled as caught ("in the round"), i.e., ungutted, until processing for canning begins.

Fraser River sockeye stocks differ in their behaviour on arriving at the Fraser mouth. Those peaking in July or early August (summer runs) enter the Fraser without apparent hesitation, while those which arrive thereafter (late runs) delay in the vicinity of the river mouth from a few days to several weeks, varying with stock and year, before ascending the river (Gilhousen 1960; Henry 1961; Verhoeven and Davidoff 1962). Late runs in the lower river may peak from mid-September to early October. Delaying sockeye are frequently subject to fishing both prior to and during their upstream migration. This difference in migration pattern has necessitated separate treatment of summer and late stocks in the present report.

Each of the many stocks comprising an annual Fraser River return tends to spawn at a specific time. Stocks are named after their spawning grounds or lake rearing areas (Figure 3); descriptions of the various stocks may be found in Thompson (1945), Killick (1955), Verhoeven and Davidoff (1962), and Killick and Clemens (1963). Differences in timing and migratory behaviour are concluded to be hereditary (Thompson 1945; Gilhousen 1960; Brannon 1967, 1987).

Most Fraser sockeye spend one year in freshwater (lake residence) and return to spawn from the ocean in their fourth year. However, there is some variability in this pattern with a minority spending more than one year in freshwater and some returning in their third, fifth or sixth year to spawn (Gilbert 1913 to 1925; Clutter and Whitesel 1956; Killick and Clemens 1963).

Sockeye age-groups are designated by the system of Gilbert and Rich (1927). A large numeral gives the age at maturity and a subscript numeral denotes the year of life at seaward migration. Thus, for example, 5_2 indicates a sockeye which left a lake in its second spring (one-year-in-lake) and returned to spawn at the end of its fifth year.

Since most sockeye return to spawn in their fourth year of life, each year's spawning perpetuates the stock returning four years later, creating, within each quadrennium, four

---

[2] Throughout IPSFC reports, the term "race" was used consistently in referring to self-perpetuating biological units. The word stock would now seem to be more appropriate in light of modern usage.

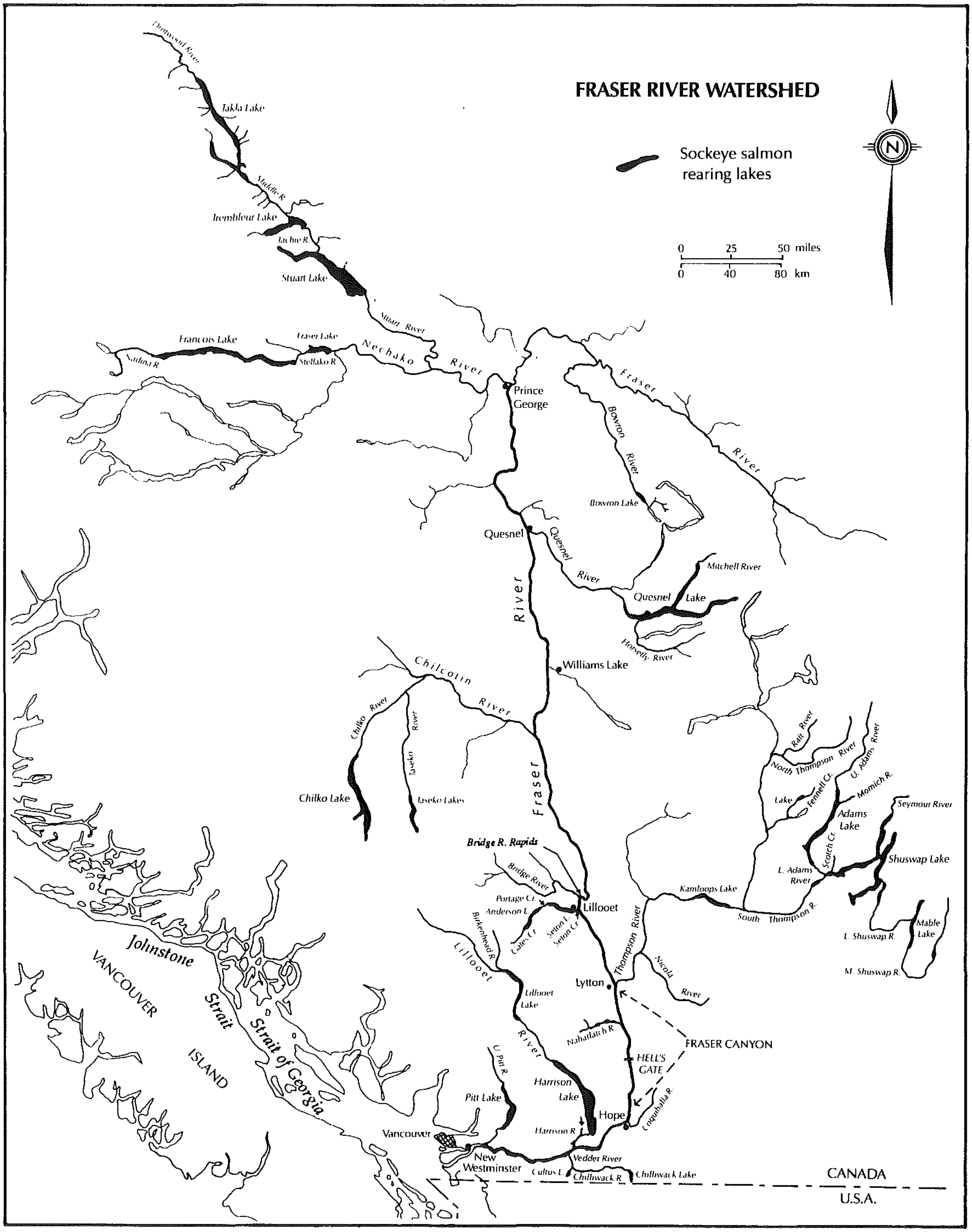

Figure 3. Major sockeye rearing lakes and spawning areas in the Fraser River watershed.

more or less separate "cycles". For as yet unexplained reasons, most stocks are much more abundant in one cycle than in the other three. This phenomenon, termed "quadrennial dominance", was very evident in the early stages of the commercial fishery; the abundance of the runs in dominant cycle years 1893-1897-1901 etc., was greatly in excess of that in the intervening years. Following the drastic decline of the runs after 1913, cyclic dominance became erratic and the dominant cycle-year in some important stocks shifted (Thompson 1945, Royal 1953). With the recent strong increases in Fraser sockeye abundance, the original dominant cycle has shown evidence of restoration (PSC 1990).

The average size of Fraser sockeye returning in a given year varies from about 5 lb (2.3 kg)[3] to 7 lb (3.2 kg), reflecting, in part, the varying proportions of different age classes making up the returns (Killick and Clemens 1963). "Jacks" (one year in ocean) are distinctly smaller (average weight about 2.8 lb or 1.3 kg) than other age-groups ("adults"). Three-ocean-year sockeye (mainly five-year-olds) have annual average weights from around 6-8 lb (2.7 to over 3.6 kg). Four-year-old sockeye (with two-ocean-years) are the most abundant component, especially in dominant cycles. Age 4_2 sockeye in Each of the resulting four cycle-years has a unique long-term average weight (Killick and Clemens loc. cit.). As illustrated below, the differences have been maintained despite large changes in abundance.

	Average Weight (lb)	
Cycle Years	Mean	Range
1915-1959	5.9	5.1 to 6.2
1916-1960	6.1	5.2 to 6.5
1917-1957	5.6	5.0 to 5.9
1918-1958	6.4	5.9 to 6.7

Annual variations in the size of sockeye have important effects on the rates of exploitation by the gillnet fishery since different sized meshes vary in the efficiency with which they can entangle and "gill" fishes of different sizes; small salmon tend to slip through large meshes and the girth of larger fish is sometimes so large that the fish back out of the nets without being caught.

HISTORY OF THE FRASER RIVER SOCKEYE FISHERY

As background for the technical analyses, the following paragraphs briefly summarize information on the historic development of the fisheries for Fraser sockeye. Sockeye were the staple food of Indian tribes settled throughout the river basin for thousands of years prior to the coming of the Europeans. From the early years of the 19th Century, the sockeye also became an important staple for the fur traders who established British Columbia's first permanent European settlements. The Fraser River commercial fishery was developed by the Hudson's Bay Company which, around 1829, began salting salmon (including sockeye) at Fort Langley in the lower reaches of the Fraser (Figure 4) for export. Fish used in this operation, which continued into the 1870s, were obtained mainly from Indian dip-net fisheries operating in the Fraser Canyon until drift gillnet fishing began on the Fraser River in the 1860s.[4]

---

3 Throughout this paper, units of measurement used are those of the British system because most of the original information was collected using that system.

4 See Shepard and Argue (1989) for information on British Columbia commercial harvests of salmon in early years (1820-1877).

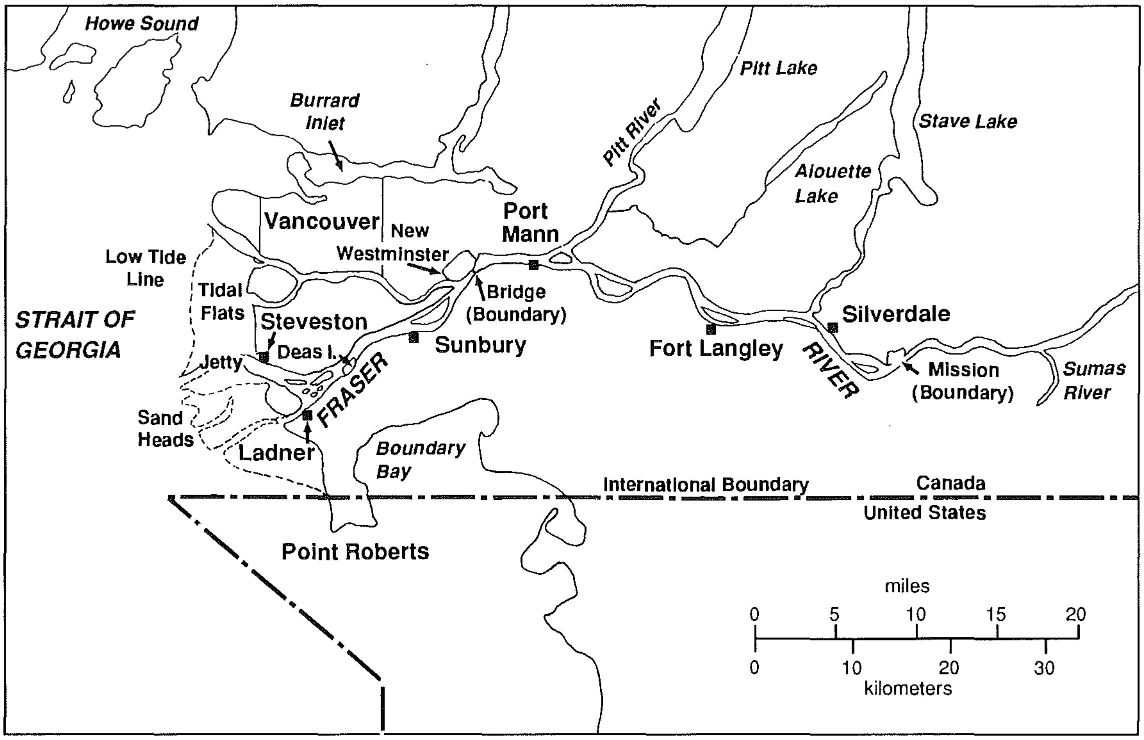

Figure 4. The Fraser River gillnet area and surrounding waters.

After 1858, when the Hudson's Bay Company lost its exclusive trading rights in the region, fish processors in the vicinity of New Westminster began salting salmon for export. Experimental salmon canning in tin-plate cans began on the lower Fraser River shortly after the successful development of the industry on the Columbia and Sacramento Rivers in the 1860s. Canneries began operations in the early 1870s in the vicinity of New Westminster (Lyons 1969). As shown in Figure 1, catches increased rapidly thereafter, reaching an average annual total of over two million by the end of the 1880s.

Whereas in the early years of the fisheries, several species (mainly chinook and coho), were included in the pack, by the late 1870s, sockeye accounted for the bulk of the fish processed (Lyons, 1969).

Appendix 1 provides a brief historical account of the development of gillnetting and gillnetting vessels on the Fraser. With the advent of commercial canning at New Westminster around 1870, the gillnet fishery spread rapidly up and downstream, so that at least by 1885, gillnets were being fished at the "Sandheads" (Figure 4), the seaward edge (low tide mark) of the Fraser River tidal flats (Rathbun 1900). Rathbun attributed the movement of fishing effort toward the river mouth to its first-in-line location, greater fishing space and the prevalence of wind to return gillnet boats to the start of their next drift. As a consequence, most new canneries in the late 1880s and after were built around Ladner and Steveston, where the industry soon became centred. Appendix 1 contains a brief account of the development of regulatory limits on the Fraser River gillnet area.

Another factor in the location of gillnet fishing was the use of small steam-powered vessels to transport salmon from the more distant fishing areas to the canneries, beginning in the 1870s. These were also used to tow the fishing skiffs and canoes to fishing areas along the river, mainly in an upstream direction (Babcock 1907). Although the upper fishing boundary was legally at the Sumas River mouth until about 1900, the greater prevalence of shifting sandbars and snags in upriver areas would have drastically limited gillnet drifting above the vicinity of Fort Langley. Sockeye were occasionally shipped from the native Indian fishery in the Fraser Canyon to the canneries (e.g., *Inland Sentinel*, August 25, 1881), but this was prohibited by law no later than 1889 (Lyons 1969).

With the introduction of more seaworthy gillnet boats in the 1890s, nets were fished to the outer extent of the silt-laden water discharged by the Fraser River (Rathbun 1900). In the clear seawater beyond the river effluent, sockeye were not caught efficiently due to daytime net visibility, phosphorescent plankton at night, and probably sockeye migration depth. Areas fished since the 1890s have changed little except that synthetic nets have allowed more effective night-time fishing in the clear water off the Fraser River mouth.

From the beginning of the driftnet fishery until the early 1950s, nets were made of linen twine and were of a more or less standard design.[5] In the early 1950s, linen was replaced with synthetic twine which, as will be discussed later, had quite different catching characteristics.

Although the gillnet fishery at the mouth of the Fraser River is the focus of the present study, it is important to take into account several other fisheries that take substantial numbers of Fraser-bound sockeye. Indeed, in most years, these other fisheries take far more sockeye than does the Fraser River gillnet fishery. The first of these fisheries to develop was the United States fishery along the San Juan Islands and off Point Roberts. Originally utilizing mainly traps, the United States fishery expanded rapidly in the 1890s and by the turn of the Century took more sockeye than did the Fraser gillnet fishery (Figure 1). When traps were eliminated in 1935, other types of gear, mainly purse seines and reef nets (and some drift nets) took over. Early in the 20th Century, Canadian fisheries began expanding into areas more remote from the Fraser mainstem, namely Juan de Fuca Strait and Johnstone Strait. Troll fisheries operating along the west coast of Vancouver Island added to the dispersal of the sockeye fishery. At present (e.g., 1987-1990) over 80% of the total commercial harvest of Fraser sockeye is taken in fisheries other the Fraser River gillnet fishery.

With the foregoing as background, the next two sections develop approaches to the estimation of harvests and exploitation rates in the Fraser River gillnet fisheries.

ESTIMATES OF HARVESTS

APPROACH

To estimate escapements from catch data, the first task is to derive estimates of harvests in the Fraser River gillnet fishery. As outlined the foregoing section, because late-season stocks tend to delay for varying periods in the approaches to the river, there are often in-season differences in vulnerability of Fraser sockeye to fishing. Also, particularly in the early years of the Century, there have been some periods when exploitation rates in the fishery have varied due to factors other than changes in fleet capacity (e.g., when canneries placed limits on the numbers of fish they bought at times when catches exceeded cannery capabilities). To account for such sources of variability, it is desirable, to the extent possible, to obtain catch data by day or by week within the season rather than just on an annual basis.

---

5 From the 1880s onward virtually all nets were machine knitted.

In the following paragraphs, available data on harvests are used to develop annual estimates of the numbers of sockeye harvested in the Fraser River gillnet fishery from 1893 through 1944, the span of years selected to apply exploitation rate data to estimate escapement levels.

ESTIMATED ANNUAL GILLNET HARVESTS

Direct Estimates of Numbers of Sockeye Caught

Data on the actual numbers of sockeye taken in the Fraser River gillnet fishery for 1938-1944 come from the extensive compilations of IPSFC. Babcock (1907 and 1914) listed numbers of sockeye caught during the 1906 and 1913 seasons. The *British Columbia Yearbook* (Gosnell 1903) presented sockeye catches for 1902 through the end of August (there was little fishing afterward). Data from these sources were used to provide the estimates of total harvest in Column VIII of Table 1 for the appropriate years.

Estimates Derived from Canned Pack Data

During the period under study (1892-1944), by far the greatest portion of the sockeye landed from the Fraser River gillnet fishery were canned in processing plants located on the banks of the river. For years other than those discussed in the preceding paragraph, the starting point of the analysis was to examine data on the quantities of salmon packed and from those data to estimate the numbers of sockeye that had been required to fill the cans.

Data on the annual quantities of salmon canned are available in annual reports of the Canadian Department of Fisheries (CDF).[6] Unfortunately, prior to 1901, the species composition of the pack was not recorded. However, Rounsefell and Kelez (1938), using both published and unpublished material[7] developed estimates of the quantities of sockeye that were packed in the Fraser area (including small quantities canned in Victoria, Georgia Strait and Johnstone Strait), presumably involving subtraction of quantities of other species from the total packs. For the period 1893-1900, Rounsefell and Kelez data are accepted as the best estimates of basic canned sockeye production and listed in data Column I of Table 1.

For 1901-1944, canned sockeye production data, as extracted from CDF Annual Reports, are listed in Column I of the table. Column II of the table provides estimates of the number of sockeye required to produce a 48 lb case of finished product. For most of the early years of the fishery, data on fish-per-case came mainly from Rounsefell and Kelez (1938). Data for a few other years came from newspaper accounts. Motherwell (1938) provided sockeye per case data for 1937. From 1938 onward, IPSFC programs provided daily figures for catch in the river. Sources of the data given in Column II are indicated in footnotes to the table.

Column III of the table applies the sockeye per case data to the information on the numbers of cases packed to provide estimates of the total numbers of sockeye landed to produce the pack.

---

6 The Canadian government body responsible for fisheries has had several different names during its existence, e.g., Department of Marine and Fisheries; Fisheries Branch, Department of the Naval Service. However, (Canada) Department of Fisheries has been the most common designation and the abbreviation CDF will be used in this report.

7 See footnote on p. 758 of their paper.

Table 1. Estimation of annual commercial catches of sockeye from the Fraser River gillnet fishery, 1889 - 1944.

YEAR	I Reported Fraser R. Pack [1]	II Sockeye per Case [2]	III Estim. No. Sockeye Packed [3]	IV Can. Trap Catch [4]	V Can. P.S. Catch [5]	VI Non-pack Uses; Export; Wastage [6]	VII Import From U.S. Traps [7]	VIII Estim. Total Can. Gillnet Catch [8]	IX Rounsefell & Kelez G.N. Catch Estimate	X Estim. Late Run Component [9]
	(cases)		(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)
1889	303,875	12.41 *	3,770			300	70	4,000	3,651	
1890	225,000	10.77 *	2,420			100	20	2,500	2,263	
1891	131,000	12.87	1,690			150	20	1,820	1,297	
1892	59,000	12.75	750			100		850	543	
1893	455,000	12.41 *	5,650			1,500	50	7,100	5,397	
1894	360,000	10.67 *	3,850			50	100	3,800	3,737	
1895	360,000	11.76	4,230			250	220	4,260	4,034	
1896	325,000	10.80	3,510			50	300	3,260	3,121	
1897	850,000	12.41 *	10,550			2,000	500	12,050	9,959	
1898	216,000	10.77 *	2,330				50	2,280	2,294	
1899	486,409	11.38 *	5,540				300	5,240	4,514	
1900	172,617	10.90	1,880				50	1,830	1,874	
1901	974,911	13.4	13,100			1,500	1,500	13,100	11,793	1,270
1902	295,679	11.5	3,400				350	3,050	3,143	
1903	204,848	11.43 *	2,340				100	2,240	2,339	
1904	73,175	12.20	895	100				795	742	
1905	838,813	13.0	10,900	350		1,500		12,050	10,144	1,500
1906	185,440	11.14	2,070	50				2,020	1,984	
1907	65,061	10.62	690	30				660	584	
1908	79,211	10.99	870	135				735	707	
1909	585,935	12.39 *	7,260	560		100	100	6,700	4,869	1,250
1910	151,595	11.15	1,690	200				1,490	1,459	100
1911	64,470	11.33 *	730	45				685	659	
1912	124,967	10.86	1,360	165				1,195	1,186	
1913	739,601	13.5	9,980	700		370	285	9,365	8,761	900

* Apparently an average weight for the cycle or a slight modification thereof.

- Footnotes follow end of table -

Table 1 (Continued).

YEAR	I Reported Fraser R. Pack [1]	II Sockeye per Case [2]	III Estim. No. Sockeye Packed [3]	IV Can. Trap Catch [4]	V Can. P.S. Catch [5]	VI Non-pack Uses; Export; Wastage [6]	VII Import From U.S. Traps [7]	VIII Estim. Total Can. Gillnet Catch [8]	IX Rounsefell & Kelez G.N. Catch Estimate	X Estim. Late Run Component [9]
	(cases)		(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)
1914	201,498	10.61	2,140	145				1,995	2,036	95
1915	95,407	11.41 *	1,090	25				1,065	1,051	95
1916	35,070	10.75	375	50				325	311	(few)
1917	154,415	12.16	1,880	300				1,580	1,042	200
1918	21,598	11.22	240	30				210	197	20
1919	38,854	12.10	470	75				395	368	40
1920	49,184	10.82	530	40				490	486	10
1921	41,731	11.65	485	45				440	434	60
1922	54,829	10.58	580	35				545	514	95
1923	34,574	10.45	360	25				335	300	55
1924	39,732	11.13	440	45				395	372	10
1925	36,954	12.28	455	50				405	397	25
1926	86,765	10.52	915	25				890	891	500
1927	65,154	10.96	715	50				665	648	370
1928	30,128	10.33	310	30				280	267	35
1929	60,823	11.92	725	45				680	605	50
1930	103,662	10.06	1,045	60	30			955	965	700
1931	40,947	11.19	460	30	5			425	451	200
1932	69,792	10.51	735	50				685	657	45
1933	54,146	13.41	725	120	25			580	546	25
1934	139,276 **	10.27	1,430	70	375	225	150	1,060	1,231	600
1935	62,822	N/A	825	75	155	45		640		100
1936	184,854	N/A	1,955	45		170		2,080		80
1937	72,735 **	13.5	980	100	10			870		25

* Apparently an average weight for the cycle or a slight modification thereof.

** Reported packs for 1934 and 1937 vary; see Motherwell (1935 and 1938).

- Footnotes follow end of table -

Table 1 (Concluded).

YEAR	I Reported Fraser R. Pack [1]	II Sockeye per Case [2]	III Estim. No. Sockeye Packed [3]	IV Can. Trap Catch [4]	V Can. P.S. Catch [5]	VI Non-pack Uses; Export; Wastage [6]	VII Import From U.S. Traps [7]	VIII Estim. Total Can. Gillnet Catch [8]	IX Rounsefell & Kelez G.N. Catch Estimate	X Estim. Late Run Component [9]
	(cases)		(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)	(1,000s)
1938	186,794	N/A	1,780	40	230			1,510		950
1939	47,539	N/A	570	55	90			425		175
1940	93,361	N/A	1,035	30				1,005		92
1941	159,279	N/A	2,115	130	5			1,980		42
1942	426,979	N/A	5,050	100	2,055			2,895		2,000
1943	30,277	N/A	350	20				330		110
1944	88,150	N/A	1,005	30				975		30

FOOTNOTES:

1 Data from Rounsefell and Kelez (1938), except 1934 and 1937 from CDF annual reports (Motherwell 1935 and 1938).

2 Calculated from total pack and total catch of sockeye (total fishery) as reported by Rounsefell and Kelez (ibid.), except:
1895: Daily Columbian, Oct. 28.
1901: World; Aug. 6, 27: Province, Sept. 26.
1902: Daily Columbian, Aug. 21.
1905: Province, Aug. 5; Daily Columbian, Aug. 18.
1913: Babcock (1914).
1937: Motherwell (1938).

3 Calculated from columns I and II, except 1935 - 1937 from Sloan (1940); 1938 - 1944 from IPSFC records.

4 Calculated from reported pack, except 1904 from Daily Province, July 4, 19, 22, 23, 30; Aug. 3, 8; Daily Columbian, July 12; Aug. 27.

5 1930 to 1939 from CDF Annual Reports; 1941 and 1942 from IPSFC records.

6 1889: No direct data; estimated on basis of large run, reported non-pack uses, and in relation to better estimates for later runs. Non-canning uses for all species reported as 2,620,700 lbs.
1890: Daily Columbian: Aug. 6 and 13. Non-canning uses of salmon reported as 1,898,100 lbs.
1891: Daily Columbian; Aug. 29. Non-canning uses of salmon reported as 2,117,153 lbs.
1892: Daily Columbian; Aug. 1 and 10. Non-canning uses of salmon reported as 2,893,309 lbs.
1893: Daily Columbian; July 5, 20; Aug. 1, 14, 17, 23, 24, 25. Non-canning uses of salmon reported as 4,197,700 lbs.
1894: Daily Columbian; July 30; Aug. 7, 13, 14; Oct. 25. Non-canning uses of salmon reported as 2,190,500 lbs.
1895: Daily Columbian; July 11,15; Aug. 14, 21, 23, 27. Non-canning uses of salmon reported as 1,871,992 lbs.
1896: Daily Columbian; June 1; July 20; Aug. 8, 12, 19. Weekly World; Aug. 18. Non-canning uses of salmon reported as 1,249,695 lbs.

Footnotes continued on next page.

6 1897: Daily World; July 26; Aug. 4, 5, 10. Daily Columbian; July 27, 28, 30, 31; Aug. 2, 3, 5, 9, 13. Non-canning uses reported as 2,777,669 lbs. The shipment of fresh or frozen sockeye had apparently become negligible by 1898; such disposals were not mentioned in the press after 1897.

1901: Daily World; Aug. 2, 9. Daily Province; July 29; Aug. 2, 3, 12, 17. Salmon salted in barrels increased by 2,981 barrels over 1900, presumably due to the 1901 sockeye surplus (Sword 1903).

1905: Daily World; Aug. 8. Daily Columbian; Aug. 3, 4, 7, 12, 14, 16; Sept. 26. Daily Province; Aug. 8, 12; Sept. 25 (late run sockeye for 75,000 cases exported to U.S. canneries).

1909: No sockeye surplus (Daily Columbian; Aug. 6, 7, 9, 11, 14. Babcock 1910). No fresh shipments (Daily Columbian, Aug.23).

1913: Babcock, 1914. Daily Province; Aug. 7. World; Aug. 7. British Columbian; Aug. 7, 8, 11.

1934: Exported to U.S. canneries; Motherwell 1935.

1935: Pacific Fisherman, Yearbook (1936).

1936: Clemens and Clemens (1937).

7 Includes sockeye from Canadian traps in Boundary Bay, operated from 1894 (Rathbun, 1900) to 1897 (last year trap licences listed (McNab 1899).

1889 and 1890: Based on estimate for 1891 and on number of U.S. traps. All trap sockeye to Fraser canneries (Rathbun 1900).

1891: Difference between reported pack and catch of U.S. traps in Rathbun (1900).

1892: Small run; assumed no surplus for Fraser canneries.

1893: Some sockeye exported to Fraser canneries, despite great surplus on Fraser (Daily Columbian; Aug. 14). However, the Daily Columbian (Sept. 25, 1894), implied that this was a small number.

1894: No direct data; estimate based on 1895 and 1896.

1895: Daily Columbian; July 25, Oct. 28. Rathbun (1900).

1896: Daily Columbian: Aug. 10, 19; Sept. 1.

1897: Daily Columbian; July 13, 16, 22, 23, 26, 27; Aug. 21.

1898: Small run; no reports of trap sockeye to Fraser canneries, but some Fraser canneries had traps at Point Roberts (Daily Columbian, June 13, 1899).

1899: Daily Columbian; June 13; July 27; Aug. 4, 8, 9; Sept. 15.

1900: Daily World; July 9, 18. Daily Columbian, July 9.

1901: Daily Columbian; July 30, 31; Aug. 3, 21. Daily Province; July 15; Aug. 2, 3, 8. World, Aug. 2, 9.

1902: Daily Province: Aug. 21; Sept. 2.

1903: Daily Columbian; July 29. Daily Province; Aug. 6.

1904: Daily Columbian, Aug. 27, lists components of pack; no mention of U.S. trap fish.

8 Calculated by adding columns III and VI, and subtracting columns IV, V and VII, except for 1902 (Gosnell 1903), for 1906 and 1913 (Babcock 1907 and 1914), 1936 - 1937 from Sloan (1940), and 1938 - 1944 from IPSFC records.

Footnotes continued on next page.

9 1901: Calculated from difference between end August pack (Daily Province, Aug. 28) and total season pack (Sword 1903).
1905: Calculated from difference between summer pack (Daily Columbian, Sept. 11) and total season pack (Babcock 1911).
1909: Calculated from Babcock (1910) reported pack of late run sockeye.
1910: Calculated from the difference between summer pack (Daily Columbian, Aug. 26) and total season pack (Babcock 1911).
1913: Babcock 1914.
1914: Calculated from daily landings reported from two canneries, by proportion to total season catch.
1915: Reported catches small but heavy effort for pink salmon; British Columbian, Sept. 10, 15. Total catch by proportion from reported daily catches at one cannery.
1917: High salmon prices, heavy effort; British Columbian, Sept. 10, 22. Estimated by proportion from two canneries reporting daily landings.
1918, 1919, 1920: Estimated by proportion from two canneries with records of daily landings or packs.
1921: Difference between sockeye pack of summer sockeye (Daily Province, Aug. 30) and total season pack (Motherwell 1922).
1922 through 1926: Clemens and Clemens (1927).
1927: Babcock 1932. Estimate 15,000 cases late run sockeye from pattern of cannery daily landings.
1928 and 1929: Howe (1929, 1930).
1930: Babcock 1931. Also, cannery records (daily landings) for 56% of total catch.
1931: Babcock 1932. Also, cannery records of daily landings for 37% of total season catch.
1932: Pearson 1933. Also, cannery records of daily landings for 48% of total season catch.
1933: Pearson 1934. Also, cannery records of daily landings for 53% of total season catch.
1934: Records of daily landings from canneries representing 65% of total season catch. Motherwell 1935.
1935: Pearson 1936. Also, cannery records of daily lantings at four canneries comprising 70% of total season catch.
1936: Pearson 1937.
1937: Records of daily landings at three canneries comprising 36% of the total season catch.
1938 through 1944: Records of IPSFC.

Adjustments for Sockeye Processed by Means Other Than Canning; for Transfers and for Wastage

Newspaper reports of the times reveal that, in some years, small quantities of sockeye were processed by means other than canning. In some years also, there was wastage of fish when cannery capacities were exceeded. On occasion, some sockeye caught in the Fraser were exported before processing. Reviews of newspaper articles of the times provide some documentation of quantities of sockeye involved under these various circumstances. Estimates based on these articles and additional sources, noted in the footnotes in Table 1, are listed in Column IV.

It is extremely difficult to assess the quantities of salmon that were caught but not utilized by processing plants. Such wastage would have occurred mainly in the big years prior to 1914. There are no accurate records of quantities of fish discarded in these years. Newspapers of the times provide some accounts of wastage, provided mainly through interviews with fisheries officials. It is difficult to assess the accuracy of such estimates, since it would be expected that there would be a desire to downplay these occurrences. Some authors considered that the quantities could have been very large. Ricker (1987) noted that: ... *some estimated that the number of sockeye caught and wasted in a big year was as great as the number caught.*

Other authors, however, felt that reports of wastage could have been exaggerated. Thus, Babcock (1914) discussed the wastage problem during the peak of the fishing season for the huge 1913 return, concluding that: *The report that millions of fish were thrown away is absurd ... I do not believe that 300,000 were wasted during the entire season.*

Use of sockeye for purposes other than canning varied. In years of scarcity, cannery prices tended to be higher and few fish were processed by means other than canning. In years of abundance, however, prices were low and quantities of sockeye were shipped fresh on ice to eastern markets or pickled in barrels. In general, however, such quantities probably formed only small proportions of the production.

Considering the lack of firm documentation, data on wastage and use of sockeye for purposes other than canning must be considered as being subject to major uncertainty.

Non-Gillnet Catches

Quantities of salmon packed in the Fraser Area included some salmon caught by gear other than gillnets. Although Canadian purse seines had fished in northern British Columbia areas at least as early as 1915 (Cunningham 1917), such vessels did not make their first significant catch of Fraser sockeye (about 3% of the Canadian catch) in the southern Strait of Georgia until 1930 (Rounsefell and Kelez 1938). Thereafter purse-seine catches in the Fraser River District varied from none to over 40% (1942) of the sockeye catch in the area. These catches (listed in Column V of Table 1) were assumed to have been canned in Fraser canneries.

In earlier years, some purse-seine catches of Fraser-bound sockeye had been made in Johnstone Strait (Babcock 1916). Most of the catches were either recorded as being canned locally in the Johnstone Strait area or otherwise separated in the CDF statistics from sockeye caught in the Fraser River (Motherwell 1931; years 1925 and after), but some also may have been canned on the Fraser without having been separated from Fraser caught fish in the statistics, possibly introducing some errors into the Fraser River figures. In the 1890s, there were some Canadian traps located in Boundary Bay (Figure 4), and from 1904 onward, Canadian traps operated near Sooke (Figure 2). It is believed that sockeye caught in the latter two localities were all processed in Fraser River canneries or in canneries near Victoria on Vancouver Island. Estimates of the Georgia Strait seine catch and of the Sooke and Boundary Bay trap catches are listed in Columns IV and V of Table 1. These quantities were subtracted from the total Fraser River cannery production in developing estimates of the gillnet catch on its own.

In several years, some sockeye packed on the Fraser came from fish caught in the United States fishery to the south. Estimates of such quantities are listed in Column VII of Table 1.

Consolidated Estimates of Fraser Gillnet Catches

From the foregoing array of data, the estimated harvest of sockeye by the Fraser gillnet fishery (Column VIII) was calculated as:

The number of sockeye estimated to have been canned (Column III)

Less the canned sockeye taken in traps ((Column V) and by purse seines (Column VI) and transfers of salmon to the Fraser from the United States (Column VII)

Plus sockeye transferred from the Fraser to other areas for processing and quantities of sockeye discarded during times of cannery overloads (Column IV).

The aggregate annual totals are listed in Column VIII of Table 1.

Comparison with Rounsefell and Kelez Estimates

Rounsefell and Kelez (loc. cit.) provided estimates of numbers of sockeye caught in the Fraser gillnet fishery (their Table 27). These are reproduced in Column IX of Table 1. While clearly following similar trends, there were some significant differences between data from the latter authors and data developed in the present paper.[8] Estimates from the present paper exceed those of the other authors in 37 of the 46 years for which paired data were available. As indicated in Table 1, differences tended to be greatest in some of the old "big years" on the Fraser, particularly 1893, 1897 and 1909. In the former two years, the higher estimates in the present paper were associated, in part, with add-on estimates to account for wastage. Although a critical assessment is not possible, it is believed that the estimates in the present paper probably represent a more complete reflection of total removals in the fishery than do the Rounsefell and Kelez data.

WITHIN-SEASON HARVEST DATA

As will be discussed later, in order to use data on rates of exploitation to develop estimates of escapements, it was necessary to assess within-season variations in catch. This was particularly necessary to assess the effects of fishing in periods when the canneries were overloaded and when the canneries placed limits on landings of individual boats ("boat limits"). Within-season data were also required to distinguish parts of the runs that moved through the fishery rapidly (summer runs) and those that tended to delay in the estuary (late runs).

---

[8] The ratios between the two sets of data for the 46 years for which data from both sets were available were significantly different from equality ($p<0.01$; logarithms of ratios tested).

As outlined above, for 1938-1944, IPSFC provides estimates of daily catches in the Fraser gillnet fishery. Other reports listed earlier also contain weekly breakdowns. These include Babcock (1907 and 1914) for the 1906 and 1913 seasons and the *British Columbia Yearbook* (Gosnell 1903) for part of the 1902 season. Data on weekly canned sockeye packs have been published for the years 1922 through 1926 (Clemens and Clemens 1927) and for 1927, 1928, 1929 and 1936 (B.C. Provincial Fisheries Reports 1928, 1929, 1930, 1937). These figures contained trap-caught sockeye in some years, but the errors were small because the trap catch was a small proportion of the gillnet catch (Table 1).

There are a number of unpublished records of catches landed by individual canneries in PSC files. As shown in Table 2, between 1892 and 1937, data on daily landings[9] were available from at least one and from as many as six canneries in any one year. On an annual basis these canneries accounted for between 5 and 73% of the annual Fraser River gillnet catch. Each cannery tended to have a relatively stable portion of the fleet delivering to it and it is believed that most canneries tended to fish their fleets throughout the season (i.e., not concentrating efforts at a particular time). For this reason, it is considered that records of individual canneries provide a reasonable reflection of seasonal patterns of harvest for the fleet as a whole.

Table 2. Numbers of Fraser River canneries operating each year during 1893 - 1937, numbers of such canneries for which data on daily landings or packs of sockeye are available and percent of total catch provided by the canneries listed.

	No. of Canneries		Proportion		No. of Canneries		Proportion
Year	Total Operated *	With Daily Data	of Total Catch (%)	Year	Total Operated*	With Daily Data	of Total Catch (%)
1892	22	3	19	1915	22	3	14
1893	26	3	13	1916	21	2	12
1894	28	3	12	1917	29	2	13
1895	33	3	13	1918	18	3	13
1896	35	3	13	1919	14	3	20
1897	43	3	8	1920	11	2	12
1898	49	4	12	1921	13	2	9
1899	41	4	10	1922	10	2	10
1900	45	4	10	1923	11	2	8
1901	49	4	8	1924	9	1	5
1902	42	4	12	1925	10	1	5
1903	36	3	13	1926	10	1	4
1904	25	3	24	1927	10	2	8
1905	38	5	11	1928	8	3	32
1906	23	2	10	1929	9	3	36
1907	18	2	19	1930	8	5	56
1908	10	2	27	1931	7	5	45
1909	34	3	8	1932	8	3	48
1910	21	1	4	1933	10	3	53
1911	15	1	5	1934	11	4	67
1912	15	2	9	1935	10	4	70
1913	35	6	12	1936	11	4	73
1914	20	4	9	1937	10	3	36

* Data for 1892-1934 from Rounsefell and Kelez (1938); for 1935-1937 from C.D.F.

9 Landings on a given day included fish caught the day before and fish caught on the day of record. Since most gillnetting occurred at night, it was assumed that fish landed on a given day had been caught the calendar day before.

Within-season catch data listed above are utilized later in the report to adjust estimates derived from exploitation rate data.

In the foregoing section, estimates were developed of total harvests of sockeye in the Fraser River gillnet fishery from 1889-1944. The next Section examines information on the relation between fishing and the numbers of salmon escaping from the fishery upstream as a basis for estimating the abundance of upstream escapement from the harvest data.

PATTERNS OF EXPLOITATION IN THE GILLNET FISHERY

APPROACH

The following section examines data on rates of exploitation in the Fraser River gillnet fishery as background for development of models to apply exploitation rate data to the harvest information outlined in the previous section in order to estimate the abundance of escapements.

Knowledge of the effect of varying closed times on the rates of exploitation has been an important element in the management of the Fraser fisheries by IPSFC over the years and provides a useful basis for estimates of annual exploitation rates developed in the present study.

In the present section, consideration is first given to deriving approximate estimates of the fishing power of a single gillnet, based on test fishing experiments conducted by IPSFC using chartered commercial vessels fishing during periods when the commercial fishery was closed. Attention is then turned to an assessment of the fishing power of the fleet as a whole. Finally, the patterns of escapements from the commercial fishing area, deduced from the results of the test fishing, are analyzed in order to estimate the likely rates of exploitation in the fishery resulting from variations in the amount of fishing time permitted each week.

However, such relative estimates had to be adjusted because sockeye of different sizes are not equally vulnerable to capture by gillnets of different mesh sizes. Analyses to permit such adjustments are described in later sections of the report.

The combined analyses permitted the development of models relating exploitation rates to duration of closed periods and average size of sockeye which could be applied to data on annual catches of sockeye harvested to develop estimates of total escapements of sockeye from the fishery.

The models developed were felt to be appropriate for most early-run sockeye bound for the Fraser, stocks which migrate quickly and directly through the Fraser River gillnet area. The same procedures were not felt to be appropriate for late season runs because the latter do not move through the Fraser fishing area in a consistent pattern. For the late runs, therefore, empirical information on fisheries events in the years in question were used to derive independent estimates of escapements and hence of total run sizes. These estimates are in a later section of the report.

FISHING POWER OF AN INDIVIDUAL VESSEL

Commercial salmon gillnetting in the Fraser River involves laying the net (usually 150 fathoms long by 60 mesh openings deep of varying mesh sizes dependent on the species being targeted) out across the current, which, depending on tide, river volume and location, may be either upstream or downstream. The net may be set in an arc or in a crooked line, or may have a "hook" at one end. In many locations, some of the net may be kept aboard the boat. The net is allowed to drift from a few minutes to several hours. Duration of the drift is determined by the direction and speed of the current, the presence of obstructions, the abundance of salmon, or the proximity of other nets. After a time, the net is twisted by the current into an inefficient position, which often limits the drift duration. Fishermen prefer to remove the fish as the net is retrieved, but in restricted situations, the net may be picked up rapidly without removing the catch. Each fishing location has its own requirements and techniques are quite variable.

In the present paper, the basic unit of fishing effort is considered to be the setting of a net for one drift. The fishing power of the net can be expressed in terms of efficiency, reflecting the proportion of the salmon run passing the fishing site that is harvested by the gillnet set. In the present paper, the efficiency of a single drift of a net, expressed as a proportion of the population vulnerable to fishing removed per set (termed the Unit Drift Efficiency, **U**) is considered to be the catch (**c**) made in a single drift divided by the estimated number of salmon passing the fishing site during the appropriate 24 hour fishing day ($\mathbf{E_{24}}$):[10]

$$U = c/E_{24}$$

Test fishing experiments carried out during weekly closures by IPSFC between 1951 through 1963, coupled with estimates of daily escapements, provided a rough basis for estimating unit drift efficiencies during the experiments.

The experiments involved chartered commercial fishing vessels making drifts using commercial techniques to develop indices of the abundance of passing runs and to obtain samples of scales to distinguish between stocks. The vessels operated in the commercial fishing area at times when the commercial fishery was closed. Estimates of daily escapements related to individual net catches were made mainly by using data on total seasonal escapements (from spawning ground surveys, statistics of commercial gillnet and Indian food fish catches and observations on fish passing Hells Gate) and prorating them using the test fishing catches themselves as indices of relative abundance.[11]

The results are summarized in Table 3. Based on averages for individual sites for separate years, estimates of unit drift efficiency varied from .0005 to .0062, averaging .002; i.e., on average, a single set by a test fishing net would catch 2 salmon out of every 1,000 passing.[12] The bimodal value was .001. The average duration of each set was 51 minutes.

It is likely that the unit drift efficiencies for the test fishing vessels would be higher than that for vessels operating in the normal commercial fishery. Although the test boats used commercial nets, they selected locations and times when it was expected that the best catches would be made, a luxury seldom possible for commercial fishermen competing

---

[10] It would be impractical to develop estimates of the numbers of salmon passing in intervals of less than a day. **U** is a "term" rate, a catch made during a part of a day. Gillnets usually make a number of sets each day and therefore **U** is not a reflection of a daily rate.

[11] The test fishing unit catches and related daily escapements therefore are not completely independent quantities.

[12] Drifts with zero catches were not included because it was considered that in most such cases nil catches reflected a virtual absence of passing sockeye (e.g., in the opening test fishing sets immediately following closure of the commercial fishery).

Table 3. Unit drift efficiencies of test fishing gillnets set at various sites in the Fraser River during commercial fishing closures.

AREA AND NAME OF DRIFT	YEAR	STOCKS (Races)	ESTIMATED EFFICIENCIES Range	Mean
Main channel below Steveston	1954	Adams	0.0009 to 0.0023	0.0013*
	1962	Adams	0.0005 (one drift)	-
Deas Id. - Cottonwood Drift	1961	Mixed	0.0005 to 0.0011	0.0008
	1962	Mixed	0.0000 to 0.0076	0.0040
Sunbury Bar Drift	1957	Mixed	0.0008 to 0.0019	0.0012
Port Mann - Douglas Id. Drift	1951	Mixed	0.0002 to 0.0014	0.0007*
Albion - Island Drift	1957	Mixed	0.0001 (one drift)	-
Albion - Center Drift	1962	Mixed	0.0007 to 0.0029	0.0019
Albion - Graveyard Drift	1954	Adams	0.0001 to 0.0018	0.0006*
	1955	Chilko	0.0002 to 0.0025	0.0012
	1955	Mixed	0.0006 to 0.0013	0.0008
	1956	Early Stuart	0.0002 to 0.0025	0.0012
	1956	Mixed	0.0003 to 0.0027	0.0011
	1958	Mixed	0.0004 to 0.0013	0.0007
Albion - Farmer's Drift	1957	Mixed	0.0004 to 0.0009	0.0005
	1962	Mixed	0.0018 to 0.0040	0.0031
	1963	Early Stuart	0.0000 to 0.0072	0.0051
	1963	Mixed	0.0060 to 0.0067	0.0062
	1963	Chilko	0.0027 to 0.0059	0.0036
Whonnock - Channel Drift	1958	Mixed	0.0004 to 0.0036	0.0023
	1959	Chilko	0.0016 to 0.0024	0.0019
	1959	Mixed	0.0017 to 0.0035	0.0026
	1960	Chilko	0.0002 to 0.0024	0.0014
	1960	Mixed	0.0013 to 0.0022	0.0020
	1961	Mixed	0.0002 to 0.0028	0.0019
	1962	Mixed	0.0001 to 0.0031	0.0018
	1962	Adams	0.0013 to 0.0048	0.0031
	1963	Chilko	0.0002 to 0.0037	0.0018
	1963	Mixed	0.0016 to 0.0026	0.0021
Glen Valley - Bar Drift	1957	Mixed	0.0054 to 0.0081	0.0057
	1959	Chilko	0.0002 to 0.0029	0.0012
	1960	Chilko	0.0005 to 0.0014	0.0012
	1961	Early Stuart	0.0052 to 0.0077	0.0062
Silverdale - Duncan Bar Drift	1951	Early Stuart	0.0005 to 0.0022	0.0014*
	1951	Mixed	0.0006 to 0.0029	0.0012*
	1954	Adams	0.0003 to 0.0027	0.0011*
Silverdale - Yankee Drift	1951	Mixed	0.0004 to 0.0009	0.0007*
* Linen gillnets; all other nets nylon.			Mean of 285 drifts:	0.0020

for available fishing places and times.

Tentatively, it is assumed that the unit drift efficiency of a vessel operating in the commercial fishery would be half the average of the efficiency of the vessels operating as test fishing vessels during commercial closures, i.e., .001.[13] The consequences of the true value being greater or smaller than this figure are discussed in the next part of this section dealing with fleet fishing capacity.

EFFECTS OF FLEET SIZE

Using the preliminary estimate of Unit Drift Efficiency developed above, the effects of variations in the numbers of vessels in the fleet can be examined. For such an assessment, it is convenient to consider an idealized situation wherein the run of sockeye enters the fishery in constant numbers and passes through the fishery at a constant rate. It is also assumed that, within the fishing area, the fleet is evenly distributed. Under such circumstances, the units of the fleet compete with each other so that the fish removed by one unit downstream decreases the availability of fish available to the next net upstream resulting in a lower catch for that vessel with expenditure of the same amount of effort. The relationship between exploitation rate of the combined fleet and the number of vessels deployed may be represented by:

$$F = 1 - e^{-ufn} \qquad (1)$$

Where: F = Fishing Capacity of the fleet,[14] the proportion of the run removed by the fleet during time t;
U = Unit Drift Efficiency;
u = Instantaneous Unit Drift Efficiency, where: $U = 1-e^{-u}$;
e = the base of natural logarithms (i.e., 2.71828--);
f = number of vessels; and
n = number of drifts made by a vessel in time t.

In modern times, when sockeye runs are passing at substantial levels, there are seldom fewer than 500 gillnet vessels operating in The Fraser River gillnet area (f = 500). When operating effectively each vessel can make in the order of eight drifts a day (n = 8).[15] Using the provisional estimate of unit drift efficiency (U = .001), the corresponding instantaneous drift efficiency, u = 0.0009995 and, the Fishing Capacity of the fleet:

$$F = 1 - e^{(.0009995)(500)(8)}$$
$$= .9816$$

[13] By coincidence this value is approximately the same as the modal efficiency of the entire series of test fishing operations.

[14] Fishing capacity reflects the maximum fishing power of the fleet, i.e., the rate of removal that could be exerted by the fleet if its efforts were not restricted. Later in the report, the term Fleet Fishing Efficiency is used. This is different from Fleet Fishing Capacity; the term Fleet Fishing Efficiency reflects the rate of removal of the fleet as limited by regulations, etc. (e.g., weekly closures).

[15] The actual number of sets varies. When only a few boats are operating more or longer sets may be made. When a large fleet is present, fewer or shorter drifts may be made. However, a daily operation of eight sets is probably quite representative of normal fishing conditions when the bulk of the sockeye run is passing.

Thus, fishing without time limitations, the 500 vessel fleet would remove 98% of the passing run. With such a high rate of removal, it is evident that the fishing grounds are virtually "saturated" with fishing vessels and that addition of more vessels would not result an a significant increase in catches. Figure 5 shows the theoretical relationship between numbers of vessels and fishing capacity assuming different levels of drift efficiency. In the first curve, using a Unit Drift Efficiency (U) of .002, equal to that of the test fishing vessels, the fishery would be saturated once about 200 vessels were operating. If U were half of the .001 (i.e., .0005) estimated for the commercial fleet, the saturation effect would be approached when about 1,000 vessels were operating. A U value of one quarter that of the commercial fleet (i.e., .00025) would provide a saturation level approaching 2000 vessels. The significance of these alternative estimates is discussed later in the paper when effects of fleet size on exploitation rate in the early days of the fishery is discussed.

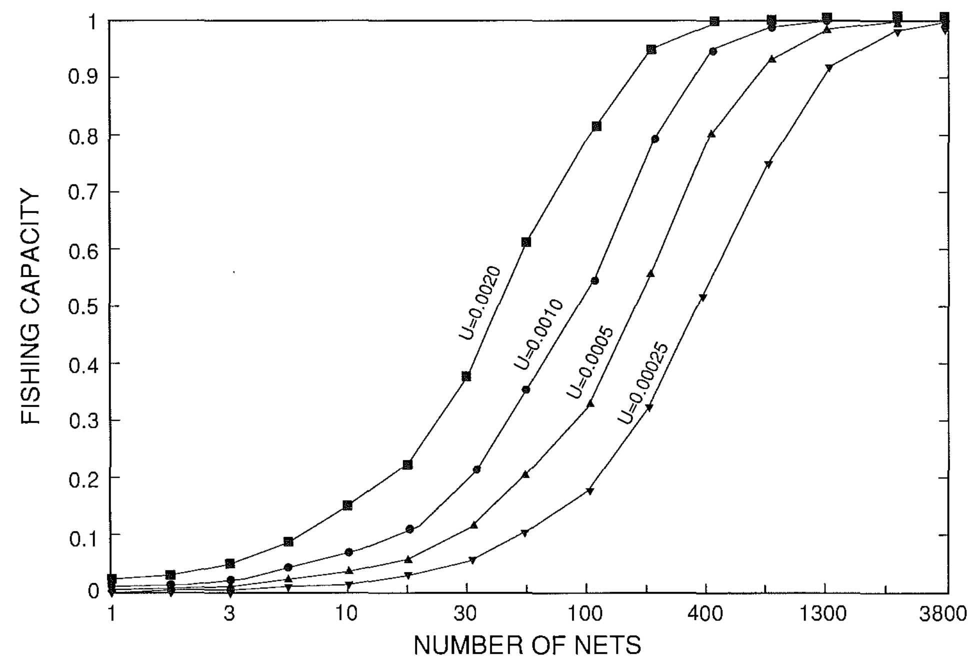

Figure 5. Fleet Fishing Capacities (F) at different levels of Unit Drift Efficiency (U) assuming 8 drifts a day by each unit.

For the time being, the analysis indicates that in modern times, at least since nylon gillnets were introduced around 1953, variations in amount of fishing effort deployed was not an important factor affecting exploitation rate, i.e., the fishery consistently operates at a saturation level. The field data discussed in succeeding paragraphs confirm this conclusion.

With the foregoing background, the effects of the operation of the highly intensive fleet on the abundance of passing sockeye runs will be examined.

FISHING PATTERNS AS REVEALED BY TEST FISHING

The 1951 Test Fishing Experiment

In 1951, to provide information on patterns of exploitation in the fishery, IPSFC carried out experimental fishing in the Fraser River gillnet area close to the upper limit of commercial fishing during weekly periods of closure of the commercial fishery.[16] In 1951, all closures began at 8:00 A.M. (Pacific Daylight Time) on Fridays; the below New Westminster closures were of 72 hours duration and above that point, 76 hours.

The experiment involved the charter of a commercial gillnet vessel which set its net at intervals of six hours during seven weekly closures from early July until late August at Silverdale, near the upper end of the fishery (Figure 4). A second test gillnet was fished during four weekly closures downstream at Port Mann, just above New Westminster. Linen gillnets with the maximum legal 150 fathom length and 60 mesh depth were used for all drifts although at Silverdale part of the net was kept aboard the boat. Drifts at the 72nd hour were made only during the first three closures at Silverdale, and the first two at Port Mann.

Because the test drifts varied in duration and length of net fished, the catch data were standardized to permit comparability using the method described by Henry (1961). The number of sockeye caught in each drift was divided by the product of net length in fathoms and the average immersion time in minutes, and the quotient multiplied by 1000 to give catch per 1000 fathom minutes of fishing. The data were also normalized to correct for differences in the magnitudes of the catch between weekends. This involved expressing the catches within each weekend as a percentage of the total standardized catch from the 6th to the 66th hour during the closure. For comparative purposes, catches for the five 72nd hour drifts were also expressed as a percentage of the 6-66 hour totals.

Variations in Catches

The relative catches by the test fishing vessels varied in a similar manner during each of the weekly closed periods (Figure 6). Catches rose sharply during the first 24 to 36 hours after the closure began as sockeye migrated upriver, followed by a more gradual change thereafter. The onset of rising catches at Port Mann was clearly earlier than at Silverdale. Average relative catches in each 6th-hour test drift at Port Mann were also higher than at Silverdale.

Catches during the first two weekends at Silverdale showed that the quick rise in sockeye catches there usually ceased after the 30th hour rather than after the 36th hour as in the five following weekends.

The reason for this difference is not clear. The Early Stuart stock predominated in the catch on the first two weekends. It is possible that this stock migrated more rapidly than following stocks. An alternate explanation was that river height or some vagary of the tide interfered with the fishery at the mouth of the river, allowing sockeye a "head start" during the first two weekends. Tidal fluctuations were not extreme during the first

---

[16] It is of interest that almost a century ago, Rathbun (1900) first advocated studies of escapements during weekly closed times as a means of assessing the impact of the fishery on the stocks. Thus, he stated that: "In the interest of the protection of the fish, it would be important to ascertain what proportion of the run is removed by the large amount of netting used on the Fraser...[using]...evidence presented by the circumstances attending the weekly close time". It was thus over fifty years later that Rathbun's perceptive advice on approaches to studying the effects of the fishery received *de facto* acceptance.

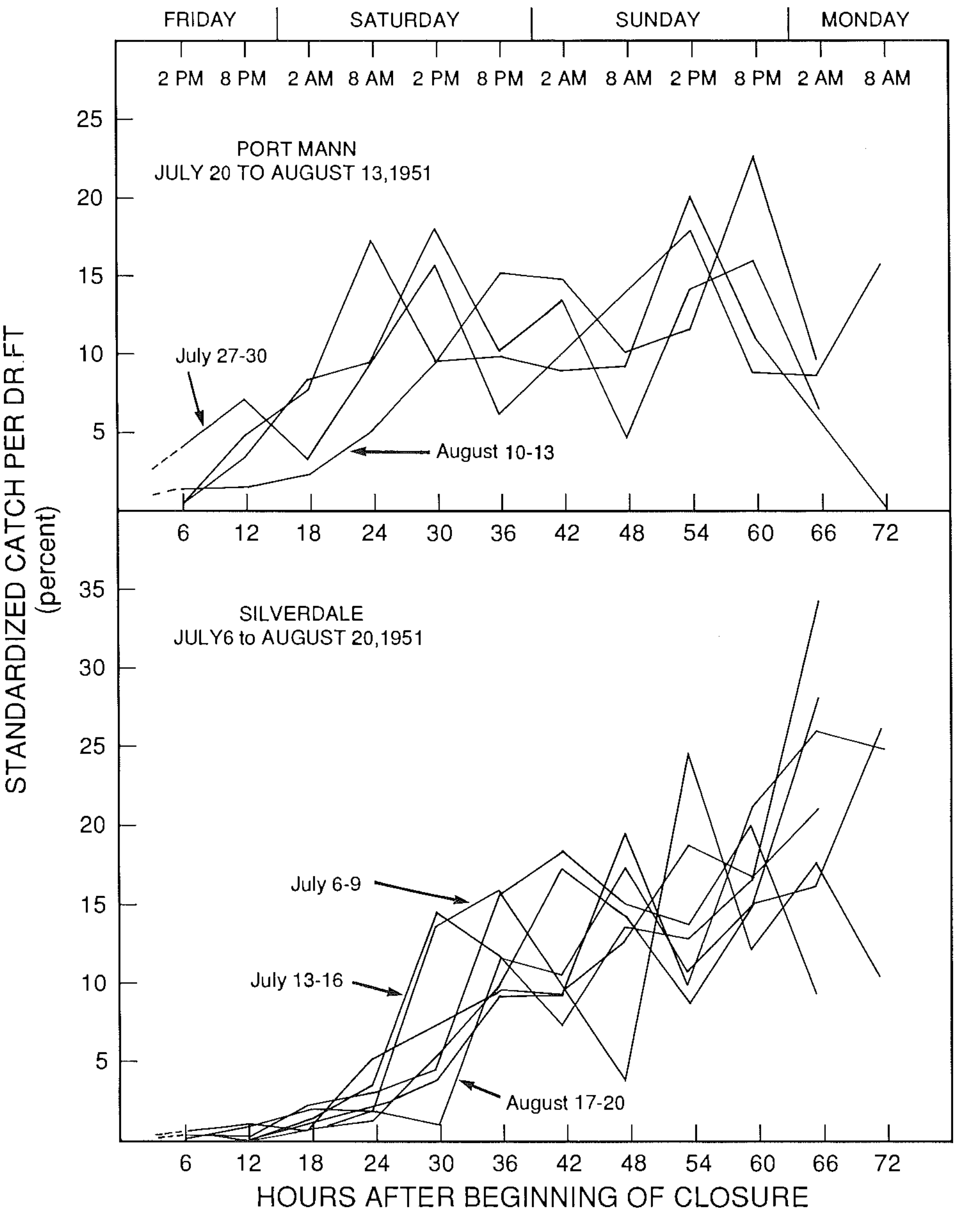

Figure 6. Normalized catches made by test gillnets operated at six-hour intervals during weekly closures at Port Mann and Silverdale during 1951. (Daylight Saving Time in effect).

two weekends, but the river was high and fell rapidly after thereafter. It is to be expected that there would be significant variations in migration rates and that the analyses to follow are based on assessments of average conditions. Within such a framework, the minor variations described above would not be expected to have a major effect on the validity of the conclusions reached.

Test Fishing Catch Trends

Figure 7 combines the data for all seven closures by averaging the normalized catch data for each six-hour time interval. For both Silverdale and Port Mann, relative catches rose rapidly at a constant rate for a day or a day and half. From relative catches of .2-1.0[17] during the first test fishing catches six hours after the closure began, the catch levels rose at least ten fold (to around 10.0) around the 24-30 hour points before levelling off (at Port Mann) or continuing to rise at a much more modest rate (at Silverdale). In each case the trends are well represented by two intersecting straight lines on a semi-logarithmic plot.

During the first 24-30 hours, successive increases in catches made at six hour intervals reflect the increasing protection the migrating fish received as the result of the closure, i.e., the segment of the run passing the test fishing site at the twelfth hour would have been fished six hours less than that passing at the sixth hour, and so on. The levelling off of the catches at the 24th hour (Port Mann) to 31st hour (at Silverdale) points implies that maximum protection had been achieved, i.e., runs passing after 24 or 31 hours had not been exploited to any extent in the Fraser River commercial gillnet fishery. The implications of this observation are that the runs migrate from the bottom end of the fishing area (at the Sandheads - Figure 4) to Port Mann in about 24 hours and to Silverdale in about 31.

The situation at Silverdale differed somewhat from that at Port Mann in that after the initial period of rapid increase, the catches continued to increase, albeit at a much slower rate. This suggests that after the initial "refilling" of the river following the closure (over a period of about 31 hours), instead of entering at a constant level as apparently was the case at Port Mann, the abundance of the run tended to increase during the closed period, approximately doubling. There is no ready information to explain the difference between the Port Mann and the Silverdale data. In any event, the difference does not invalidate the conclusion that the sharp change in the slope of the Silverdale line in Figure 7 reflected the time at which relatively unfished portions of the runs first passed the Silverdale test fishing site after the fishery closed. As such, this provides a useful estimate of the average length of time taken by the fish to travel from the lower end of the fishing area (at the deep water off the Sandheads - Figure 4) to Silverdale, i.e., approximately 31 hours.

With a distance of about 48 miles (77 km) along the river channel between the Sandheads and Silverdale, this implies a speed of 1.55 miles per hour or 37 miles (60 km) per day. This speed was greater than the fastest observed by Killick (1955) among stocks migrating over longer distances upriver. It is similar, however, to speeds observed by Henry (1962) for sockeye migrating through the saltwater approaches to the Fraser.

Because the fishery may have extended a few miles farther from the river mouth, an even faster speed through the fishing area is possible. The break in relative abundance at Port Mann at about 25 hours after the closure began indicated a slower migration speed over the approximately 28.5 miles (46 km) from the Sandheads of 1.14 miles per hour or 27.4 miles (44 km) per day, possibly because test fishing was not carried out at Port Mann during the first two closures, thus excluding the faster arriving early fish.

[17] As outlined above, relative catches are expressed as the percentage a test fishing catch made during one six hour interval during the experiments formed of the total test fishing catch between the sixth and 66th hour of the experiments. Thus in Figure 7, for the Silverdale data, the catch during the first six hour sets comprised about 0.2% of the aggregate catches made in the experiments between 6 and 66 hours. The catch at 30 hours averaged about 7% of the aggregate catch.

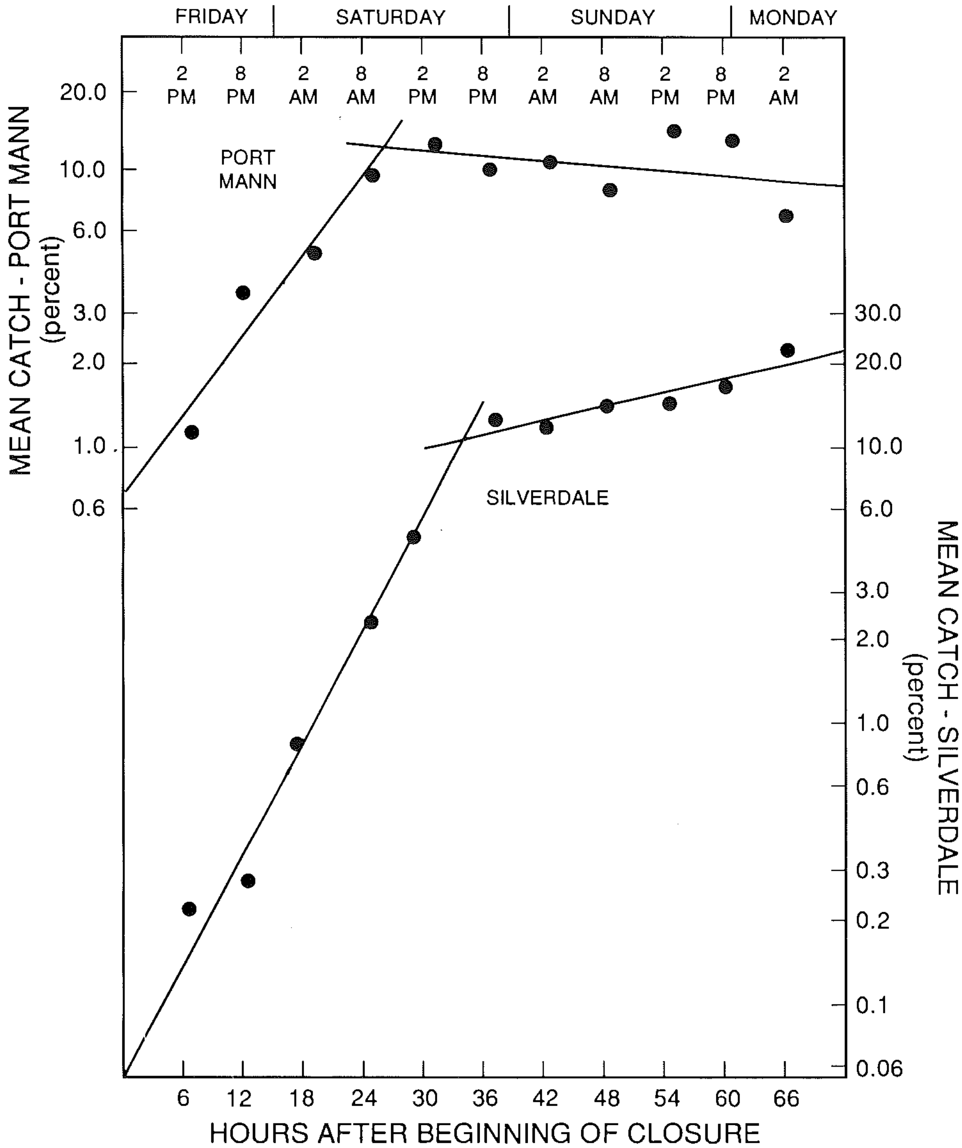

Figure 7. Normalized catches averaged for successive six hour intervals (logarithmic scale) for weekend test fishing conducted at Port Mann and Silverdale during 1951 (lines fitted by least squares).

Extrapolation of the migration speed from Silverdale data to the 54 miles (87 km) from Sandheads to Mission gives a travel time of about 35 hours through the full length of the Fraser gillnet fishery.

Data from Figure 7 can be used to provide a "snapshot" of the relative abundance of sockeye at various points along the Fraser fishery at the moment the fishery closed for a 72-76 hour weekend. In Figure 8, catch rates from the Silverdale curve are plotted against the distances that would be related to the times of each test fishing set. Thus, the fish represented by the catch level at the 31 hour point were assumed to have been associated with the body of sockeye that had just arrived at the lower limit of the fishing area (the deep water of the Sandheads - see Figure 4) at the beginning of the closure, whereas catch rates at the six hour point would reflect the relative abundance of fish that had only been downstream a few miles at the time of the closure and had already been fished during their upstream migration for more than a day when the closure began.

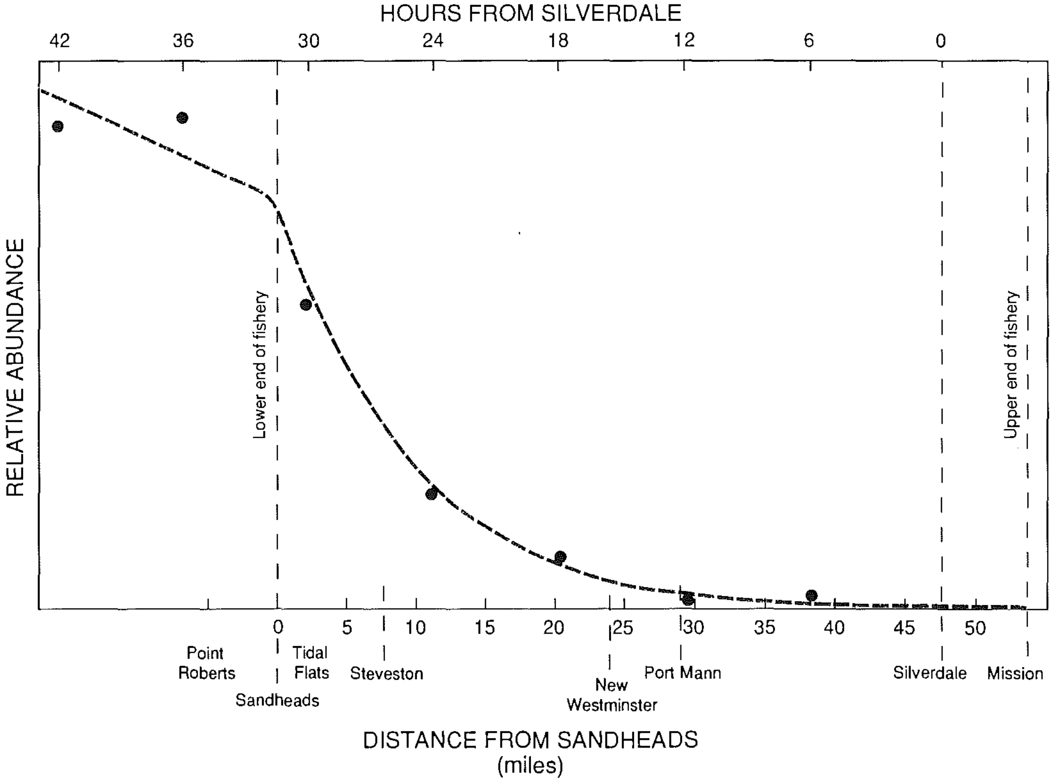

Figure 8. Relative abundance at various points along the Fraser River seaward from Mission at the end of a weekly fishing period as implied from data presented in Figure 7. (A uniform migration rate through the fishing area was assumed).

The picture presented is one of rapid depletion of the run as it passes through the fishery. Traversing the distance between the Sandheads and Steveston (about six miles) would be attended by a loss through fishing of about two thirds of the run. The high rate of removal suggests that once the fishery opened the runs in the upstream part of the fishery would rapidly become depleted, with the bulk of the catch being taken in the downstream end of the fishing area. This is, in fact, what is observed during commercial fisheries in the river of two or more days in duration and, indeed, is what Rathbun (1900) recorded regarding the 1895 gillnet fishery.

PROVISIONAL ESTIMATE OF FISHING CAPACITY

The data in Figure 7 may be used to develop a provisional estimate of the fishing capacity of the commercial fleet during the 1951 season independent of that developed earlier on the basis on data on unit drift efficiency. Extrapolating the initial, sharply ascending line of relative catches for the Silverdale data back to time zero provides an estimate of what the relative catch would have been at the beginning of the closure. This would reflect the relative abundance of a portion of the run that had been fished throughout its entire migration upstream through the Fraser River gillnet area. From Figure 7, the estimated relative catch at time zero would be about 0.05. This compares with a relative catch of about 10.0 at the point of change in slope of the curve, concluded to reflect the relative abundance of the run that had not been subject to fishing. The relative abundance of the totally fished run (0.05) is thus only 1/200th of the abundance of the unfished run, and the implied rate of exploitation of the run when it was fully exposed to the fishery was:

$$(10.0\text{-}0.05)/10 = 0.995 \text{ or } 99.5\%$$

This value is slightly higher than that developed from the unit drift efficiency estimate (.9816). There are two reasons the new estimate could be too high. First, the line of rapidly rising abundance at Silverdale may have followed an upward concave curve at its lower end due to low fishing effort late in the fishing period in the above New Westminster fishing area. Second, there is always some escapement of small sized sockeye through the gillnets. Nevertheless, despite such possible qualifying factors, it is evident that the rate of removal in the gillnet fishery was very high during the 1951 season.

To reinforce the information on changes in abundance associated with the closing of the fishery, it would have been worthwhile to continue test fishing after the commercial fishery opened. If such experimental fishing had been conducted, it would have been expected to show an exponential decline in abundance as time passed, essentially providing a mirror image of the rapid buildup observed when the fishery closed. Unfortunately, such experimental fishing was not conducted. However, during the 1951 season, the Silverdale test fisherman (who also participated in the commercial fishery) recorded his catches after the beginning of commercial fishing for the first three weeks in which test fishing was done at the same drift location. Sets by individual fishermen at this location were made in rotation, with the order determined by drawing lots. The catch made on the first drift (noon daylight time) by the fisherman chosen by lot was also recorded by the test fisherman. Although the times of subsequent drifts by the test fisherman were not recorded, he did report the change of date (midnight), and because the drifts would have been fairly evenly spaced, they were assigned an approximate time assuming they were evenly spread throughout the period. Because net length and drift duration were not recorded, catches could not be standardized in the same manner as was done for the test fishing operations. Drift duration would have varied with the tide at this location, but tidal variation was not large, dampened by high river discharge in this early part of the sockeye season. Whereas these deficiencies undoubtedly introduced variability in the results, they are not believed to be serious enough to invalidate conclusions drawn below.

Catches during the three periods of beginning of fishing at Silverdale (Figure 9) showed a rapid decline in sockeye abundance as would have been expected in light of the test fishing results given previously. Spacing of the catches after the first few hours may have been too wide because some fishermen on the drift quit fishing when catches became small; consequently, the semi-logarithmic plot in Figure 9 may have been straighter than indicated until it approached minimum catch levels. With such small catches, the time when minimum catch was reached is difficult to determine with precision. The declining semi-logarithmic plot in Figure 9 is steeper than the rising line at Silverdale after fishing ceased (Figure 7), appearing to approach minimums well before 24 hours. This may have resulted, in part at least, from the possibly more rapid migration rate of the early sockeye runs. It may also be associated with the fact that below the New Westminster fishery began four hours earlier than did the fishery at Silverdale.

Limiting consideration to data for commercial fishing by the Silverdale test fishermen (i.e., not including catches by other fishermen), a second estimate of the fishing capacity of the Fraser gillnet fishery can be made from the catch sequence of July 8-9 (Figure 9). The first catch on July 8 was 52 sockeye, and the catch in the last four drifts averaged 0.5 sockeye. If the latter average catch is taken as the minimum catch equilibrium, Fishing Capacity is then (52 - 0.5)/52 = 0.99 or 99%, close to the estimate derived from the test fishing data illustrated in Figure 7.

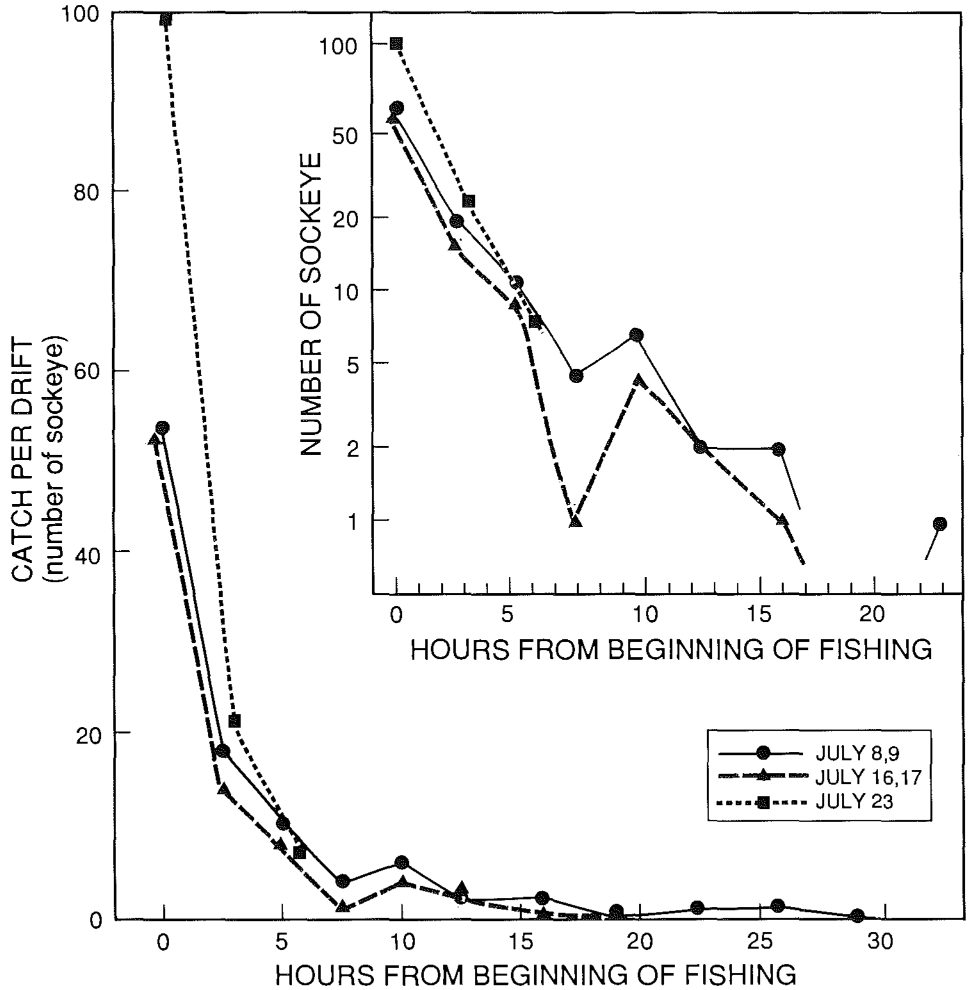

Figure 9. Sockeye catches per drift at Silverdale in sets made by the IPSFC test fishermen during the first 29 hours of the commercial fishery during three periods during July 1951. Inset shows data plotted on a logarithmic scale. (Note: first catches on July 16 and 23 made by other fishermen).

BASIC MODELLING

On the assumption of an exponential buildup in abundance of the run passing through the fishing area after it has closed and a reverse exponential drop in abundance of escaping fish as the fishery reopens, geometric models of the abundance of the runs in terms of time and location within the fishing area can be developed. The theory on which the modelling is based is included in Appendix 2.

In the model, the run is considered to enter the fishery in constant abundance, to move through the fishing area at a constant rate and to be subject to equal fishing effort along the entire course of the migration. Figure 10 represents the results of such modelling to illustrate the patterns of relative fish abundance at different stages and locations along the migration route of the sockeye in and above the Fraser River gillnet area. It was assumed that 1.5 days (36 hours) were required for the run to migrate through the fishing area.

On the basis of similar models, the theoretical relationships between rates of removals of fisheries with different capacities and with different weekly closed periods were

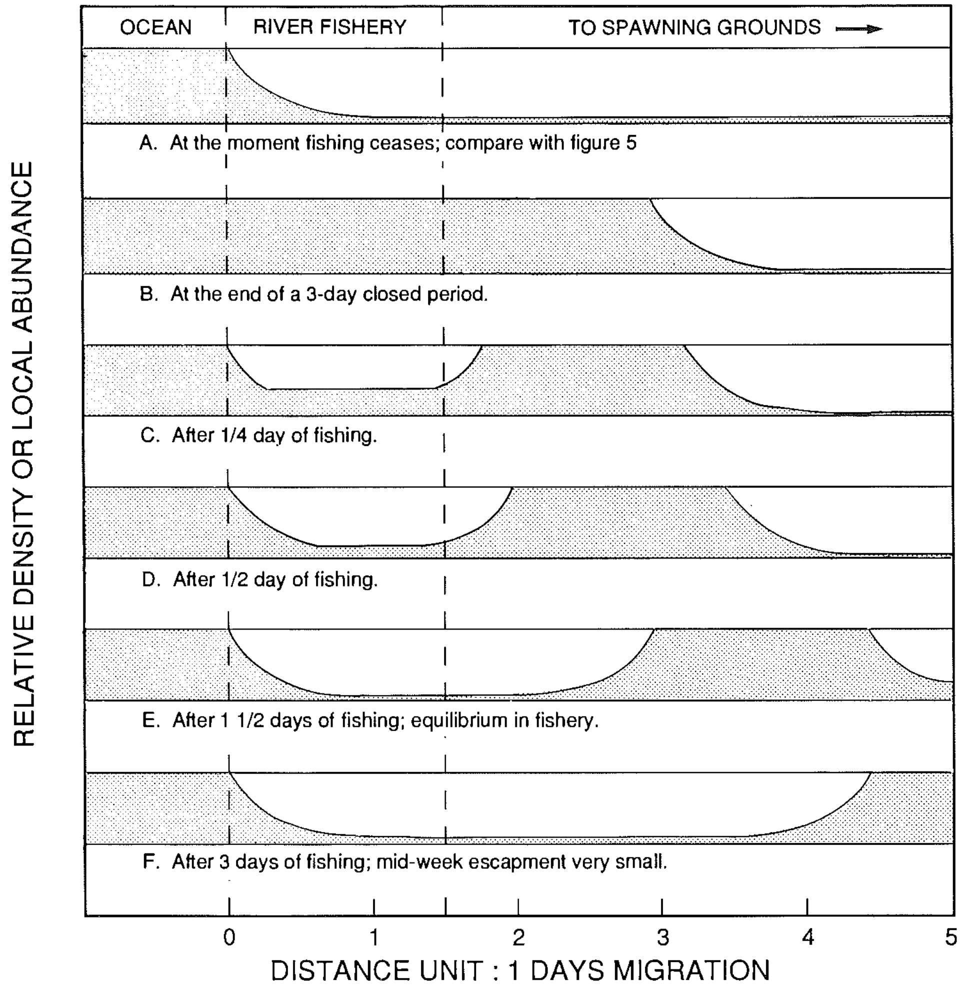

Figure 10. Hypothetical relative abundance of sockeye at various points along the Fraser River after a closure and during various times within a three-day fishing week. Data developed in Appendix 2.

calculated. These are arrayed in Figure 11.[18] At low fishing capacities, the relationship between length of fishing time and exploitation rate is virtually linear, but at higher rates (e.g., above 95%), the rates asymptotically approach a maximum level after the 6th day.

TESTS OF REASONABLENESS - APPLICATIONS TO 1940-1961 DATA

As outlined earlier, IPSFC began to collect accurate records of catch and escapement for the Fraser sockeye runs shortly after the Commission was established in 1937. As a test of the reasonableness of the models illustrated in Figure 11, actual data on the average seasonal rates of exploitation for summer-run sockeye (measured by dividing total recorded catch for the season by the sum of the catch plus observed escapement) for 1940-1961 were compared with what would have been expected on the basis of the

[18] See Appendix 2 for more detail.

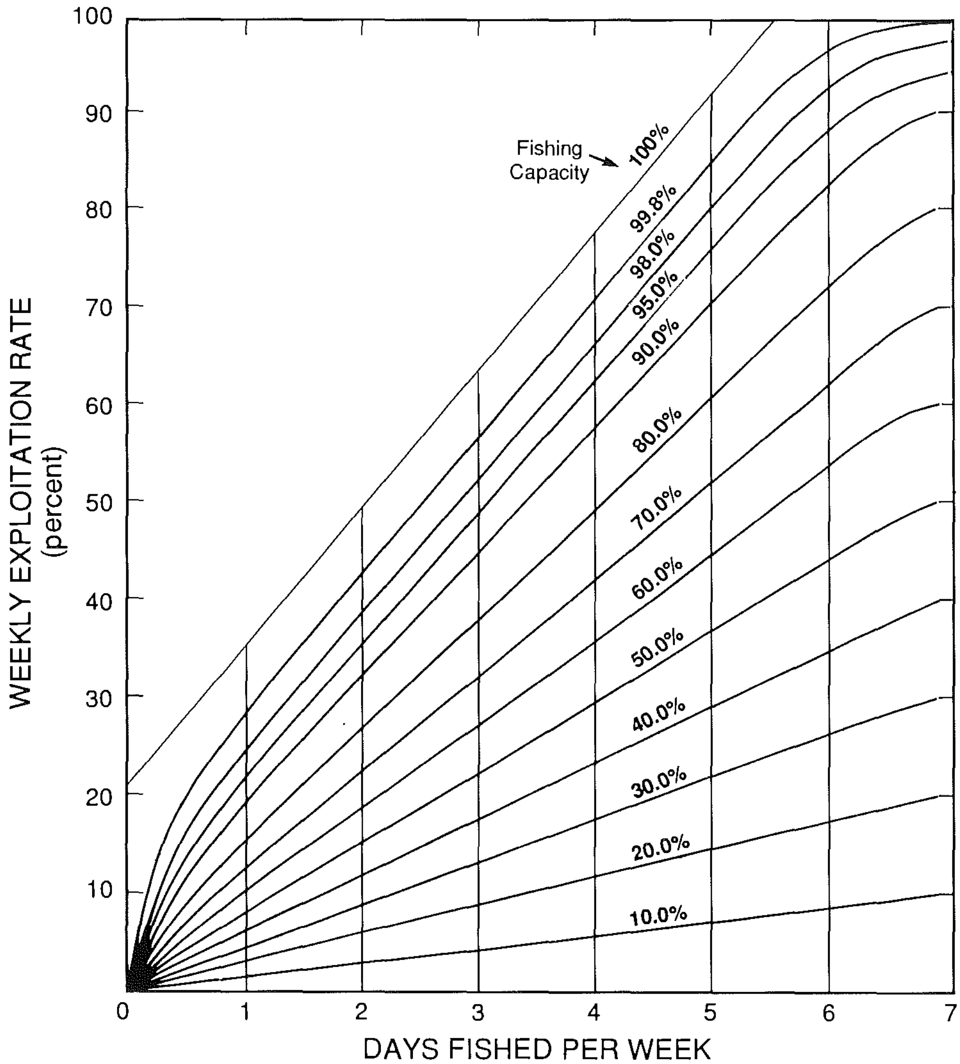

Figure 11. Weekly rates of exploitation for fisheries of different durations and different Fleet Fishing Capacities.

observed durations of weekly fishing times.[19] Data for 14 years were suitable for such comparisons (Table 4).

To illustrate the approach used, for the 1961 fishery, the recorded catch was 716,000 and the estimated escapement was 1,253,000. Two adjustments were made. First, delaying fish, amounting to 5,000 and 64,000 were removed from the catch and the escapement respectively. Second, 107,000 sockeye were transferred from escapement to catch to compensate for a week-long strike and 3 extra days of fishing. The quantities

[19] Selection of effective length of weekly fishing periods in Figure 11 required exact definition due to the time offset between the Below New Westminster and Above New Westminster fishing areas up to 1955. Although the two areas were of about equal length, most of the catch was taken in the Below Bridge area except in the first few hours of fishing. Sockeye escapement up the river began as soon as the Below New Westminster fishery ceased operating and continued until Above New Westminster fishing began (Figure 4). For all years, including those with offset times (prior to 1956), effective weekly fishing period length was then from the hour Above New Westminster fishing began until the hour Below New Westminster fishing ceased.

Table 4. Predominant numbers of fishing days per week and variations from such periods for summer run fisheries during the 14 years used to test the reasonableness of the models for relating fishing time to exploitation rates illustrated in Figure 11.* Reasons for rejection of other years during 1938 - 1961 are listed under Remarks.

Year	Predominant** Fishing Period Lengths Days/(Hrs)/Week	No. of Days in Non-standard Weeks	Remarks
1938	---	---	Delaying sockeye not accurately separable.
1939	5 (114)	All standard	Enumeration of spawners apparently inaccurate.
1940	4 (90)	5,5,5,5,5	Five day fishing periods had small catches.
1941	5 (114)	All standard	Escapement loss at Hells Gate not separable.
1942	---	---	Delaying sockeye not accurately separable.
1943	4 (90)	5,5	Five day fishing periods had small catches.
1944	5 (114)	All standard	
1945	5 (114)	4	Short fishing period had small catch.
1946	---	---	Delaying sockeye not accurately separable.
1947	---	---	Delaying sockeye not accurately separable.
1948	4 (92)	E/C	Extended closure prior to peak of summer run.
1949	4 (92)	5; E/C	Extended closure prior to peak of summer run.
1950	---	---	Delaying sockeye not accurately separable.
1951	4 (92)	5	Long fishing week at beginning of season.
1952	4 (92)	5,3	Short strike (3 days); extra day at season peak.
1953	3.75 (86)	3,3	One of the short periods at season peak.
1954	---	---	Week-long strike (no fishing); delaying sockeye not accurately separable.
1955	3 (68)	4,4,4,4	Four-day fishing periods first half of season; catches smaller than in latter half.
1956	2 (48)	3,3,3,3,3	First half of season had the longer fishing periods; peak catch in second half.
1957	3 (72)	1	Large correction required for single day's fishing at season peak.
1958	---	---	Very large delaying run not accurately separable.
1959	---	---	Reduced effort due to two-week strike.
1960	3 (72)	1,2	One-day fishery near season peak; large correction required.
1961	2 (48)	4,3; E/C	One weekly fishing period eliminated.

* All years required corrections for catches of delaying sockeye. Both catches and escapements of delaying sockeye deleted prior to calculation of season exploitation rates.

** Choice of principal fishing period length determined by periods with largest catches, even when such periods were in the minority.

were estimated by interpolation from graphs showing daily catches and from data developed from escapement enumeration surveys.

On the basis of these modifications, the adjusted total early season catch of sockeye in the Fraser River gillnet fishery was estimated to be 818,000. The adjusted spawning escapement of early-run sockeye was estimated to be 1,082,000 and the Indian food catch of early-run fish was approximately 138,000, giving a seasonal rate of exploitation of 40.1%:

$$= 818{,}000/(818{,}000+1{,}082{,}000+138{,}000)$$
$$= 818{,}000/2{,}040{,}000$$
$$= .401$$

A two day fishing week prevailed throughout the 1961 season. Plotting the 40.1% exploitation rate on Figure 11 at the 2-day per week point indicated a fishing capacity of approximately 96%. Similar calculations were carried out for the other 13 years. The results for all 14 years are illustrated in Figure 12.

The entire array of seasonal exploitation rates, with one exception (1948)[20], suggests fishing capacities of 88% or more each year. The two bodies of independent data (test fishing and catch/escapement comparisons) therefore seem to present a relatively consistent picture indicating a very high fishing capacity for the Fraser River gillnet fleet as it operated in the 1940-1961 period.

Statistically, the least squares slope of the regression of calculated exploitation rates is not significantly different from that of either the 95% or the 98% fishing capacity lines in their straight sections ("Students" t test; Snedecor 1946).

The comparison made in Figure 12 ignores a number of factors affecting exploitation, one of the most important of which is size selectivity by gillnets, the subject of a later section of this report.

Nevertheless, the results described above are consistent enough to proceed with the assembly of information on weekly patterns of openings and closures which can then be used to estimate seasonal rates of exploitation (as was done in assembling Figure 12) and such rates applied to the information on catches estimated earlier in the report to develop estimates of gross escapements.

DOCUMENTATION OF WEEKLY CLOSED PERIODS

The first step in using information on the length of closed periods to estimate exploitation rates is to determine the scheduled timing and durations of weekend closed periods established through Government regulations (and variations therefrom) both within and between seasons for the years included in the present study (1892-1944). Annual Reports of CDF provide considerable information on this subject with newspaper reports providing supplementary data.

From very early in its history, the Fraser River commercial fishery was regulated through a system of weekly (weekend) closures, instituted as much to provide for orderly processing of fish as for conservation purposes. Originally it appeared that the lengths of weekend closures were designed to allow the canneries to operate as long as possible with a minimum of work on Sundays (Wilmot 1891).

---

[20] The 1948 gillnet fishery was impeded by a major flood in the Fraser which left many snags and which changed the underwater topography of the gillnet fishing area.

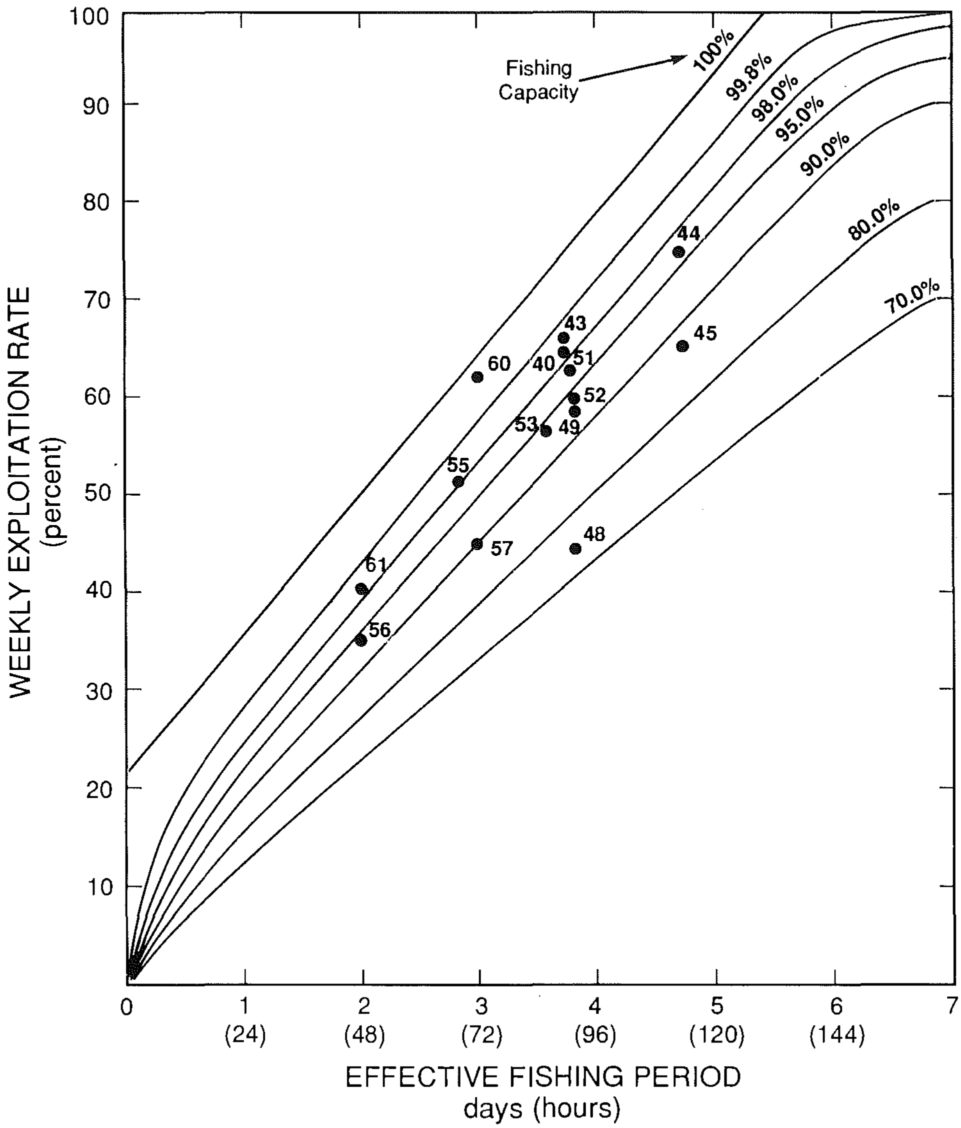

Figure 12. Early- and mid-season exploitation rate of the Fraser River gillnet fishery for fourteen selected years plotted against fishing time allowed. Lines showing the theoretical fishing capacities from Figure 11 have been added.

According to CDF records, between 1873 and 1893, weekend closures varied between 30 and 48 hours (Table 5). In at least one year, however, there appeared to have been no closed period at all, at least during part of the season. Anderson (1882) stated that in 1881, when sockeye were extremely abundant, the weekly "close season" was abolished for several weeks. Closures variously began at 6:00 A.M., noon, or 6:00 P.M. on Saturday, and ended at 6:00 P.M. or midnight on Sunday or at 6:00 A.M. on Monday. Although Rounsefell and Kelez (1938; their Table 4) give a closure length of 40 hours for this period, available data indicate enforcement of other closure lengths. For example, Smith (1894) stated that in 1878, the 40 hour official closure (8:00 A.M. Saturday to midnight Sunday) was reduced to 30 hours (noon Saturday to 6:00 P.M. Sunday) on the suggestion of the Fisheries Inspector for British Columbia, at least for that season. Again, Wilmot (1891) indicated that the official weekend closure for 1890 (6:00 P.M. Saturday to 6:00 A.M. Monday, 36 hours) was unofficially changed to 6:00 A.M. Saturday to 6:00 P.M. Sunday (still 36 hours), and implied that in other years, closures had been altered at the request of the canning industry.

TABLE 5. Weekly (weekend) closures to fishing in the Fraser River gillnet fishery, 1877 - 1906.

YEAR	START Hour	START Day	END Hour	END Day	DURATION (Hours)	SOURCE OF INFORMATION AND REMARKS
1877	6:00 p.m.	Sat.	6:00 a.m.	Mon.	36	Smith (1894); "Big year" run; Closures possibly not enforced.
1878*	Noon	Sat.	6:00 p.m.	Sun.	30	Smith (1894); Mainland Guardian, July 6, 1878.
1879	Noon	Sat.	6:00 p.m.	Sun.	30	Anderson (1880).
1880	Noon	Sat.	6:00 p.m.	Sun.	30	Inland Sentinal, May, 1880.
1881	No weekend closures July 10 to August 25					Anderson (1882).
1882-1887	--	--	--	--	--	No data. Possibly same as 1878 to 1880.
1888	6:00 p.m.	Sat.	6:00 a.m.	Mon.	36	Wilmot (1891).
1889	6:00 p.m.	Sat.	6:00 a.m.	Mon.	36	Tilton (1890); Wilmot (1891); Smith (1894). "Big year"; closures possibly same as 1880.
1890**	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	Wilmot (1891); Smith (1894).
1891-1893	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	Daily Columbian, various dates.
1894-1899	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	Rathbun (1900); Daily Columbian, various dates.
1900-1901	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	Daily Columbian, various dates.
1902	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	Daily Columbian, various dates; Gosnell (1903).
1903-1906	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	Daily Columbian, various dates.

* Altered from proposed closure of 8:00 a.m. Saturday to midnight Sunday.
** Changed from official hours of 6:00 p.m. Sat. to 6:00 a.m. Mon. on request of industry.

According to Rounsefell and Kelez (1938), and with no contradictory information in the local press, from 1894 to 1906, a standard weekly closure of 36 hours (6:00 A.M. Saturday to 6:00 P.M. Sunday) was apparently in force (Table 5). Rathbun (1900) listed the same closure as part of the regulations issued on May 1, 1894, and listed no amendments through the 1899 season.

Cannery records during these years showed packs for six days-per-week except for periods of great sockeye abundance, when canneries packed continuously. Such continuous operations may have been carried out solely to process the backlog of fish from heavy fishing earlier in the week. On the other hand, with no facilities for preserving fish, it is unlikely the canneries would have held fish for much more than a day. Under such circumstances, it is possible that the weekly closed periods were shortened or even cancelled to maintain the flow of raw material.

In 1907, the Fraser River gillnet area was reportedly divided into two sections,[21] the area below New Westminster and the area from New Westminster upstream to

[21] *Daily Columbian*, May 29, 1907

Mission. The change was made in order to create a system of offsetting closed periods to increase the number of salmon escaping upstream. Table 6 lists the details of these closures. The regulations provided a further restriction in that for the area upstream from New Westminster, only residents living along the river in the area could fish.

In general, closed periods of 36-54 hours were applied, but more generous fishing hours were allowed in some dominant years, viz., 1909, 1913, 1917 and apparently also in 1921. In the "off years" 1910 through 1922, the closure was six hours longer "Above (New Westminster) Bridge"; the upper area closure began six hours later and ended twelve hours later. In 1923, the "Below Bridge" closure was lengthened by six hours to give a twelve-hour offset between areas at beginning and end, and the big-year shortenings were eliminated. The final change listed in Table 6, instituted in 1934, reduced the offset between the two areas but lengthened the Above Bridge closure to 54 hours.

Rounsefell and Kelez (1938, their Table 4) indicated that the differential weekly times of beginning of fishing above and below New Westminster for 1907 were not enforced until 1908. However, the *Daily Province* (Aug. 5, 1907) reported that fishermen Above Bridge were allowed to start fishing Sunday evening until August 4 of the 1907 season.

In 1908, the British Columbia Provincial Government was reported to have tried to enforce Provincial fishery regulations on the Fraser River; these stipulated a longer weekend closure Above Bridge than the Federal regulations in order to increase spawning escapements.[22] Many fishermen ignored the Provincial regulations and test prosecutions were scheduled for the courts.[23] The test cases were not discussed again in the press but all regulations thereafter were issued by the Canadian government.

The regulations of 1908[24] specified closures Below Bridge from 6:00 A.M. Saturday to midnight Sunday (Table 6). Above Bridge closures were to be the same as Below Bridge in the big years but in the three intervening years, were to end six hours later, i.e., at 6:00 A.M. Monday. Official regulations for the dominant year 1909 have not been found. Babcock (1910) gave 1909 weekend closures as midnight Friday to 6:00 P.M. Sunday (42 hours) with no mention of a between area difference. Regulations from 1909 through 1922 followed the schedule in Table 6 with no reported variations.

However, regulations found in Canada Department of Fisheries files dated April 24, 1919, had given the Chief Inspector in British Columbia authority to lengthen weekend closures if escapement to the spawning grounds was too little. No use of this authority was noted during a sockeye season until August 27, 1927, when longer weekend closures were enforced from that date through most of the autumn. Lengthened weekly closures and special longer closures were effected locally in occasional years thereafter, mainly during late runs of sockeye and other species of salmon in September and later.

Until the 1940s, standard regulations proclaimed for 1934 and following years were generally not modified during the main sockeye season in July and August. Lengthened weekend closures were enforced in July and/or August of 1940, 1943, 1944 (one weekend only) and in 1945. Regulations thereafter were set by the IPSFC but hours of beginning and ending of closures usually conformed to Fisheries Department practice. The

---

[22] *Daily Province*, Aug. 17, 1908

[23] *Daily News*, Aug. 10, 1908.

[24] *Daily Columbian*, June 23, 1908.

TABLE 6. Weekly (weekend) closures in the Fraser River gillnet fishery below and above the New Westminster Bridge during the sockeye seasons of 1907 - 1944.

YEAR	BELOW BRIDGE START Hour	BELOW BRIDGE START Day	BELOW BRIDGE END Hour	BELOW BRIDGE END Day	BELOW BRIDGE DURATION (Hours)	ABOVE BRIDGE START Hour	ABOVE BRIDGE START Day	ABOVE BRIDGE END Hour	ABOVE BRIDGE END Day	ABOVE BRIDGE DURATION (Hours)	SOURCE OF INFORMATION AND REMARKS
1907	6:00 a.m.	Sat.	6:00 p.m.	Sun.	36	6:00 a.m. (6:00 a.m.	Sat. Sat.)	6:00 a.m. (6:00 p.m.	Mon. Sun.)	48 (36)	Daily Columbian, May 29 & Aug. 5; See text for variances.
1908	6:00 a.m.	Sat.	12:00 p.m.	Sun.	42	6:00 a.m.	Sat.	6:00 a.m.	Mon.	48	Conflict concerning regulations; See text.
1909	12:00 p.m.	Fri.	6:00 p.m.	Sun.	42	12:00 p.m.	Fri.	6:00 p.m.	Sun.	42	Babcock (1910); newspapers.
1910	12:00 p.m.	Fri.	6:00 p.m.	Sun.	42	6:00 a.m.	Sat.	6:00 a.m.	Mon.	48	British Columbian, Aug. 9, 1910; B.C. Year Book (1911).
1911,1912	-	-	-	-	-	-	-	-	-	-	No data for 1911-1912; 1910 regulations assumed.
1913;1917; 1921	12:00 p.m.	Fri.	6:00 p.m.	Sun.	42	12:00 p.m.	Fri.	6:00 p.m.	Sun.	42	Newspapers. "Big Year" regulations.
1914-1916 & 1918-1920	12:00 p.m.	Fri.	6:00 p.m.	Sun.	42	6:00 a.m.	Sat.	6:00 a.m.	Mon.	48	"Off Year" regulations. Newspaper confirmation incomplete.
1922	-	-	-	-	-	-	-	-	-	-	No data; "Off Year" regulations assumed.
1923-1933	6:00 a.m.	Sat.	6:00 a.m.	Mon.	48	6:00 p.m.	Sat.	6:00 p.m.	Mon.	48	Official regulations; British Columbian, April 20, 1923; newspaper items in most years. Alteration in 1927; see text.
1934-1944	6:00 a.m.	Sat	6:00 a.m.	Mon.	48	6:00 a.m.	Sat.	12:00 noon	Mon.	54	Official regulations as issued. Alterations in some years; see text.

differential ending times for the Above and Below New Westminster areas were eliminated in 1956, and residence restrictions in the upper area were also removed.

The foregoing information on closures was used to estimate the weekly closed times used in the analyses in a later section of the report following to develop estimates of seasonal exploitation rates during 1893-1944.

EXTENDED CLOSURES TO FISHING

In addition to weekly closed periods, periodic longer closures were applied in a number of years. In some years there was a closure late in the season, termed in the regulations as an "annual close time". These were apparently based on practices in eastern Canada and elsewhere (Wilmot 1891). It was generally believed that sockeye bound for all spawning grounds were intermingled throughout the salmon migration season. Hence, it was probable that these closures were viewed as having a general conservation value since it was believed that the more mature (but less desirable for canning) sockeye appearing late in the season were bound for rivers throughout the Fraser system and all stocks (and not just specific stocks bound for a few specific systems as was first outlined in detail by C.H. Gilbert in his papers in the Annual Reports of the Province of British Columbia of 1916-1924) would receive some protection.

The first such statutory closure was apparently applied in 1889,[25] prohibiting the taking of sockeye between August 24 and September 1 (Table 7). According to Smith (1894), such a closure was discussed as early as 1878, but both he and Wilmot (1894) indicated that no closure existed prior to 1890. However, the *Weekly World* (August 29, 1899) and the *Daily Columbian* (Sept. 1, 1891) indicated that a closure was applied in 1889 if not earlier. Rounsefell and Kelez (1938) list late August "summer season" endings from 1882 on, but prior to 1889 these may have been merely the dates that canneries ended operations because sockeye became too scarce for efficient canning, or when the supply of tin cans had been exhausted.

Late season statutory closures (October or later), proclaimed prior to the fishing season continued to be applied in most years until 1946 (Table 8). From 1946 onward, closures were set by the IPSFC until sockeye ceased to predominate in the catches, usually sometime in September. In most years with statutory closures, large-mesh gillnets were permitted during the closure (Tables 7 and 8) to allow the harvest of the larger species of salmon.

The foregoing information on extended closures is considered later in the report when distinguishing between late- and early-run segments of the runs and when making corrections to estimates of exploitation rates based solely on information on the length of weekly closed times.

SIZE SELECTION BY GILLNETS

APPROACH

Gillnets entrap fish by entangling them as they attempt to pass through the nets. The size of the mesh openings in the nets is a critical factor in determining the effectiveness of the gear. If the mesh openings are too big, fish will escape by swimming through. If too small, fish, after attempting to move through the mesh will back out and find their

[25] The *Weekly World* of August 29, 1889 included the closure in a list of "new regulations".

TABLE 7. Dates of extended closures to sockeye nets in the Fraser River gillnet fishery, 1889 - 1909.

YEAR	CLOSURE DATES Beginning	CLOSURE DATES End	MESH SIZE DURING CLOSURE	FISHING AFTER CLOSURE	SOURCE OF INFORMATION AND REMARKS
1889	Aug. 24	Sept. 1	-	-	Weekly World (Aug. 29, 1889).
1890-1891	Sept. 1	Sept. 30	-	S/N	Daily Columbian (Aug. 30, 1890; Aug. 31,Sept. 1, 26, 1891).
1892	Sept. 1	Sept. 18	-	S/N	Daily Columbian (Aug. 18; Sept. 3, 15, 17).
1893	Aug. 31	Sept. 17	-	S/N	Daily Columbian (Aug. 18, 31; Sept. 1, 21).
1894	Aug. 25	Sept. 24	7 3/4 in.	S/N	Rathbun (1900), Daily Columbian (Aug. 25, Sept. 17, 24).
1895	Aug. 31	Sept. 15	7 3/4 in.	S/N	Daily Columbian (Aug. 21, 30; Sept. 13, 14).
1896	Aug. 31	Sept. 25	7 3/4 in.	S/N	Daily Columbian (Aug. 20. Sept. 19, 22).
1897	Aug. 25	Sept. 25	7 in.	S/N	Pack records; Daily Columbian (June 3, Aug. 25, Sept. 23).
1898	Aug. 25	Sept. 15	7 in.	S/N	Daily Columbian (Aug. 24, 26; Sept. 21).
1899	Aug. 25	Sept. 25	7 in.	S/N	Daily Columbian (Aug. 24, Sept. 16, 25).
1900	-	-	-	N/A	Closure rescinded (Gordeau 1901).
1901	-	-	-	N/A	No closure reported; good sockeye catches reported in Sept.
1902	-	-	-	N/A	Catch record continued to Sept. 6.
1903	-	-	-	N/A	Closure rescinded (Daily Province, Aug. 28, 29).
1904	Aug. 25	Sept. 15	7 in.	S/N	Daily Province (Aug. 26).
1905	Aug. 25	Sept. 15	7 in.	S/N	Daily Columbian (Aug. 24, Sept. 15).
1906	Aug. 25	Sept. 16	7 in.	S/N	Daily Columbian (Aug. 20, 24).
1907	Aug. 24	Sept. 15	7 in.	S/N	World (Aug. 23); Daily Columbian (Aug. 23).
1908	Aug. 25	Sept. 15	7 in.	S/N	Daily Columbian (Aug. 24, Sept. 16).
1909	Aug. 25	Sept. 15	7 in.	S/N	World (Aug. 25); Daily Columbian (Sept. 16).

S/N - Sockeye nets apparently allowed after closure, at least in even numbered years.
N/A - Not applicable.

TABLE 8. Dates of extended closures to sockeye nets in the Fraser River gillnet fishery, 1910-1944.

YEAR	CLOSURE DATES Beginning	CLOSURE DATES End	FISHING DURING CLOSURE Mesh Size	FISHING DURING CLOSURE Beginning	FISHING DURING CLOSURE End	SOURCE OF DATA AND REMARKS
1910	Aug. 25	Sept. 15	--	--	--	British Columbian (Aug. 24, Sept. 13, 17). 7 in. nets from Oct. 1.
1911-12	Oct. 1	-	7 in.	Oct. 1	*	Sept. closures cancelled (World, Aug. 22, 1911; Daily Province, Aug. 26, 1912).
1913	Oct. 1	-	7 in.	Oct. 1	*	World (Aug. 30); British Columbian (Oct. 8).
1914-15	Oct. 1	-	7 in.	Oct. 1	*	British Columbian (Aug. 24, 1914). Daily Province (Aug 24, Sept. 27, 1915).
1916	Nov. 1	_	7 in.	Nov. 1	*	British Columbian (Aug. 8, Sept. 20).
1917-20	Oct. 1	-	7 in.	Oct. 1	*	Official regulations.
1921	Sept. 6	Sept. 20	6 1/2 in.	Sept. 6	Sept. 14	British Columbian (Sept. 3, 13). Sockeye nets Sept. 20 - 30; Oct. 15 - Nov. 10 (British Columbian; Oct. 15, Nov. 2).
1922	Sept. 23	-	6 1/2 in.	Sept. 23	Nov. 5*	British Columbian (Sept. 21, Nov. 2).
1923-28	Oct. 1	-	6 1/2 in.	Oct. 1	*	Official regulations.
1929	Oct. 1	-	6 1/2 in.	Oct. 1	Nov. 16	Official regulations; Columbian (Sept. 27, Nov. 6).
1930	Sept. 20	Oct. 20	(Complete closure; 6 1/2 in. mesh thereafter)			Columbian (Sept. 17, Oct. 18).
1931-44**	Oct. 1	-	6 1/2 in.	Oct. 1	*	Official regulations.

* Late season closures variable; closures possible throughout October to end December.

** Similar regulations applied until 1955.

way around the nets. It is not only the dimensions of the net that are important; the size of the fish varies both from year to year and within the season, resulting in a variation in their vulnerability to capture by meshes of given sized openings. Fishermen attempt to adjust the mesh sizes of their nets to account for these selectivity factors and fisheries administrators use mesh size regulations to limit exploitation.

Such selective factors can obviously have important effects on the rate of exploitation of the fisheries. The previous section of the report was based mainly on the results of test-fishing studies conducted using commercial gillnets in upstream fishing areas. These nets would have the same selective characteristics as the nets of the fleet under study and thus cannot tell us much about variations in exploitation that occurred as the result of changes in mesh and fish sizes.

Gillnet selectivity of Fraser salmon has, however, been the subject of a considerable amount of study by IPSFC over the years. The purpose of the present section is to review such studies and, from them to develop procedures for adjusting estimates of exploitation rates to account for annual variations in mesh and fish sizes.

EVIDENCE OF SELECTIVITY

Selectivity of the Fraser River gillnet fishery was first shown quantitatively by comparisons of length measurements of sockeye from the United States (non-selective traps) and Canadian (selective gillnet) fisheries (Gilbert 1914). Gilbert noted that the traps took a wider range of sizes of sockeye and termed the selective removal by the gillnets of larger fish "screening". Peterson (1954) analyzed test-fishing experiments done in 1947 and 1948, plus other data, to show that the mesh sizes of linen gillnets used in the Fraser gillnet fishery tended to select the larger sockeye, and demonstrated several effects of selectivity on both catch and escapement. Another test-fishing experiment, undertaken by IPSFC in 1963 (unpublished) to derive selection curves for nylon gillnets, is presented later in the present report.

Net-Marked Sockeye

Sockeye forcing their way through gillnets and surviving to continue their upstream migration often bear scars of their encounter with the nets, most commonly consisting of encircling marks at the point of maximum girth. The incidence of net marks and fork lengths have been recorded from live sockeye during IPSFC tagging at several Fraser sockeye spawning grounds. The most complete records are for the Chilko sockeye run. For this stock, correlation analysis (12 years data; 1952-1961, 1963 and 1964; percentages logged for normality) showed a significant multiple correlation between net-mark frequency (dependent variable), average length and estimated exploitation rate for Chilko sockeye in the gillnet fishery ($R=0.738$, $p=0.03$). Net-mark percentage was significantly correlated with annual average length independent of exploitation rate (partial correlation $r=0.673$, $p=0.04$) while net-mark percentage was less well correlated with exploitation rate independent of average length ($r=0.584$, $p=0.06$).

These correlations indicate that escapement through the meshes of gillnets in the Fraser River fishery varies with the length of sockeye and appears to be greater when sockeye are smaller.

The data were not sufficiently precise to permit their use to develop direct measures of selectivity. One problem that would be encountered if such data were used is that large sockeye which contact a gillnet probably back out of the net and do not receive a recognizable net mark, thereby introducing bias into assessments of the portions of the run that had escaped from the nets.

Size Differences in United States and Canadian Fisheries

Information on average weight differences between non-selective gear types and the selective Fraser River gillnets provides a useful method of evaluating the effect of selectivity on fishing capacity.

The numbers of sockeye required to produce a standard 48 lb case of canned salmon reflects the average size of the fish utilized in the canning operation. Comparisons of the numbers of sockeye-per-case between the Canadian (mainly gillnet) fishery and the largely non-selective United States (mainly purse seine) fishery provide another means of assessing selectivity by the gillnets (Figure 13). Such a comparison can only be indicative since some of the United States catch (usually less than one-third, but around 40% in one year, 1956) also came from gillnets and some of the Canadian catch came from purse seines. The observed differences in size are therefore likely to be less than if the

Canadian catch had in fact all come from the gillnet fishery and the United States catch all from the purse seine fishery.

There is another source of bias in the data which would tend to maximize rather than reduce differences between the purse seine and gillnet data. Three-year-old sockeye, or "jacks" are very small (about half the weight of four-year-olds). They appear to be fully vulnerable to the purse seine fishery but are much less frequently caught in gillnets.[26] However, in addition to this difference in selectivity associated with girth, a much higher weight of the small sparsely fleshed jacks would be required to produce a pound of canned salmon than would be provided by larger sockeye.[26] For this reason, for years when jacks were abundant, United States fish-per-case values would be much too large.

From the foregoing, it is obvious that the fish-per-case data must be used with caution. Nevertheless, the associations shown in Figure 13 indicate that when the average size of Fraser sockeye is small, the average weight of sockeye in the gillnet fishery is higher than that in the non-selective United States fisheries, strongly suggesting that the Canadian gillnet fishery had failed to catch smaller fish in the same proportion they occurred in the passing run. An interesting corollary of the associations shown in Figure 13 is that when the average fish size was very large, the Canadian (gillnet) fish-per-case figures tended to be smaller than those in the United States (purse seine) fishery, suggesting that the gillnets "under selected" very large fish as well as small ones. Ricker (1982) also found evidence of selection for smaller sockeye when the average size was very large. As mentioned previously, the largest sockeye are not taken as frequently by the gillnets because they often can push against the meshes and then back out without becoming entangled.

Differences Between Fraser River and Point Roberts Sockeye Catches

Another indication of the selectivity of Fraser River gillnets was found in a comparison of weekly average weights of sockeye in the relatively non-selective Point Roberts purse-seine catch with corresponding weekly average weights in the selective Fraser gillnet catch. A comparison was made of size differences during the early parts of the 1944-1964 seasons.[27] Since early season sockeye migrate from Point Roberts to the Fraser River gillnet area in about a day, comparisons were made of data collected in each of the two areas in the same weeks.

The analysis, illustrated in Figure 14, reinforces the conclusions drawn from the fish-per-case data discussed in the previous section, namely that there was an inverse correlation in the weight difference between non-selective purse-seine caught and selective gillnet caught sockeye, indicating that the gillnets were less efficient in catching small sockeye than the purse-seine gear.[28]

A complication in analyzing the size difference data was the variable annual occurrence of jack sockeye in the fisheries. Jacks, with average weight normally below

---

[26] Killick and Clemens (1963).

[27] Comparisons were limited to the early season period, usually from late June or early July through the first or second week of August before significant numbers of delaying sockeye appeared at the mouth of the Fraser River.

[28] It should be noted that the two variables correlated in Figure 14 are not completely independent since the weight differences were computed using the purse-seine average weights. However, a regression analysis of the paired weekly average weights (independent variables) yielded a slope significantly different from equality (1.0); $p<0.01$.

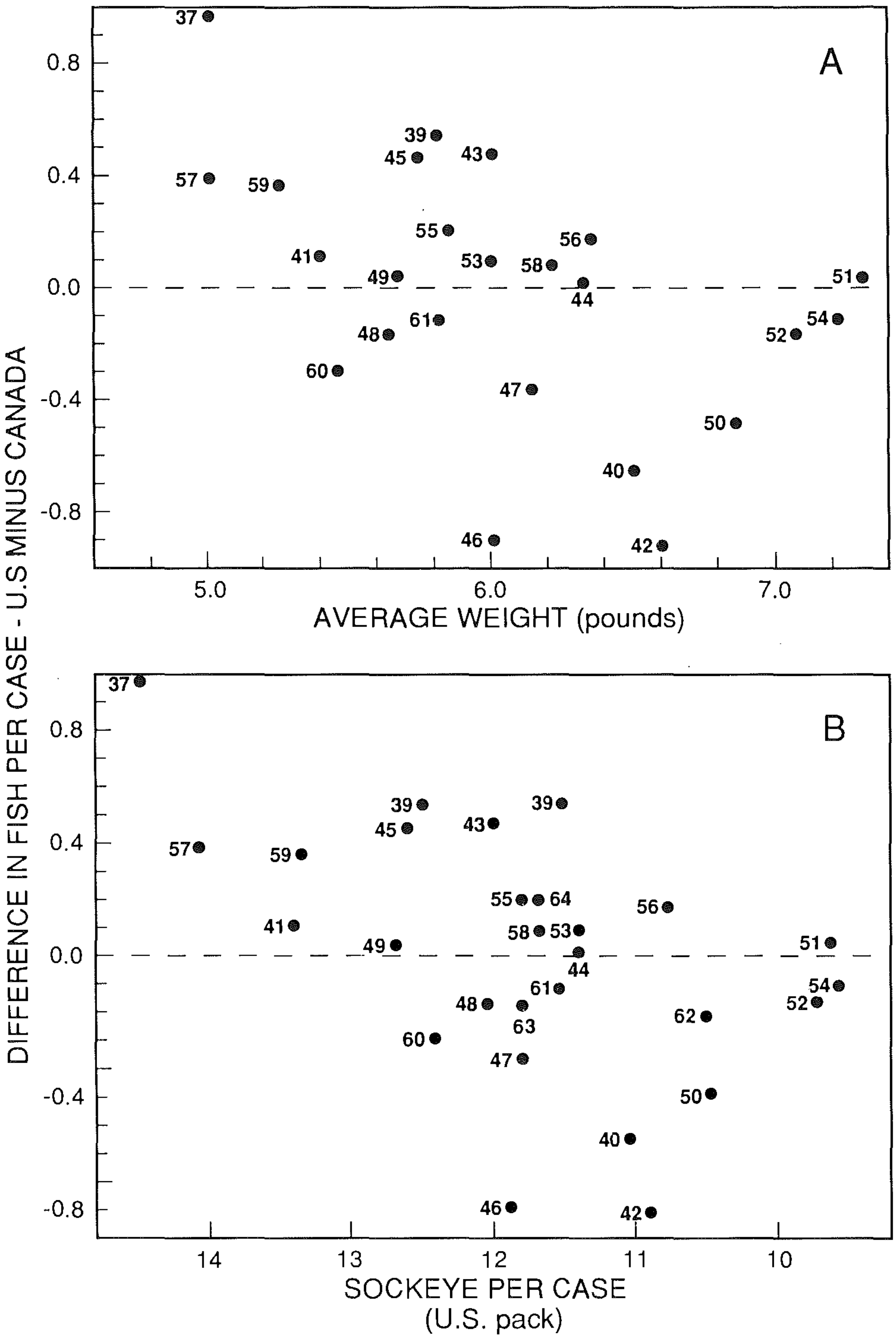

Figure 13. Annual difference in numbers of sockeye per case compared to: A - Annual average weight of sockeye in the United States purse seine fishery and B - Annual average sockeye per case from the United States sockeye pack. Data mainly from Killick and Clemens (1963).

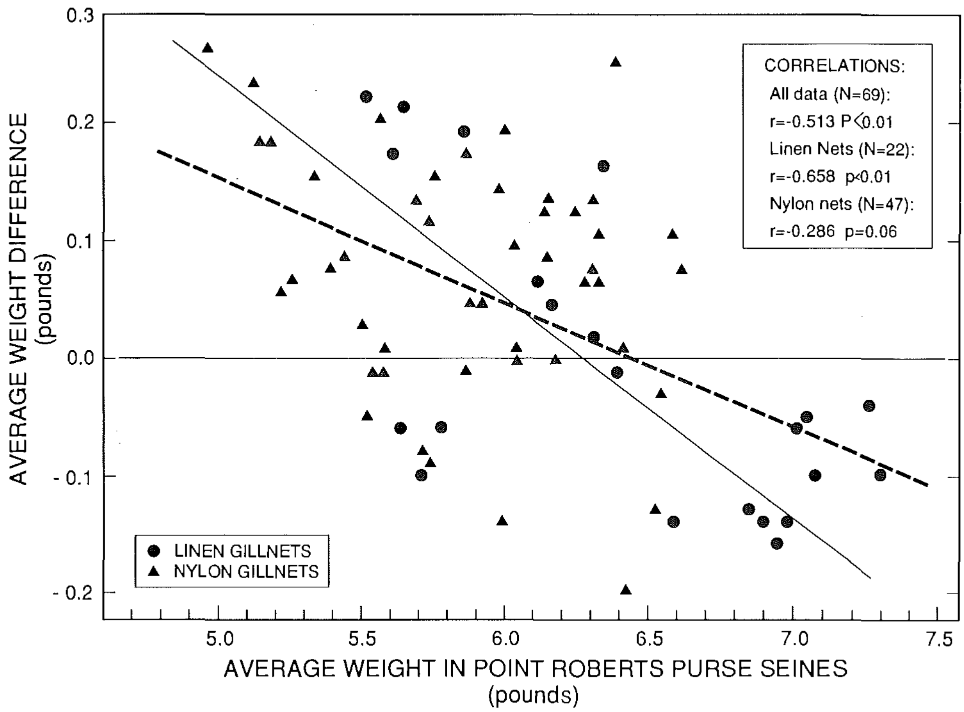

Figure 14. Differences in weekly average weights between sockeye catches by Fraser River gillnets and by Point Roberts purse seines (former minus latter) during 1944-1964. Data for non-delaying sockeye only. Solid line fitted by the method of Bartlett (1949). Dashed line fitted by least squares.

3 lb, were caught by Point Roberts purse seines about as efficiently as adults, whereas Fraser gillnets caught them with very low efficiency. Such great differences, when jacks were abundant, would tend to mask the more subtle selective effects associated with differences in catchability of four- and five-year-old fish, the dominant components of the runs.

To overcome this possible source of distortion, the estimated weights of jacks in both fisheries (based on data obtained from extensive sampling beginning in 1952) were subtracted from compilations of catches in both areas from 1952 onward. This correction lowered the weight differences in Figure 14 by an average of about 0.05 lb approximately equally over the whole sockeye size range. Because linen gillnets (mostly in use prior to 1953) were less efficient than nylon nets at catching jacks, the points in Figure 14 for years with linen gillnets may have been lower by slightly more than the 0.05 lb derived when nylon nets were in use. However, these corrections were considered too small to be applied to the data of Figure 14.

No significant difference was found in Figure 14 between the least squares regressions of average weight differences for the period with nylon gillnets and that with linen nets (analysis of covariance: adjusted means, $F=1.3$, $P>0.05$; regression coefficients, $F=2.2$, $P>0.05$; Snedecor 1946). These statistical tests have questionable validity because, as noted above, the two variables are only partially independent. While a difference is therefore possible between the weeks with linen gillnets and weeks with nylon nets, the adjusted mean weight for nylon nets is larger than the adjusted mean for weeks with linen nets in the gillnet fishery, opposite to what would be expected if the nylon nets were less selective.

EMPIRICAL MEASURES OF THE SELECTIVE EFFECT

From the foregoing analyses of data on net-marked sockeye, fish-per-case differences, and differences in average weight between sockeye caught in the selective gillnet fishery and in the non-selective purse seine fisheries, it is concluded there is a significant relationship between the proportional effectiveness of the gillnets and the size of the sockeye being exploited. Such a relationship could have important effects on the rate of exploitation of the gillnet fishery, effects completely independent of those associated with the duration of weekly closed periods discussed in the preceding section.

To take such factors into account, it is necessary to quantify the extent of their effects. Although all three lines of evidence described above had deficiencies, it was concluded that the weight differences characterized in Figure 14 (comparing purse seine and gillnet size differences) would provide the most accurate representation of the size selectivity phenomenon.

Considering the variability of the data,[29] Bartlett's (1949) approach was used to compute a regression line relating the weekly difference in weights between purse seine and gillnet caught sockeye and average size of sockeye.

At the lower limit of sockeye size, the Bartlett line of Figure 14 was in agreement with sockeye-per-case data of Figure 13. For a population of sockeye averaging 5 lb, Figure 14 called for an average weight excess of about 0.25 lb in the Fraser gillnet fishery over Point Roberts purse seines. In Figure 13 the decrease for Fraser canneries in fish-per-case for 5 lb sockeye would have been in the range of 0.5 to 1.0 fish-per-case, assuming that a steep regression was valid (i.e., the Bartlett line). If an average difference of 0.75 sockeye-per-case is assumed, and given canning efficiencies of 70 lb of sockeye in-the-round per case for each country, an average weight difference of about 0.28 lb results, close to 0.25 lb from Figure 14.

At the other end of the sockeye size range, the regression of Figure 13 is diffuse and the correspondence with Figure 14 is less clear. Taking the Figure 13 regression as is, for a 7 lb sockeye average weight, a sockeye-per-case increase for Fraser canneries of at least 0.8 lb might be expected. At 70 lb of sockeye-per-case in both fisheries, an average weight difference of about 0.5 lb is calculated whereas Figure 14 indicates a difference of only 0.14 lb. Elimination of the possibly erroneous fish-per-case values for the years 1942 and 1946 from Figure 13 would bring the two sets of data into closer agreement.[30]

---

29 In unadjusted least squares fit (dashed line in Figure 11) assumes no error in the Point Roberts purse-seine average weights, a condition not met by the data. The latter approach was therefore rejected in favour of Bartlett's (1949) method, which assumes equal error in the two factors compared. The latter method divided the dispersion of points into three equal groups along the trend of the regression; a line was fitted through the general mean of all points using the slope determined from the means of the two end groupings.

30 In 1942 and 1946, substantial Canadian purse seine fisheries were conducted to exploit large runs of the Late Shuswap stock. Large Canadian purse-seine catches should have resulted in there being close to equal fish-per-case values in the Canadian and United States fisheries. If the data are accurate, the relatively much larger Canadian sockeye-per-case suggests an inefficiency in U.S. canneries for large sockeye catches. This is uncertain since equally large U.S. catches of pink salmon had been processed in previous years. There is however, some doubt as to the reliability of the information used. The two years, 1942 and 1946 were among years when Clemens and Killick (loc. cit.) noted that the United States fish per case data were in error. Also, in these years, very large catches of delaying sockeye were made which may have lowered canning efficiency. In this light, it is difficult to form a critical judgement regarding the relationship between fish size and differences in fish per case between the United States and Canadian fisheries in the two years

Lacking firmer information, the Bartlett line of Figure 14 is considered to be the best representation of the change in selectivity of the Fraser River gillnet fishery with sockeye size variation. It is used in the next section of this report which develops the gillnet selectivity curves to generate the final model relating exploitation rate to variations in duration of weekly fishing periods, fish size and gillnet mesh size.

GILLNET SELECTION CURVES FOR INDIVIDUAL MESH SIZES

Approach

Having established the variable nature of the selective effects of gillnet fleets, it remains to quantify these effects to develop appropriate corrections for the estimation of escapements from the catch data. In considering the development of adjustment techniques, it must be kept in mind that selective effects are not only associated with variations in the size of the fish but also with variations in the size of net meshes utilized by the fishermen. To account for such sources of variations, it was necessary to develop a series of mesh selection curves reflecting the fishing power of different mesh sizes for different sized fish.

Selection curves describe the relative efficiency of a net to catch fish of different sizes. Such curves are constructed by expressing the relative abundances of fish of given sizes that are retained by a net expressed as a fraction of the theoretical proportion of fish of each size that came in contact with that net. In general, a net with a given mesh size will catch fish of a particular girth most effectively, and will catch both larger and smaller fish less effectively. Such curves tend to be smooth unimodal curves, falling off steeply on both sides of the peak or mode representing maximum efficiency (e.g., see Gulland and Harding 1961, and Todd and Larkin 1971). Efficiencies on either side of the bimodal efficiency may be termed Unit Size Efficiencies, and are often expressed as fractions of the bimodal efficiency.

In the present paper, selection curves were developed empirically, following the general method of Gulland and Harding (loc. cit.), rather than the more theoretical approaches of the type developed by Holt (1964). A generalized selection curve assumes that any gillnet of a given type, over the range of mesh sizes used in the fishery, has the same physical characteristics in relation to sockeye capture, e.g., roughness and elasticity of twine. Further, it assumes that sockeye have the same general shape and "elasticity" over the range of sockeye size found in the Fraser River. Fishing effort is also assumed to be proportional to the area of a net panel and to immersion time, regardless of mesh size. Biases caused by departures from these assumptions are believed to be minor.

Prerequisites for developing adequate selection curves include sufficient numbers of fish-size measurements from enumerated catches of the test gillnet with panels of a graded range of mesh sizes exploiting, with known amounts of fishing effort, a population of a specific kind of fish with a constant size distribution. Mesh-size panels may be of different dimensions if they are fished in a uniform manner so that catches can be weighted by panel area to represent equal units of effort. Catches in the most effective panels must not be so large that loss of efficiency results from catches saturating the net.

Selection curves are commonly based on fish length, since length is related by theoretically constant proportion to the girth of the fish, which interacts most directly with mesh lumen (opening) perimeter (McCombie and Fry 1960). However, the only historical data on sockeye size variation involved average weights derived from fish-per-case information. Selection curves were therefore calculated on the basis of weight, which was

---

in question.

measured for each sockeye caught in all experiments. Although sockeye weight varies approximately as the cube of the length, few length:weight regressions for sockeye on spawning migrations displayed significant curvature, apparently because the range of length and weight was restricted and variation from trend was large, i.e., condition factor was highly variable. As will be apparent in the results presented later, such variability does not invalidate the basic adjustment factors developed in the analyses.

The results of two series of gillnet selectivity studies conducted by IPSFC were utilized, one on linen gillnets conducted in 1947 and 1948 (Peterson 1954) and another on nylon gillnets in 1963 (unpublished).

Limitations in the Data

Linen Gillnet Selectivity Experiments in 1947 and 1948: The 1947 and 1948 experiments were not conducted specifically to develop selectivity curves and consequently some of the prerequisites for developing selection curves listed in the preceding section were not met. Fishing was in the main Fraser River channel, at or below Steveston, where the tidal cycle caused large changes in water level and current speed, and river current was strongly reversed. The two linen nets tested (fished simultaneously by two boats) contained equal area panels (equal length and linear depth) for ten mesh sizes (five to each net). Panels were laced together. Each net included a range of mesh sizes from small to large, distributed between nets by a pairing system. Panel positions were redistributed for each weekend test fishing period by lot. Ends of the nets held by the boat during the drifts were changed infrequently resulting in large differences in average immersion times between end panels. An analysis with details of the experiments is found in Peterson (1954). The latter variations necessitated sizable corrections in order to standardize the data in terms of duration of net immersion.

Test fishing was conducted throughout the sockeye season in both years. Changes in sockeye size from week to week required restriction of selection curve analysis to a three week period in 1948 when catches in the two nets were large (2,342 fish caught) and sockeye size distribution remained relatively constant.

Nylon Gillnet Selectivity Experiment of 1963: The selection experiment with nylon gillnet mesh in 1963 was designed to equalize panel fishing times by breaking the single drift gillnet in the middle periodically through a fishing period covering five days and alternately rotating the halves, which contained three panels each. In addition, the boat changed net ends during most of the 62 drifts (ten drifts excepted) to equalize immersion times for each end of the net. Longer mesh-panels were employed for the larger and smaller than optimum mesh sizes to get a better catch representation in mesh sizes where small catches were expected. As in 1947 and 1948, panels were fastened together with vertical seams and panel depths were a constant linear measurement.

There were deficiencies in the 1963 experiment, including drifts noted above in which net ends were not changed. Of the 2,567 sockeye caught in the 1963 experiment, only 2,381 usable weight measurements were obtained due to errors (10 fish) and tags lost in transit between the location of catch and the measuring station. Because no weights were taken from the 176 sockeye with lost tags, no statistical test of differences could be made; it was necessary to assume that they did not significantly distort the distribution of sockeye weights caught in any mesh-size panel.

The 1963 test gillnet was fished during a fisherman's strike when partial commercial fishing was in progress, consequently selection by the gillnets downstream may have variably affected the size of sockeye in test catches. However, no consistent difference was found in mean weight of sockeye in catches in individual mesh sizes between the approximately 3.5 days which could have been affected by competitive fishing and the following 1.5 days which were unaffected. The 12 "Student's" t tests of differences by sex within the six mesh size panels showed only three with probabilities (of larger t) of 0.05 or less. Moreover, in five of the 12 cases, sockeye were smaller after the influence of other fishing had ended whereas larger sockeye might have been expected; the probability of no effect of commercial fishing (i.e., significance of difference from 6:6 ratio) is approximately 0.4 (Chi^2 test). Assuming that all catches made after the influence of other fishing had ceased should have had larger average weights, the five decreases are significant (p=0.02), also by Chi^2.

Examination of the mean weight of catches in the various mesh sizes in 1963 failed to indicate that large sockeye, rejected by one mesh size were led into the next panel (of a larger mesh size) due to lack of spacing between panels. In the eight cases where mesh size of adjacent panels was changed by reversal of the net halves, the shift in mean weight in a given panel with change in mesh size in the adjacent panel was not consistent. In the 16 comparisons (sexes separate) of catch mean weight before and after such change, only two showed a significant change ("Student's" t; probabilities ≤ 0.05). It is concluded that any leading of sockeye between panels was too little to show an effect in the data. Presumably, this would also apply to the linen gillnet selectivity experiment.

DERIVATION OF SELECTION CURVES

As previously mentioned, to assess the selectivity of the gillnet fleet resulting from variations in the average size of sockeye in the runs and in the meshes and construction of the nets used by the fishermen, the procedures developed by Gulland and Harding (1961) were applied to the 1947-48 and 1963 test fishing data to develop a series of selection curves.

Data from the test fishing catches were first standardized to account for variations in immersion time (for both experiments) and for panel length (for the 1963 experiment), providing lists of catches per standard fishing effort and standard fishing time.

For both the 1947-48 and the 1963 experiments, standardized catches in each mesh size were tabulated into .25 lb weight intervals (weight groups). Weights in 1947-48 were to the nearest ounce and in 1963 to the nearest .25 lb. Frequencies were smoothed by threes with 1:2:1 weighting (normally weighted smoothing; Loucks 1964) to minimize "saw-tooth" frequency distribution effects, which can result when measurements are recorded into intervals with observer bias, e.g., preference for even values.

Smoothed frequencies within each weight group were then plotted against panel mesh size. For example, as illustrated in Figure 15, using the 1948 data, the smoothed weighted catch of 6 lb fish in the 5.25 in. mesh was 39.7, in the 5.5 in. mesh 52.5, in the 5.75 in. mesh 102.9, in the 6.00 in. mesh 70.8, in the 6.25 in. mesh 29.2, and in the 6.5 in. mesh 3.2. Drawing a smoothed curve through the points suggests a theoretical optimum mesh size indicated by the arrow) of 5.79 in.. At that mesh size the catch would have been about 106 sockeye. Data for all sizes of sockeye between 4.75 and 7.5 lb are shown in Figure 16.

The next step in developing the model was to use data such as that illustrated in Figure 16 to develop a generalized selection curve for the type of gillnet used in the Fraser River fishery; that is, an average curve representing the efficiency of any mesh size (within a net type) for individual sockeye size over the range of sockeye sizes encountered in the Fraser River.

Based on such data, selection curves can be derived for meshes of any given size. For purposes of the present analysis this is best done by calculating efficiencies in relation to catches of sockeye of a given individual weight of fish in a net of optimum mesh size.

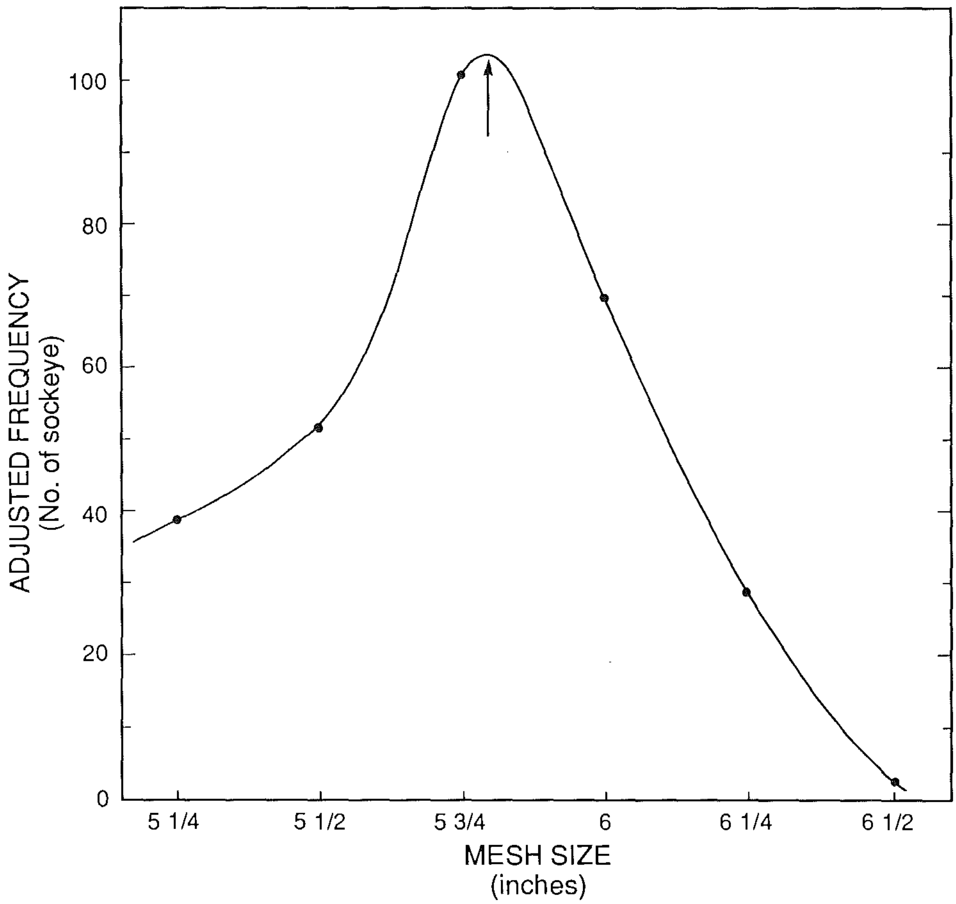

Figure 15. Smoothed curve relating weighted test fishing catches of 6 lb sockeye in different mesh-sized panels. Data from catches by linen gillnets during three weekend closures in 1948.

This is done for a series of mesh sizes used in the commercial fishery varying from 5.25 in. to 6.5 in..

To illustrate the procedure, consider the data for the 5.25 in. mesh. From Figure 16, for 4.75 lb sockeye (top left hand panel), the optimum mesh size was estimated to be about 5.18 in., yielding a weighted catch of about 114. From the same curve, the catch of 4.75 lb fish in the 5.25 mesh was 110.6. Expressed in relative terms it was 110.6/114 = .970 of optimum efficiency. Moving to the curve for 5.0 lb fish, the weighted catch at maximum efficiency was 122 (in a mesh of about 5.31 in.) and the catch in the 5.25 in. mesh was about the same. Similarly the optimum catch for 5.25 lb sockeye was 131 and the catch in the 5.25 in. mesh was 110. For 5.5 lb sockeye, the optimum was 123 and the catch in the 5.25 in. mesh, 109.5. The relative efficiencies therefore were, for 5 lb fish, 122/122 = 1.000, for the 5.25 lb fish 119.5/131 = .836, and for the 5.5 lb fish, 84.5/123 = .687. Carrying out similar calculations for other fish sizes (from 4.75 up to 7.5 lb provides the basis for drawing a comprehensive selection curve for the 5.25 in. mesh. The curve is illustrated at the left side of Figure 17. Curves for other mesh sizes up to 6.5 in. are included to the right of the curve for 5.25 in. in the figure.

At this point, deficiencies in the data become apparent. The largest discrepancies were found in the catches of the 6.25 in. mesh panels. This mesh size caught too many sockeye in the 6.0 and 6.25 lb groups and too few in the size groups of 7 lb and above, relative to the other mesh panels, probably due to the irregularities in the fishing

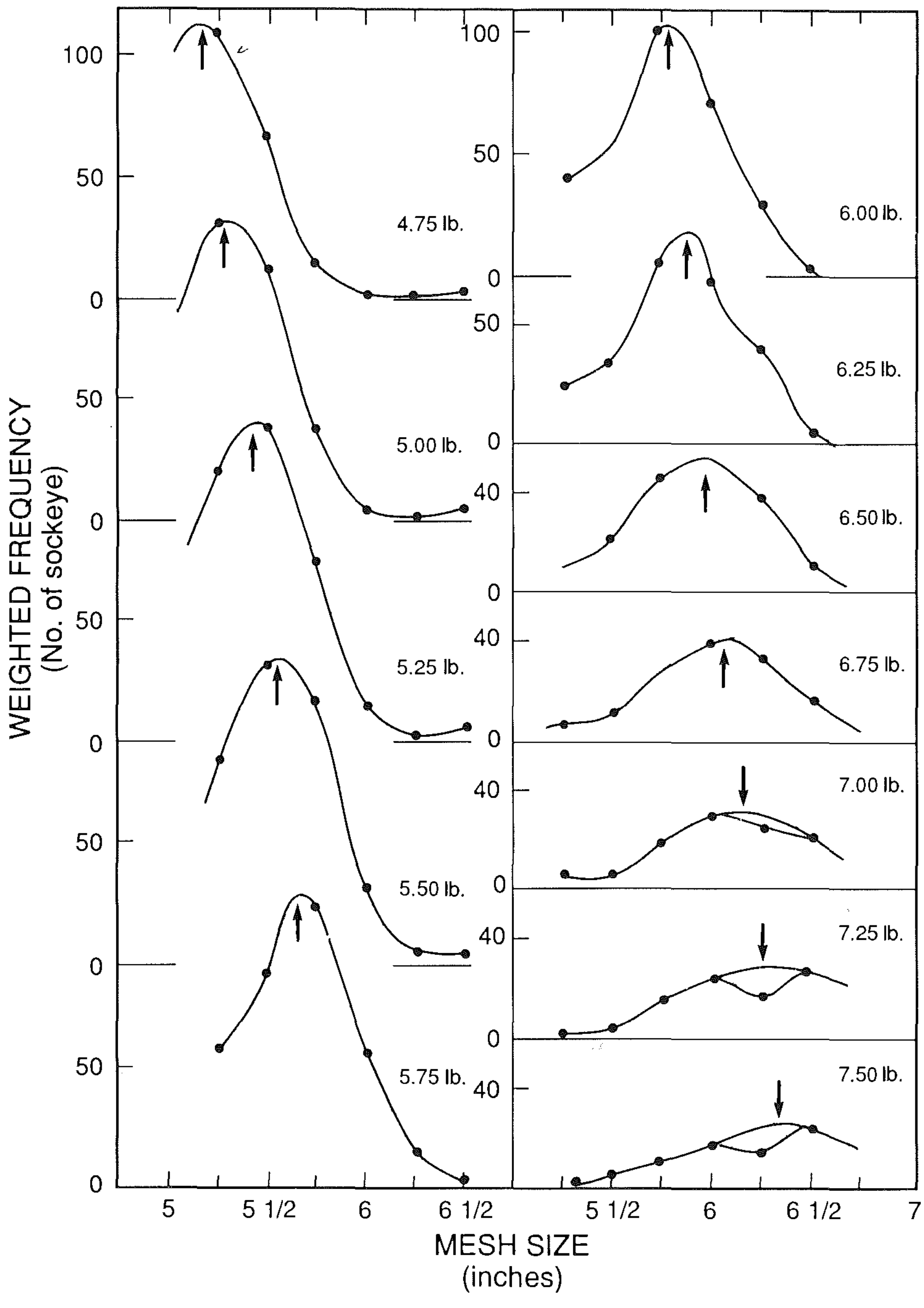

Figure 16. Corrected and smoothed sockeye catches within 0.25 pound weight plotted against gillnet mesh sizes. Data for catches by linen gillnets during three weekend closures in 1948. Arrows indicate estimated optimum mesh sizes for each weight group.

procedure.

Nevertheless, on the basis of the plots, assessments were made of apparent optimum mesh size for each weight group of sockeye (indicated by arrows in Figure 16). Plotting optimum mesh size against fish weight resulted in a virtual straight line relationship (Figure 18). Data for the 6.25 in. mesh size was omitted due to its obvious inconsistency with data for the other meshes.

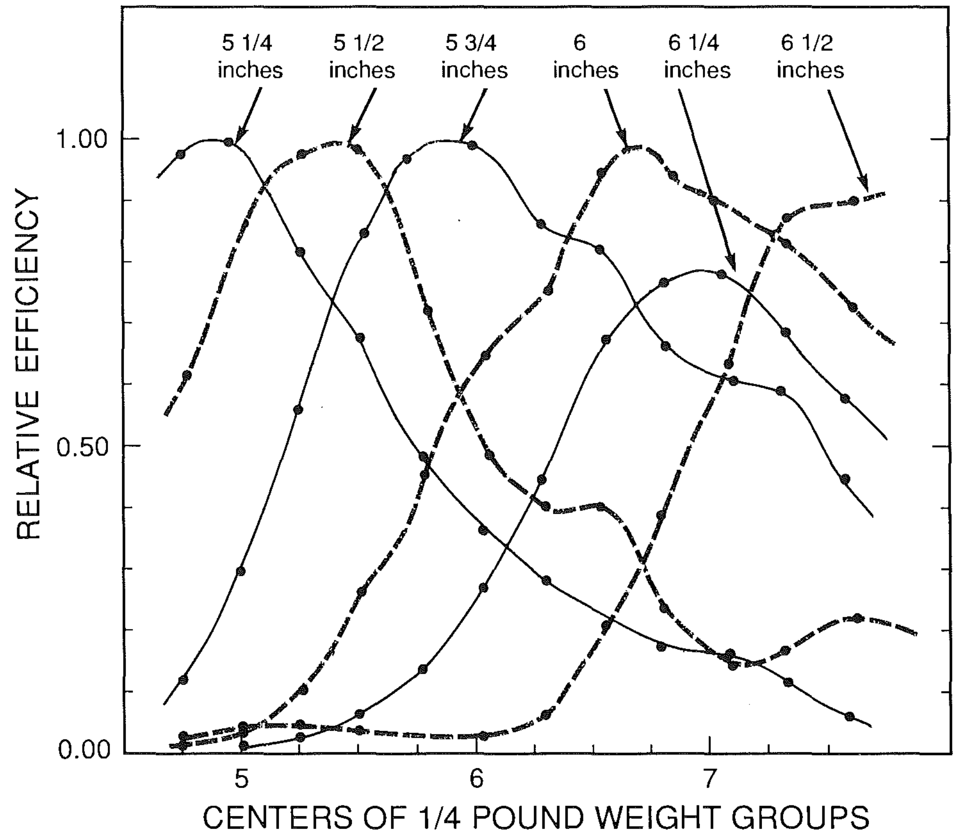

Figure 17. Selection curves for the six most effective mesh sizes in the 1948 linen gillnet selectivity experiment (sexes combined) plotted as relative efficiencies.

Because the individual selection curves of Figure 17 were somewhat irregular, it was desirable for later computations to it was desirable to combine them into a single, smooth generalized curve representing all the mesh sizes involved. This might be done by placing them together, with the modes coinciding, so that the local curve efficiencies are plotted against difference in weight from the bimodal weight rather than the actual weight. However, because selection curves would be expected to become narrower for the smaller mesh sizes, a different horizontal scale would be required to make the curves of Figure 17 coincide more closely. Such a scale may be taken from Figure 18, using mesh sizes corresponding to the weight of fish at any point, from which the ratio of optimum mesh size to mesh size for any local selection efficiency is obtained. This ratio compensates for the effect of decreasing mesh size noted above since the optimum mesh size lines of Figure 18 are slightly curved. As an example, the 5.5 in. mesh size of Figure 17 has, for 5.75 lb sockeye, an optimum mesh size of 5.68 in.; the ratio of optimum mesh size to mesh size in question is 5.68/5.50 = 1.033. The relative catch of 5.75 lb sockeye by the 5.5 in. mesh from Figure 17 was 0.728; this latter value is then plotted against the mesh size ratio given above. Figure 19 shows the six selection curves of Figure 17 superimposed in this fashion. Figure 20 represents generalized selection curves for males, females and both sexes combined derived by drawing smoothed curves through composite plots such as that illustrated in Figure 19.

Comparison of generalized selection curves for linen and nylon gillnets show a wider range of acceptance by weight for nylon nets (Figure 21). Maximum efficiency of the two net materials were considered to be equal. A wider acceptance range in nylon nets is ascribed to the increased strength and elasticity of nylon (and other synthetic materials) among other attributes. Some of the wider selection of the 1963 nylon net resulted from

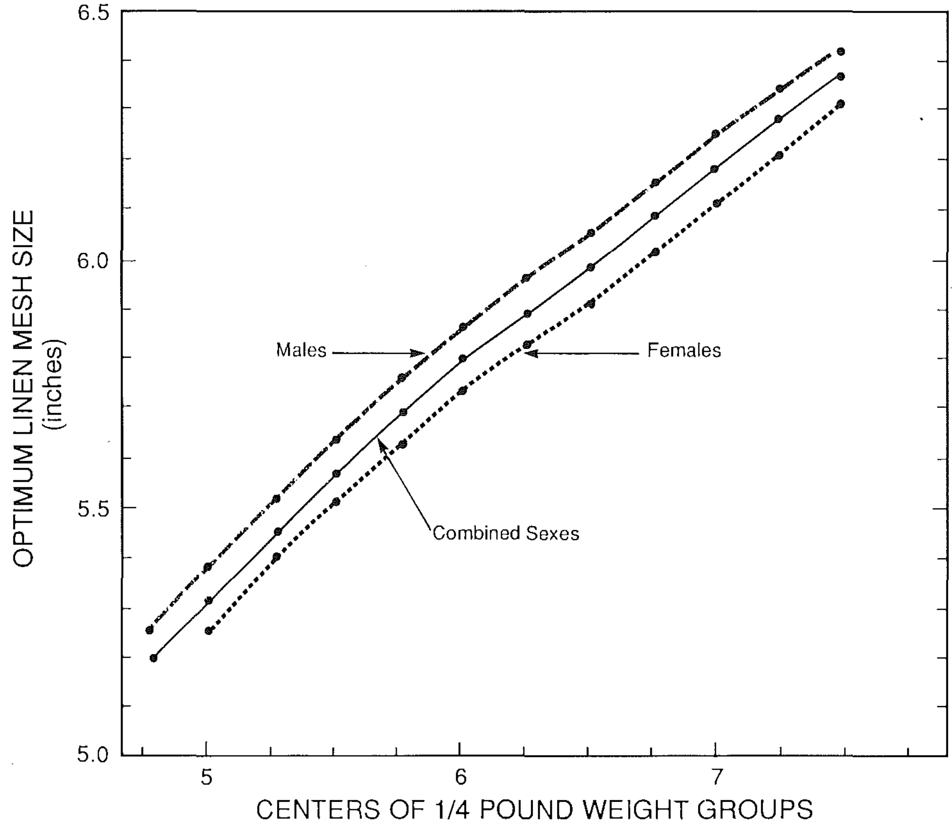

Figure 18. Optimum mesh sizes for male, female and sexes combined by weight determined from data from the 1948 linen gillnet selectivity experiment.

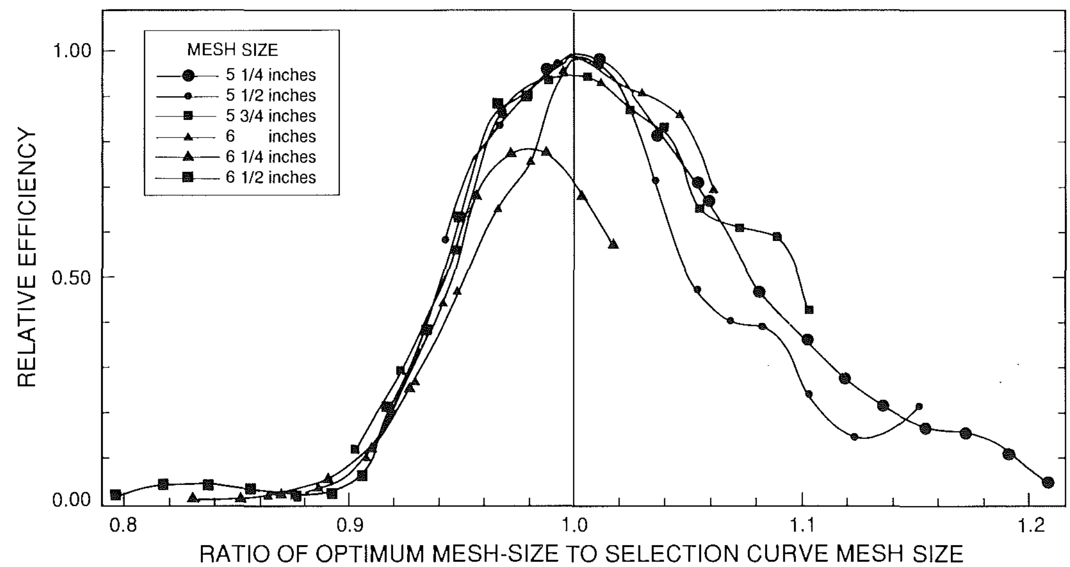

Figure 19. Superimposed selection curves for the six most effective mesh sizes from the 1948 linen gillnet selectivity experiment, sexes combined.

its tangling propensity due to the "hanging in" of almost a third more netting along the net lines compared with the linen nets tested in 1948.

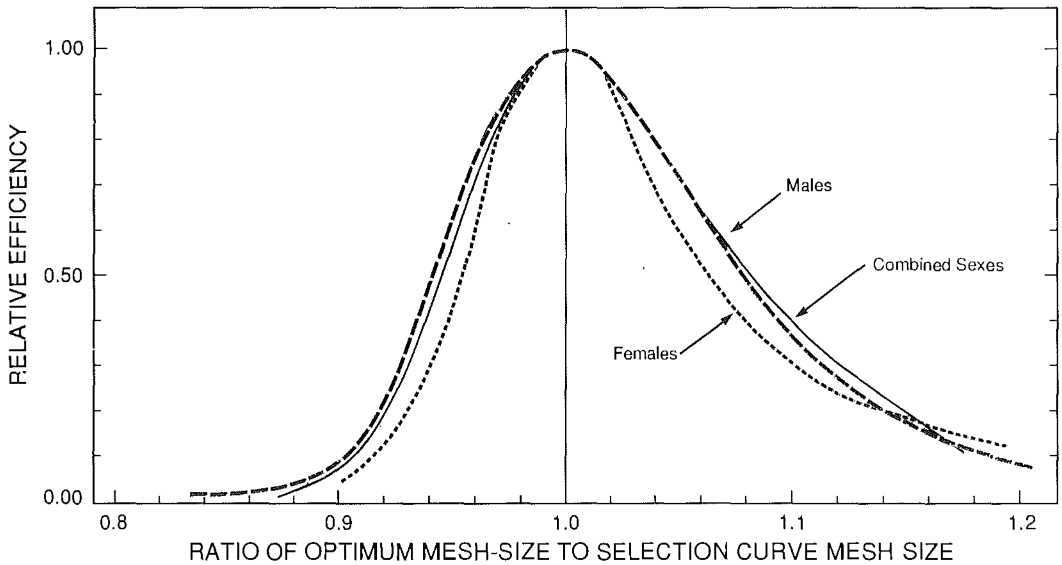

Figure 20. Generalized selection curves for male, female and sexes combined derived from the 1948 linen gillnet selectivity experiment.

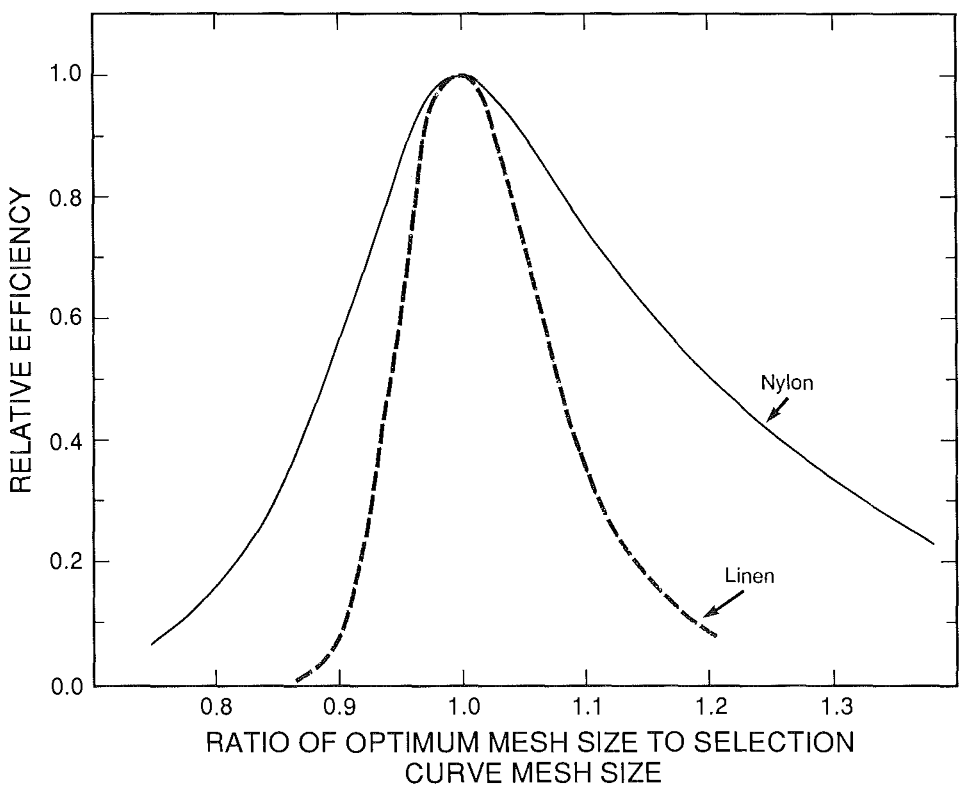

Figure 21. Selection curves for sockeye (sexes combined) for linen (1948 experiment) and nylon (1963 experiment) gillnets.

Selection curves derived from either length or weight are approximations at best, for several reasons. In sockeye at least, catches which are not near the optimum size for a given mesh will have a somewhat distorted length vs weight relationship because either long-and-slim or short-and-plump fish will be selected, due to the variable condition factor in the population. Obscuring this distortion are a variety of non-optimum size interactions such as entanglement at the gill covers and in the teeth, whereas most sockeye are caught by wedging between the head and the maximum girth at the dorsal/ventral fin enlargement. This perhaps explains some of the irregularities in the individual curves of Figures 16 and 17.

The selection curves developed above were used to estimate the selectivity of various meshes of nets used in the commercial fisheries. As will be outlined in the next section, these curves permitted development of composite curves reflecting the variability in selectivity exhibited by the Fraser River gillnet fleet fishing returning sockeye runs exhibiting different average annual sizes.

DEVELOPMENT OF EMPIRICAL SELECTION CURVES FOR GILLNET FLEETS

To use the selectivity data to adjust estimates of exploitation in the Fraser River sockeye fishery, it is desirable to develop two bodies of information:

- The mixtures of nets of different mesh sizes and materials used by the fleet in each year; and,
- annual estimated weight/frequency distributions of the unselected sockeye runs returning to the river.

Mesh Sizes in Use

Information on the mesh sizes of nets actually used by the fleet is fragmentary except for some information collected by the IPSFC in the 1940s. Peterson (1954, his Figures 20 and 25) listed mesh size distributions for 1946 and 1948. Because large fish were expected in 1946, the most frequently used mesh size was 6 in., whereas 5.75 in. mesh was most common in 1948 when sockeye of intermediate size were the prospect. Unpublished data for 1949, a year of the cycle with the lowest average weight, indicated that 5.5 in. mesh nets were most prevalent, followed by 5.75 in. nets. Records from a small cannery at Steveston listing net purchases in the spring (prior to the sockeye season) in the years 1926 through 1940, included no nets smaller than 5.75 in. mesh except in 1937 when the run consisted of near-record small sized sockeye. Small sockeye may have been anticipated from the low average weight of sockeye in 1933. Possibly the gillnets used by fishermen who fished for this cannery were not completely representative of the whole fishery, since fishermen farther up the river sometimes used nets with slightly smaller mesh than those fished around the Fraser mouth. General information for the years before the 5.75 in. mesh minimum was removed (in 1929) indicated mainly 5.75 in. or 5.8125 in. (5 13/16 in.) mesh nets in use in most years.

Cursory examination of these facts confirms fishermen's beliefs that the meshes they use tend to maximize the <u>weight</u> of fish caught rather than numbers, i.e., the nets select for larger rather than smaller fish. A subsidiary reason for the fishermen selecting nets with meshes possibly above optimum mesh size is that use of such large meshes facilitates the removal of fish from the nets. With the larger mesh sizes, most of the gilled fish may be quickly pulled through the mesh lumen rather than having to be tediously "backed out" of the net. These factors appear to have caused the average mesh size in normal use on the Fraser to be larger than optimum from the point of view of maximizing the numbers of fish caught, thus allowing increased escapement of small sockeye.

These conclusions suggest that the Fraser River gillnet fleet adjusted its mesh size distribution only partially toward the most efficient dimension for the size of sockeye present in any year. The strong tendency to use linen nets of about 5.75 in. mesh size in most years was probably to minimize expense for those fishermen who could only afford, or were only supplied with, one net. Transfer of small mesh nets (5 in. to 5.5 in. mesh) to the Fraser from early season sockeye fisheries in other areas when Fraser sockeye were smaller than average was apparently infrequent. When Fraser sockeye were very large, "fall" nets of 6 in. mesh or slightly larger could be used. Fall nets were ordinarily used on coho and chum salmon runs in September and later but apparently not all fishermen had these nets or could obtain them.

Based on the foregoing information, four different mixtures of nets with different mesh sizes were chosen to characterize the possible selective patterns of the Fraser gillnet fishery during the period under consideration, varying from mixtures of 5.5 and 5.75 in. meshes (Bar diagram A in Figure 22 to mixtures of 5.75 and 6 in. meshes (Bar diagram D).[31] It is recognized that the four arbitrarily chosen mixtures represent part of a continuous series of mesh mixtures that would have been used in the fishery. However, the four cover the probable range of mixtures used and are adequate for assessing likely year to year differences in size selectivity exhibited by the gillnet fleet.

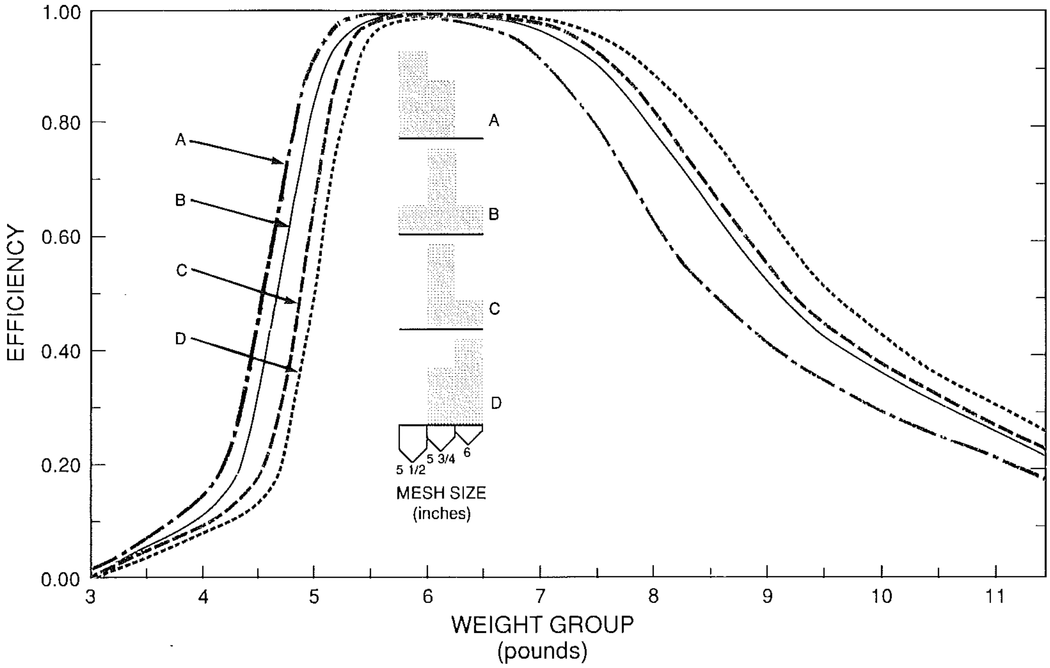

Figure 22. Selection curves for four hypothetical Fraser River gillnet fleets using different combinations of meshes (indicated in the histograms labelled A-D in the centre of the figure).

Following development of estimates of the selective effects of individual mesh sizes on sockeye populations comprising fish with differing size compositions, the aggregate effects of the four mixtures were considered as a basis for estimating exploitation rates of the fishery during 1892-1944.

Selection Curves for Linen Net Mesh Mixtures

The analysis first involved determining the efficiency of the selected net mesh mixtures in exploiting sockeye runs exhibiting different size distributions.

[31] Mesh mixture proportions: A, 60% 5.5 in.; 40% 5.75 in.; B, 20% 5.5 in.; 60% 5.75 in.; 20% 6 in.; C, 80% 5.75 in.; 20% 6 in.; D, 40% 5.75 in.; 60% 6 in..

Idealized Size Distributions: Ten years of size composition data were selected from the extensive sampling information summarized by Killick and Clemens (loc. cit.) for 1927 through 1957. The years were selected to provide a wide range of average sizes from 5.01 lb (1937) to 7.23 lb (1951). Weights for each of these ten years were plotted and smoothed curves developed (Figure 23). Data for one of the years (United States seine-caught sockeye in 1956), are listed in Column II of Table 9, with smoothed frequencies entered under Column III and expressed as percentages in Column IV).

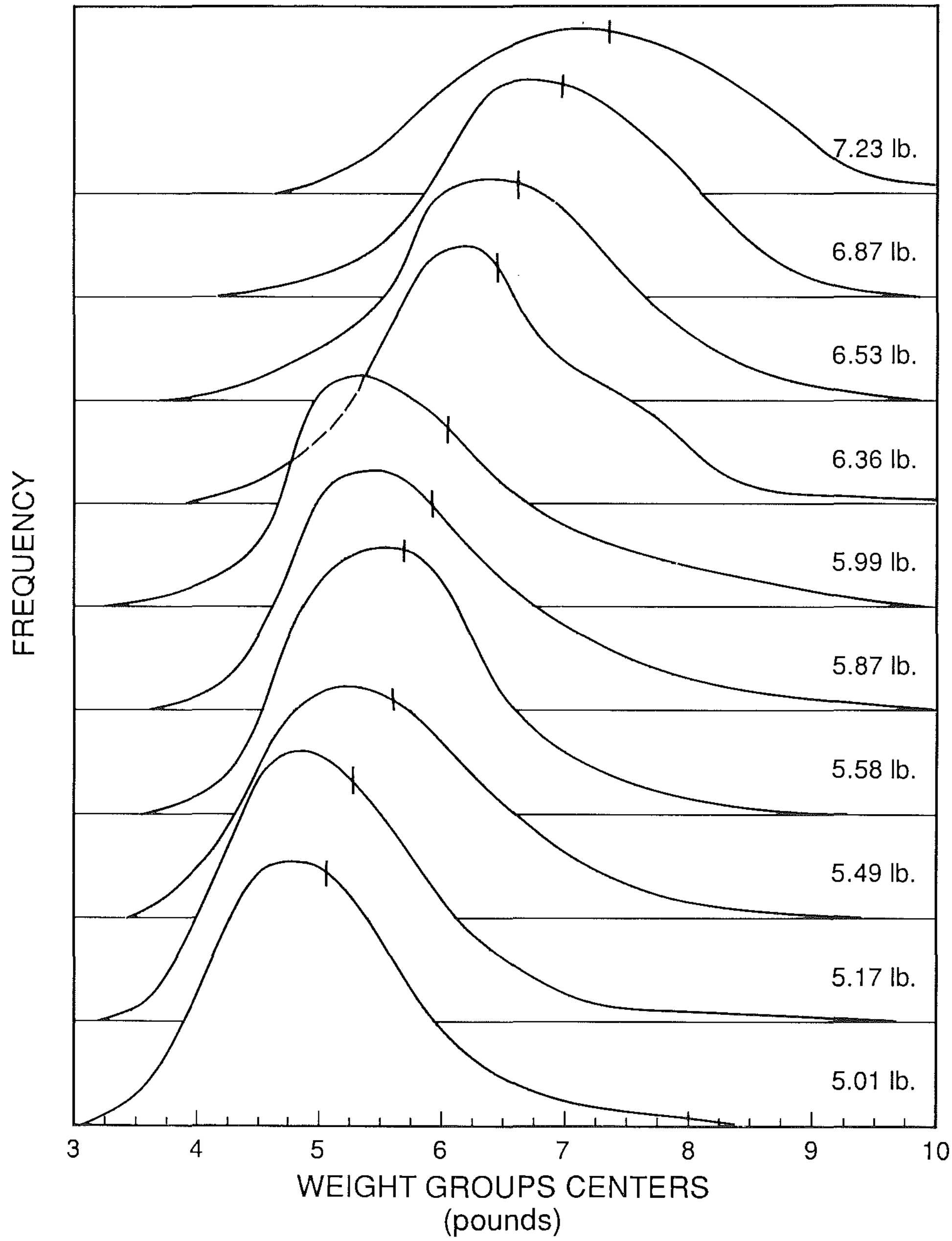

Figure 23. Smoothed weight frequency distributions of Fraser sockeye catches sampled during selected years during 1927-1957. Source: Killick and Clemens (1963).

Mesh Size/Fish Size Interaction: To illustrate the procedures followed to establish the mesh size/fish size interrelationship, consider the selective characteristics of the 5.75 in. linen mesh exploiting a run with size distribution listed in column II of Table 9. As

TABLE 9. Estimation of the efficiency of a 5.75 inch mesh linen gillnet hypothetically exploiting a sockeye population with average weight of 5.99 lbs.*

I	II	III	IV	V	VI	VII
	Population Weight Distribution					
Centers of 0.25 lb Weight Groups	Raw Frequencies	Idealized Frequencies	Normalized Frequencies (Percent)	Unit Selection Curve Efficiencies	Product of Columns IV and V	Column V Changed to Absolute Efficiencies
3.50	1	0.4	0.1	0.008	0.0008	0.000104
3.75	2	1.8	0.4	0.012	0.0048	0.000156
4.00	4	3.5	0.8	0.017	0.0136	0.000221
4.25	7	7.1	1.6	0.022	0.0352	0.000286
4.50	12	13.3	3.0	0.030	0.0900	0.000390
4.75	14	24.3	5.5	0.082	0.4510	0.001066
5.00	43	45.1	10.2	0.252	2.5704	0.003276
5.25	54	49.9	11.3	0.570	6.4410	0.007410
5.50	47	49.5	11.2	0.850	9.5200	0.011050
5.75	50	46.0	10.4	0.978	10.1712	0.012714
6.00	43	40.2	9.1	0.994	9.0454	0.012922
6.25	30	31.4	7.1	0.907	6.4397	0.011791
6.50	25	23.9	5.4	0.781	4.2174	0.010153
6.75	17	19.0	4.3	0.656	2.8208	0.008528
7.00	27	16.4	3.7	0.523	1.9351	0.006799
7.25	16	14.1	3.2	0.427	1.3664	0.005551
7.50	13	12.4	2.8	0.336	0.9408	0.004368
7.75	12	10.6	2.4	0.269	0.6456	0.003497
8.00	7	8.8	2.0	0.215	0.4300	0.002795
8.25	6	7.1	1.6	0.179	0.2864	0.002327
8.50	4	5.8	1.3	0.148	0.1924	0.001924
8.75	5	4.4	1.0	0.123	0.1230	0.001599
9.00		3.1	0.7	0.103	0.0721	0.001339
9.25	2	2.2	0.5	0.090	0.0450	0.001170
9.50		1.3	0.3	0.080	0.0240	0.001040
9.75		0.4	0.1	0.073	0.0073	0.000949
10.00	1	0.0		0.067	0.0000	0.000871
Totals	442	442.0	100.0	N/A	57.8894	N/A
Average Weight (lbs)	6.00	5.99	5.99	N/A	5.99	N/A

Relative efficiency of 5.75 inch mesh on the population is sum of column VI divided by the sum of column IV; 57.8894/100 = 0.578894 (58% approximately).

* Weight frequency measured from purse-seine caught sockeye in U.S. fishery in 1956.

shown in Figure 18, a 5.75 in. mesh would be optimal for catching sockeye of about 5.99 lb.) Column V of Table 9 lists the appropriate relative efficiencies for each size of fish listed in Column I. The efficiencies were taken from the generalized selection curve (sexes combined) illustrated in Figure 20. Thus, at fish sizes near the optimum, the relative efficiency was near 1.0. At about 6.5 lb, the optimum mesh size would have been about 6 in. (about 1.04 times larger than the 5.75 in. mesh). From Figure 20, it is indicated that the 5.75 in. mesh would have been only about 77.8% as efficient as an optimum sized approximately 6 in. mesh. In a similar way, for fish of about 5.5 lb (for which the optimum mesh size would have been slightly over 5.5 in.), the relative efficiency would have been about 85% of that of the optimum 5.5+ in. net.

Values were calculated in a similar manner for all the other weight intervals listed in Column I of Table 9. These values were then applied to the frequencies for each of the intervals. Thus, for example, 6 lb sockeye, near the optimum weight frequency for the 5.75 in. net, formed about 9.1% of the idealized weight frequency of the sample. For fish of this size, the relative efficiency of the net was considered to be 99.4% (Column V). Taking into account this efficiency, it would be estimated that the relative proportion of the population of this size that would be taken by the net would be .994 X 9.1 = 9.0454%. In a similar way for 6.5 lb fish the adjusted percentage would have been 4.2174 (compared to an unadjusted 5.4) and for 5.5 lb fish, 9.52 compared to 11.2.

For the entire spectrum of fish sizes and the frequencies for the idealized population being considered, the table indicates that, compared to maximum efficiency of 100%, a 5.75 in. net would have taken 57.9% of the total that would have been taken had all size classes of fish been caught by optimum meshed nets.

Similar calculations were carried out for the other ten years of size frequency data. The results are shown in Figure 24. This figure shows that for years when the average was substantially higher or lower than the approximate 6 lb optimum size for the 5.75 in. net relative efficiencies dropped; around 35% when average weights were around 5 lb and around 55% when average weights were slightly over 7 lb This compares with an apparent peak of about 63% when average fish size was slightly over 6 lb.

Calculation of Absolute Efficiencies

The foregoing calculations provided estimates of relative efficiency. In order to estimate actual rates of exploitation exerted by the nets, such relative efficiencies must be transformed into absolute efficiencies, i.e., the absolute proportions of fish of given size characteristics exposed to fishing by the net. Earlier in the paper, it was estimated that the absolute efficiency of a single set of one net was 0.001, and with a reasonable average of eight sets a day, the daily efficiency would be in the order of 0.008.

However, this efficiency does not reflect the efficiency of the net for fish of different size groups. The figure 0.008 would be an aggregate efficiency for fish of all sizes coming into contact with the net. The efficiency of the net for fish for which it was optimally suited would be higher than 0.008 whereas its efficiency for significantly smaller or larger fish would be less. On the basis of the general selectivity curve shown in Figure 20, it was concluded that overall efficiency of a net for sizes of fish available to it was about 60% of the efficiency of the net for fish of its appropriate optimum size group. Thus, for fish of that optimum size, the daily net efficiency would be about 0.008/.6 = 0.013. The absolute efficiency of the net for all other size groups will be given by prorating their relative efficiencies (and abundance, as represented in one of the ten historical size frequency series). Thus, in Table 9, Column VII gives appropriate absolute daily efficiencies for the 5.75 in. net for each of the size groups for the 1956 size series.

The purpose in calculating absolute efficiencies for individual size groups for individual nets is to permit estimating the overall selective effects of several nets of different sizes used in combination, such as Series A-D in Figure 22.

Since the nets compete with one another, efficiencies of combinations of nets cannot be calculated by using simple sums. Instead, efficiencies must be expressed in terms of instantaneous rates. Adding the instantaneous efficiencies gives the total instantaneous efficiency, which can then be converted back to an arithmetic rate for ease of computation.

On the basis of the selectivity data presented above, it should be considered that each net has a different efficiency for catching fish of each size, i.e., the net exerts a specific

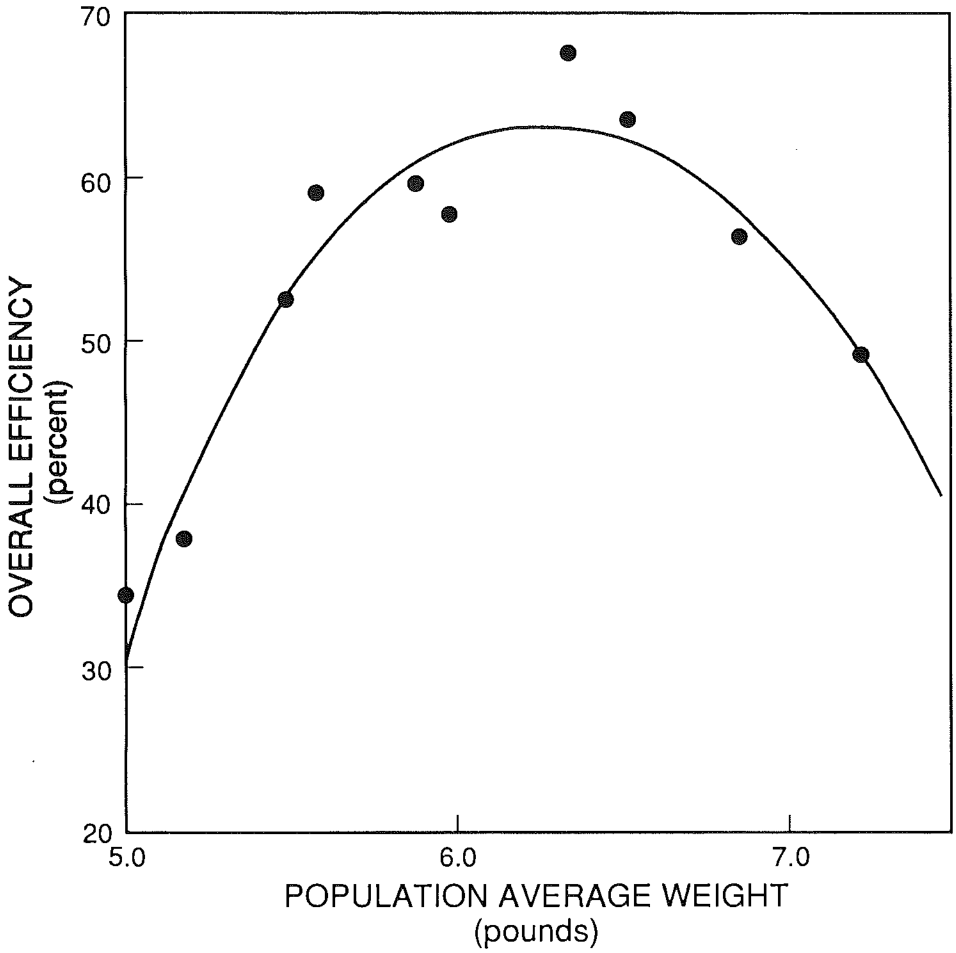

Figure 24. Estimated fishing capacities for linen nets fishing sockeye populations with different annual average weights.

rate of exploitation (efficiency) on each size group. The efficiency for each size group might be termed the Unit Size Efficiency, **S**. If the corresponding instantaneous Unit Size Efficiency rate is **s**, then:

$$(2) \qquad S = 1 - e^{-s} \text{ , and}$$
$$s = -\log_e (1-S)$$

As described above, for a given net, for the fish size at which the net is optimally efficient, S = 0.013. The equivalent instantaneous rate (s) is 0.013085.

For a series of nets of the same mesh size, the aggregate efficiency (S_n) would be calculated as:

$$S_n = 1 - e^{-ns}$$

Where n = the number of nets.

For example, for 400 nets with the same efficiency, for the size class of maximum efficiency, the aggregate efficiency, S_{400} would be:

$$S_{400} = 1 - e^{-(400)(0.013085)} = 0.9947$$

This value applies to the single weight group selected. To develop the selection curve for all size groups involved, similar calculations are carried out for each pertinent size group.

Combined selection curves for mixtures of nets with different meshes are developed by adding ns values for each sockeye weight group. The resultant total is then converted to arithmetic terms to provide the combined Unit Size Efficiency. For example the following table illustrates the calculation to obtain the combined Unit Size Efficiency (S_c) for 5 lb sockeye for a mixture of 400 5.75 in. nets and 100 6 in. nets:

400 5.75 in. Nets			100 6 in. Nets			l_c	L_c
L_1	l_1	400 l_1	L_2	l_2	100 l_2	400 l_1 + 100 l_2	Local Efficiency
0.003276	0.003281	1.312557	0.000481	0.000481	0.048115	1.360662	0.74351

Values for each 0.25 lb size class are calculated to provide the selection curve for the entire range of weight classes of sockeye being encountered (Table 10).

The combined selection curves for the four different combinations of meshes illustrated in Figure 22 are included in the same figure. The curves for all four groups of nets exhibited the same shape, being flat on top, but with efficiencies dropping sharply for smaller fish sizes and declining more gradually as fish sized increased (the curves are skewed to the left). The curves were somewhat similar to the broad-domed curves derived experimentally for Skeena River sockeye and pink salmon by Todd and Larkin (1971).

Fishing Capacity Variation Associated with Changes in the Weight Frequencies of Sockeye Populations

Fishing capacities for the four hypothetical gillnet fleets utilizing the combinations of mesh sizes illustrated by bar diagrams in Figure 22 fishing each of the ten hypothetical sockeye populations were then calculated. This was done following the procedure illustrated in Table 10, by applying the appropriate absolute Unit Size Efficiency to the normalized frequency of each size group in each of the hypothetical populations.

The sum of the products for all weight groups was divided by the frequency (100.0 due to normalizing) to yield the mean weighted efficiency, i.e., the overall fishing capacity of the given fleet selection curve for the given hypothetical population.

Reflecting the sharp drop in fishing capacities as fish size decreases (Figure 22), the results, illustrated in Figure 25, indicate a relatively larger decrease in fishing capacity for annual sockeye populations with small average weights than for populations with large average weights. Thus, for example for the population exhibiting an average weight of around 5 lb, depending on the mixture of nets, fishing capacities were between 50 and 75%. This compared to a maximum capacity (for fish around 6-6.5 lb) of slightly over 90%. For the population with an average weight of over 7 lb, the capacity was only slightly lower, depending on the mixture of nets between 80 and 90% over the range of observed population average weights.

To assess the effects of fleet selection on the composition of the escapements, it is useful to compare the average size of sockeye taken by the four hypothetical fleets with the average size of sockeye in the hypothetical populations from which the catches were taken (Figure 26). An example for fleet "C" (Figure 22) exploiting a sockeye population of 5.99 lb average weight is shown in Table 10: the difference in average weight is 0.10 lb, the "catch" being the heavier (6.09 lb). In an extreme case where large nets (fleet "C")

Table 10. Estimation of the fishing capacity and the average weight of sockeye caught by the net mixture of fleet C in Figure 22, exploiting a sockeye population with an average weight of 5.99 lb.

I Weight Group Center (lbs)	II Population Frequency (Normalized)	III Local Selection Curve Efficiency	IV Product of Columns II and III (Theoretical Catch)	V Product of Columns I and IV (Weight of Theor. Catch)
3.50	0.1	0.0440	0.00440	0.015400
3.75	0.4	0.0693	0.02772	0.103950
4.00	0.8	0.0961	0.07688	0.307520
4.25	1.6	0.1267	0.20272	0.861560
4.50	3.0	0.1642	0.49260	2.216700
4.75	5.5	0.3675	2.02125	9.600937
5.00	10.2	0.7439	7.58778	37.938900
5.25	11.3	0.9560	10.80280	56.714700
5.50	11.2	0.9921	11.11152	61.113360
5.75	10.4	0.9972	10.37088	59.632560
6.00	9.1	0.9982	9.08362	54.501720
6.25	7.1	0.9975	7.08225	44.264063
6.50	5.4	0.9954	5.37516	34.938540
6.75	4.3	0.9908	4.26044	28.757970
7.00	3.7	0.9789	3.62193	25.353510
7.25	3.2	0.9596	3.07072	22.262720
7.50	2.8	0.9241	2.58748	19.406100
7.75	2.4	0.8757	2.10168	16.288020
8.00	2.0	0.8133	1.62660	13.012800
8.25	1.6	0.7507	1.20112	9.909240
8.50	1.3	0.6822	0.88686	7.538310
8.75	1.0	0.6124	0.61240	5.358500
9.00	0.7	0.5492	0.38444	3.459960
9.25	0.5	0.4854	0.24270	2.244975
9.50	0.3	0.4482	0.13446	1.277370
9.75	0.1	0.4090	0.04090	0.398775
Totals	100.0	---	85.01131	517.478160
Calculated Fishing Capacity		---	0.8501	---
Ave. Wt. (lbs)	5.99	---	---	6.09

fishes on very small fish (i.e., 5.0 lb), the average size of fish in the hypothetical catch was almost one half pound heavier than that of the population from which it was taken. Conversely, for populations with average weights over 6.5 lb, the fleet mesh mixture "A" produced hypothetical catches about 0.1 to 0.2 lb lighter than the population averages.

It is unlikely that such gross mismatches between average weight and the mesh-size distribution actually used would occur. When the Bartlett line of Figure 14 is superimposed on these data (Figure 26), the placement suggests that mesh-sizes used by the Fraser River gillnet fleet were, in fact, adjusted to reduce the losses of fishing capacity (i.e., fishermen knew or observed the actual size of fish and adjusted by using appropriate mesh sizes to efficiently harvest the run). Although much variation is found around the Bartlett line in Figure 14, few of the weight differences exceed 0.2 lb for sockeye with small average weights. In general, for years when there were no limitations on minimum mesh sizes, the Bartlett line reasonably depicts the actual changes in fleet selectivity with varying sockeye population average weight. The four lines representing the hypothetical

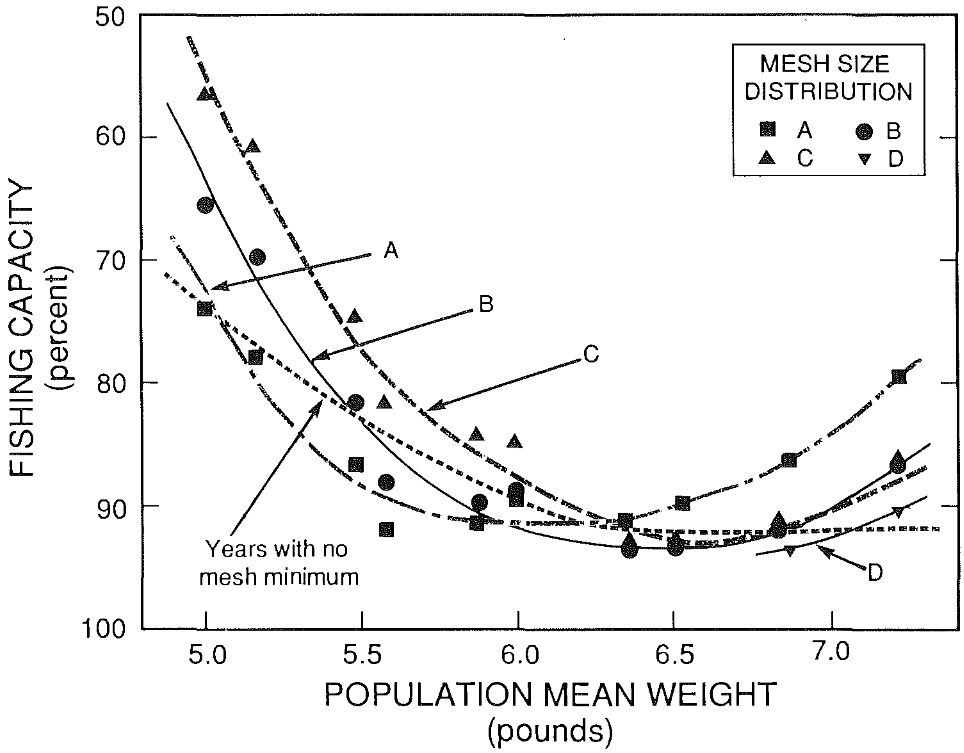

Figure 25. Estimated fishing capacities for the four hypothetical fleets shown in Figure 22 fishing sockeye with different average fish weights.

mesh-size mixtures are, therefore, only valid at single points along a continuum in mesh-size distribution in the fleet. In reality, there will be much variation from mesh-size distributions suggested by the Bartlett line.

Accepting that, for populations with smaller fish sizes, the Bartlett line provided a reasonable fit, based on the left side of the line, a smooth curve was developed relating fishing capacity to the mean weight of sockeye populations. The following procedure was employed. Three points in Figure 26 were identified where the Bartlett curve was synchronous with points on the curves for the hypothetical mesh mixtures. Each of these points were then associated with corresponding points in Figure 25, relating fleet fishing capacity to mean population weight and the new curve then drawn through these points. Thus, as indicated in Figure 26, the Bartlett line crosses the line for net mixture A at a point where the mean population weight was 5 lb. In Figure 25, for mesh mixture A, the corresponding fishing capacity was about 0.74. Similarly, in Figure 26, the Bartlett line crosses the curve for net mixture B at a weight of about 5.5 lb and about 0.82 fishing capacity. To complete the new curve, for the sake of simplicity, at its lower end the relationship was assumed to level off at fish sizes greater than 6.5 lb (approximately the minimum value reached by curve C.[32]

The new line has been incorporated in Figure 25. The relationship is assumed to represent the relationship between fishing capacity and average population mean weight for years when the regulations did not limit minimum mesh sizes (1929 and thereafter). For 1928 and earlier, the regulations prohibited the use of mesh sizes smaller than 5.75

[32] It might have been assumed that the curve would continue to decrease beyond the 6.5 lb. point. However, average sizes this large and larger were rare and, in any event, the deviation from the levelled off line would have been minor.

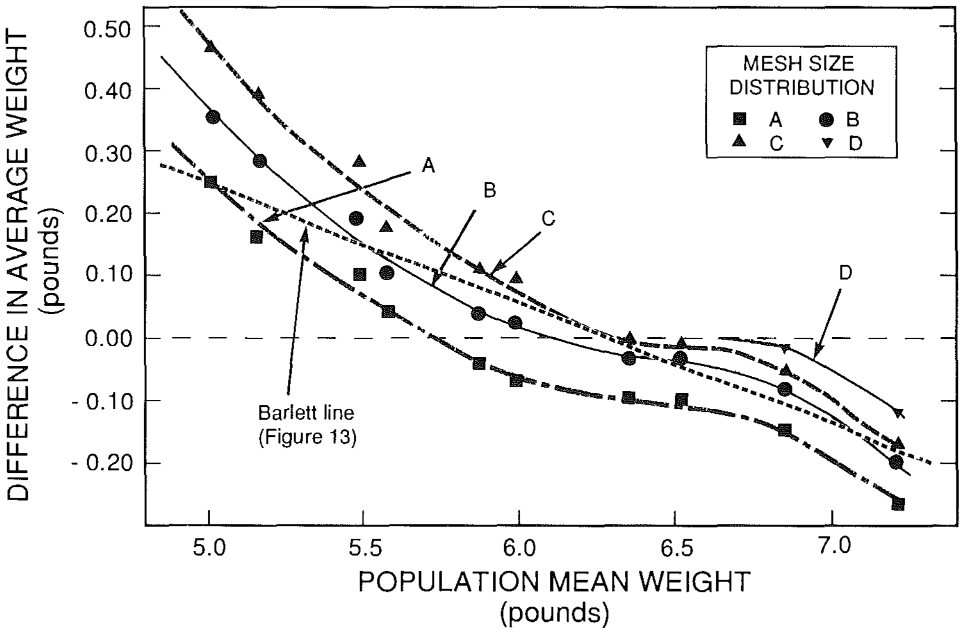

Figure 26. Estimated average weight of sockeye in gillnet catches minus average weight of sockeye in the total population for fisheries by each of the hypothetical fleets shown in Figure 22 for each of the ten size distributions illustrated in Figure 23.

in.. For the years prior to 1929, when only fleet mesh-size distributions C and D (Figure 22) would have been valid, the left limb of efficiency curve C in Figure 25 was taken to near its minimum point; it was again extended to the right along the 92% fishing capacity line, neglecting any decrease in fishing capacity due to large sockeye size. The two lines are shown in Figure 27.

The fishing capacity values adopted above were converted to a set of fishing capacity grid lines (taken from Figure 11) for each sockeye population average annual weight interval so that exploitation rates for different weekly fishing duration and different average weights could be estimated (Figure 28). However, an adjustment was made since the maximum fishing capacity assumed from Figure 24 (92%) was less than the mean fishing capacity of 96.5% of Figure 12. Because the fishing period length: exploitation rate relationship of Figure 12 was more realistic than the hypothetical schedules of Figure 25, the working relationship was based on Figure 12. For both the years before 1929 and those following, the highest fishing capacity for large average sockeye weights was taken as the 96.5% fishing capacity line of Figure 11 and labelled by the appropriate population average weight range. Fishing capacity lines for lower population average weights in 0.2 or 0.4 lb increments were calculated as proportionate decreases below the 92% value in Figure 25 and placed in Figure 28 to complete the relationship over the range of fishing period lengths and average weights.

Possible Sources of Error: The adjustment of fishing capacities in Figure 25 to higher values opens questions concerning choice of the various factors employed in the previous analyses, such as selection curves and unit efficiencies, to obtain Figures 26 and 28. Four factors determine the hypothetical fishing capacities calculated from the selection curves: 1) daily unit gillnet efficiency, 2) fleet size, 3) selection curve shape, and 4) the distribution of sockeye weight in the annual population fished.

Sample calculations of fishing capacities were made with a gillnet fleet size increased to 1000 nets but with unit efficiency and proportion of the various mesh sizes unchanged.

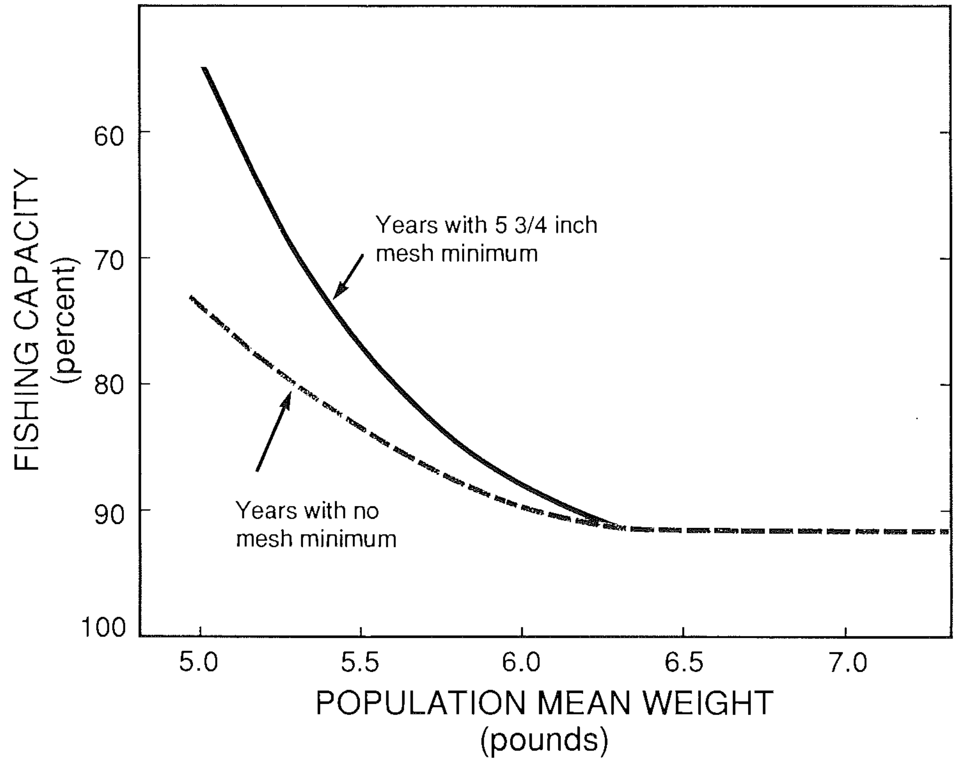

Figure 27. Estimated Fleet Fishing capacities for sockeye populations with different average annual weights for years before and after removal of the 5.75 in. minimum mesh size regulation.

Fishing capacities as high as 97.7% resulted for sockeye population weight distributions best suited to the mesh-size distribution. However, the difference in average weight between the hypothetical gillnet catch and the exploited population was decreased.

It is apparent that the constraints of average weight difference, maximum fishing capacity, and the shape of both the selection curve and the annual population weight distribution confine the resulting hypothetical fishing capacities to a narrow range. Widening the unit gillnet selection curve or narrowing the distribution of fish weight in the population fished will increase calculated fishing capacity but reduce the weight difference in the hypothetical catch. Increasing either the unit gillnet efficiency or the fleet size will have the same effect. Apparently the only ways the average weight differences could be increased would be to narrow the mesh size distributions or the selection curve. However, no justification for such adjustments could be found. The adjustment made to the fishing capacities of Figure 25 suggests that the schedule of weight differences between the Fraser River gillnet catch and the annual sockeye population average weight (Figure 14) may be a little too steep. Alternately, the fishing capacities in the regression of Figure 12 may be too high. It was concluded that the discrepancy lay in the least accurate data, i.e., the differences in weight between gillnet catch and the population fished.

From the foregoing, it must be concluded that the grid lines in Figure 28 may be subject to significant error. Nevertheless, it is believed that the relationships provide the most reasonable reflection of the probable selective effects of the gillnets in used in the fishery.

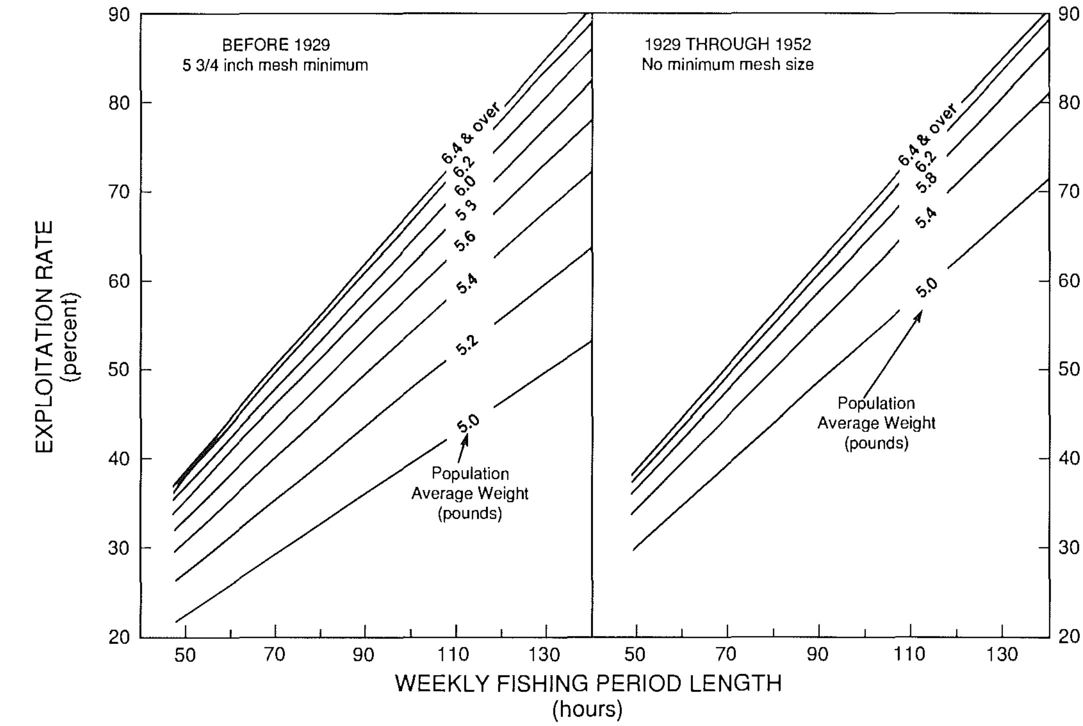

Figure 28. Relationship between estimated exploitation rates and length of weekly fishing periods for sockeye populations exhibiting different average weights. Left and right panels provide estimates for years before and after removal of the 5.75 in. minimum mesh size regulation.

Accepting the relationship developed, it is further concluded that exploitation rates in Figure 28 are relatively low when sockeye are very small, the logical result of selective effects in which the average weight of sockeye in the gillnet catch departs considerably from the population average weight. The effect was greater for years prior to abolition of the 5.75 in. mesh minimum. No provision was made for correcting fishing capacities and exploitation rates for selective loss of catch of the largest fish in annual populations with very large average weights. Such populations have been rare, especially in large runs in the early years of the fishery when sockeye tended to be small.

With the foregoing outline of methodology used to account for variations in size selectivity, the next section will apply such methodology to the estimation of early season escapements of Fraser sockeye during 1892 through 1944.

ESTIMATION OF ESCAPEMENTS

APPROACH

As indicated in the previous section, use of information on exploitation rates based on assessments of test fishing results and from size selectivity studies is only appropriate for those portions of the Fraser sockeye runs migrating rapidly and directly through the Fraser River gillnet fishing area. In general, these are the summer runs migrating from late June or early July through mid to late August. Later runs tend to delay at the lower end of the fishing area and the rate of exploitation on them can be quite variable. In an earlier section, estimates of annual harvests were developed for 1889-1944, where possible dividing the catches into summer and late season segments. In the present section, information on exploitation rates developed earlier in the report is applied to summer-run catch data to develop corresponding estimates on the abundance of the escapement.

Escapements calculated in this section represent gross escapements from the fishery and not the number of sockeye reaching the spawning grounds, i.e., the escapements before they were subsequently reduced by the native Indian subsistence fishing in the river and by other sources of freshwater mortality. The gross escapement estimates provided in this section include only sockeye of Age 4 and older because jack sockeye, being small, were not significantly exploited by linen gillnets and were therefore not taken into account in the selection curve calculations.

EARLY SEASON ESCAPEMENTS

The Saturation Effect

Procedures for estimating exploitation rates developed earlier in the report were based on the assumption that the number of gillnet vessels operating in the Fraser River gillnet area were sufficient to "saturate" the area and that the addition of more vessels would not significantly increase exploitation. To use the procedures, therefore, it is first necessary to determine, for different periods, whether or not the fleets were operating at the saturation level.

The Fraser River gillnet fishing area may be envisaged as comprising a specific number of productive drift locations on which only a limited number of effective drifts may be made in a given time interval regardless of the number of boats present. The availability and extent of drifts will vary with rate of river flow and with weather conditions, at least in the exposed areas at the river mouth. It will also vary with sockeye abundance since, with large catches, gillnets become less efficient because fish gilled in a net lower the chance of other fish being caught and with extremely high sockeye density, nets must be retrieved before they sink from excess catch.

As outlined earlier, the almost total lack of catches at the upper end of the fishing grounds after the opening of the commercial fishery after a closure indicates that modern gillnet fishery harvests virtually all sockeye that are vulnerable to the nets implying that additional effort would not increase catches. This situation existed before the fleet switched to nylon nets around 1953.[33] It would appear that, in modern times, there have always been enough vessels present on the grounds to fully occupy productive drifts regardless of ambient circumstances, and the fishery is therefore always "saturated". As outlined earlier (e.g., see Figure 5), it would appear that, under the circumstances of the modern fishery, the saturation level is reached when about 500 boats are fishing.

When did the fishery achieve this intensive level of exploitation? Some insight into this question can be gained from examination of information on catches and licensing in the late 1800s. As shown in Figure 1, following its beginnings in the 1860s, the Fraser River gillnet fishery began a rapid expansion around 1890. During the quadrennium 1893-1896, catches more than doubled from the previous quadrennium to reach an average annual total of over four million sockeye.

There are no firm data on the number of gillnet vessels operating in the Fraser River area in the earliest years. There are, however, records of the numbers of boats licensed

---

[33] This may explain why the introduction of synthetic gillnets has not increased the exploitation rate of the fishery appreciably although synthetic nets have been shown to be more efficient than linen nets under test fishing conditions (See Stacey, 1986.)

to fish in the area. Rounsefell and Kelez (1938, their Table 2), depending mainly on CDF records, provided a listing of the number of vessels licensed annually from 1877 through 1934.[34]

Table 11 lists Rounsefell and Kelez information plus data for 1935 through 1944 taken from CDF reports. The table shows that from a level of 285 vessels in 1877 the number of licenses rose to almost 1,000 in 1887 before dropping to 500 in 1888. As reported by Rounsefell and Kelez (1938), and Rathbun (1900), during 1888 through 1891, a 500 license limit was applied through Dominion Fisheries regulations. Although the effects of the regulations were viewed favourably by the fisheries administration (Wilmot 1891), recommendations for their continuation beyond that year were apparently overridden by economic pressures, and the limitations were abandoned from the 1892 season onward. The numbers of licenses mushroomed from then on, reaching a peak of 3,683 in 1900. Numbers of licences were probably a fairly accurate measure of the number of nets fished prior to 1895 since, as described by Rathbun (loc. cit.), each licensed net was apparently fished every open day for the largest part of the season.

The data in Table 11 indicate that the early 1890s was the time of rapid increase in effort (licenses rising from 500 in 1891 to 2,646 in 1896, an over five-fold expansion).

Accounts of the times indicate that by 1895, the effects of the fishery on upstream-bound runs had reached a level of intensity not much different than that reflected in the test fishing experiments of 1951 discussed earlier in the report. Prior to the 1890s, when the fleet size was relatively small, reports in the press concerning catch-per-gillnet around and upstream of New Westminster and in the vicinity of the river mouth indicated that fishing success at the upper locations remained generally high during the week's fishing.[35] As the fleet grew, catches in the upper areas fell off during the weekly fishing period until only one day of good fishing occurred each week.

Rathbun (1900), reporting on his 1895 visit to the fishery, stated that "*On Sunday evening ... about New Westminster, ... the catch per net [was] as good as at least the average on the lower drifting grounds ... Such success does not continue long, and during the remainder of the week, few boats remain on the upper grounds*". Reports in the *Daily Columbian* through the 1895 fishing season confirmed this observation. In contrast, press reports from the same newspaper in 1892 and 1894 and especially during the large run of 1893, had reported generally good gillnet catch-per-net throughout the fishing week in the upper section of the fishery. From this kind of anecdotal information, it would appear that the gillnet fishery reached the kind of "saturation" level observed in modern times by about 1895.

Identifying 1895 as being an important year, newspaper accounts commented on the escalation in numbers of licenses issued. Four successive newspaper accounts in 1895 reported the number of licenses as increasing over the 1,734 listed in Table 11. The final reported count reached 2,100 (*Daily Columbian*, August 31). The figure of 2,100 more closely fits the steady increase in licences from 1892 until 1900, suggesting that the larger

---

[34] Prior to 1893, these authors used data obtained by Rathbun (1900). From 1893 to 1899, they apparently calculated the number of licences from the combined length of all gillnets as recorded by CDF (made possible because, according to Rathbun, almost all nets were of the same length). After 1899, published CDF licence information was available. The latter data appeared to have included licences issued in other areas and transferred into the Fraser River district during the fishing season.

[35] *Daily Columbian.* July 9, 10 and Aug. 12, 1892. *Daily Columbian.* July 29, and Aug. 12,16,23,25,and 26, 1893.

TABLE 11. Annual number of gillnet licences issued in the Fraser River District, 1877 - 1944*.

Year	Number	Year	Number	Year	Number
1877	285	1900	3,683	1923	964
1878	449	1901	3,526	1924	969
1879	304	1902	2,674	1925	969
1880	274	1903	3,096	1926	1,063
1881	396	1904	2,215	1927	1,249
1882	666	1905	2,774	1928	1,303
1883	764	1906	1,746	1929	1,473
1884	702	1907	1,726	1930	1,523
1885	655	1908	1,363	1931	1,358
1886	734	1909	2,728	1932	1,446
1887	935	1910	1,576	1933	1,685
1888	500	1911	1,396	1934	1,803
1889	500	1912	1,430	1935	1,663
1890	500	1913	2,560	1936	1,784
1891	500	1914	2,656	1937	2,082
1892	721	1915	2,616	1938	2,319
1893	1,174	1916	2,240	1939	2,161
1894	1,667	1917	2,627	1940	2,237
1895	1,734	1918	1,583	1941	2,025
1896	2,646	1919	1,337	1942	2,754
1897	2,318	1920	1,228	1943	2,613
1898	2,642	1921	1,437	1944	2,582
1899	2,772	1922	1,296		

* 1877-1934 from Rounsefell and Kelez (1938, Table 2); 1935 - 1944 from C.D.F. Annual Reports.

figure is probably correct. The cause of this discrepancy is unknown. With the exception of 1895, the number of licences reported in the press in the 1890s agreed, approximately, with those in Table 11.

On the basis of the foregoing, it is assumed that the fishery reached the saturation level in 1895 and that this level of efficiency has persisted to the present. Under circumstances existing in 1895, this saturation level was assumed to have been achieved with a fleet size of around 2,000 boats.

Exploitation in 1892, 1893 and 1894

As discussed above, except for 1895, figures for numbers of licenses issued listed in published reports in the 1890s probably provided a reasonably accurate representation of the numbers of boats fishing. As shown in Table 11, the numbers of vessels licensed in 1892, 1893 and 1894 (721, 1,174 and 1,667) were substantially less than the 2,000 vessels operating in 1895, the year it was assumed the fishery reached the saturation level.

Calculations were made to estimate the fishing capacities in 1892, 1893 and 1894 taking into account that the fleet was operating at less than capacity level. The calculations were based on the assumed relationship developed earlier (Equation 2):

$$F_n = 1 - e^{-nu} \text{ or } nu = -\ln(1 - F_n)$$

where F_n is the fishing capacity of n gillnets, and u is the unit efficiency of a single net, interpreted as an instantaneous rate. Fishing capacity was determined from Figure 11 after obtaining the estimate of a saturated fishery exploitation rate from Figure 28 using the length of the weekly fishing period and sockeye population average weight for the year. Annual average weights in 1892, 1893 and 1894 were derived from the relationship of weight to fish-per-case of Killick and Clemens (1963, their Figure 26) using the cycle average fish-per-case. Unit gillnet efficiency was calculated from the equation using a fleet size of 2,000 on the assumption that it would be constant over all fleets up to saturation. The reduced fishing capacity and exploitation rate for the smaller fleet was calculated by reversing the procedure.

As an example, the year 1893 (1,174 nets) was calculated using the following data:
Effective length of weekly fishing period = 132 hours.
Population average sockeye weight (1893) = 5.4 lb.
Saturated fishery exploitation rate (from Figure 28) = 0.685
Saturated fishery fishing capacity (from Figure 11), $F_{2000} = 0.81$

Substituting F = 0.81 and n = 2000 into the above equation, the unit efficiency, i = 0.000830, was obtained. When the equation was solved for F_{1200} by substituting n = 1200 and u = 0.000830, a fishing capacity of 0.631 (63.1%) was obtained, with a corresponding exploitation rate of 52% from Figure 11. If sockeye had been large (i.e., 6.4 lb average weight or more; Figure 28), calculated unit efficiency would have been u = 0.00161 with a derived exploitation rate of about 72.5%.

Unadjusted Estimates of Escapement

Escapement estimates for 1892 through 1944 are developed in Table 12. Column I provides estimates of harvests for the summer-run segment of the runs, extracted from Table 1. Column II provides the estimated duration of the weekly closed period in each year, derived from data summarized in Tables 5 and 6. Column III provides estimates of the average weight of sockeye for each of the years. Except for 1892, 1893 and 1894 (see previous section), Column IV provides estimates of annual rates of exploitation derived by applying the estimates of weekly fishing time and size from Columns 2 and 3 to the relationships represented in Figure 28. Column V provides unadjusted estimates of escapements derived by applying the estimates of rate of exploitation to the harvests recorded in Column I.

As shown in Table 12, unadjusted gross escapement estimates for Fraser River sockeye summer runs for the years 1892 to 1944 varied from a low of 65 thousand to a maximum of almost eight million.

Adjustments to Minimum Escapement Estimates

Adjustments added to the minimum gross escapement estimates for summer runs in Table 12 ranged from none in many years to over half the minimum escapement (in 1897). For the dominant years up to 1913, adjustments were required to account for excessive escapement during periods of cannery overloads, when limits were set on the number of sockeye which each boat could deliver each day. The year 1909 was possibly an exception, since Babcock (1910) stated that "*... the [Fraser gillnet] catch this season*

TABLE 12. Estimation of gross annual escapements for early and mid-season sockeye runs (late June to about mid-September) for the years 1893 through 1944.

Year	I Gillnet Catch	II Effect. Weekly Fishing Period Length (hrs)	III Population Average Weight (lbs) b	IV Maximum Exploitation Rate (%)	V Minimum Gross Escapement	VI Additional Escapement and Source	VII Total Gross Escapement
1892	850,000	132	5.5	38c	1,500,000	When catches poor, cannery boats tied up, contract fishermen used large mesh nets; 100,000 extra escapement estimated	1,600,000
1893	7,100,000	132	5.6a	56c	5,600,000	2,000,000 in week of cannery overload	7,600,000
1894	3,800,000	132	6.5a	82c	835,000	Record flood; lowered efficiency probable, (Daily Columbian, July 31); 1948 flood effect suggests additional 50% escapement	835,000
1895	4,260,000	132	6.0a	81	1,000,000	750,000 during peak week cannery overload 300,000 during 8/31 to 9/15 closure	2,050,000
1896	3,260,000	132	6.4a	86	530,000	100,000 during closure of 8/31 to 9/25	630,000
1897	12,050,000	132	5.6a	74	4,250,000	5,000,000 during 2 weeks of cannery overload 1,000,000 during closure of 8/25 to 9/25	10,250,000
1898	2,280,000	132	6.5a	86	370,000	200,000 during short partial strike, and closure of 8/25 to 9/25	570,000
1899	5,240,000	132	6.1a	83	1,075,000	300,000 in early season high water levels and short cannery overload mid-August	1,375,000
1900	1,830,000	132	6.4a	86	300,000	100,000 in partial strike most of July	400,000
1901	11,830,000	132	5.2	60	7,890,000	5,000,000 in 2 peak weeks (August) overload	12,890,000
1902	3,050,000	132	6.5a	86	500,000	(no known closure)	500,000
1903	2,240,000	132	6.1a	83	460,000	(no known closure)	460,000
1904	795,000	132	5.8	78	225,000	(no known closure)	225,000
1905	10,550,000	132	5.4	68	5,000,000	2,000,000 during 2 periods of cannery over- loads in August	7,000,000
1906	2,020,000	132	6.3	85	360,000	100,000 during closure of 8/25 to 9/15	460,000
1907	660,000	120 & 132	6.6	81 (79 - 86)	155,000	35,000 during closure of 8/25 to 9/15	190,000
1908	735,000	108 & 120	6.4a	78 (72 - 79)	210,000	30,000 during closure of 8/25 to 9/15	240,000

a - From cycle average fish-per-case. b - From Killick and Clemens (1963); their Figure 26. c - Corrected for small fleet size (see text).

Table 12 continued:

Year	I Gillnet Catch	II Effect. Weekly Fishing Period Length (hrs)	III Population Average Weight (lbs) b	IV Maximum Exploitation Rate (%)	V Minimum Gross Escapement	VI Additional Escapement and Source	VII Total Gross Escapement
1909	5,450,000	126	5.4a	71	2,225,000	500,000 during closure of 8/25 to 9/15	2,725,000
1910	1,390,000	114	6.3	75	465,000	200,000 during closure of 8/25 to 9/15	665,000
1911	685,000	114	6.2	74	240,000	(no closure)	240,000
1912	1,195,000	114	6.4	76	375,000	(no closure)	375,000
1913	8,465,000	126	5.4	66	4,260,000	1,000,000 during strike and cannery overload 8/4 to 8/7; no closure	5,260,000
1914	1,900,000	114	6.6	76	600,000	(no closure)	600,000
1915	970,000	114	6.2	74	340,000	(no closure)	340,000
1916	325,000	114	6.5	76	105,000	(no closure)	105,000
1917	1,380,000	126	5.8	75	460,000	(no closure)	460,000
1918	190,000	114	6.3	75	65,000	(no closure)	65,000
1919	355,000	114	5.8	68	165,000	(no closure)	165,000
1920	480,000	114	6.5	76	150,000	(no closure)	150,000
1921	380,000	126	6.0	78	110,000	Mesh min. 6 1/2 inches 9/6 to 9/14, then closed; 20,000 extra escapement	130,000
1922	450,000	114	6.7	76	140,000	(no closure)	140,000
1923	280,000	108	6.8	72	110,000	Light early Sept. fishing (catch records); 50,000 extra escapement	160,000
1924	385,000	108	6.3	71	155,000	(no closure)	155,000
1925	380,000	108	5.7	64	215,000	(no closure)	215,000
1926	390,000	108	6.7	72	150,000	(No closure)	150,000
1927	295,000	108	6.4	72	115,000	(no closure)	115,000
1928	245,000	108	6.8	72	95,000	No closure; 15,000 escapement during short strike 8/20 to 8/22	110,000
1929	630,000	108	5.9	69	285,000	No closure; 25,000 early season escapement due to few boats operating	310,000

a - From cycle average fish-per-case. b - From Killick and Clemens (1963); their Figure 26.

Table 12 concluded:

Year	I Gillnet Catch	II Effect. Weekly Fishing Period Length (hrs)	III Population Average Weight (lbs) b	IV Maximum Exploitation Rate (%)	V Minimum Gross Escapement	VI Additional Escapement and Source	VII Total Gross Escapement
1930	255,000	108	7.0	72	100,000	(no closure)	100,000
1931	225,000	108	6.3	71	90,000	(no closure)	90,000
1932	640,000	108	6.7	72	250,000	(no closure)	250,000
1933	555,000	108	5.3	63	325,000	No closure; 50,000 early season escapement due to high river flow	375,000
1934	460,000	114	6.8	75	155,000	(no closure)	155,000
1935	540,000	114	6.1	74	190,000	(no closure)	190,000
1936	2,000,000	114	6.7	75	665,000	(no closure)	665,000
1937	845,000	114	5.0	59	590,000	(no closure)	590,000
1938	560,000	114	6.8	75	185,000	(no closure)	185,000
1939	250,000	114	5.8	72	100,000	(no closure)	100,000
1940	913,000	114 & 90	6.5	67 (75 - 62)	450,000	3 weekly closures at peak lengthened 24 hrs	450,000
1941	1,938,000	114	5.4	67	955,000	(no closure)	955,000
1942	895,000	114	6.6	75	300,000	(no closure)	300,000
1943	220,000	90	6.0	60	145,000	2 short weekend closures; 10,000 subtracted	135,000
1944	945,000	114	6.3	75	315,000	78 hr closures from 8/25; 5,000 additional escapement estimated	320,000

b - From Killick and Clemens (1963); their Figure 26.

at no time exceeded the canning capacity". Newspaper accounts largely supported Babcock's observations.[36] In all other dominant years in this period, cannery overloads of at least two or three days were recorded. Excess escapement was estimated by the following five steps on the assumption that the available data for one or a few canneries represented the total fishery:

1. The available daily Fraser gillnet catch or pack record for one cannery, or two or three canneries combined, was plotted and fitted with a smooth daily abundance curve, on the assumption that daily sockeye abundance follows quasi-normal patterns with rounded peaks and smooth ascending and descending limbs. An example is shown in Figure 29 for the year 1905.

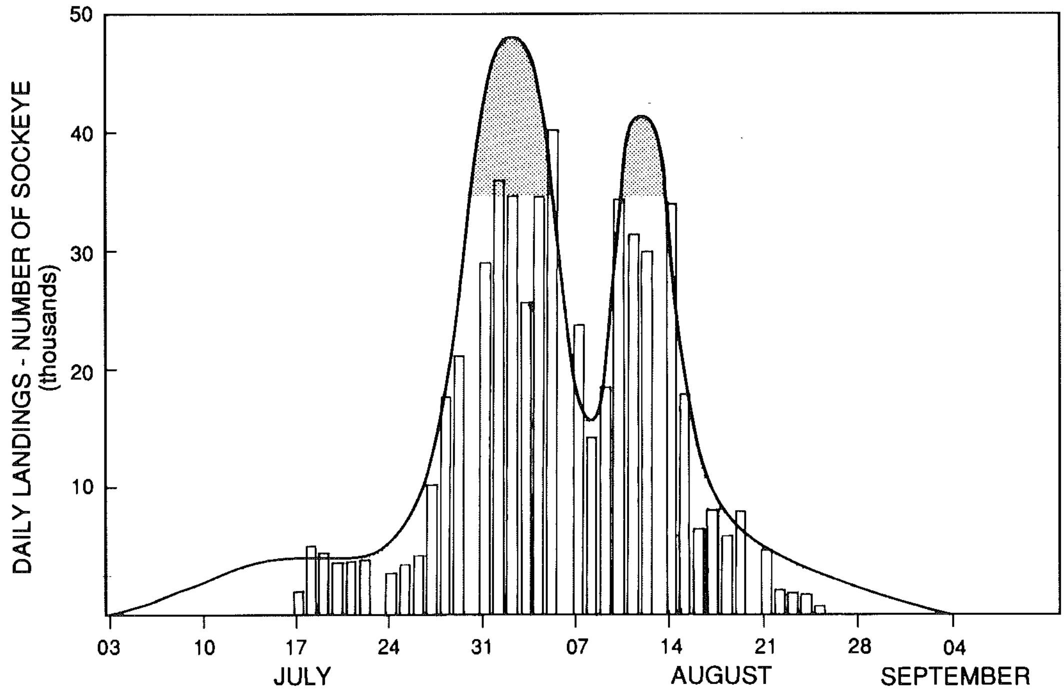

Figure 29. Smoothed abundance curve fitted to daily landings at two Fraser River canneries in 1905. Hatched areas above recorded level of daily landing indicated assumed levels of landings if canneries had not applied daily limits on fishermen.

2. Using a planimeter, the relative areas under the curve in Figure 29 representing the actual landings and the estimated catches foregone as the result of the cannery limitations, were measured;

3. The unrestricted (maximum possible) total catch (C_t) by the whole fishery, the daily components of which would have extended approximately up to the smooth fitted curve during the periods of restriction, was calculated from the proportion:

$$\frac{C_t}{C_r} = \frac{A_t}{A_r}$$

[36] The *Daily Columbian* of August 6 reported that canneries at the mouth of the Fraser applied boat limits. However, since the *Daily Province* of August 7 reported no over supply the next day, the limits presumably were short lived and the fishermen involved were able to sell their excess catch elsewhere.

where A_t is the total area under the curve, A_r is area under the curve less the hatched area and C_r is the restricted catch, i.e., the recorded catch for the whole fishery.

4. Escapement (E_t) which would have occurred with unrestricted fishing was obtained from the exploitation rate for the fishery for the year being analyzed, i.e., from Figure 28 using the population average weight and the effective weekly fishing period length. The hypothetical escapement (E_t) was then obtained from the equation given on page 3 ($E = C(1\text{-}R)/R$), with C in this case being C_t.

5. Total estimated escapement was then the sum of the hypothetical total escapement (E_t) and the difference between hypothetical total catch and the recorded catch, i.e., $E_t + (C_t - C_r)$, since the catch difference is the extra catch which would have been made if the canneries had not applied boat limits.

The two peaks in the 1905 mid-season sockeye run were probably characteristic of the dominant years. Similar bimodal patterns were observed during the 1893, 1909 and 1913 seasons. Two peaks were assumed also to have occurred during 1897 and 1901, although the actual landings data did not show bimodality. However, this assumption is supported by the extended duration of boat limits in these years, too long to have been the result of a single peaked run; alternately, if several overlapping, even-sized stocks had formed a long, flat peak, the results would have been about the same as with two peaks separated by a gap.

ESTIMATION OF LATE-RUN ESCAPEMENTS

The foregoing paragraphs covered the estimation of summer-run escapements. In addition to these early stocks, beginning about mid-September, there are a number of later runs which have markedly different physiological and behavioral characteristics. In particular, the late runs tend to spend long periods off the mouth of the river before beginning their final upstream migrations to the spawning grounds. In many years, the advanced state of maturity of some of the fish makes them less desirable for canning than the "fresher" summer-run fish. As a consequence, in a number of early years, fishing effort for these late runs was reduced by extended closures, use of large mesh sizes (6.5 in. or larger - see Tables 7 and 8), lowered fish prices (which sometimes precipitated strikes), cannery closures, or interference with fishing because of the presence of large quantities of pink, chum and white-fleshed chinook salmon.[37]

Because of these factors, exploitation rate data such as that developed in earlier sections of this report could not be used to estimate escapements of late-run sockeye. Instead, the remaining part of the present section reviews data on the abundance of the late runs in the fisheries and makes some very general assessments on the magnitude of the escapements, some of which can only be characterized as "best guesses".

The most important contributor to the late runs in two years out of four was probably the Adams (or late Shuswap) run. In modern times, the Adams run has a return of several million fish every fourth year (dominant cycle); cyclic peak returns have varied between 2.75 and 15 million fish since the first Hells Gate fishways were built (1945). The cycle year immediately following has always been smaller, in recent years averaging about 1.4 million total return. Adult sockeye total returns in the two remaining cycle years have been less than 100,000. Originally the Adams run was dominant with most other sockeye runs on the 1901-05-09-13 cycle, but due to logging operations (Thompson 1945), became dominant on the 1922-26-30 cycle. There were three other significant late

[37] In early years pinks, chums and white-fleshed chinook salmon were unsaleable yet had to be removed from the nets and discarded.

sockeye runs, those bound for Weaver Creek, Harrison River, and Cultus Lake, with upriver migrations from September to as late as December.

Total catches of late-run Fraser sockeye were reported as approximate pack or catch in many years from 1901 onward (Table 13). The number of boats exploiting these runs, however, were not often reported and so it is impossible to develop any picture of likely exploitation rates from fleet information.

Runs Prior to 1901

In respect of runs prior to 1901, one can only speculate on the abundance of late season runs. It is possible that the pattern of abundance resembled that of recent years. Large runs occurred every fourth year before any important commercial fisheries began (Ward and Larkin 1964) and spawning grounds were undoubtedly heavily populated. In years since objective enumeration of sockeye salmon populations began around 1938, the three dominant late Shuswap brood years with more than 2 million spawners (which saturate the spawning grounds) have produced an average return of over 8 million sockeye. Similar sized Late Shuswap returns in the dominant years before 1901 were likely.

Dominant Runs, 1901-1913

As shown in Table 13 it was estimated that in 1901, 1905, 1909 and 1913 relatively large late-run catches of 900,000 to 1,500,000 sockeye were made. Exploitation rates during the late season were probably less than those occurring earlier in the season (estimated in Table 12 at 60-76%). For the late runs, it was known that many of the canneries had already closed and, as outlined above, fishermen had difficulties disposing of their catches. Subjectively, it would seem reasonable to suggest exploitation rates of no more than 50%.

An extremely large late run was reported in 1905, with cannery overloads, low sockeye prices, large shipments to U.S. canneries. Fishing effort greatly decreased after the end of September (*Daily Columbian*, Sept. 13 to 26; Oct. 2). In 1913, sockeye nets could not be used after September 30 (Table 8) although sockeye were still being caught after that date (*Daily Columbian*, Oct. 8). It is therefore likely that exploitation rates in 1905 and 1913 were less than in the other cycle years. On this basis, an exploitation rate of 50% is suggested for 1901 and 1909 and 40% in 1905 and 1913.

Other Years, 1910-1914

Table 13 includes estimates of late-run sockeye escapements for 1910 and between 1913 and 1944, based variously on:

- Late season catch data often calculated from incomplete cannery data;
- calculation of differences between packs reported in the press at the end of the summer and final recorded packs for the entire season;
- general newspaper accounts regarding late-season fisheries;
- spawning ground estimates; and,
- catch-per-gillnet data from fisheries on delaying sockeye prior to upriver migration.

For the years 1926, 1930, and 1934, the size of late-run sockeye escapements was estimated from catch-per-net in night-time fishing off the Fraser River mouth on delaying fish just prior to the rather sudden beginning of migration into the river, usually in mid-September (Table 14). The procedure used involved determining an approximate relationship between the average catch per gillnet and the estimated abundance of late-

TABLE 13. Estimation of escapements for late sockeye runs (1901 - 1944), which enter the Fraser River mainly after early September; also notes regarding 1893 and 1897. See Appendix 3 for information on estimation of exploitation rates.

Year	Late Season Catch	Late Season Restrictions	Estimated Exploitation Rate	Estimated Late Run Escapement
1893	(unknown)	Closed 8/31 to 9/17; then 8 in. mesh min.	(low)	Large late run
1897	(unknown)	Closed 8/25 to 9/25; then 7 in. mesh min.	(low)	Large late run
1901	1,270,000	No known closures; 5 3/4 in. mesh min.	50%	1,270,000
1905	1,500,000	7 in. min. 8/25 to 9/15; then open	40%	2,250,000
1909	1,250,000	Closed 8/25 to 9/15; then 5 3/4 in.	50%	1,250,000
1910	100,000	Open to 9/30; then 7 in. mesh min.	33%	200,000
1913	900,000	Open to 9/30; then 7 in. mesh min.	40%	1,350,000
1914	95,000	Open to 9/30; then 7 in. mesh min.	30%	220,000
1915	95,000	Open to 9/30; then 7 in. mesh min.	40%	140,000
1916	(few)	Open to 10/31; then 7 in. mesh min.	(heavy)	50,000 e
1917	200,000	Open to 9/30; then 7 in. mesh min.	60%	135,000
1918	20,000	Open to 9/30; then 7 in. mesh min.	50%	20,000
1919	40,000	Open to 9/30; then 7 in. mesh min.	50%	40,000
1920	10,000	Open to 9/30; then 7 in. mesh min.	20%	40,000
1921	60,000	Mesh min. 6 1/2 in. 9/6 to 9/15. Closed 9/15 to 9/20; 5 3/4 in. mesh min. 9/20 to 11/10	40%	90,000
1922	95,000	Mesh min. 6 1/2 in. 9/22 to 11/5	40%	150,000
1923	55,000	Mesh min. 6 1/2 in. 10/1 to 11/15	25%	165,000
1924	10,000	Mesh min. 6 1/2 in. 10/1 to 11/15	10%	90,000
1925	25,000	Mesh min. 6 1/2 in. 10/1 to 11/21; partial strike late Sept.	40%	40,000
1926	500,000	Mesh min. 6 1/2 in. 10/1 to 11/20; short period boat limits end Sept.	45% *	600,000 **
1927	370,000	Mesh min. 6 1/2 in. 10/1 to 11/19; short strike late Sept.; longer weekend closures from 9/23	40%	555,000
1928	35,000	Mesh min. 6 1/2 in. 10/1 to 11/?	40%	55,000
1929	50,000	Mesh min. 6 1/2 in. 10/1 to 11/16	40%	75,000
1930	700,000	Fishing curtailed 9/15 to 9/20 (low prices); closed 9/20 to 10/20	22% *	2,500,000 **
1931	200,000	Closed 9/30 to 10/7; then 6 1/2 in. mesh min.	45%	245,000
1932	45,000	Mesh min. 6 1/2 in. 10/1 to 12/30	35%	85,000
1933	25,000	Catches much reduced after 9/15 (cause?); longer weekend closures 9/15 to 9/30; mesh min. 6 1/2 in. from 10/1	40%	40,000
1934	600,000	Closed from 9/15 to 9/30, then no mesh min.	22% *	1,300,000 **
1935	100,000	Closed from 9/21 to 10/2, then 6 1/2 inch mesh min.	35%	185,000
1936	80,000	Closed 10/10 to 10/18	50%	80,000
1937	25,000	Closed 9/25 to 10/7	30%	60,000
1938	950,000	Closed 9/11 to 10/2	47% *	1,050,000
1939	175,000	Closed 9/15 to 9/24; 6 1/2 inch mesh min. from 10/1; longer weekend closures 9/29 to 11/13	56% *	135,000
1940	92,000	Mesh min. 6 1/2 in. from 10/1. Weekend closures lengthened 24 hrs. after 9/6	44% *	115,000
1941	42,000	Mesh min. 6 1/2 in. from 10/1. Weekend closures lengthened 24 hrs. after 9/26	39% *	65,000
1942	2,000,000	Strike and closure, 9/17-9/30;	61% *	2,600,000
1943	110,000	No closure; 6 1/2 in mesh min. from 10/1	61% *	70,000
1944	30,000	Three-day weekend closures; 6 1/2 in mesh min. from 10/1	38% *	48,000

* Values are calculated from escapements estimated by other means. e - Estimate only.

** Escapements estimated from catch per gillnet data (Table 14; Figure 30).

Table 14. Maximum daily driftback catches by purse seines at Point Roberts, estimated average catch per gillnet on delaying sockeye and estimated abundance of delaying fish during Adams River sockeye dominant years from 1926 through 1946.

YEAR	MAXIMUM DAILY DRIFTBACK CATCH	APPROX. AVERAGE CATCH PER GILLNET	GILLNET FLEET	ESTIMATED NO. DELAYING SOCKEYE*
1926	No data	25	800	1,000,000
1930	255,000	50	1,200	3,000,000
1934	160,000	35	1,000	1,500,000
1938	40,000	40	1,500	1,500,000 **
1942	265,000	75	900	5,500,000 **
1946	100,000	50	1,400	4,000,000 **

* Includes estimated escapement plus catches made after the listed gillnet average catch was made.
** Based on enumerated escapements.

season spawners determined by IPSFC during the period when linen gillnets were in use. Usable data are available for 1938, 1942 and 1946.[38] A smoothed curve was developed for these three years (with the origin at zero) and values for the dominant cycle years 1924, 1930 and 1944 estimated by interpolation (Figure 30). It is admitted that the three-point line provides a very tenuous relationship on which to base the estimates. However, lacking other information, the assumed relationship was considered to provide the best estimates available.

The late-run sockeye escapement in 1942 (Table 13) was estimated from the catches before the September 17 to 30 period of no significant fishing. A curve of daily abundance was created for this period assuming a unimodal and asymmetrical migration into the river characteristic of this group of sockeye in order to get an estimate independent of the spawning ground enumeration data. The escapement was the area under the curve during the no fishing period. Late-run escapements in 1939-1941 and 1943 and 1944 were also derived from catch information only since these were to be compared with spawning ground enumeration data.

Appendix 3 lists the information used as a basis for estimates of exploitation rates and the resulting escapement estimates for the other years between 1910 and 1944.

TOTAL ANNUAL ESCAPEMENT ESTIMATES

Estimates of total escapements for 1892-1944 (the sum of summer- and late-run escapements for which data were available in Tables 12 and 13 are listed in the next section, which compares estimates derived in the present paper with those developed by other authors. In general, the estimates developed are incomplete for years up to 1914 except for the dominant years 1901 to 1913 and for 1910. The estimated escapement levels are felt to be conservative mainly due to inability to assess the magnitude of the late season segments.

---

[38] The 1950 Adams sockeye run was small; no fishing was allowed in the Fraser River on delaying Adams fish at the mouth or of migrating fish in the river. For this reason, it was not possible to derive an estimate of run abundance for the late 1950 season.

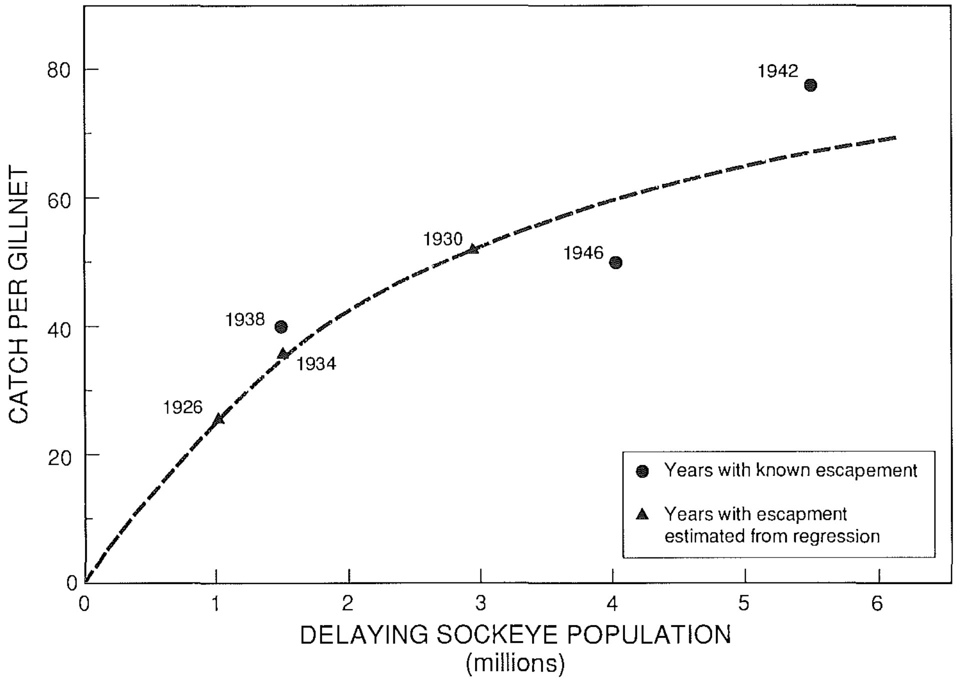

Figure 30. Relationship between average nighttime catch per gillnet and abundance of delaying sockeye runs for 1938, 1942 and 1946 with interpolated values for 1926, 1930 and 1934.

COMPARISON WITH OTHER ESCAPEMENT ESTIMATES

APPROACH

In the following section, estimates developed in the present report are compared with estimates derived by other authors. In general, two types of estimates have been made by such authors; first, estimates based on accounts by observers of the number of salmon reaching the spawning grounds, occasionally supplemented by information on Indian subsistence catches and on losses of salmon at obstructions and, second, estimates developed, as in the present paper, from data on the operations of the commercial fishery.

DIRECT OBSERVATIONS OF ESCAPEMENTS

Beginning in the late 1800s, mainly in connection with hatchery operations, officials of the Dominion Government and of the Province of British Columbia carried out assessments of the relative abundance of spawning runs in accessible locations on the Fraser River (e.g., see Babcock, 1902 and Sword, 1900). Most of these assessments were expressed in more or less qualitative terms (e.g., statements on the relative magnitude of an escapement in a particular year compared to that of another). Coverage was often incomplete[39] or based on second-hand information. For this reason, the information is difficult to use in making comparisons with the quantitative estimates derived in the present paper.

---

[39] Not surprising, considering the remoteness of many of the Fraser tributaries and the primitive nature of transport at the time.

However, for certain systems, the early accounts contain some quantitative information of importance. Prior to 1917, the Quesnel system was obviously one of the most important contributors to the large 1901 dominant cycle runs to the system. The principal observer at the time, John Pease Babcock, provided valuable observations on the importance of the Quesnel run in the early 1900s (Babcock, 1903). The construction of a dam there in 1898 (to facilitate mining downstream) focused attention on the numbers of sockeye utilizing the system. When the dam was constructed, an inadequate fishway was installed which severely obstructed the dominant 1901 cycle. To overcome this problem, in 1904 (in advance of the 1905 dominant run), Babcock designed and supervised construction of a much larger and more suitable fishway.

In the dominant years 1909, 1913, and 1917, Babcock commissioned a watchman to count the number of sockeye passing upstream through the fishway in short time periods at intervals during each day. From these observations, Babcock derived average daily numbers-per-minute, from which he made estimates of the total escapement to the Quesnel system. These were: 1909, 4 million; 1913, 550,000; 1917, 26,000.

Removal of the dam in 1921 precluded counts for 1921 and later years. The 1909 estimate is of particular interest because it is larger than the estimate for the summer escapement to the entire Fraser River developed earlier in this report (2.725 million - see Table 12).

Babcock's figure for the 1909 escapement may have been too large. It was noted that although sockeye migrated through the fishway at night, no night counts were made. While 24 hour populations were calculated on the basis of daytime counts only, sockeye migration probably decreased at night.[40] Offsetting this, however, was the report that, during the five peak days of the migration, the watchman noted that sockeye were too numerous to be counted accurately.

All possible errors considered, it would be difficult to place the 1909 Quesnel escapement at less than three million fish. The Quesnel sockeye run may have been larger than all other early runs combined, but Babcock (1910) reported a very large run to Chilko Lake, and in a discussion of the 1913 escapements, large 1909 runs were indicated for the Stuart Lake and Nechako River districts (Babcock 1914). A reasonable total escapement of summer-run sockeye in 1909 would be at least 5 million fish, substantially larger than the 2.725 million estimated in the preceding section of the present report (Table 12).

Underestimation of the 1909 sockeye summer-run escapement in the present study could have been due to the use of a too large sockeye average weight in estimating exploitation rate as affected by gillnet selectivity. If an average sockeye weight for 1909 had been 5.0 lb rather than the assumed 5.4 lb average, estimated early-run escapement would have been nearly six million sockeye.

The estimated Fraser River sockeye escapement for 1893 (Table 12; 7.6 million plus unknown late run), appeared to be low compared to estimates for the runs in the subsequent two dominant cycle years, 1897 and 1901 (Table 12). In contrast to 1897 and 1901, in 1893, virtually the entire run reached the Fraser estuary without having been exploited to a significant extent in the still infant United States fishery on the seaward

---

[40] In twenty-four hour counts made by IPSFC staff in 1953, 1957 and 1961 (unpublished data), fewer sockeye passed at night than during the day.

approaches to the Fraser.[41] The total run was estimated to have been only about 15 million sockeye plus possibly several millions more for the reported large late run (*Daily Columbian*, Sept. 21, 23, 25). Comparisons with the later years suggest that either the 1893 escapement was underestimated, or there was poor survival from the 1889 spawning. A possible reason for underestimation was that, as was hypothesized for 1909 (see above), the sockeye in 1893 might have been smaller than the cycle mean average weight assumed for determining the exploitation rate.

In the 1920s and 1930s, Fisheries Officers and other observers began to make numerical estimates for many Fraser River sockeye spawning ground populations rather than relative statements such as "larger than", "smaller than" or "equal to" previous years. Using these later data, Clemens and Clemens (1933 to 1936), Clemens (1938) and Ricker (1987) derived total escapement estimates and directed attention to the high exploitation rates in the fishery. Their escapement estimates (Table 15) were smaller than those listed in Tables 12 and 13. A possible reason for lower estimates would be losses at obstructions below the spawning grounds, especially in the Fraser Canyon. Unfortunately, however, there are no quantitative estimates of the magnitude of such losses or even indications of the years in which such losses might have occurred.

Table 15. Comparison between annual sockeye escapement estimates developed in the present report with those of Clemens and Clemens (1930 - 1938), Ricker (1987) and I.P.S.F.C. (Annual Report and file data, 1938 - 1944).

YEAR	CLEMENS' ESTIMATE	SPAWNING GROUNDS	TABLES 12 PLUS 13	
1929	About 250,000	All areas	385,000	
1930	More than 400,000	Late Shuswap only	2,600,000	
1932	Less than 140,000	All areas	335,000	
1933	No improvement over 1929a	All areas	415,000	a
1934	About 750,000	All areas	1,455,000	
1935	150,000b (Ricker 1987)	All areas	375,000	
1937	Little more than 255,000	All areas	650,000	
	I.P.S.F.C. ESTIMATE b			
1938	930,000	All areas	1,235,000	
1939	195,000	All areas	235,000	
1940	535,000	All areas	565,000	
1941	570,000	All areas	1,020,000	
1942	2,855,000	All areas	2,900,000	
1943	140,000	All areas	205,000	
1944	480,000	All areas	368,000	

a Est. 30-45,000 Early Stuart sockeye lost due to high water.
b Including Native Indian subsistance catch (from CDF).

Motherwell (1927, 1928, 1931, 1932, 1935 and 1936) reported sockeye in streams below Hells Gate in the autumn in years of significant Late Shuswap migrations, but while these were generally attributed to returns from hatchery operations, no complete

[41] As shown in Figure 1, the United States fishery had just begun to develop in the quadrennium beginning in 1893, but expanded rapidly in the succeeding two quadrennia to exceed the Canadian fishery in terms of total catches.

estimates were made. Differences between the estimates in Table 15, largest in years of the dominant Late Shuswap runs (1930 and 1934), cannot be explained.

Fraser River sockeye escapements estimated by the technical staff of the IPSFC for the years 1938-1944, although not quite complete and only partially based on more comprehensive and accurate methods developed later, were nevertheless in reasonable agreement with the sums of estimates from Tables 12 and 13, except for 1941 (Table 15). The means of the two sets of escapements were not significantly different ($t=0.32$, $p=0.76$), nor were the differences between individual years different from zero ($t=2.07$, $p=0.08$). Late-run IPSFC escapement estimates in all seven years listed in Table 15 are based on field data. The 1938 IPSFC estimate of the late Shuswap escapement was based on recovery of Hells Gate tags on the spawning grounds, giving a slightly larger escapement than that listed in official figures.

The pronounced difference between the 1941 IPSFC estimate (570,000) and that developed in the present report (1,030,000) was most probably the result of blockage of sockeye by unusual flow conditions at Hells Gate. Analysis of tags applied at Hells Gate and recovered from dead fish below that point yielded several estimates of the blocked population. Calculations by Peterson and Mason (MS 1947) gave estimates of 500,000 to 900,000. Another calculation by Gilhousen (MS 1966) gave an estimate of about 500,000. The difference of 460,000 between observed spawning ground escapement plus Indian catch and estimated gross escapement based on gillnet exploitation rate (Tables 12 plus 13) compared favorably with the estimates based on spawning ground surveys plus the tagging estimate of the loss at Hells Gate.

ESTIMATES BASED ON EXPLOITATION RATE DATA

Thompson (1945), Rounsefell (1949) and Killick and Clemens (1963) developed estimates of Fraser sockeye escapements based in part at least on data from the commercial fisheries.

Noting the apparent great efficiency of the total sockeye fishery, Thompson (1945) estimated that escapement in 1913 "might approach 10 percent" (i.e., of the total run). Combining his extreme estimate of a 90% exploitation rate by the total fishery in 1913 with the amount of fishing effort deployed annually during 1897 through 1934, and using a mathematical model based on competitive fishing, he constructed an index of the success of reproduction for each year of spawning. The index was in effect the ratio of estimated total run in the return year to the total run in the year of spawning. Thompson assumed an invariable 4 year life cycle, a constant efficiency for each standard unit of gear (each gear type was weighted to an overall standard efficiency), and uniform fishing regulations in all years.

Estimates of annual escapements from Thompson's model (Table 16) were obtained by using his units of effort (his Table 1), a revision of his unit efficiency and the total annual catch reported by Rounsefell and Kelez (1938). A revised unit efficiency of 0.00023026 was employed since the stated unit efficiency (0.0004605) appeared to be in error.[42] Estimates based on Thompson's analysis tended to be smaller than estimates presented in Tables 12 and 13 in years of large abundance and larger in years of small abundance, possibly because:

---

[42] Solution of Thompson's equation (Thompson 1945, p.32), $100(1-e^{-10,000r})$ yields $r=0.00023026$, not 0.0004605; this equation assumed 10,000 units of fishing effort (standardized) and an exploitation rate of 90% for the combined Canadian and United States fisheries in 1913.

- As discussed earlier in this report, in the largest dominant years it is likely that gear efficiency was diminished due to limitations on landings dictated by cannery capacities; and/or,
- the use of more gear during large runs resulted in increased interference between gear units and consequent efficiency loss; and/or,
- at least in the United States fishery, less efficient units (mainly traps) were fished only in years when large catches were expected.

A more complex estimation of annual Fraser River sockeye escapements was made by Rounsefell (1949). He adapted a method developed by DeLury (1947) for determining population size in a non-migratory fish population to the situation occurring with migratory populations of salmon. In place of a steadily decreasing catch-per-unit-of-effort during continued fishing on a static population in DeLury's examples, Rounsefell used an array of Fraser sockeye populations, each producing a different average annual catch-per-gillnet in the Fraser River fishery with a unique annual fleet size. Population size was proportioned to the abundance index from United States trap catches treated as logarithms (Rounsefell and Kelez 1938, their Table 32), which was an average annual catch for a set of index traps weighted to correct each index trap for years when it was not fished. Rounsefell applied an "analysis of multiple covariance" (Snedecor 1946) to the multiple regressions of (log) catch-per-gillnet on fleet size and (log) population index to standardize differences between cycles, deriving annual indices of unfished population size at the Fraser River mouth from the intercepts at zero gillnet fleet size. Using published IPSFC catch plus escapement information for 1941 through 1945, Rounsefell weighted his indices of abundance to actual abundance in these five years and then calculated escapements and total runs for the years 1894 through 1945 (Table 16). Like the escapements calculated from Thompson's (1945) analysis, Rounsefell's escapements tended to be smaller in the years of great sockeye abundance and larger in years of low abundance than those of Tables 12 and 13 combined (Table 16), probably for similar reasons.

A number of weaknesses were apparent in Rounsefell's (1949) analyses. Use of the trap catch index as abundance at the Fraser mouth implied that the United States fishery removed a relatively constant fraction of the sockeye run each year, which was unlikely. For example in a number of years, a substantial part of the Fraser run approached from the north through Johnstone Strait (Gilhousen 1960) and would not have been vulnerable to the United States trap fishery.

Analyses based on the trap catches also do not take into account competition with other gear and efficiency changes during the sockeye season. Trap efficiency decreased markedly from early July through August. Traps were limited by law to shallow inshore waters and also by the depth that piles could be driven. Later running sockeye tend to migrate in deeper water and thus would be less vulnerable to capture by the traps than earlier running fish. An extreme example occurred during the 1930 run, which consisted largely of Adams River fish. In that year, the *Pacific Fisherman* (October, 1930) reported that purse seines took an estimated 75% of the United States sockeye catch; the trap index for 1930 was correspondingly low. This same phenomenon must also have occurred in earlier years with large Adams run, e.g., the dominant runs of 1897-1913.

In addition, averaging the regressions for the four cycles removed cycle differences in exploitation rate; the difference was especially important in the dominant years when sockeye were usually quite small, with larger proportional escapements due to net selectivity effects.

Finally, it was assumed that for constant population size, catch-per-gillnet varied exponentially (i.e., semi-logarithmically) with fleet size, indicating competition but no

Table 16. Comparison between estimates of escapements developed in the present report and those developed by Killick and Clemens (1963), Thompson (1945) and Rounsefell (1949).

YEAR	Killick and Clemens (1963)	Thompson (1945)	Rounsefell (1949)	Tables 12 & 13 combined
1894			3,431	835 *
1895			3,507	2,050 *
1896			1,196	630 *
1897		6,528	4,629	10,250 *
1898		1,973	767	570 *
1899		3,296	1,431	1,375 *
1900		797	374	400 *
1901		3,969	2,372	12,900
1902		1,951	1,214	500 *
1903		907	610	460 *
1904		841	389	225 *
1905		4,708	4,708	9,250
1906		1,634	1,251	460 *
1907		742	418	190 *
1908		1,527	676	240 *
1909		3,944	1,636	3,975 **
1910		1,809	1,157	865
1911		907	658	240 *
1912		1,220	1,094	375 *
1913		5,203	7,157	6,610
1914		892	689	820
1915	368	221	347	480
1916	269	239	117	155
1917	1,459	636	435	595
1918	185	194	135	85
1919	196	313	318	205
1920	245	513	431	190
1921	339	417	354	220
1922	293	541	456	290
1923	162	413	442	325
1924	259	796	549	245
1925	392	744	619	255
1926	391	671	1,268	750
1927	384	340	804	670
1928	228	384	314	165
1929	532	535	617	385
1930	1,033	1,465	944	2,600
1931	284	425	502	335
1932	453	665	678	335
1933	554	647	469	415
1934	1,100	1,413	972	1,455
1935	354		709	375
1936	973		2,030	745
1937	578		593	650
1938	1,063		1,277	1,235
1939	269		364	235
1940			725	565
1941			1,,392	1,020
1942			2,397	2,900
1943			180	205
1944			542	368

* Excludes estimate of late run escapements.
** Probable underestimation of gillnet selective loses; see text.

interference between nets. However, the extremely high exploitation rates calculated for the Fraser gillnet fishery (in all analyses considered here) left no scope for free competitive interaction between units of gear except with very small fleet sizes; the available catch was essentially fixed and was divided between gear units. That is, for constant abundance, catch-per-net varied hyperbolically (inverse logarithmic relationship) with fleet size. Conversion of gillnet fleet size to logarithms obviates the calculation of intercepts at zero fleet size fundamental to Rounsefell's method. Furthermore, Ricker (1975) also pointed out that the rate of removal must be low for the DeLury method to be valid.

Killick and Clemens (1963) presented a set of annual gross escapements for the years 1915 through 1960 (Table 16), derived from mean percentage exploitation in the total fishery for 1940 through 1960, but modified by the preliminary results (mean percent escapement) of the present analysis. Their estimates were generally larger than those of Tables 12 and 13 combined.

All four sets of estimates of annual escapements presented in Table 16 are closely correlated because all relate escapement estimates to a common variable - the catch (Table 17). Geometric mean escapements of paired sets of years in the four series of estimates were significantly different in only one comparison in six, i.e., between Thompson (1945) and the present set of estimates (Table 17). Variances for logarithms of escapements were significantly different in two of the six comparisons; Thompson (1945) and Rounsefell (1949) versus the estimates from the present study. These differences required modification of Student's t test for difference between geometric means (smaller variance used). Geometric means were much smaller than arithmetic means in the three comparisons where the large dominant 1897-1913 runs were involved. Primarily because the estimates of the present analysis were larger than those from other sources for both the large dominant years and for the years of the large late Shuswap runs, and generally smaller than those from the other sources for the "off" years, the arithmetic means derived from the present study were larger than those of the other three sets, while the geometric means were smaller.

Slopes of paired sets of estimates from Table 16 differed significantly from unity in only one of the pairs (Table 17; t_b; Snedecor, 1946). Since neither set of any pair could be considered as the independent variable, slopes were calculated twice (independent variable switched) and averaged; errors of estimates of the slopes were also averaged. The single significant slope difference involved Rounsefell's estimated escapements, possibly because he combined the regression for the large dominant runs with those of the small runs.

As demonstrated by the statistical tests of Table 17, differences between the four sets of annual escapement estimates shown in Table 16 are mostly minor. Differences are most important for the dominant years of 1897 to 1913 and for the years of large, late Shuswap runs.

ESTIMATION OF DOMINANT RUN ESCAPEMENTS PRIOR TO 1917

The run of 1913 represented the zenith of Fraser River commercial sockeye production. The total catch in the combined Canadian and United States fishery, exceeding 30 million sockeye, was made with the Fraser River fishery at times being limited because cannery capacities were exceeded. Had such limitations not been applied in that year, catches would have been higher. Even when cannery limitations were not applied, a number of observers felt that the fleet was not capable of harvesting the immense run and that the rate of exploitation in 1913 was much less than that in earlier years. Because of the importance placed in assessing peak production levels of Fraser sockeye, there has been lively interest in attempting to develop accurate estimates of the

TABLE 17. Statistical comparisons between the four sets of annual escapement estimates presented in Table 16 (data converted to logarithms to provide approximately normal distributions).

ESCAPEMENT ESTIMATE SET	D. Killick and Clemens 1963	C. Thompson 1945	B. Rounsefell 1949
A. TABLES 12 plus 13	N=25 (1915-1939) r=0.81, p<0.01 A.M.E.(A)=536,000 A.M.E.(D)=495,000 G.M.E.(A)=389,000 G.M.E.(D)=407,000 F=1.60, p>0.05 t_m=0.23, p>0.50 t_b=1.32[b], p>0.10	N=38 (1897-1934) r=0.83, p<0.01 A.M.E.(A)=1,575,000 A.M.E.(C)=1,432,000 G.M.E.(A)=575,000 G.M.E.(C)=931,000 F=1.86, p<0.05 t_m=2.30[a], p<0.05 t_b=1.40[b], p>0.10	N=51 (1894-1944) r=0.85, p<0.01 A.M.E.(A)=1,406,000 A.M.E.(B)=1,183,000 G.M.E.(A)=601,000 G.M.E.(B)=785,000 F=1.70, p<0.05 t_m=1.55[a], p>0.10 t_b=1.52[b], p>0.10
B. Rounsefell 1949	N=25 (1915-1939) r=0.63, p<0.01 A.M.E.(B)=539,000 A.M.E.(D)=495,000 G.M.E.(B)=523,000 G.M.E.(D)=407,000 F=1.28, p>0.05 t_m=1.42, p>0.10 t_b=2.29[b], p<0.05	N=38 (1897-1934) r=0.89, p<0.01 A.M.E.(B)=1,105,000 A.M.E.(C)=1,432,000 G.M.E.(B)=718,000 G.M.E.(C)=931,000 F=1.12, p>0.05 t_m=1.28, p>0.20 t_b=1.39[b], p>0.10	
C. Thompson 1945	N=20 (1915-1934) r=0.67. p<0.01 A.M.E.(C)=579,000 A.M.E.(D)=456,000 G.M.E.(C)=502,000 G.M.E.(D)=375,000 F=1.22, p>0.05 t_m=1.61, p>0.10 t_b=1.86[b], p>0.05	A.M.E. - arithmetic mean escapement estimate (for the set indicated by the letter). G.M.E. - geometric mean escapement estimate (for the set indicated by the letter). F - ratio of variances of sets compared. t_m - Student's t for difference between means. t_b -Student's t for difference of slope from 1.0 a - variances significantly different; smaller variance used for t test. b- mean slope and mean error or estimate of slope used for t test; see text.	

levels of exploitation and of escapements that occurred in 1913.

As outlined in the previous section, analyses presented in the current study provided an escapement estimate of 6.6 million which, with the recorded commercial landing of about 30 million, and even with wastage of several million sockeye in the United States fishery would have provided a total run of no more than 45 million sockeye. Thompson's (1945) escapement estimate of 5.203 million and that of Rounsefell (1949) of 7.157 million, bracket the estimate derived in the present report.

Ricker's Estimate

Ricker (1950 and 1987) estimated that the total annual Fraser River sockeye run of 1913 was at least 100 million fish. His conclusions were based primarily on the observation that 5-year old sockeye were relatively more abundant in non-dominant years than in the large dominant cycle years which culminated in the 1913 run. He assumed that the number of 5-year-olds considered to originate mainly in the Birkenhead River and other systems below Hells Gate, was relatively constant from year to year.

Based on sampling carried out in the commercial fishery by C. H. Gilbert during 1911-1914 (Gilbert 1913a, b, 1914 and 1915), Ricker noted that the ratio of the percentage of 5-year-olds in 1913 to the geometric mean of comparable percentages in 1911, 1912 and 1914 was 0.35:19.0 (less than 1:50, see Table 18). Applying this estimate to the estimated average abundance of sockeye in the three smaller years (4.406 million), he developed a provisional estimate of abundance from the 1913 run of about 240 million (4.406 X 19.0/0.35).[43] Ricker adjusted this figure downwards to 210 million, in part to take into account "... *the few* 5_2*s in upriver stocks* ..."

TABLE 18. Data used by Ricker (1987) on total sockeye catches and on numbers of 5-year-olds sampled during 1911-1914 (Gilbert 1913a, 1913b, 1914 and 1915) in order to estimate the abundance of the 1913 sockeye return.

YEAR	Frequency of 5-year-olds (%)	Total Sockeye Catch * (1000s)	Sampling Dates
1911	46	2,180	August 2,3,4
1912	10	3,365	July 29; August 5,6
1913	0.35	31,345	July 25,26 August 11-15
1914	15	5,695	June 27; July 28 August 5-7

* From Rounsefell and Kelez (1938).

As Ricker noted, the number of 5-year-old fish in Gilbert's 1913 sample was very small (nine of 2,575 sampled), resulting in very broad 95% confidence limits about the estimates of the size of the 1913 return (100 - 390 million about the assumed mean of 210 million). In the end he concluded that "... *something of the order of 100 million is not at all an unreasonable estimate of the sockeye present in the old big years.*" He cited other data, including narrative accounts of the abundance of sockeye on the spawning grounds, returns to hatchery ponds, etc. as supporting his conclusion.

Evidence from Sampling

As noted above, Ricker's conclusions depend most importantly on the estimate of the proportion of 5-year olds in the 1913 run. There are a number of reasons which suggest that estimates of the proportion of 5-year-olds derived from the very limited sampling data may be too low or that the number of 5-year-olds which returned in 1913 was less than in preceding and succeeding "off years".

The first concern relates to the representativeness of the sampling on which the estimates were based. The quadrennium 1911-1914 was the first during which sampling was carried out to provide annual estimates of age, size and sex composition of the Fraser sockeye run. Work begun in those four years was the forerunner of an unbroken series that continues to-day. However, the sampling in the initial four years was very restricted in time and extent compared with that of later years. Figure 31, illustrating proportions of 5-year-olds in Fraser fishery samples from 1911 through 1922, shows the very limited nature of the sampling in 1911-1915 (mainly two or three samples per year). The figure

---

[43] Based on proportions of 5-year-old sockeye in off years and in 1913 of 19 and .035% respectively and an off year average run size of 4.406 million, the same figures listed above, Ricker apparently erroneously computed the estimated 1913 total stock as 220 million.

also shows the marked variability in the proportion of 5-year-olds at different times during the season. More extensive and representative sampling in 1911-1914 might have produced different results.

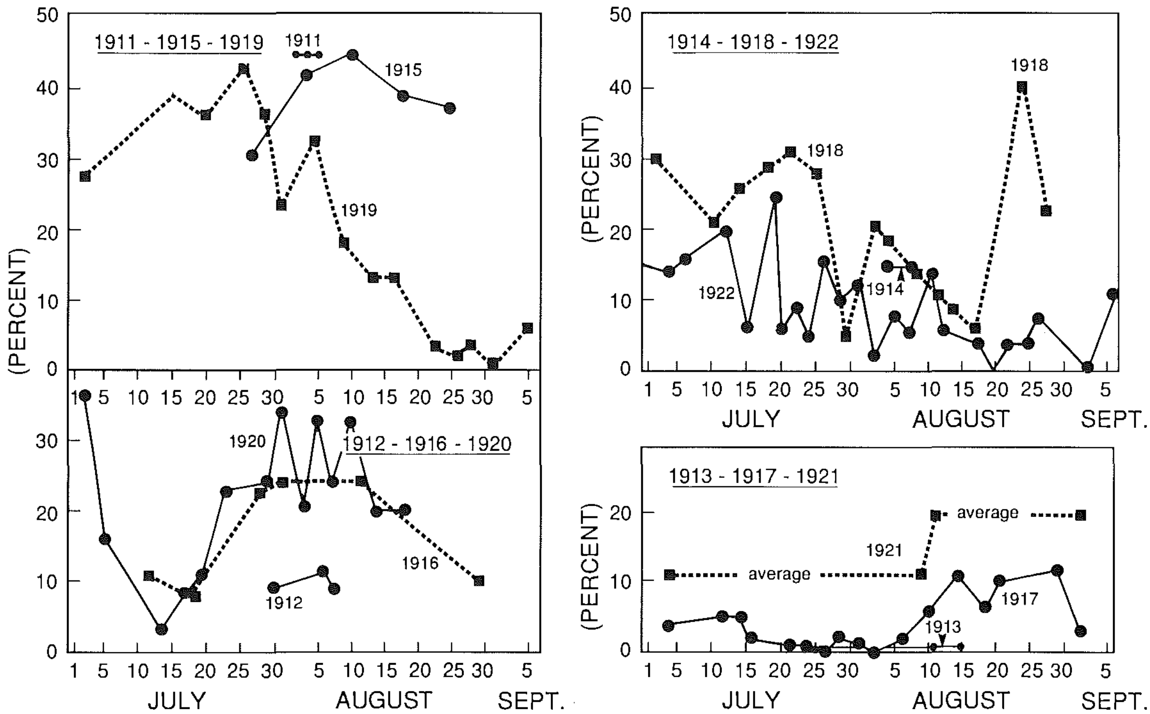

Figure 31. Daily percentages of 5-year-old sockeye sampled in programs reported by C.H. Gilbert during 1911-1922 (grouped by cycle year).

There are also some questions regarding the validity of Ricker's assumptions concerning the contributions of 5-year-olds from Fraser sockeye systems below Hells Gate. On the basis of recent information, Lower Fraser River sockeye stocks are usually present only in small proportions during the late July - early August period (Figure 31) when the 1911-1914 sampling took place and when the upriver runs are at peak abundance. Only the upper Pitt stock has peak migration at this time; its largest known production of 5_2 sockeye was about 175,000 in the 1947 brood year with a total return for that generation to the system of less than 250,000. The Birkenhead stock, which has produced more than 350,000 5_2s (1982 brood year; total return of the stock of 1.6 million), usually has a later than normal migration in years when it is large. Thus the downriver stocks may not have been important contributors to the run passing at the time of sampling.

The assumption that up-river 5_2s contributed little to the fishery is also open to question. Again based on recent information, systems above Hells Gate do produce substantial numbers of 5_2s. From the 1980 brood year, for example, the production of the Chilko stock included 500,000 5-year-olds (58% of all 5-year-olds and about 3.6% of the total 1985 Fraser sockeye run) while the Stellako also produced 220,000 5_2s (about 26% of all 5_2s in the 1985 return). The 1981 brood year of the Quesnel sockeye run produced about 145,000 5_2s.[44] It would thus appear that the year following the dominant year run would have had a large number of 5_2s in the period up to 1914.

[44] Although the numbers of 5-year-olds were substantial, they formed only a small proportion of the approximately 5 million total summer run which returned in 1986.

However, the occurrence of upper river 5-year-olds, contrary to the assumptions in Ricker's hypothesis, does not necessarily invalidate Ricker's large estimate for the 1913 sockeye run size. It does not matter where the 5-year-olds were produced if they were relatively constant in number annually. Unfortunately, there are no independent sources of information that could shed further light on the question of the levels of occurrence of 5-year-olds in the big cycle years.

Information from Other Sources

If one accepted Ricker's estimate of a 100 million stock size in 1913, the excess production over that estimated in this paper (about 37 million) would have to be accounted for by one of three possibilities:

- A higher gross escapement and, as a corollary, a lower rate of exploitation in the Fraser River gillnet fishery than estimated in the present report; and/or,
- substantial unrecorded wastage in the Canadian gillnet fishery; and/or,
- extensive unrecorded wastage in the United States trap fisheries.

Direct Evidence on Escapements: Unfortunately, firm quantitative evidence of the abundance of the escapement in 1913 does not exist; the Hells Gate slide destroyed the major part of the run and it was impossible to estimate how many fish were actually blocked by the slide. Information for other years was discussed above and, as in the case of the Quesnel stock, it is possible that in some years, escapements did exceed those estimated in the present paper.

In arguing that escapements in pre-1917 dominant cycles were much higher than had been estimated by other authors, Ricker cited evidence of very large numbers of sockeye arriving in Seton Creek (See location in Figure 3) in the big years and estimated that the ratio between the abundance of dominant and off year upriver runs was 100:1. He did not, however, distinguish between early- (July to early September) and late-run (mid-September and after) Seton-Anderson system sockeye, which utilized different spawning grounds and had different patterns of annual returns. Nor did he consider that sockeye bound for areas above Bridge River Rapids were often severely delayed at the Rapids and that many blocked fish were then diverted to Seton Creek. Difficult migration at Bridge River Rapids occurred at low water levels and thus varied markedly from year to year. In some years only a small proportion of sockeye entering the Seton-Anderson Lake system were the progeny of sockeye spawning in that system. Indeed, Babcock (1913) indicated that most of the 1912 sockeye run into the Seton-Anderson system was a result of difficult passage conditions at Bridge River Rapids.[45] The numbers of sockeye arriving at Seton Creek cannot consistently be associated with production from the local system and the ratios of big year to other year abundance cannot therefore be considered as a measure of the relative production of upriver stocks in different years.

Evidence of Low Rates of Exploitation in the Canadian Fishery: As outlined earlier, rates of exploitation in the Fraser River gillnet fishery were probably lower in times of high abundance because nets would tend to become full of fish, fishermen would take longer to remove fish from their nets and to deliver fish to the canneries, etc. How much such factors would lower the rate of exploitation is hard to assess. Most of the time there would appear to have been a more or less natural balance between the capability of the fishermen to harvest and land the fish and the capacity of the cannery to process them. Under such circumstances, it would not seem likely that the fishery was exploiting the runs by an order of magnitude less, as would be implied if it were assumed that the actual 1913 escapement was in the order of 65 million rather than about 6.6 million.

---

[45] Fishways were later built at these rapids to alleviate migration difficulties (IPSFC 1947).

Major reductions in exploitation would be expected under circumstances where canneries placed limits on the numbers of fish each fisherman was allowed to land, as was the case during some periods in some years. However, in 1905, 1909 and 1913, the periods during which limits were put on daily deliveries by individual gillnets were short or nonexistent. Based on contemporary accounts (Babcock 1910), in 1909 at least, there was no time when cannery limits would have reduced exploitation drastically below the normal potential of the fleet. During periods of high abundance in 1905 and 1913, limits of 200 sockeye-per-gillnet-boat were in force on the Fraser for four days and two days respectively (Babcock 1906 and 1914). However, a second short period of restricted catches was indicated by newspaper reports in 1905 and single short periods in 1909 and 1913 (Table 12 and Figure 29). It is hard to see how such short periods of limitations could account for the major differences in estimates of escapement abundance.

Evidence of Wastage in the Canadian Gillnet Fishery: In the 1890s, wastage of sockeye in the Canadian gillnet fishery was a concern to Canadian authorities. This concern was as much focused on the disposal of cannery offal as it was on actual discard of unused whole fish.[46] Waste of excess sockeye undoubtedly occurred in the 1890s when the fishery was developing. However, such waste of sockeye in the Fraser gillnet fishery was much reduced after 1901, since periods of cannery overload were short thereafter. As discussed earlier, Babcock (1914) put the total wastage of gillnet sockeye in 1913 at less than 300,000. Thus, wastage of sockeye in the Canadian fishery in 1913 would not appear to have been substantial even considering the immense abundance of the passing run.

Evidence of Wastage in the United States Trap Fishery: In the first decades of the United States trap fishery for sockeye, there were frequent allegations regarding wastage. References were noted in British Columbia newspapers concerning dumping of sockeye by the United States industry in the 1890s. In 1893, vacationers complained of fish which washed up on the shores of Boundary Bay after being discarded by a cannery at Point Roberts (*Daily Columbian*, August 1, 2); the cannery owner then promised to dump the fish in deep water in the Strait of Georgia. Again, in 1899, the *Daily Columbian* (August 12) reported "stupendous waste of stale fish" during "the big run a couple of years ago - - -" (probably 1897). Babcock (1910) reported similar waste during the big run of 1901; he reported that the number wasted was greater than the number canned. However, Babcock did not arrive on the west coast until late 1901 and his conclusions were apparently based on hearsay. Significantly, he made no mention of wasted sockeye in 1905 or 1909 (Babcock 1906 and 1910).

Reports of large numbers of sockeye suffocating and dying in United States traps and of scowloads of rotting fish appeared in British Columbia newspapers in 1905 (e.g., *The World*, July 28). This was denied by a representative of the United States industry. No further reports appeared regarding such waste. It would therefore seem that the initial report exaggerated the circumstances. Indeed, a trap full of dead sockeye would have been an economic disaster. Live sockeye could be collected in a brail and removed or allowed to swim free but masses of dead fish lying on the bottom of the trap would have created an extremely difficult disposal problem.

Waste of valuable sockeye, dominant year after dominant year, would seem to have been very unlikely. The United States fishery simply could not have afforded the waste of an amount of fish greater than the number canned. It would have been grossly uneconomic to remove such a large number from the gear, haul them to the canneries and dump them either there or remove them to offshore waters. The increase in canneries in

[46] For example, *Daily Columbian*: Aug. 4, 24, 1893; Aug. 18, 24, 1894.

the United States kept pace with the development of the fishery so that, in general, they could handle all the sockeye in a dominant year.

Pink salmon, which began migrating through the United States fishery in the latter part of August in odd-numbered years, probably suffered much greater wastage than sockeye (Rathbun 1900). Wastage would have increased as the season progressed until unwanted pinks became so abundant that sorting out the sockeye became uneconomic. In the earlier years before pink salmon were canned in large numbers, traps were taken out of use when pinks became abundant in the latter part of August (Rounsefell and Kelez 1938). Trap fishing was extended later in the season as larger parts of the pink run became utilized. Thus, reports of great wastage of "salmon" in the earlier years may have had their origin mainly in the discard of dead pink salmon.

Traps could be operated to block entrance of salmon or release them alive. Traps were reported to have been "closed" (when full of sockeye) "until they could be emptied" (*Daily Columbian*, July 30, 1901). Also, as described by Rathbun (1900) and Rounsefell and Kelez (1938), additions to the traps called spillers were devised in the 1890s to hold excess catches until they could be processed at the canneries. Excess catches were apparently liberated when necessary; the *Daily Columbian* (July 30, 1901) reported (from United States sources) that:

> *"Fish are being left in the traps because the canneries cannot put them up. As salmon will keep in good shape in the traps for at least a week, if not over-crowded, the boats take out enough to keep them from suffocating each other, and leave the balance until such time as the cannery can take care of them. ... one trap was estimated to have had 50,000 fish, which were liberated on account of there being no market for them ... Seine men ... are said to have caught 5,000 in one haul, and were compelled to turn the fish loose for lack of buyers".*

Thus, as early as 1901, measures were being taken to avoid wastage of trap-caught fish. It is therefore considered to be unlikely that 12 years later in 1913, wastage could have formed a substantial part of the total catch.

Summary: Whereas it is admitted that escapement estimates derived in the present report for the big dominant years prior to 1917 are more subject to error than those for other years, the very large estimate made by Ricker, mainly on the basis of a very limited sampling of fish in the 1913 run, is very difficult to support. While the truth may well lie between the 6.6 million estimate of gross escapement in the present report and Ricker's estimated total gross escapement plus wastage of around 70 million,[47] it is far more likely to be in the lower part of the range.

CONCLUDING REMARKS

The various estimates of historical annual Fraser River sockeye escapements reviewed here (excepting those of Ricker 1987) all tend to follow the general changes in annual total sockeye abundance and are not grossly different from each other. All suggest a high rate of exploitation in the total fishery. They were based on total catch or some index of a large part of that catch, usually modified by numbers of gear. Because the catch formed the major portion of annual runs, which varied markedly in size, and because gear numbers varied within a limited range, calculated annual escapements were necessarily correlated with probable annual escapements. However, estimates published previous to

---

[47] Total stock 100 million with an estimated catch of about 31 million.

those of the present report ignored the effect of changes in regulations, of fishing stoppages and curtailments, and of variable gillnet selectivity as included here.

Two other sources of variation may have affected the efficiency of the Fraser River gillnet fishery, which were not considered in the present analysis. Pulsed recruitment into the Fraser River gillnet fishery resulting from the weekly closures applied in the United States fishery beginning in 1909 may have affected rates of escapement. In addition, the analysis of the present report did not consider the effect of variable catch handling time with different size of catches on the efficiency of the Fraser River gillnet gear; this factor, which would have changed with the introduction of the powered net reel, may have been important in the years of great abundance. Without firm evidence, it had to be assumed that the very large gillnet fleet sizes in the early years of the fishery have balanced this lower efficiency.

While extreme accuracy cannot be claimed for the present estimates, which in many cases were necessarily conservative, they are offered here as the best possible escapement estimates obtainable from the data now surviving.

These escapement estimates allow the calculation of total annual run sizes and of the production from various sizes of spawning populations in the historical period of the developed fishery. They also allow study of the phenomenon of quadrennial dominance during that period. However, such studies are beyond the scope of the present report and will be left for others to address.

SUMMARY

1. A study of the Fraser River gillnet fishery for sockeye salmon was made to elucidate the loss of productivity resulting from the 1913 rock slide at Hells Gate, and to provide background information for management in completing the rebuilding of the formerly larger annual sockeye returns. Estimates of annual escapements from the fishery were derived from harvest data by assessment of exploitation rates.

2. The runs of maturing Fraser River sockeye leave the open ocean from late June to September, migrate through coastal waters and ascend the Fraser to the home spawning grounds of the particular stock to which they belong. Runs peaking in July and early August in estuarial waters enter the river with little or no hesitation, while later runs delay off the river mouth for from a few days to several weeks. Sockeye mature largely at age four years, creating four more or less independent cycles with usually distinct average size (weight) and historically large differences in abundance.

3. Gillnet fishing on the Fraser River began in the 1860s, first supplying salteries and then canneries from the 1870s. The sockeye catch was predominantly taken by the canneries. Both fishing and canneries spread from the New Westminster area to the river mouth very early, and the industry became centered in the lower area during the 1880s.

4. Fraser gillnet sockeye harvest data were compiled from a number of sources; annual production was calculated mainly from the canned pack while within-season catch patterns were obtained from surviving records of a few canneries. Annual sockeye catches, estimated from packs, required correction for wastage, exports to and imports from other areas, and for local uses other than canning.

5. The pattern of weekly exploitation in the Fraser gillnet fishery, regulated mainly by the weekly closure length, was investigated through test fishing experiments. The fishing power of a single net (unit drift efficiency) was estimated from sockeye catches in routine test fishing during closures, related to 24 hour abundance estimates. The pattern of hourly abundance through a seven-day cycle of a weekly fishing period plus closure was ascertained from a specially designed test fishing experiment.

6. Results from the test fishing analyses allowed derivation of a relationship (model) between exploitation rates in the gillnet fishery, the length of the weekly fishing period and the fishing capacity of the fishery (i.e. its efficiency if the gillnets fished continuously, without closed periods). First estimates of fishing capacity for sockeye were high, from 98 to over 99.5%. Selective loss of catch by gillnets was not considered in this model.

7. The reasonableness of the model of exploitation rate, fishing period length and fishing capacity was tested against calculated sockeye exploitation rates for the gillnet fishery for 14 years (between 1940 and 1961) when IPSFC catch and escapement data were available. Derived fishing capacities were above 90% for all but two years and were consistent with the model trend of exploitation rate vs fishing period length.

8. Weekly closed period lengths, and dates of extended closures to gillnetting in the Fraser River were compiled from newspaper items and official records. Weekly closure lengths were usually 30 or 36 hours up to 1906, 42 or 48 hours 1907-1933, and 54 or more hours thereafter. Extended closures were generally a week or more in length and were applied after the main sockeye season.

9. Evidence of gillnet selectivity, i.e. the loss of catch by sockeye passing through the net meshes or avoiding capture after attempting to penetrate the mesh, was noted in size differences between sockeye caught in the U.S. fishery (largely non-selective) and the selected catch by Fraser gillnets. Selection was apparent both in comparisons of the number of sockeye required to fill a 48 lb case of canned product in the two fisheries and in weekly average weight differences between the purse seine catch at Point Roberts and the closely adjacent Fraser gillnet fishery harvest. The difference was most apparent when sockeye had low average weights.

10. Selectivity was analyzed from two test fishing experiments designed for the purpose, yielding a generalized selection curve for the linen nets used in the Fraser River fishery from its inception until about 1953. The unimodal curve was asymmetrical, with gradual loss of efficiency for larger than optimum size sockeye and a more rapid cutoff for smaller than optimum fish. Selection curves were calculated for sockeye weight distributions grouped into 0.25 lb intervals.

11. From limited information, four simplified schedules of Fraser gillnet fleet mesh sizes mixtures used for varying annual sockeye average weights were created. This allowed evaluation of selectivity-caused reduction of fishing capacity resulting from varying mismatch between size of nets used by the fleet and the average weight of sockeye in different annual runs.

12. Four absolute fleet selection curves were derived by combining unit selection curves for the hypothetical number of nets of each mesh size in each of the four mixtures. Unit selection curves were first converted to absolute efficiency values based on unit gillnet efficiency, estimated for 24 hours of fishing, and overall efficiency on representative sockeye population weight distributions.

13. Selective loss of fishing capacity by the four simulated gillnet fleets was estimated by applying each absolute selection curve to ten representative annual sockeye population weight distributions with average weights from 5 to 7.2 lbs. The relative frequency in each 0.25 lb weight group was multiplied by the local efficiency for that group, the sum of the products then yielding the hypothetical fleet fishing capacity and average weight of the simulated catch (and thus average weight difference from the population). Forty such calculations were made.

14. The forty sets of simulated fishing capacity values and average weight differences for the fishery allowed the regression of average weight differences taken from the Point Roberts purse seine vs. Fraser gillnet comparison to be converted into two schedules fishing capacity vs. sockeye population mean weight. The first was for years before 1929 when a 5.75 in. mesh-size minimum was enforced and the second for subsequent years without mesh size restrictions for sockeye fishing.

15. The variations in fishing capacity with sockeye population average weight were combined with the model of exploitation rate variation with fishing capacity and weekly fishing period length. This provided two diagrams linking exploitation rate change with weekly fishing period length and sockeye population average weight, covering the years before and after the abolition of the 5.75 in. mesh size minimum.

16. Application of this derived model for predicting Fraser River gillnet exploitation rate required separate treatment of early (summer) and late migrating components of an annual sockeye run. The model was applied directly to the summer season since there was no delay at the river mouth to enlarge the catch of migrating sockeye. Delaying sockeye, which migrate upriver beginning about mid-September, are subject to additional fishing between arrival at the river mouth and river entry. These late

runs have also been protected in part by extended closures and often by reduced fishing effort.

17. Annual summer season gross escapements were estimated for the years 1892-1944. Annual average sockeye weight was calculated from sockeye-per-case in published data. Corrections were made for cannery overloads when catches were restricted, for cessation of fishing due to fishermen's strikes or extended closures, and for periods of low fishing effort reported in the press. Annual summer season sockeye escapement estimates varied from 65,000 (1918) to over 12 million (1901).

18. Annual late-run gross sockeye escapements were derived for the years 1901, 1905, 1909 and 1910, plus all years from 1913 and after. Escapements were based on exploitation rates estimated from the summer season exploitation rates, as modified by reduced fishing effort (as reported in newspapers or government reports), by extended closures and by restrictions on minimum mesh size usually enforced in the autumn. Late-run sockeye escapements were, in all but a few years, much smaller than summer-run escapements.

19. Total annual sockeye escapement estimates were compared with published estimates made from spawning ground observations. The present estimate of escapement in 1909 was found to be too small, compared with Babcock's (1910) report for the Quesnel sockeye; a more reasonable estimate would have resulted if 1909 sockeye average weight (unknown; cycle average used) had been smaller. Escapement estimates were much larger than those published for seven years between 1929 and 1937, but close to those given by the IPSFC for 1938-1944, excepting 1941. For the latter year, the present estimate agrees well when the calculated loss at Hells Gate is included.

20. Comparison of present estimates of total annual sockeye escapements with three other sets based on exploitation rate data (Thompson 1945, Rounsefell 1949 and Killick and Clemens 1963) showed varied differences. The present estimates were generally larger in years of large runs (e.g. 1897, 1907, 1905, 1909, 1913) but tended to be smaller than earlier estimates in years with small sockeye runs. All estimate series were significantly correlated since they were all based on the annual sockeye catches.

21. Estimated Fraser River sockeye abundance in 1913 by Ricker (1950 and 1987) was much larger than the present estimate (about 100 million vs. 40 million). Ricker's estimate is based on the hypothesis that the number of 5-year-old sockeye was relatively constant in both the large dominant run of 1913 and in the small "off" years preceding and following, as deduced from Gilbert's 1911-14 sampling of sockeye. From analysis of all of Gilbert's sampling data and consideration of modern information, the assumption was judged to be suspect.

22. Ricker's (1987) estimate of 100 million fish in the 1913 Fraser sockeye return was also found to conflict with information on escapement from the gillnet fishery and on wastage in both the U.S. and Canadian fisheries. Estimates by knowledgeable people, newspaper reports, and general economic considerations all suggest low wastage. Examination of daily Fraser River gillnet catches, with only two days of cannery overload, suggests a moderate escapement rather than the vary large escapement that would result from a return of 100 million.

23. The present estimates of historical annual Fraser sockeye escapements and the other estimates reviewed (excepting those of Ricker 1987), all follow the general changes in sockeye abundance and indicate a high rate of exploitation for the total fishery. The present estimates have many deficiencies but are probably the best that can be obtained from the surviving information.

ACKNOWLEDGEMENTS

Much credit is due Loyd A. Royal, former Director of the International Pacific Salmon Fisheries Commission (1950-1971), who recognized the possibility of calculating sockeye escapements from the intermittent nature of the Fraser River gillnet fishery and the pulsed escapements resulting therefrom. This study and certain of the experiments upon which it is based were the result of his insight.

Criticism and suggestions for improvements have come from A.C. Cooper, also a former director of the I.P.S.F.C. (1971-1982); later criticism and advice has been given by Bruce White and Ian Guthrie of the Pacific Salmon Commission, successor to the I.P.S.F.C. Help with computer programs has been generously given by the staff of the Pacific Salmon Commission. Dr. M.P. Shepard provided substantial assistance in the editing of the final version of the report.

Finally, credit must be given to W.A. Forsythe (for many years a Fisheries Inspector with CDF; died 1947), who spent untold hours making the numerous newspaper extracts concerning the Fraser River salmon industry: these provided much information for the report.

LITERATURE CITED

Alaska Fish and Game. 1988. Salmon fishing methods of the Yukon River. A.F.&G. Wildlife Use Notebook Series 2: 4 p. (In A.F.&G. 20 (4), July-Aug).

Anderson, A.C. 1878. Report of Inspector of Fisheries for British Columbia for 1877. Ann. Rep. Dept. Marine and Fish., Sessional Paper No. 1 (41 Victoria, A 1878), Ottawa.

1880. Report of Inspector of Fisheries for British Columbia for 1879. Ann. Rep. Dept. Marine and Fish., Sessional Paper No. 9 (43 Victoria, A 1880), Ottawa.

1882. Report of Inspector of Fisheries for British Columbia for 1881. Ann. Rep. Dept. Marine and Fish., Sessional Paper No. 5 (45 Victoria, A 1882), Ottawa.

Babcock, J.P. 1902 to 1907. Report(s) of the Fisheries Commissioner for British Columbia for (1901 to 1906). Victoria, B.C.

1908 to 1910. Report(s) of the (Deputy) Commissioner of Fisheries for British Columbia for 1907, 1908, 1909. Victoria, B.C.

1912 to 1932. The Spawning Beds of the Fraser. In: Rept. Comm. Fish. B.C. (1911 to 1931).

Bartlett, M.S. 1949. Fitting a straight line when both variables are subject to error. Biometrics 5(3): 207-212.

Brannon, E.L. 1967. Genetic control of migrating behavior of newly emerged sockeye salmon fry. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 16: 31 p.

1987. Mechanism stabilizing salmonid fry emergence timing. In: Sockeye salmon (*Oncorhynchus nerka*); population biology and future management (H.D. Smith, L. Margolis and C.C. Wood, Ed.). Can. Spec. Publ. Fish. Aquatic Sci. 96: 120-124.

British Columbian - Newspaper published in New Westminster, 1860 to 1866, and 1910 to 1927.

Clemens, W.A. 1938. Contributions to the life history of the sockeye salmon. (No. 23). Rept. Prov. Fish. Dept. (B.C.), 1937: 32-49.

1956. Some historical aspects of the fisheries resource of British Columbia. Proc. 9th B.C. Nat. Res. Confer. (Victoria): 119-130.

Clemens, W.A., and L.S. Clemens. 1926 to 1936. Contributions to the life history of the sockeye salmon. (No.s 11 to 21). Rept. Fish. Comm. B.C., 1925 to 1935.

1937. Contributions to the life history of the sockeye salmon. (No. 22). Report Prov. Fish. Dept. (B.C.), 1936: 26-44.

Columbian, Newspaper published in New Westminster, B.C., 1927-1970.

Cunningham, F.H. 1917. Report of the Chief Inspector of Fisheries for British Columbia. In: Fiftieth Annual Report of the Fisheries Branch, Dept. of the Naval Service, 1916-17 (Ottawa): 230-273.

1921. Report of the Chief Inspector, Western Fisheries Division (British Columbia), for 1920. In: 54th Ann. Rep. Fisheries Branch, Dept. Mar. Fisheries, 1920 (Ottawa): 47-51.

Daily Columbian - Newspaper published in New Westminster, B.C., 1889 to 1910.

Daily News - Newspaper published in New Westminster, B.C., 1906 to 1914.

Daily Province - Newspaper published in Vancouver, B.C., 1899 to the present.

Daily World - Newspaper published in Vancouver, B.C., 1903 to 1914.

Dawson, E.M. 1881. The Northwest Territories and British Columbia. C.W. Mitchell, Ottawa.

De Fieux, C. 1967. Twine knitted by women to make first gill net. Of Ships and Men; *Vancouver Sun*, June 28, 1967.

DeLury, D.B. 1947. On the estimation of biological populations. Biometrics 3 (4): 145-167.

Gilbert, C.H. 1913. The Fraser River sockeye run of 1912. Report Comm. Fish. B.C., 1912: 19-24.

1913. Age of maturity of the Pacific salmon of the genus *Oncorhynchus*. Report Comm. Fish. B.C. 1912: 57-70.

1914-1916; 1918-1920; 1922-1925. Contributions to the life history of the sockeye salmon. No.s 1-10. Rept. Comm. Fish. B.C., 1913-1915; 1917-1919; 1921-1924.

Gilbert, C.H. and W.H. Rich. 1927. Investigations concerning red salmon runs in the Karluk River, Alaska. Bull. U.S. Bur. Fish. 43, Pt. II: (69 pp).

Gilhousen, P. 1960. Migratory behavior of adult Fraser River sockeye. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 7: 78 p.

MS 1966. Estimation of sockeye population blocked at Hells Gate in 1941. Internat. Pacific Salmon Fish. Comm.

1980. Energy sources and experditures in Fraser River sockeye salmon during their spawning migration. Internat. Pacific Salmon Fish. Comm., Bulletin 22: 51 p.

Gosnell, R.E. 1903. *The Year Book of British Columbia and Manual of Provincial Information.* Victoria: 394 p.

1911. *The Year Book of British Columbia and Manual of Provincial Information.* Victoria: 406 p.

Gordeau, F. 1901. Report of the Deputy Minster of Marine and Fisheries. 33rd Ann. Rept. Dept. Marine Fish. 1900 (Ottawa): i-xxxviii.

Gulland, J.A., and D. Harding. 1961. The selection of *Clarias mossambicus* (Peters) by nylon gill nets. J. du Conseil Explor. Mer XXVI(2): 215-222.

Halladay, A.P. 1915. Report on the fisheries of District No. 1. In: 48th Ann. Rep. Fisheries Branch, Dept. Naval Serv., 1914-15 (Ottawa): 252-254.

1916. Report on the fisheries of District No. 1. In: 49th Ann. Rep. Fisheries Branch, Dept. Naval Serv., 1915-16 (Ottawa): 251-254.

Henry, K.A. 1961. Racial identification of Fraser River sockeye salmon by means of scales and its application to salmon management. Internat. Pacific Salmon Fish. Comm., Bull. 13: 97 p.

Holt, S.J. 1963. A method for determining gear selectivity and its application. Internat. Comm. North Atlantic Fish., Spec. Publ. 5 (The selectivity of fishing gear), Paper No. 9: 106-115.

Howay, F.W. 1914. British Columbia: from the earliest times to the present. Vol. II. S.J. Clarke Publishing Co., Vancouver, B.C.: 727 p.

Howe, S.L. 1929 to 1933. Report(s) of the Commissioner of Fisheries for the year ending Dec. 31 (1928-1932). Victoria, B.C.

Hudson's Bay Co. 1827-1830. Fort Langley Journal. H.B. Co. Archives (Winnipeg), B113/a/1, a/2, a/3, b/1.

Inland Sentinel. Newspaper published at Yale, B.C., 1880 to 1884.

International Pacific Salmon Fisheries Commission. New Westminster, B.C. 1937-1985. Annual Reports for 1938-1985, published in year following.

Killick, S.R. 1955, The chronological order of Fraser River sockeye during migration, spawning and death. Internat. Pacific Salmon Fish. Comm., Bull. 7: 95 p.

Killick, S.R., and W.A. Clemens. 1963. The age, sex ratio and size of Fraser River sockeye salmon, 1915 - 1960. Internat. Pacific Salmon Fish. Comm., Bull. 14: 140 p.

Knox, B.M. 1962. Letter from director of W. and J. Knox, Ltd., Kilbirnie, Scotland (makers of linen nets and twines).

Loucks, R.H. 1964. Notes on running means. Fish. Res. Bd. Canada, Pacific Oceanog. Group (Nanaimo, B.C.), Circ. 1964-4: 5 p.

Lyons, C. 1969. Salmon and our heritage. Brit. Columbia Packers, Vancouver, B.C.: 768 p.

Mainland Guardian. Newspaper published in New Westminster, B.C., 1869 to 1889.

McCombie, A.M., and F.E.J. Fry. 1960. Selectivity of gill nets for lake whitefish, *Corregonus clupeaformis*. Trans. Am. Fish. Soc. 89 (2): 176-184.

McNab, J. 1899. Annual Report on the fisheries of British Columbia for the year 1897. In: 31st Ann. Rep. Dept. Mar. Fish., 1898, Fisheries (Ottawa): 221-230.

Motherwell, J.A. 1922 to 1928. Annual Report(s) of Chief Inspector, Western Fisheries Division (British Columbia), for (1921-1927). Ann. Rep., Fish. Branch, Dep. Marine Fish., Ottawa.

1929 to 1930. Annual Report(s) of Chief Supervisor, Western Fisheries Division (British Columbia), for (1928-1929). Ann. Rep., Fish. Branch, Dep. Marine Fish., Ottawa.

Motherwell, J.A. 1931 to 1947. Annual Report(s) of Chief Supervisor, Western Fisheries Division (British Columbia), for (1930 - 1945). Ann. Rep., Dep. Fish., Ottawa.

Pacific Fisherman. Trade journal published monthly in Seattle, Wash., 1901-1967.

Pacific Fisherman Yearbook, published annually in conjunction with Pacific Fisherman magazines dated by year after that covered.

Pearson, G.S. 1934 to 1946. Report of the Commissioner of Fisheries for the year ending Dec. 31 (1933-1945). Victoria, B.C.

Peterson, A.E. 1954. The selective action of gill nets on Fraser River sockeye. Internat. Pacific Salmon Fish. Comm., Bull. 5: 101 p.

Peterson, A.E., and J.E. Mason. MS 1947. The population of sockeye salmon below Hells Gate in 1941. Internat. Pacific Salmon Fish. Comm.

Rathbun, R. 1900. A review of the fisheries in the contiguous waters of the State of Washington and British Columbia. U.S. Comm. of Fish and Fish. (Part XXV), Rep. Comm. year ending June 30. 1899. 253-350.

Ricker, W.E. 1950. Cycle dominance among the Fraser sockeye. Ecology, 31 (1): 6-26.

1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Bd. Canada, 119: 300 p.

1973. Linear regressions in fishery research. J. Fish. Res. Board Can., 30 (3): 409-434.

1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can., Bull. 191: 382 p.

1982. Size and age of British Columbia sockeye salmon (*Oncorhynchus nerka*) in relation to environmental factors and the fishery. Can. Tech. Rep. Fish. Aquat. Sci. 1115: 117 p.

1987. Effects of the fishery and of obstacles to migration on the abundance of Fraser River sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 1522: 75 p.

Rounsefell, G.A. 1949. Methods of estimating total runs and escapements of salmon. Biometrics 5 (2): 115-126.

Rounsefell, G.A., and G.B. Kelez. 1938. The salmon and salmon fisheries of Swiftsure Bank, Puget Sound, and the Fraser River. U.S. Bureau Fish. XLIX (27): 693-823.

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

Shepard, M.P., and A.W. Argue. 1989. The commercial harvest of salmon in British Columbia, 1820-1877. Can. Tech. Rep. Fish. Aquat. Sci. 1960: 39 p.

Sloan, G. M. 1940. Royal commission on salmon trap-net fishing in Sooke area (B.C.). Rep. Proc., Part I: 1-535.

Sloan, W. 1928. Report of the Commissioner of Fisheries for the year ended December 31, 1927. Victoria, B.C.

Smith, W. 1894. Report of the Deputy Minister for 1893. 26th Ann. Rep. Dep. Marine Fish.; Fisheries; Ottawa: ix-clxxxv.

Snedecor, G.W. 1946. Statistical methods. Iowa State Coll. Press, Ames, Iowa.: 485 pp.

Stacey, D. 1986. History of gear technology in the West Coast fishing industry. Environ. Canada; Can. Park Service, Microt. Rep. Ser., No. 354: 237 p.

Sun. Newspaper published in Vancouver, B.C., 1886 to the present.

Sword, C.B. 1902. Annual Report on the fisheries of British Columbia for the year 1901. In: 35th Ann. Rep. Dept. Mar. Fish., 1902, Fisheries (Ottawa): 102-113.

Talbot, G.B. 1950. A biological study of the effectiveness of the Hells Gate fishways. Internat. Pac. Salm. Fish. Comm., Bull. 3 (I): 1-80.

1954. Factors associated with fluctuations in abundance of Hudson River shad. U.S. Fish and Wildlife Service; Fish. Bull., Vol.56 (101): 373-413.

Thompson, W.F. 1945. Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. Internat. Pacific Salmon Fish. Comm., Bull. 1: 175 p.

Tilton, J. 1890. Sixth Annual Report of the Deputy Minister of Fisheries for the Year 1889. Ann. Rep. Dep. Fish. (Canada): i-xlii.

Todd, I. St.P., and P.A. Larkin. 1971. Gillnet selectivity on sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) of the Skeena River system, British Columbia. J. Fish. Res. Bd. Canada 28: 821-842.

Verhoeven, L.A., and E.B. Davidoff. 1962. Marine tagging of Fraser River sockeye. Internat. Pacific Salmon Fish. Comm., Bull. 13, 132 p.

Ward, F.J., and P.A. Larkin. 1964. Cyclic dominance in Adams River Sockeye salmon. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 11: 116 p.

Western Fisheries. 1938a. Gillnet drums. (Trade journal, Vancouver, B.C.). 16 (1): 15.

1938b. The use of powered drums for putting out and taking in gill-nets. 16 (5): 14.

1939a. History of British Columbia fishing industry (1846-1938). 18 (2): 22-23.

1939b. Use of gillnet drums challenged. 18 (5): 15.

Wilmot, S. 1891. Special report on the salmon fishery and fishery regulations of the Fraser River, B.C. Rep. Dep. Fish. 1890: 65-77.

World. Newspaper published in Vancouver, B.C.; weekly 1888-1889; semi-weekly 1889-1902.

APPENDICES

APPENDIX 1: DEVELOPMENT OF THE FRASER RIVER GILLNET FISHERY

THE DRIFT GILLNET

Prior to the arrival of Europeans, native Indians are believed to have employed gillnets to capture Fraser sockeye but apparently only as set nets (anchored), although primitive driftnets had long been used by natives in Alaska (Alaska Fish and Game 1988). Dawson (1881) described a set net used to capture salmon in salt water areas in British Columbia and the Western Fisheries (1939a) stated that Indians in the early years fashioned a "fairly good gillnet out of spun nettle hemp". However, prior to the beginning of commercial fishing, not many sockeye (the species most desired for drying and winter storage) were caught in the Fraser below Hope, possibly because salmon were so easily dipnetted in the Fraser Canyon. The Fort Langley Journals (Hudson's Bay Co., 1827 to 1830) described the ascent of hundreds of Indians, some apparently from as far as villages at Point Roberts, to the Fraser Canyon each summer to obtain salmon for winter food. Thus the drift gillnet, which would have provided natives nearer the river mouth with all the salmon they could use, appeared to have been introduced by Europeans.

Credit for introduction of the drift gillnet was given by *Western Fisheries* (1939a) to Alexander Ewen, who arrived in New Westminster from Scotland in the 1860s and later became a prominent cannery owner and operator. However, De Fieux (1967) attributed the drift gillnet to William Vianen, of the Hudson's Bay Co. at Fort Langley; this first net was made of all the available shoemakers twine (undoubtedly linen) and knitted by Indian women, who probably had previous experience in net weaving. Apparently other types of gear were tried in the lower Fraser in the 1860s and found unsatisfactory (Howay 1914), and the drift gillnet was subsequently adopted as the only legal salmon fishing gear.

Linen (flax) nets apparently were employed from the beginning, since Knox (1962) stated that, prior to 1874, manufacturers in Scotland and Northern Ireland sold large quantities of linen twine on the Pacific Coast for the hand knitting of gillnets. Knox further said that he could find no evidence that nets other than linen were ever used on the West Coast, although the companies involved (W. Barbour and Sons, and W. and J. Knox, Ltd) had sold quantities of hemp twine in Eastern Canada. Rathbun (1900) also noted that Fraser drift gillnets were of flax, although his observations were made in 1895. Further remarks by Knox (loc. cit.) suggested that machine knitted nets became common in the 1880s. Thus the linen gillnet was the standard form of fishing gear in the Fraser River from the start of commercial fishing until the 1950's, when nylon nets were introduced and linen nets rapidly disappeared. The main variations in the driftnets over the years were changes in length and depth, and in the boats from which the gillnets were fished.

GILLNET BOATS

Native dugout canoes as well as flat-bottomed skiffs made of planks were used in the first years of the commercial fishery, since native fishermen were employed almost entirely (Rounsefell and Kelez 1938). Skiffs were apparently the mainstay of the fishery until the 1890s, when round-bottomed boats began to appear, probably because fishing in the often rough water at the river mouth required more seaworthy craft, which could also handle sails better. Babcock (1903) included a beautiful photograph showing boats off the mouth of the Fraser River near Steveston, some using oars and some with sails set (reproduced in the present report as the frontispiece). The boats, apparently waiting for the beginning of a weekly fishing period, include both skiffs and the round-bottomed craft, which according to Rounsefell and Kelez (loc. cit.) became common by 1900.

Rounsefell and Kelez (1938) also reported that gasoline motors were introduced as early as 1902 (probably in cannery support vessels at first) but did not become common until 1911-1913. However, they based this on the records of a cannery at Steveston, where fisherman may have continued to rely on wind power for economic reasons. Farther upriver, the conversion was earlier, since the *British Columbian* (May 21, 1907) reported that a large number of boats were adopting gasoline power. "It is thought that over half the boats on the river will be equipped with power by the season's opening", the paper stated. The decrease in the number of licences shown by Rounsefell and Kelez (their Table 2) between 1902 and 1912 probably was abetted by the impact of motorized gillnet boats as well as the increasing removal of sockeye by the American fishery and a concurrent fall in salmon prices. Motor power allowed fishermen to travel faster upstream and thus repeat the downstream fishing drift more often, allowing the available drift areas to be fully exploited by a smaller number of boats.

An equally important innovation in the gillnet fishery was the power driven net-reel or drum, with which a fisherman could retrieve his net with little physical effort. Furthermore, if he was in a hurry to get his net aboard because he was drifting down on some hazard to his net, he could wind ("lump") the net, fish included, onto the reel. Powered net-reels originated in British Columbia in the late 1930s (*Western Fisheries* 1938a, b; 1939 b). Most gillnet boats were fitted with the device within a very few years, since it shortened net haul time and allowed easy one-man gillnet operation.

FISHING AREA RESTRICTIONS

The first restriction on the area of commercial salmon fishing in the Fraser River was the Canada-wide prohibition of net fishing above the limits of tide in rivers. In the Fraser, the limit of tide is approximately at the mouth of the Sumas River (Figure 1); this boundary was first proclaimed in 1878 (*Mainland Guardian*, July 6, 1978). However, cannery operators in the New Westminster area met with the Fisheries Inspector for British Columbia in 1877 and a set of proposals were drafted and submitted to the Federal government (Smith 1894). Among them was a request for a vessel to pull snags from gillnet drifts as far upstream as St. Mary's Mission (now the town of Mission), which suggested that most commercial fishing took place below that point.

Wilmot (1891) argued for placing the upper fishing boundary near New Westminster but it apparently remained at Sumas until 1900. Rathbun (1900) gave Sumas as the upper boundary in 1899 and the *Daily Columbian* (Aug. 12, 1899) concurred. The *Daily Columbian* (May 29, 1907), in reporting residence restrictions for fishing above New Westminster, implied that the upper fishing limit was placed at Mission by the regulations of May 1, 1900. Only temporary changes have been made since that time.

The seaward boundary of the Fraser River gillnet fishing area was, in general, the extent of the discoloured water off the mouth of the river, beyond which gillnets were usually ineffective (Rathbun 1900), and the International Boundary to the south (Figure 4 of the main report). Before engines were introduced, fishermen stayed close to shore due to the limitations of sails and oars. When the boundaries of the Fraser gillnet area were defined in regulations, most Canadian waters in the southern Strait of Georgia were included. However, this had no practical effect on exploitation rates in the gillnet fishery except during the period when large late-season sockeye runs delayed in the southern Strait of Georgia and could be caught during hours of darkness.

Restrictions on spacing of drifting gillnets were specified in regulations at least as early as 1880 (*Inland Sentinel*, May, 1880). Smith (1894) gives them as part of the regulations of 1888, and Rathbun (1900) lists them as being current from 1894 to 1899. No net was to obstruct more than one third of the width of the river, and were to be fished no nearer than 250 yards (230 m) from another net, the purpose being to allow salmon an unobstructed passageway in the river. No evidence of enforcement of these restrictions has been found, and Rathbun (loc. cit.; 1895 observations) explained why it was a practical impossibility: legal net length was more than one third of the river width in many places, river currents moved drifting nets erratically, nets could be alternated to obstruct the whole river width, and there were too many boats to allow the wide spacing. The restrictions were apparently removed from the regulations around 1900 or not long thereafter, hence it was assumed that these specifications had no practical effect on exploitation rates in the fishery prior to that time.

APPENDIX 2: RELATIONSHIP BETWEEN EXPLOITATION RATE, AMOUNT OF FISHING PER WEEK, AND FISHING CAPACITY IN AN IDEALIZED SALMON FISHERY

LINEAR SALMON FISHERIES

Many salmon fisheries are spread linearly along a segment of a salmon's coastal or river spawning-migration path and have been described by Paulik and Greenough (1966) as "gantlet" or "gauntlet" fisheries. The exploitation rate of salmon fisheries in North America and probably in other areas is regulated by varying the proportion of time during the season that is allowed for fishing, usually with intermittent fishing periods and closures. The result is escapement past the fishery in pulses.

Fishing has often been allowed at weekly intervals, especially in the earlier years of a fishery when gear efficiency was moderate. The exploitation rate (and complementary rate of escapement) is a complicated relationship between the number of days (or fractions thereof) allowed each week and the "fishing capacity" (absolute fishing power or potential exploitation rate with continuous fishing) of the fishery. This relationship is analyzed below.

ASSUMPTIONS AND DEFINITIONS

1. The salmon pass through the fishery in a uniform band.
2. Migration is constant in speed and direction.
3. Fishing gear is spread uniformly over the migration path within the fishing area.
4. Units of gear fish constantly and with constant efficiency during the allowed fishing period and do not interfere with each others operations, (i.e. all can fish without imposed periods of idleness) although each unit removes salmon that other gear could have caught (i.e. competitive fishing).
5. The fleet size and number of hauls made per day by each gear unit are sufficiently large that an exponential limit adequately represents the fishing capacity, a, of the fleet (DeLury 1947):

$$a = 1 - e^{-fr}$$

where f is fleet size, r is unit efficiency and e is the base of natural logarithms.
6. Fishing regulations are constant from week to week, i.e. the length of the fishing period and its location by days of the week do not change; however, differences in regulations can be handled with appropriate variations of the following analyses. Several definitions are required. Time will be measured in "traverse time" units (T), the time required by a salmon to swim the length of the fishery. Each unit of gear will have an individual efficiency or fishing capacity, a_k, and a corresponding instantaneous efficiency, i_k, where:

$$i_k = -\log_e (1 - a_k) \quad \text{or} \quad a_k = 1 - e^{-i_k}$$

A salmon which has passed part way through the fishery will have been in the fishery for time t, a fraction of T. Since gear is evenly distributed, the salmon will have passed the fraction t/T of the fleet, which has n units of gear. The cumulative fishing capacity of the nt/T units of gear will be:

$$a_t = 1 - e^{-1_k} \qquad (1)$$

where:

$$i_t = \sum_0^t i_k$$

The cumulative fishing capacity, a_t, is the fractional catch removed from a small group of salmon which has been migrating through the fishery for time t. When the group of salmon have passed completely through the fishery (t=T), the fractional catch, a, will have been removed. The total instantaneous rate of the fishery will be:

$$i = -\log_e (1-a) \quad \text{or} \quad a = 1 - e^{-i} \tag{2}$$

The partial and total instantaneous rates are related by:

$$i_k = i \frac{t}{T} \tag{3}$$

Density of salmon, N, is the number of salmon passing any point in a unit of time. The number of salmon within the fishing area when no fishing has occurred is NT, a unit of population. When a small group of salmon have migrated through the fishery for time t, their density will have been reduced by the partial catch:

$$C_t = a_t N \tag{4}$$

and after passing completely through the fishery their density will have been reduced to:

$$N - C = N - aN$$

GEOMETRIC INTERPRETATION

The interaction between the salmon and the fishery can be shown diagrammatically, with numbers of salmon shown by areas on a graph. Density of salmon (i.e. salmon per unit distance) is plotted as an ordinate and distance - equivalent to time because swimming speed is constant - is plotted as an abscissa. The basis for this is given in text Figures 3, 5 and 7. An idealized diagram is given in Figure A1, with the definitions given above shown as dimensions.

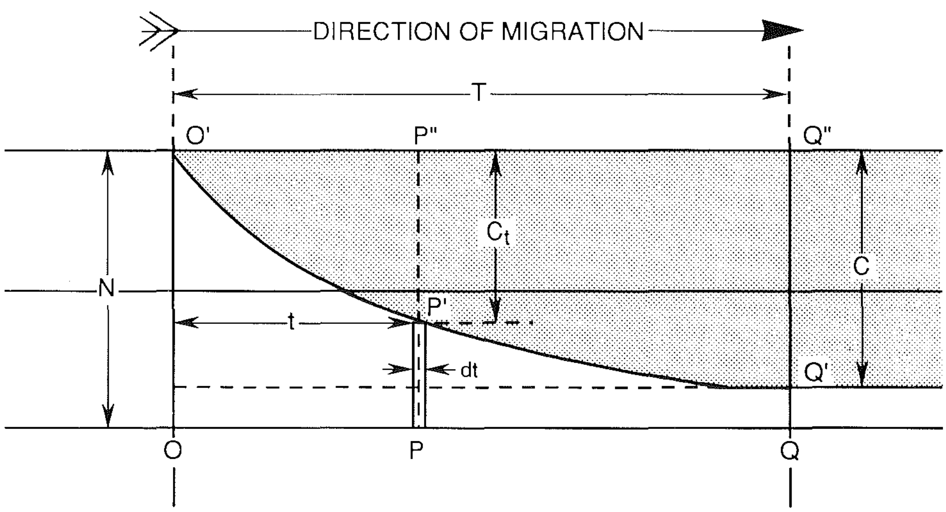

Figure A1. Geometric representation of a salmon migration being continuously exploited by a uniform fishery between points O and Q. Shaded area represents catch. Dimensions defined in Appendix text.

To determine the exploitation of salmon which occurs when the fishery stops and starts (at the beginning and end of a closed period), the area O' Q' Q" in Figure A1 must be evaluated in terms of salmon density, fishing capacity and time. This area, evaluated by integration, is:

$$A = NT - \int_0^T (N - C_t)\, dt = \int_0^T C_t\, dt$$

Substituting from equations (1) and (4):

$$A = \int_0^T N(1 - e^{-i_t})\, dt$$

Substituting further from equation (3):

$$A = \int_0^T (1 - e^{-it/T})\, dt$$

and integrating:

$$A = NT\ (1 - \frac{1 - e^{-i}}{i}) = NT\ (1 - \frac{a}{i}) \qquad (5)$$

Thus at time t, the relationship for the smaller area in Figure A1 (O', P' P") would be:

$$A_t = Nt\ (1 - \frac{a_t}{i_t}) \qquad (6)$$

The area A is the catch removed from a population unit NT which has completely entered the operating fishery at the moment fishing ceases. As a fraction of the population unit, the area is:

$$\frac{A}{NT} = 1 - \frac{a}{i} \qquad (7)$$

The area A is also equal to the catch removed from a population unit which was in the fishing area at the moment fishing began after a closed period of duration T or longer. To verify this, consider a small group of salmon in the exact center of the fishery at the moment fishing begins. These salmon would be subject to the same fishing mortality as a group of salmon which had reached the center of the operating fishery at the moment fishing stopped. Similarly, salmon which had penetrated three quarters of the way through the fishery when fishing ceased would experience the same fishing mortality as fish which were one quarter of the through the fishery when fishing began. Thus the area A in Figure A1 will be a mirror image of the area in a graph representing the catch removed from a population unit which was in the fishery at the instant fishing began and which then migrated completely out of the operating fishery.

The relationship derived above allows the estimation of the fishing capacity of an intermittent salmon fishery when the following factors are known: (1) the observed exploitation rate (catch divided by catch plus escapement) over the duration of a regulatory period, (2) the length of the fishing and closed periods within the regulatory period, and (3) the average migration time of the salmon through the fishery. Three separate situations in this relationship are possible, depending on the lengths of the closed and fishing periods and of the traverse time. A regulatory period of seven days only will be considered here, i.e. one closed and one open fishing period each week, although the methods could be extended to regulatory periods of different lengths. Equations for exploitation rates are given as implicit functions of the fishing capacity a, since the explicit relationships may not be expressed in simple algebraic form.

The units employed in the following analyses are defined as follows:

T = traverse time in days.
m = number of days fished per week.
M = m/T = fishing period length in traverse time units.

The observed exploitation rate, on a weekly basis, is:

$$E = \frac{\textit{Catch during a week's fishing period}}{\textit{Number of salmon entering the fishery in a week}}$$

The denominator is the number of fish (before fishing) which passes a point in seven days, and may be taken as the seven-day period approximately centered on the fishing period.

CASE I

Both fishing period and closed period lengths in a week are as long or longer than the traverse time. The catch taken from a seven day migration of salmon which has just passed through the fishery is shown in Figure A2; the fishing period length plus one traverse time must not exceed seven days. The weekly exploitation rate (i.e. the catch in Figure A2 as a fraction of the weekly migration) will be, with all time in days:

$$E = \frac{2A + B}{7N} = \frac{2NT\,(1 - a/i) + C\,(m - T)}{7N}$$

Converted to traverse time units, the equation becomes:

$$E = \frac{2N\,(1 - a/i) + C\,(M - 1)}{7N/T} = \frac{T}{7}\,2\,(1 - a/i) + a(M - 1)$$

This relationship is invalid if T is greater than 3 1/2 days, since (a) either the fishing period will be so short that no salmon will penetrate the complete fishery while fishing is in progress, or (b) the fishing period of one week will exploit some salmon which will still be in the fishery when the next week's fishing period begins. In these circumstances, one of the two following relationships must be used.

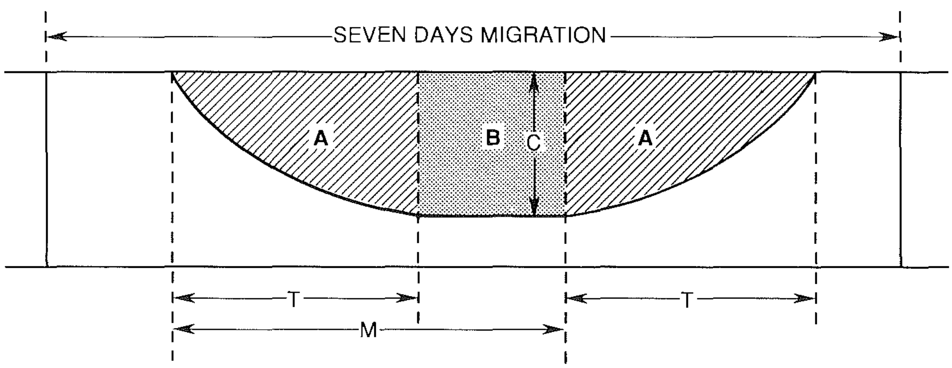

Figure A2. Geometric representation of the catch (shaded areas A and B) taken from a seven-day migration of salmon which had passed through a fishery with a duration of m days, where T ≤ m ≤ 7-m. Dimensions defined in Appendix text.

CASE II

Fishing period length is shorter than the traverse time. The catch taken from a seven-day migration of salmon, which has passed completely through the fishery, is shown in Figure A3. Because no salmon pass all the fishing gear during the short fishing period, the partial fishing capacity, a_t, will be used to represent the fishing rate on any group of salmon which is inside the fishing during the fishing period - equations (1) and (4). The amount of fishing on these salmon, in terms of the equivalent instantaneous rate i_t, will be that fraction of the total fishery instantaneous rate (i) given by the fraction of the traverse time during which the fishery operates, that is:

$$i_t = \frac{m}{T} i = Mi \qquad (8)$$

The weekly exploitation rate (i.e. the catch in Figure A3 as a fraction of the weekly migration) will be, with all times in days:

$$E = \frac{2A + B}{7N} = \frac{2mN\,(1 - a_t/i_t) + C_t(T - m)}{7N}$$

This may be converted to traverse time units by dividing denominator and numerator by T and substituting from the definitions and from equation (4):

$$E = \frac{T}{7}\, 2M(1 - \frac{a_t}{i_t}) + a_t\,(1 - M)$$

Substituting from equations (1), (6) and (8), and simplifying:

$$E = \frac{T}{7}\, M(1 + e^{-Mi}) + (1 - e^{-Mi}) - 2(\frac{1 - e^{-Mi}}{i})$$

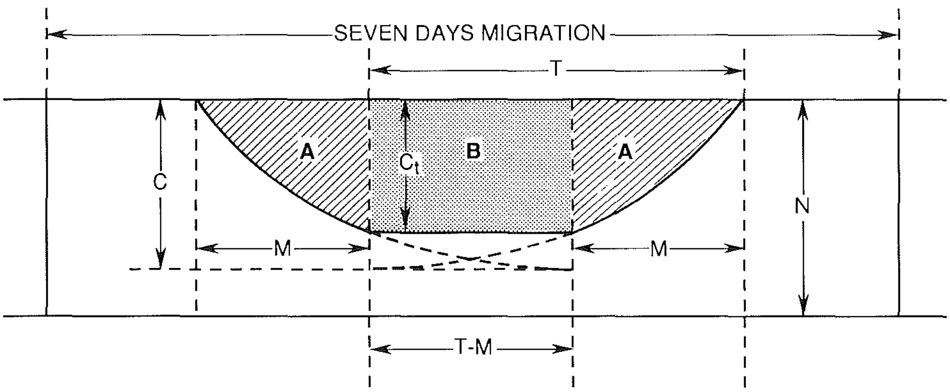

Figure A3. Geometric representation of the catch (shaded areas A and B) taken from a seven-day migration of salmon which had passed through a fishery with a duration of m days, where $0 < m \leq T$. Dimensions defined in Appendix text.

CASE III

The period closed to fishing is shorter than the traverse time, consequently some salmon which had entered the fishery before fishing ceased will not have left the fishery when fishing again begins. Thus the fishing in two different regulatory periods will in effect overlap. The graphical interpretation of the catch as shown in Figure A4 is complicated at the overlap of fishing effort between points O and P (or O' and P'). Salmon in this position on the diagram are fished both on entering the fishery before the closure begins and on leaving the fishery after the closure ends. The longer that fish in this section are fished on entering the fishery, the less they are fished while leaving (before and after the closed period). On any small group of salmon, the fishing before and after is complementary, therefore the total fishing mortality is constant for all salmon in this section resulting in constant abundance in the escapement between points O and P.

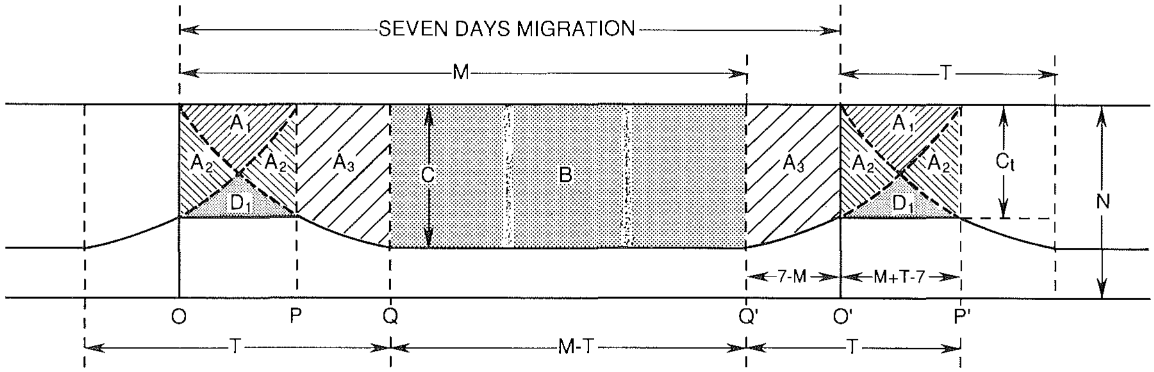

Figure A4. Geometric representation of the catch (shaded areas $A_{1\text{-}3}$,B,D) removed from a seven-day migration of salmon when it passes through a fishery with a duration of m days per week, where 7-T≤m≤7. Dimensions defined in Appendix text.

The weekly exploitation rate from Figure A4, i.e. the hatched area as a fraction of a seven-day salmon migration, is calculated as follows, with time measured in days:

$$E = \frac{B + A_1 + 2A_2 + 2A_3 + D}{7N}$$

$$E = \frac{B + 2(A_1 + A_2 + A_3) - 2(A_1 + A_2) + (A_1 + 2A_2 + D)}{7N}$$

To express the exploitation rate in terms of fishing capacity and length of fishing period, the length and height of the small rectangle in Figure A4, i.e. $A_1 + 2\ A_2 + D$, must be evaluated. The length is equal to (m + T - 7) days, the time a small group of salmon which had just reached the outer boundary of the fishery when fishing ended and would be in the fishery after fishing began again. The height is the effective instantaneous fishing rate (i_t) of the gear fishing between points O and P, and is the fraction of the total instantaneous rate of the fishery (i) given by:

$$i_t = \left(\frac{m + T - 7}{t}\right) i$$

with time measured in days. In traverse time units, the partial instantaneous rate will be:

$$i_t = (M + 1 - 7/T)\ i = Zi$$

where the quantity Z is used to simplify the equations. The reduction in salmon density between points O and P (Figure A4), from equations (1) and (4), is:

$$C_t = N\ (1 - e^{-Zi})$$

Substituting from equations (1), (2), (5) and (6), the weekly exploitation rate will then be:

$$E = \frac{C(m-T) + 2NT(1 - a/i) - 2N(m+T-7)(1 - a_t/i_t) + C_t(m+T-7)}{7N}$$

To obtain a usable relationship, the numerator and denominator are divided by T to convert to traverse time units, and the results simplified:

$$E = \frac{T}{7}\ a(M - 1) - Z(1 + e^{-Zi}) + 2\left(1 - \frac{a - 1 + e^{-Zi}}{i}\right)$$

The computation in Case III assumes that the same number of days will be fished in the preceding and following weeks as the week in question. If the long fishing period in the week under consideration is unique and the closure at either end is T days or longer, then the Case II computation must be used. If overlap with fishing in another week occurs only at one end of the fishing period, then Case III would be more appropriate with slight modification. Because the Case III situation is uncommon and because the amount of overlap correction would usually be small, this modification has not been worked out here.

DETERMINING FISHING CAPACITY FROM EXPLOITATION RATE

Because an explicit function of the fishing capacity (a) cannot be obtained, a graphical method was used to determine numerical values of fishing capacity. To minimize effort, the relationship between fishing capacity (a), exploitation rate (E) and fishing time per regulatory interval (M) need only be calculated in the region where values of these variables are expected to occur. For illustrative purposes, the graphical presentation in text Figure 8 was made more complete than necessary. Lines of fishing capacity were calculated at intervals close enough to allow linear interpolation with errors less than errors in other variables used in the analysis.

LITERATURE CITED (APPENDIX)

DeLury, D.B. 1947. On the estimation of biological populations. Biometrics 3 (4): 145-167.

Paulik, G.J., and J.W. Greenough. 1966. Management analysis of a salmon resource system. In: Systems Analysis in Ecology, Academic Press, New York.

APPENDIX 3: NOTES CONCERNING ESTIMATED EXPLOITATION RATES LISTED IN TABLE 13

GENERAL

Several factors are involved in the estimates of late season exploitation rates. In all years, it was assumed that the late season rate was less than for the main July-August sockeye fishery, due to usually fewer boats fishing, to added restrictions on fishing time and to the imposition of larger mesh-size minimums normally applied for fishing targeting coho and chum salmon ("late season species") in the years when these species were in demand commercially. While the capture of delaying sockeye added to the catch of stocks made after upriver migration began, other restrictions usually decreased total exploitation; e.g., large late sockeye runs were favored by extended closures (Tables 6 and 7). The more severe autumn weather sometimes inhibited fishing, especially in exposed areas around the Fraser mouth. Sockeye prices were often lowered in September and after since the late runs are lower in fat content than early runs (Gilhousen 1980) and have thickened skins and other advanced secondary sexual characteristics which made them less desirable for canning. Pink salmon were often considered undesirable for canning with low prices paid and heavy grading (i.e. few fish accepted for purchase). In some years of large late runs, U.S. canneries purchased quantities of late sockeye (and often pinks) when prices were low, adding to the fishing pressure.

In only one year for which estimated escapements were available (1943; Table 13) was the late season rate comparable to that of the main sockeye season; there was a 6 1/2 in. mesh minimum from Oct. 1, 1943 (Table 7) - it is possible that late-run sockeye escapements were underestimated or that a significant percentage were lost below Hells Gate thereby resulting in an overlarge calculated exploitation rate.

INDIVIDUAL YEARS

1901 - Well over 1,000 boats fishing (*Province*, Sept. 16). Good catches (*Daily Columbian*; Sept. 14, 17, 24; Oct. 9). Catches above New Westminster good all the peak week (*Daily Columbian*; Sept. 21, 23).

1905 - Closure 8/25 - 9/15. Ten canneries operating; U.S. canneries bought sockeye; prices and effort reduced after Sept. 20 (*Daily Columbian*; Sept. 13, 15, 16, 23, 25. *Province*; Oct. 2, 16).

1909 - Closure 8/25 - 9/15. Canning continued into October; U.S. canneries bought sockeye (*Daily Columbian*; Sept. 16, 17, 21, 23, 24, 27; Oct. 4, 6, 11, 12, 18).

1910 - Oct. 1 on, mesh min. 7 in. Closed 8/25 - 9/15 but fishing allowed outside Sandheads; catches poor in October (*Daily Columbian*; Sept. 13, 17; Oct. 12, 19, 27).

1913 - From Oct. 1, mesh min. 7 1n. Moderate fishing effort (*Province*; Sept 15, 17; *Daily Columbian*; Sept. 15, 22, 25).

1914 - No press reports. Mesh minimum 7 in. from Oct. 1. Fleet size large in main season; oversupply of chum salmon; wartime demand not yet set in (Halladay 1915).

1915 - Mesh minimum 7 in. from Oct. 1. U.S. canneries buying late season salmon (*British Columbian*, Sept. 20). Prices high (Halladay 1916).

1916 - Mesh minimum 7 in. from Nov. 1. Weekly closure lengthened 12 hrs Oct. 1 on. Most canneries operating; prices high (*British Columbian*; Sept. 11, 20).

1917 - Mesh minimum 7 in. from Oct. 1. Scarcity of 7 in. mesh nets; U.S. canneries bought late season salmon; high prices, demand and effort (*British Columbian*; Sept. 10, 27; Oct. 2, 4).

1918 - Mesh minimum 7 in. from Oct. 1. High prices; apparently high effort; *British Columbian*; Sept. 25, 30; Oct. 24).

1919 - Mesh minimum 7 in. from Oct. 1. Gillnet fleet large, good sockeye catches late Sept. (*Province*; Sept. 15; Oct. 6).

1920 - Mesh minimum 7 in. from Oct. 1. No press reports. Very low demand for late season salmon (Cunningham 1921).

1921 - No press reports. Closure 9/6 - 9/20. Mesh minimum 6 1/2 in. 9/6 - 9/14; 10/1 - 10/15; very low demand for late season salmon (Motherwell 1922).

1922 - Mesh minimum 6 1/2 in. from 9/23 - 11/5. No press reports. Some canneries operated into October (cannery records). Good sockeye catches in September (Clemens and Clemens 1927).

1923 - Mesh minimum 6 1/2 in. from 10/1. No press reports. Small fleet (*Pacific Fisherman*, Yearbook 1924). Good sockeye catches in Sept. and some in Oct. (Clemens and Clemens 1927).

1924 - Mesh minimum 6 1/2 in. from 10/1. September sockeye catches poor (Clemens and Clemens 1927). Good late lower Fraser sockeye escapements (Motherwell 1925).

1925 - Mesh minimum 6 1/2 in. from 10/1. Gillnet fleet in September 700 boats (*British Columbian*, Sept. 18). Moderate late lower Fraser escapements (Motherwell 1926). Very small sockeye catches in September and October (Clemens and Clemens 1927).

1926 - Mesh minimum 6 1/2 in. from 10/1. Good sockeye prices to late September (Babcock 1927). High demand for late season salmon and intensive fishing (Motherwell 1927). Exploitation rate calculated from escapement estimate.

1927 - Mesh minimum 6 1/2 in. from 10/3; weekend closures lengthened in September and October. Large catches and high prices (*British Columbian*; Sept. 14, 17, 19; Sloan 1928). Heavy fishing effort (Motherwell 1928).

1928 - Mesh minimum 6 1/2 in. from 10/1. Catches small (Howe 1929). Prices lowered during September (*Columbian*; Sept. 29).

1929 - Mesh minimum 6 1/2 in. from 10/1. Large pink run heavily fished; prices high (*Columbian*; Sept. 23, 27).

1930 - Complete closure 9/20 - 10/20; Mesh minimum 6 1/2 in. thereafter. Exploitation rate calculated from escapement estimate.

1931 - Low demand and prices for late season salmon; extended closure 9/29 - 10/7 (Motherwell 1932); 6 1/2 in. mesh minimum thereafter (*Pacific Fisherman*, Oct. 1931).

1932 - Mesh minimum 6 1/2 in. from 10/1. Moderate demand for late-run salmon (Motherwell 1933). Few canneries operating after main season (*Pacific Fisherman*, Yearbook 1933).

1933 - Mesh minimum 6 1/2 in. from 10/1. Demand and prices for other species improved over 1931 and 1932 (Motherwell 1934). Catches dropped sharply mid-September for unknown reason.

1934 - Extended closure 9/16 - 9/30. Mesh minimum 6 1/2 in. from 11/1. Large catches kept effort high; large sales of gillnet sockeye to U.S. canneries (Motherwell 1935). Exploitation rate calculated from escapement estimate.

1935 - Extended closure 9/21 - 10/2. Mesh minimum 6 1/2 in. from 10/3. Fishing follows pattern of 1934; the peak of upriver migration occurred during closure. Prices and demand for late season salmon still quite high (*Pacific Fisherman*, Yearbook 1936).

1936 - Mesh minimum 6 1/2 in. 10/10 - 10/18; 11/30 and after. Good demand and prices for late-run species (*Pacific Fisherman*, Yearbook 1937).

1937 - Extended closure 9/25 - 10/7, 11/13 - 12/8. Good prices for late season species (*Pacific Fisherman*, Yearbook 1938). Sockeye catches dropped sharply September 18 for unknown reason (cannery records).

The following late season sockeye runs had their exploitation rates calculated from the spawning ground enumerations of the I.P.S.F.C.; however, the rates are subject to error resulting from unknown losses in the Fraser River Canyon in some years.

1938 - Extended closure, 9/10 - 10/3, resulted in low exploitation rate.

1939 - Extended closure, 9/15 - 9/25; mesh minimum 6 1/2 in. from 10/1; weekend closures lengthened 24 hrs. 9/29 - 11/13. However, demand and fishing effort high for late season species (Motherwell 1940).

1940 - Mesh minimum 6 1/2 in. from 10/1. No extended closures. However, weekend closures increased in length to 72 hrs 9/6 - 11/29. War demand resulted in high fishing effort for chum salmon (Motherwell 1941).

1941 - Mesh minimum 6 1/2 in. from 10/1. No extended closures. Weekend closures increased to 72 hrs from 9/27. High wartime demand for canned salmon resulted in heavy fishing effort (Motherwell 1942).

1942 - Strike plus closure; no fishing 9/17 - 10/1. Mesh minimum 6 1/2 in. from 11/1. High wartime demand and effort but labor shortage (Motherwell 1943).

1943 - Weekend closures increased to 72 hrs from 7/29. Mesh minimum 6 1/2 in. from 10/1. Conditions similar to 1942 except late-run sockeye catches much smaller Motherwell 1944).

1944 - Weekend closures increased to 72 hrs from 8/25. Mesh minimum 6 1/2 in. from 10/1. Fishing closed from 11/3. Conditions similar to previous war years.