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No. 961

Background Information and Theory Related to Management of the Skeena Sockeye Salmon

by

W. E. Ricker

Biological Station, Nanaimo, B.C.

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CONTENTS

1. INTRODUCTION AND ACKNOWLEDGMENTS

This short review and possible projection of the Skeena sockeye situation was prepared initially during 1966 and early 1967 while I was briefly a member of the Skeena Salmon Management Committee. Having been out of close touch with the Skeena picture for a number of years, it seemed necessary to review recent events and assess current trends. Various commitments have delayed completion of the manuscript until December, 1967, but no attempt has been made to incorporate this year's information.

I have been assisted by Messrs. K.V. Aro, J.G. McDonald and H.W.D. Smith, who compiled or updated the various statistics tabulated, while the review presented at Vancouver by Mr. I.S. Todd, in charge of Skeena management, was extremely helpful. Dr. M.P. Shepard, Messrs. J.G. McDonald and F.C. Withler reviewed a draft of the document and made useful suggestions, while at the same time suggesting a somewhat different emphasis in the conclusions. Drs. R.R. Parker and D.W. Narver have also commented helpfully.

Skeena sockeye management has been successful in restoring the stocks reduced by the Babine River slide and has been effective in other ways. However, it has proved disappointing in one respect: the larger spawnings of recent years have not produced adult progeny as well as had been expected on the basis of past performance. The reason or reasons for this are not known. Sections 2-5 below review briefly the present state and history of the river's sockeye stocks. Sections 6-17 consider a number of possible causes of poor production from large spawnings in recent years, including pure chance (6), deterioration of the environment (7-9), differences in vulnerability and productive potential (10, 11), interaction between broods (12), selective fishing mortality (13-16), and interception by other fisheries (17). Finally, Section 18 describes the present status of forecasting adult returns from smolt estimates.

2. RECENT TRENDS IN ADULT RETURNS

Since 1955 the aim of the Skeena Salmon Management Committee has been to provide 800,000 to 900,000 sockeye spawners in the system whenever possible (SSMC Annual Reports). The reason for choosing this figure is that when returns of individual year-classes are plotted against abundance of spawners, this number has, on the average over the whole period of record, provided the maximum commercial yield (Figures 1-3)[1]. This is true no matter which of a variety of methods is used to draw a trend line through the observed points, and whether or not a steep rise and abrupt decline near the outer end of the production curve be regarded as credible. All systems tried seem to indicate a maximum surplus (distance above the diagonal in Figures 1-3) when there are 800,000 to 900,000 spawners (of ages 4_2 and 5_2).

Curve A in Figure 1 shows the original curve used by Shepard and Withler (1958), based on a smooth line drawn freehand through running averages of 5's. Addition of more recent observations does not change its shape very much. Figure 2 shows the points obtained by averaging each 5 years in succession (after arranging them in order of increasing escapement), while in Fig. 3 the points in each 100,000-fish interval are averaged, regardless of how numerous they are. On these figures is indicated some of the variety of curves that can be drawn, depending mainly on how much smoothing is allowed between successive points. Nevertheless the position of maximum surplus (marked S in the figures) is not much different on all of them. This stems basically from the fact that of the eight spawnings in the 0.8-1.0 million range, three produced returns in excess of 3 million, and two more produced more than 2 million, while spawnings smaller and larger than this produced appreciably less, on the average.

In order to build Skeena spawning stocks up to the target level of about 850,000 it was first necessary to overcome the loss of spawning potential

[1]Figures 1-4 are all based on age 4_2 and 5_2 fish only; that is, 3_2, 5_3 and 6_3 individuals are excluded from both spawning estimates and returns. Shepard and Withler (1958) describe the procedures used to obtain estimates of spawners, etc.

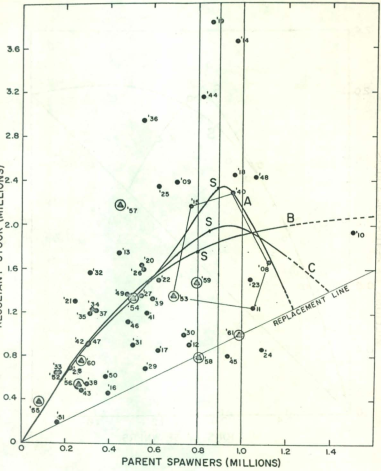

Fig. 1. Skeena spawning escapements (4_2 and 5_2 only), and resulting returns, for brood years 1908-1961. A - trend line of Shepard and Withler, based on points through 1952; B and C - possible trend lines based on all brood years shown; S - point of maximum sustainable yield for each curve. (From Shepard et al., 1964, with additions.) The polygon is discussed on page 20.

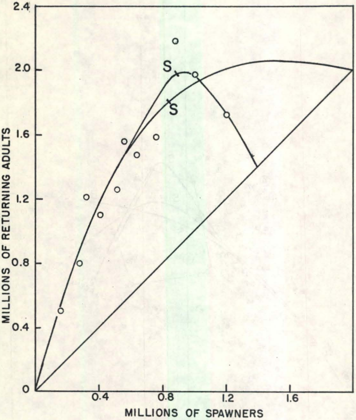

Fig. 2. Mean returns and corresponding mean escapements, 1908-61, averaged by 5-year groups beginning with the smallest (the last point has only 4 years).

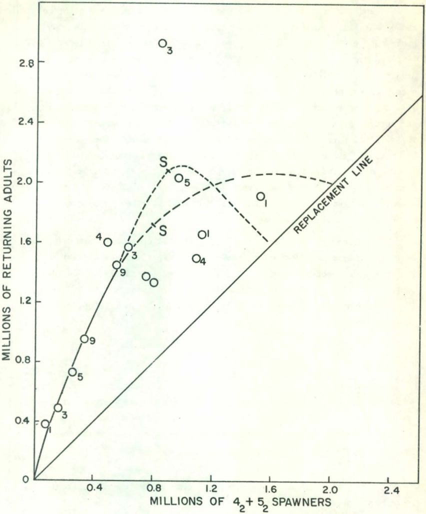

Fig. 3. Mean returns and escapements for each 100,000-fish interval starting at 0-100,000. The numbers indicate the number of brood years contributing to each point.

in 1951 and 1952 occasioned by the Babine slide. For this and other reasons escapements in the neighbourhood of 850,000 have been obtained in only 4 years since 1950 (1958, 1959, 1961 and 1964). Complete returns from 1958, 1959 and 1961 are now available (Table I, Fig. 1). The last and largest of these produced only 985,000 4_2 plus 5_2 sockeye--practically the same as the number of spawners, so that there was no surplus. This makes the third disappointing return in succession from a large spawning. On the average, the returns from the spawnings of 1958, 1959 and 1961 have produced only a 25% surplus, corresponding to an average catch of 230,000 fish per year. By contrast, since the Slide two spawnings in the 500,000-700,000 range (1953 and 1954) have produced an average surplus of 731,000 sockeye, while a spawning of 448,000 in 1957 produced a surplus of 1,731,000. Still smaller spawnings of recent years (1950, 1951, 1952, 1955, 1956, 1960) have produced rather small surpluses, averaging 280,000.

Thus recent experience with the estimated optimum escapement level does not come up to expectations based on the experience of earlier years. The returns for spawnings since 1950 are plotted separately in Fig. 4A. Considered alone, they would suggest that a maximum surplus (= distance above the diagonal) is produced at spawnings of 0.5-0.6 million, rather than 0.8-0.9.

3. SMOLT PRODUCTION AT BABINE LAKE

Beginning with the 1956 brood year, estimates of smolt production at Babine are available (Table II, Fig. 5). These show that two of the three recent big spawnings (1959, 1961) failed because of poor smolt production, while 1958 failed because of very poor ocean survival (or if the smolts of that year-class were substantially overestimated, then a combination of poor lake and ocean survivals).

Thus the graph of smolts against spawners for the Babine region is in general agreement with the recent adult returns. It suggests that a plateau or dome of smolt production was reached at about 0.6 million spawners during the period in question.

Table I. Spawning escapements and returns of 3_2, 4_2 and 5_2 sockeye in the Skeena system, for year-classes since 1941. Data from Shepard and Withler 1958, Shepard et al. 1964, and H. W. D. Smith. For earlier years see Shepard and Withler (1958, table 1).

Brood year	Spawners ($4_2 + 5_2$)	Resulting stock (catch + escapement) 4_2	5_2	Total ($4_2 + 5_2$)	Jacks (3_2)	Grand Total
1941	572	486	697	1,183	-	-
1942	305	356	549	905	-	-
1943	272	171	306	477	31	508
1944	824	2,163	993	3,156	261	3,417
1945	940	218	577	795	?	?
1946	486	334	778[a]	1,112[a]	48	1,160
1947	307	397[a]	514[a]	911[a]	179	1,090
1948	1,066	1,846[a]	581	2,427[a]	11[b]	2,438+
1949	480	759	604	1,363	28[b]	1,391+
1950	382	430	171	601	28	629
1951	163	61	123	184	10	194
1952	158	421	216	637	31	668
1953	700	524	825	1,349	18	1,367
1954	511	654	671	1,325	50	1,375
1955	87	252	127	379	31	410
1956	370	307	233	540	32	572
1957	448	1,569	610	2,179	49	2,228
1958	819	418	381	799	28	827
1959	799	357	1,126	1,483	46	1,529
1960	273	435	353	788	173	961
1961	984	526	456	982	60	1,042
1962	558	446			64	
1963	609				182	

[a]Includes an estimate of fish blocked by the Babine slide in 1951 and 1952.

[b]These are the actual counts--much too low because of slide in 1951 and 1952.

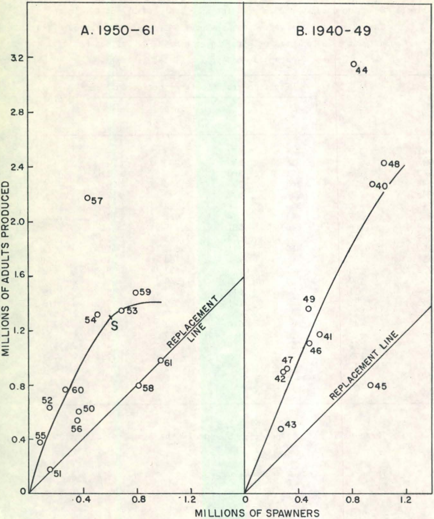

Fig. 4. A - escapements and returns, 1950-61. B - escapements and returns, 1940-49.

Table II. Numbers of size of Babine smolts, 1951-1966, and resulting adult stock (jacks excluded). (Compiled by H.W.D. Smith)

Principal brood year	Smolt year	Early run		Late run		Combined runs		Adult stock produced	
		Output	Mean weight	Output	Mean weight	Output	Mean weight	Number	Percentage
		10^6	g	10^6	g	10^6	g	10^3	
1949	1951			3.88	5.44			1363	
1950	1952			4.19	4.96			601	
1951	1953			2.78	6.17			184	
1952	1954			2.35	6.22			637	
1953	1955			23.62	5.67			1349	
1954	1956			13.19	4.94			1325	
1955	1957			5.20	6.05			379	
1956	1958	14.40	4.95	8.40	5.74	22.80	5.24	540	2.37
1957	1959	9.00	4.08	24.90	5.11	33.90	4.84	2179	6.43
1958	1960	26.00[d]	4.51	31.10[d]	5.87	57.10[d]	5.25	799	1.4-2.8
1959	1961	7.50	3.98	13.30	5.15	20.80	4.78	1483	7.12
1960	1962	4.70	5.62	12.40	5.73	17.10	5.70	788	4.61
1961	1963	7.50	4.35	6.80	5.42	14.30	4.85	905	6.32
1962	1964[b]	17.96	4.36	32.04	5.21	50.00	4.90	...	...
1963	1965	4.60	4.75	21.40	5.10	26.00	5.04	...	...
1964	1966[c]	18.28	4.19	18.69	4.39	36.97	4.29	...	...

[a]Division of runs into early and late is on the basis of 3 kinds of information:

1. Observed build-up and decline of uplake populations.
2. Changes in abundance at upper and lower trap sites.
3. Changes in mean size and weight of samples from the two divisions of the lake (North Arm+Nilkitkwa, and Main Lake).

Further evidence for the best division point may accumulate and necessitate minor changes in tabulated values.

[b]The 1964 division between early and late runs is arbitrary, but it does not appear likely we can improve on it on the basis of our present knowledge of the origin and timing of the runs.

[c]Preliminary.

[d]Because of technical difficulties it is felt that these estimates are too large, but not more than twice too large; hence the range shown in the last column.

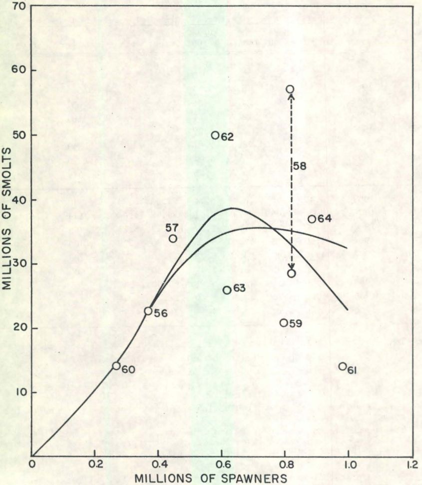

Fig. 5. Smolts produced by recent spawnings at Babine Lake. See Table II regarding the range shown for the 1958 year-class.

4. LONG-TERM DECREASE IN THE PRODUCTION OF THE SYSTEM

Has the average level of yield of sockeye by the Skeena system declined at all levels of escapement? Figure 6 examines this question, showing the escapements and returns for two time periods, averaged by classes 250,000 spawners broad. The recent period shows smaller adult returns in all categories. (There may be some question concerning the reality of the effect for the smallest escapements, which are bound up with the effects of the Babine Slide.)

The observed decline in adult production (Fig. 6) does not necessarily mean that the optimum level of spawning stock for the system has also decreased, though this may in fact be so. The various possible causes of the decline to be discussed affect the spawning requirement differently, and something depends on how severe a particular situation becomes. For example, if a stream has become totally unfit for spawning the spawning requirement of the system is obviously to be reduced. If however it deteriorates only slightly, it may even pay to increase the number of spawners to partly compensate for their lessened individual productivity.

5. RAPID DECLINE OF THE SMALLER SKEENA STOCKS

Most of the smaller sockeye stocks in the Skeena system seem to have declined seriously since the time of the Skeena River Survey in 1944-48, as shown by the following average yearly escapement estimates for the 9 principal non-Babine stocks[2]:

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[2] From figures in Brett (1952) and Smith and Lucop (1966), with minor interpolations by the writer and others. Data for the last two years were supplied by H.W.D. Smith, who points out that the apparent increase since 1962 might be largely due to improved counting facilities on the Morice-Bulkley system. It might also be that the estimate for 1944-48 is relatively somewhat too large because of possible differences between the methods used by the Skeena River Survey and those used subsequently. However there is no question of the reality of a downward trend.

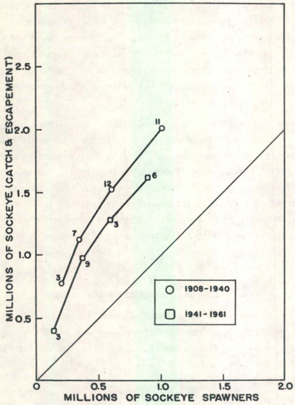

Fig. 6. Average returns from spawners in two time periods. Returns are averaged by spawning classes 250,000 fish broad, except that the last figure on each line includes all spawnings larger than 750,000.

1944-48	186,000
1950-53	98,000
1954-58	70,000
1959-63	33,000
1964-66	58,000

The process may of course have started even earlier than 1944.

For the two-years-in-the-lake stocks there is an additional and independent estimate of their abundance relative to the one-year type (the latter include the dominant Babine stocks). Figure 7A shows the percentage representation of 5_3 and 6_3 fish in the catch since 1912. Since 1946 their relative numbers have been substantially less than formerly. (The rise in their percentage in 1954-57 reflects the relative scarcity of Babine fish during that period, which resulted from the stoppages of 1951 and 1952.)

6. A MATTER OF CHANCE?

In using Figures 1, 2 or 3 as a basis for estimating best present-day escapements, it is tacitly assumed (1) that the production from each spawning year is independent of all others, and (2) that the productive capacity of the Skeena system has not deteriorated since early in the century. If these two assumptions are correct, we must conclude that since 1958 we have had the bad luck to encounter, by accident, three successive worse-than-average survivals in years of fairly large spawnings[3].

In any event, it is important to recognize that years just as bad as 1958-59-61 have occurred throughout the history of the fishery. For example, the spawners of the years 1911, 1912, 1916 and 1917 did little more than reproduce their own numbers, while 1924 and 1945 failed to do even that. If good and bad years occur at random, the probability that three below-average returns from three near-optimum spawnings in succession would occur

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[3]Alternatively, the chance factor might consist in the possibility that it was mainly by accident that prior to 1958 there were five very successful spawnings in the range 0.8-1.0 million, and only one poor one. If this were the situation, the true optimum level of spawning would probably be less than 850,000.

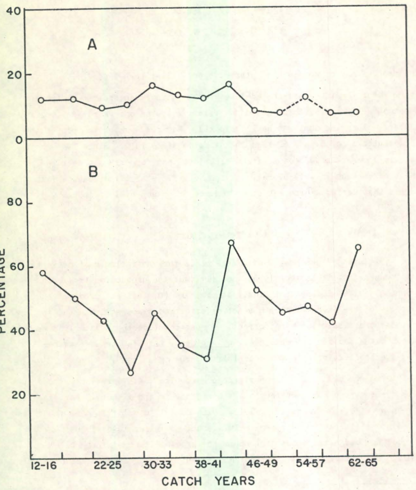

Fig. 7. A - average percentages of age 5_3 and 6_3 sockeye in Area 4 (Skeena catches. B - average percentages of age 5_2 sockeye among the 4_2-plus-5_2 portion of the catch. Figures are based on the computed total number of fish of each age type in each year's catch, averaged by 4-year periods (5-year periods for 1912-21, to accommodate the then 5-year cycle). Data from Bilton et al. (1965, 1966, 1967).

by chance is 1/8. If sequences of bad (or good) years tend to occur together, within the same decade say, then the above probability is greater than 1/8, perhaps 1/4 or 1/3. Thus, strictly as a mathematical proposition, it is very possible we have merely been unlucky in recent years.

However, if the 1964 spawning fails to produce a good return, the odds against its being merely random bad luck that now plagues the 0.8-0.9 million range will have become rather long.

7. DECLINE IN SUCCESS OF SPAWNING?

The net area of usable spawning gravel, or the average success of spawning on available gravel, may have decreased in the Skeena system because forest fires or logging have produced greater extremes of flow and/or altered the beds of streams. There are unfortunately no objective measurements of these effects, by which present and past might be compared. Extensive forest fires occurred in the Babine Lake watershed during the 1920's and 1930's, and recently logging has become active there. If there has been deterioration of some spawning grounds as a result, the present development program at Babine should help to counteract it.

8. DECREASE IN FERTILITY OF SOCKEYE LAKES?

The sockeye taken commercially do not return to the lake of origin to contribute organic or inorganic nutrients to the system. In primitive times a large fraction of the Skeena sockeye run was available to fertilize the system's lakes. If the equilibrium population at Babine were the 1.2 million suggested by curve A of Fig. 1, this would be about 7 million lb of sockeye, or say 50 lb/acre[4]. If the equilibrium were at some much higher level suggested by extrapolating curve B, the quantity could be 100 lb/acre or more[4]. Present average escapements bring only about 25 lb/acre into the Skeena lakes.

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[4]However the Babine River spawners mostly go downstream when dead, part of them fertilizing Nilkitkwa Lake, others being lost to the system.

However assessment of the possible significance of the contribution of adult sockeye to lake economy is difficult, and has not yet been attempted for any Skeena lake system. At Babine Lake even the present escapements bring much more organic matter into the lakes than goes out <u>in the form of smolts</u> (up to about 700,000 lb per year); but there are of course other inputs and outputs.

Recent work on Lake Iliamna in Alaska (where the dominant year-class of 1965 brought 200 lb/acre of salmon into the lake) leads to the conclusion that "biogenic elements from decomposed salmon carcasses enrich the lake and enable it to support the progeny of the escapements in the peak cycle years." (Donaldson,1967a; see also 1967b). Thus the reduction in annual fertilization of a lake to half or less of the potential, which is unavoidable if a fishery is to exist, may in some cases directly reduce its productivity in the year concerned. It is also possible that reducing spawning stocks may lead to a cumulative impoverishment of some nutrients in any lake basin where the rate of replacement of water is small. For either reason, the sockeye productive potential of Babine and other Skeena lakes <u>may</u> be less now than in the early years of the fishery.

9. DETERIORATION OF THE OCEAN ENVIRONMENT?

Long-term trends in ocean temperatures, currents, etc., may well have occurred during the past 60 years, and their effects may have either worsened or improved the Gulf of Alaska as a sockeye habitat, but speculation is fruitless.

The one known progressive change in the ocean habitat, that might have a direct effect on sockeye and other fish, is the increase in size of Pribilof fur seal herd from about 200,000 in 1907 to about 3,000,000 in the 1940's and early 1950's, since reduced about 2,500,000 (Roppel and Davy, 1965). A rough calculation of the annual food requirement of 2.5 million seals is 4 million tons, of which perhaps a tenth might be captured in the region inhabited by Skeena sockeye. Various plausible assumptions can be made as to the percentage of salmon in the fur seal's diet (say 20%), the fraction of Skeena sockeye among the total salmon in the area they inhabit (say 0.5%), and their average size when eaten (say 1 kg). This brings their annual consumption to $0.1 \times 0.2 \times 0.005 \times 4 \times 10^9$ = 400,000 Skeena sockeye. This could produce an appreciable reduction in returns to the river (20% of an average run). But since the figure could easily be out by 3 times in either direction, the true effect might be anything from very important to negligible.

Another consideration makes it seem likely that changes in ocean conditions (including abundance of fur seals) have not been an important factor in the Skeena decline: the fact that the sockeye productions of Rivers Inlet and Smith Inlet have shown no comparable reduction, though there has been a small decline in very recent years. This of course is not conclusive, for these areas might possibly have been underfished in earlier years, or with their more southerly location their sockeye might be less vulnerable to fur seal attack.

Somewhat similar speculations have been made with respect to harbour seals in the Skeena estuary and river (Fisher, 1952), but the evidence that these have increased substantially is largely anecdotal.

Estimates of the survival of Babine smolts, from the lake outlet to the time of their return to the fishery, are available only for 6 brood years starting with 1956 (Table II). Known survivals vary from 2.37% to 7.12%. These estimates do not go back far enough to shed light on whether sea survival is today less than it was formerly. It seems about average for smolts of this size, by comparison with other regions (Ricker, 1962, p. 536).

10. DIFFERENT VULNERABILITIES OF DIFFERENT STOCKS?

For each individual sockeye stock there is an optimum rate of utilization that will on the average produce maximum yield. Indeed, for each stock there is a best rate of utilization that differs from year to year. However, when many stocks are harvested in a common fishery it is impossible to give each one individual treatment, and inevitably the smaller stocks will receive least consideration.

Even if all stocks had the same best rate of utilization it might prove impossible to provide it. Dr. R.R. Parker points out that a stock that spends a rather long time in a fishing area tends to be harvested more completely than those that stay a shorter time; as a result it may be over-exploited and become reduced in numbers below its best sustained-yield level. Nothing is known about relative lengths of time spent in the fishing area by different stocks of Skeena sockeye. Results of tagging do not supply this information, because returns are made on spawning grounds at different distances from the point of tagging, all much above the fishing boundary. Of course in all runs there must be selection against a long stay in the fishing area, so that as time goes on we might expect them to move through the fishing area more and more rapidly. Since an initially slow-moving run would be selected most severely, extremes of behaviour in this direction presumably tend to be corrected with time, and the stock in question restored to a productive level similar to that of dominant stocks in the system that have similar productive potential. Thus this cause of differences between stocks should tend to be self-correcting in the long run.

11. DIFFERENCES IN REPRODUCTIVE POTENTIAL OF DIFFERENT STOCKS?

Different sockeye stocks may differ in their reproduction potential and hence in the percentage of their stock that may be taken for maximum sustainable harvest. But when many stocks must be harvested in common, this leads to a progressive reduction of those which produce the smaller surpluses, or in other words, those that have reproduction curves closer to the replacement line (see Ricker, 1958b). Could the long-term decline of the smaller Skeena stocks have this cause? Computations show that a stock does not immediately come to equilibrium with respect to any given rate of fishing. However, stocks that are being fished near their optimum rate will reach equilibrium, for practical purposes, in 2 or 3 generations (Ricker, 1958b). If we assume that the major Babine Lake stocks are now close to optimum harvesting, any Skeena stocks having less surplus production will (in the common fishery) be fished more heavily than optimum; each one will decline until an equilibrium point is reached (or until it becomes extinct). Calculations show that this process can be quite protracted, depending on how close the actual rate of exploitation is to the rate at which the stock will only just survive, and also on the shape of its reproduction curve. With a flattish reproduction curve (such as C in Fig. 1) and a rate of exploitation close to the limiting value, it may take a stock 10, 20 or more generations to reach equilibrium at a low level, or to disappear entirely (Ricker, MS). This is a time interval of 50 to 100 years.

Even within the Babine region, some stocks may be considerably less productive than others, and if so, they too would have been reduced disproportionately and progressively. Some of the main-basin stocks may have experienced this, or perhaps the lake spawners.

It is quite possible to make a model in which the observed decline in yield of the Skeena system would be a result solely of unequal productivity of its various component stocks. Expressed differently, on this view the early yields of the system were substantially greater than its sustainable yield; the latter is of necessity approached rather slowly, and the equilibration process may still be incomplete. Before equilibrium is achieved at the present rate of utilization (about 50%), some stocks may become totally extinct.

12. INTERACTION BETWEEN SUCCESSIVE YEAR-CLASSES OF THE STOCKS IN A GIVEN LAKE?

Consider now the situation if the productions from successive spawnings in a lake are not independent. In particular, we might suppose that extra good production in year A makes for decreased production in some one or all of years B, C, D or E. Alternatively, or in addition, a small population in one year, or in a few years in succession, might favour large production in a later year or years.

The evidence for this phenomenon on the Skeena is indirect and inconclusive, but nevertheless real:

(1) The scarcity of intermediate-size stocks from fairly large spawnings is a very puzzling feature of Fig. 1, which might be a result of interaction. A polygon is drawn on the figure in the region of 0.7 to 1.1 million spawners, which contains only two points, and those off centre. By contrast, the stocks produced from smaller spawnings are most numerous near the the trend line and scarcer as you leave it--as would normally be expected.

(2) During 1914-19-24 and again in 1936-40-44-48-52 there were regularly-occurring sequences of "dominant" catch years[5], separated by years of mostly mediocre or poor production (Milne, 1955; Shepard and Withler, 1958). In terms of interaction, the success of the large spawnings of 1940, 1944 and 1948, in Fig. 4B, would be inseparable from the existence of intermediate years of small population (1937-39, 1941-43 and 1946-47); while the one "off" year having a large spawning (1945) failed to replace itself. In fact, all the really good returns (percentage and absolute) during the 1940's were associated with a dominant line (Fig. 4B).

(3) The possibility of interaction between successive spawnings derives some support from the analogous situation in most of the lakes of the Fraser River above its canyon. This comparison will of course remain somewhat unsatisfactory until the exact nature of the interaction on the Fraser is firmly established and the mechanism is shown to work on the Skeena as well.

Evidently we cannot assume that the observed excellent survival rates from moderately large spawnings represent a goal which could be

[5]With one exception these were also peak years in their sequence, but the year 1945 had a larger pack than 1944.

attained every year; one or more intervening years of small fingerling populations may be a necessary prerequisite. To examine this point, Fig. 8 shows the returns from 4_2 plus 5_2 spawning stocks, averaged over 4-year or 5-year periods to take care of the prevailing cycle. It appears that the two largest groups of returns (1912-16 and 1917-21) were from escapements that averaged about 650,000 per year. The only two larger escapement groups (1908-11, 1922-25) produced no greater total returns, hence would produce smaller sustained yields. Thus if interaction exists, this suggests that spawnings of 0.8-0.9 million every year would not give greatest average yield.

What might be the nature of this interaction? The present favoured hypothesis to explain the cycles on the Fraser is that the large years suffer reduced percentage predation because at some stage of their life history they satiate their predators, the latter being controlled in numbers by the sparse prey populations of the off years (Ricker, 1950; Ward and Larkin, 1964). Whether or not this mechanism could produce or maintain cycles in the Skeena, it is obvious that it would provide a basis for interaction between successive broods. That is, a big fingerling population should increase the growth rate and survival of its predators, which are then present in increased numbers to attack the next brood. Equally, one or two years of small fingerling populations should result in poor growth of predator populations and possibly poor survival of the predator broods being recruited, so that predation on subsequent sockeye year-classes (whether small or large) is reduced. Both on the Fraser and the Skeena, this mechanism depends on sockeye being the main converters of invertebrate food to fish in the lakes concerned, and on the Skeena this is true of Babine Lake at least.

It is also possible that there could be some quite different mechanism of interaction. For example, work with parasitization of Babine smolts (Dombroski, 1955, and studies in progress) suggest that the cestode Eubothrium may be a serious cause of mortality. This too is a biological factor that might establish a cyclical survival pattern in a manner similar to that suggested for predation.

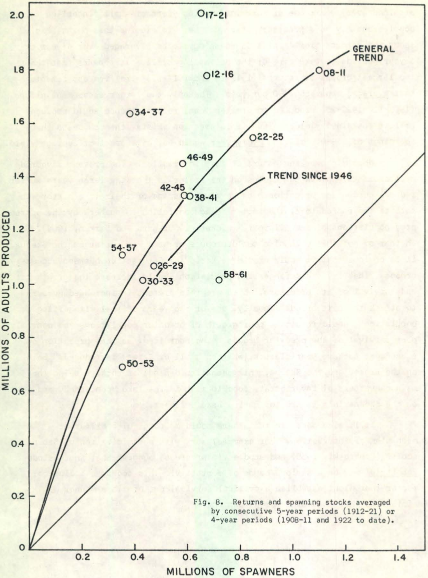

Fig. 8. Returns and spawning stocks averaged by consecutive 5-year periods (1912-21) or 4-year periods (1908-11 and 1922 to date).

13. DECREASED OVERALL SPAWNING SUCCESS BECAUSE OF UNEQUAL UTILIZATION OF RUNS MIGRATING AT DIFFERENT SEASONS?

Prior to World War II the usual pattern of fishing on the Skeena was a closed period on weekends, and a week or more of closed season in the autumn. However the latter came too late to affect sockeye very much, and there was no "natural" taper-off because the pink run began during the sockeye season and continued after it.

Apart from closed seasons, fishermen were and are especially eager to make some money in the early part of any fishing season, and tend to be particularly active then. Thus there is some tendency for runs that peak early in the fishing season to be fished more heavily than others. It might be for this reason that the early (uplake) Babine runs declined more than those that spawn in the outlet, but this is far from certain. Any run that migrates to some substantial extent before the fishing season begins is of course favoured: the Lakelse run is said to have been in this position.

Whether seasonal fishing patterns have actually produced any shifts in relative abundance of the Skeena stocks over the years can scarcely be discovered now. Whatever the reason, at Babine Lake today the main body of the lake has far fewer fingerling sockeye per unit area than the North Arm and Nilkitkwa Lake, and it seems capable of supporting more than it has. For this reason recent management has deliberately obtained larger percentages of main-basin spawning populations by reducing fishing pressure (relatively) on the earlier part of the run (SSMC, Annual Report for 1963, p. 26). Another indication of the success of this policy is seen in the increased numbers of late-run smolts (largely from the main basin) in recent years (Table II). (Estimates of early-run smolts, largely from North Arm and Nilkitkwa, are available only since the 1956 year-class).

Another possible effect of an irregular seasonal pattern of fishing may be to shift average time of spawning for a particular run away from the most favourable interval. However there is considerable leeway in this respect among most Skeena runs, which tend to lie in a lake for a time between migration and spawning, so it seems unlikely that this has been important.

14. UNFAVOURABLE CHANGES IN THE AVERAGE SIZE OF THE FISH IN A STOCK?

Gill-netting tends to put less pressure on fish of the extremes of size, and to catch intermediate-sized fish most efficiently (for an example see Foskett, 1958). In practice, it is probably the small fish that benefit most from this, because there is more chance of a large fish being caught in a net that is smaller than optimum mesh size for that fish, than of a small fish being caught in too large a net. Also, fishermen prefer large sockeye, at least since the war when payment has been by the pound rather than the piece, and they adjust their net size and 'hang' for greatest poundage returns. In consequence, any stock that consisted mainly of smaller-than-average fish would be less heavily utilized than those closer to the median size.

This selection can be demonstrated directly on the Skeena: the average size of sockeye caught in Area 4, or by the test fishing, is greater than that of the fish reaching the Babine fence, in all years of record (H.W.D. Smith).

Evidence for a cumulative effect, presumably hereditary, is presented by Godfrey (1958, p. 349-351). He found that the 4_2 and 5_2 Skeena sockeye caught in the fishery tended to become more different in size over the period 1909-1948--by about 1 lb in the case of males, and 0.5 lb in the case of females[6]. The change was most marked in the two extreme size groups: the 4_2 females became smaller and the 5_2 males became larger. However, granting the reality of these changes, they are not very great in comparison with year-to-year variability in mean size or, still less, in comparison

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[6]At Rivers Inlet the differences were greater: about 1.5 for males and 1.0 lb for females.

with the variability in individual size within a particular life-history type.

The direct within-season effect of size selection, and the (probably smaller up to now) hereditary effect, are both in the direction of reducing the average size and hence average egg content of Skeena sockeye female spawners--perhaps by as much as 20 or 25%. This represents a direct decrease in reproductive potential per unit number of spawners, except of course if there are excess spawners on a particular ground.

There may also have been an additional loss in efficiency if sockeye of some stocks have become smaller than the mean size most favourable for excavating redds in their particular spawning grounds.

The direct effect of this net selectivity has presumably been fully operative ever since the fishery became intensive; the hereditary effect is cumulative and makes things worse as time goes on.

15. CHANGES IN AVERAGE TIME SPENT IN THE OCEAN BY COMMERCIAL-SIZE SOCKEYE?

Selection by size may also involve selection by age, since three-ocean-year sockeye (ages 5_2 and 6_3) tend to be larger than two-ocean-year fish (ages 4_2 and 5_3). In both groups the females are smaller than the males, so that a fishery concentrated in the middle size range tends to attack 4_2 males and 5_2 females more severely, while 4_2 females and 5_2 males are less heavily harvested. Assuming that the two sexes are equally influential in determining the sex of their offspring, this appears to be a standoff situation.

Figure 7B shows that there has been no sustained trend in the relative abundance of 4_2 and 5_2 fish: the overall trend is toward slightly more 5_2's, but it is non-significant[7].

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[7] I would not have been surprised by the reverse trend, toward more 4_2's, since the 5_2 males have increased in size, over the years, less than the 4_2 females have decreased (Godfrey, 1958), which may suggest that the latter have gained most in survival from the selective fishery. Also, in two recent years (1964 and 1965) the Skeena catch has included a larger fraction of 5_2's than were in the Babine escapement (Bilton et al., 1965, 1966), though this comparison is complicated by the presence in the catch of fish from the system's smaller stocks.

There are also, presumably, environmental or phenotypic factors that affect age at maturity, and these may well be more important than the hereditary component in causing year-to-year changes. A possible environmental factor is variability in growth rate; a possible phenotypic factor is the effect of egg size now being examined by H. T. Bilton, which (he postulates) might lead to an alternation of ages.

At present it is difficult to say whether two or three years in the ocean gives best poundage return from a stock or some mixture of these. The loss by natural mortality during the extra year is probably more than compensated by the extra growth, though this is not certain. This is one field for fruitful experimental breeding if techniques for identifying the progeny can be developed.

16. AN INCREASE IN THE AVERAGE INCIDENCE OF JACKS?

There is obviously a strong selection pressure favouring the jack sockeye (age 3_2 or 4_3), which are only rarely taken in the commercial fishery. The tendency should be for their numbers to increase for this reason, if they are at all successful in reproduction. Hanson and Smith (1967) show that they are active as "satellite" males and that their sperm is sometimes in close contact with the eggs as they are being laid.

The only long series of data on incidence of jacks in the Skeena system are the counts at the Babine fence shown in Table I. Four years of exceptionally large numbers of jacks (1947, 1950, 1963 and 1966) suggest that non-hereditary factors weigh heavily in determining the number produced in any given year. Percentage of jacks in each year-class is shown in Fig. 9. No significant trend can be demonstrated from these data, though the occurrence of large numbers of jacks in two of the three most recent count years is perhaps a bit disturbing, in view of the events described below.

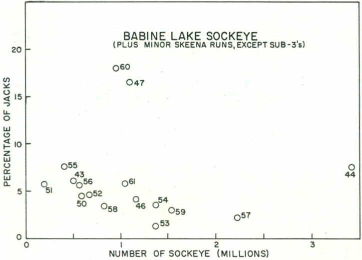

Fig. 9. Abundance of jacks in successive year-classes at Babine Lake, expressed as a percentage of the total number of adult fish of the year-class (ages 3, 4 and 5; including catch plus escapement). Figures on the graph indicate brood years.

In the Fraser system there has been a build-up of jacks in some stocks at least. (I have not checked the situation for all runs.) At Birkenhead there has been a significant tendency for percentage of jacks to increase over the brood-years 1938-1962, which is inversely related, though not necessarily causally, to the size of the run (Fig. 10). During the 1940's the incidence[8] of jacks was usually less than 10%. Since 1950 there have been 15-20% jacks in most year-classes, two broods have exceeded 30%, and the 1963 year-class produced the largest jack run ever--60% larger than the largest previous count.

For a long time there has been speculation about possible long-term effects of failure to harvest jacks upon age composition of sockeye stocks. Recent developments suggest that it may be time to take this seriously, even if in most places it is not a major immediate problem.

17. INCREASED INTERCEPTION OF ADULTS BY NON-CANADIAN FISHERIES?

Another possible factor contributing to reduced Skeena yields in Canada might be an increase in the fraction of Skeena-bound sockeye taken by other fisheries. The near-absence of tag returns to the Skeena from the Japanese fishing areas indicates that it is of negligible importance. The Alaska fishery cannot be dismissed so quickly. The available information from tagging (Shepard, Aro and Withler, 1962), suggests that their interception of Canadian sockeye has not usually been important, but for most years there is little or no direct evidence.

Table III shows recent sockeye catches in Alaska in regions near

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[8]Estimated as a percentage of the total run, on the assumption that the catch was twice the non-jack escapement each year.

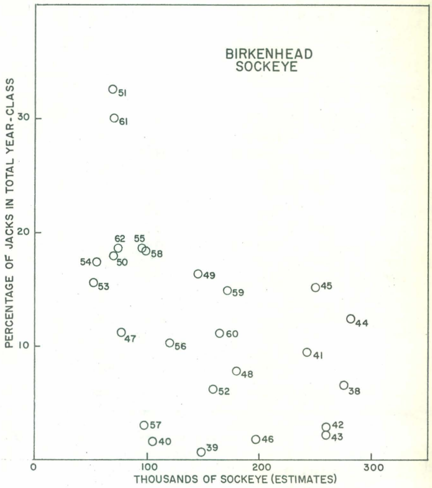

Fig. 10. Estimates of percentage jacks produced by successive year-classes of Birkenhead sockeye, Fraser system. Data are from Annual Reports of the IPSFC.

Table III. Catch of sockeye in (present) Statistical Districts 101-104 of southeastern Alaska (those near the Canadian border), and adjacent Canadian catches and escapements (compiled by K. V. Aro).

Catch year	Alaska	Skeena Catch[c]	Skeena Total	Nass Catch[d]	Skeena + Nass[b]	Alaska / Canada
	10^3	10^3	10^3	10^3	10^3	%
1951	170	691	1295[a]	226	1521	11
1952	321	1294	2538[a]	304	2842	11
1953	402	659	1422	198	1620	25
1954	306	571	1194	102	1296	24
1955	165	157	276	158	434	38
1956	246	149	534	255	789	31
1957	398	282	737	143	880	45
1958	384	602	1487	399	1886	20
1959	297	196	1050	170	1220	24
1960	177	186	506	133	639	28
1961	150	895	1894	281	2175	7
1962	246	484	1066	218	1284	19
1963	200	142	762	294	1056	19
1964	357	766	1651	170	1821	20
1965	360	294	953	136	1089	33
1966	296	593	1040	174	1214	24

[a]Includes an estimate of fish blocked by the Babine slide.
[b]Does not include Nass escapements.
[c]Statistical Area 4
[d]Statistical Area 3

the Canadian border, also Skeena catches and total stock, and Nass catches, for comparison. Not all of these Alaska fish would be of Skeena or Nass origin, of course; on the other hand, some tags have been recaptured in Canada that were put on in Alaska areas not included in the Table (K.V. Aro). Absence of significant correlation between Alaska and Skeena plus Nass (Fig. 11) does not in itself indicate that the two are largely independent stocks, because there are two opposed effects: a larger total run heading for the Skeena tends to increase the Alaska catch, but a larger fraction of any run taken by Alaska tends to increase their catch and to decrease the Skeena and Nass catches and escapements. Even so, there is some tendency for the Alaska catch to be larger when the Skeena stock is large--1961 being the outstanding exception.

Whether there has been a progressive increase in the interception of Skeena fish by Alaska is more problematical. There is no pronounced trend noticeable in the Alaska:Skeena ratio in the last column of Table III, but the data go back only to 1951.

18. ESTIMATING ADULT RETURNS FROM SMOLT MIGRATIONS

Table II compares the available smolt estimates with returning adults. Though the number of years available is small as yet, it would seem that if this order of variability continues in future, the precision of prediction will never be very good even for the total return, let alone the number that will appear at each age.

Various attempts have been made to improve forecasting, with little success to date. One or more indices involving number, size, or early growth rate of jacks have shown promise for a while, then proved disappointing (J.G. McDonald). Additional exploratory multiple-correlation studies, using all available stock characters, seem in order. Two simple relations are examined briefly below.

In other regions it has been found that survival increases with average size of smolts (Foerster, 1954). At Babine there is no suggestion

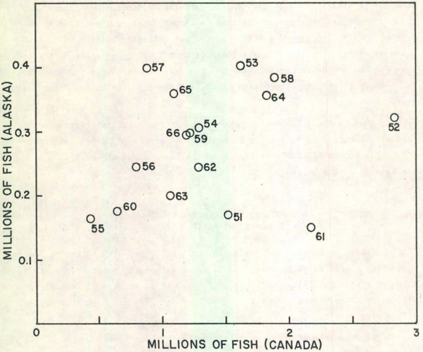

Fig. 11. Catch of sockeye in Alaska Statistical Districts 101-104, plotted against the sum of the British Columbia catches from Areas 3 and 4 plus the Skeena escapements.

of this effect in the 5 years' data available (Fig. 12); in fact the trend indicated is slightly the other way. However the range of observed smolt sizes is quite narrow.

Another survival relationship provisionally tested concerns the percentage representation of early-run smolts in the total run (Table 11, Fig. 13). Here also the relation is obviously non-significant as yet; the trend is for smaller percentage returns when the early run is relatively large, but this depends on only one good point (1956 brood) plus the doubtful one for 1958. In spite of this lack of significance, it is of some interest to compute the prospects for the large 1964 spawning using the indicated relationship. With 49% early smolts in a run of 37.0 millions, survival is estimated from the freehand trend line at 4.1%, which means 1,500,000 adults. This represents a surplus of 610,000 over the brood year spawners, less than what somewhat smaller escapements have been producing in recent years. The actual figure may, of course, be much greater or less than this.

19. CONCLUSIONS CONCERNING MANAGEMENT

1. The sockeye productivity of the Skeena system (number of adults produced by any given number of spawners) has declined progressively. Whether this is natural or a result of exploitation, we should continue our efforts to identify the cause or causes, particularly to learn whether it will be permanent under existing conditions.

2. The above decline does not necessarily mean that the optimum number of spawners for the system is less now than formerly, though this might be so (depending on the cause of the decline).

3. Returns from three recent trials of fairly large spawnings at Babine Lake are not sufficient to test current average productive capacity at this level (about 850,000 spawners); one more trial is on the way (1964 brood). In any event, we should not lightly cast aside the prospect of average annual catches of about 1.2 million fish, which

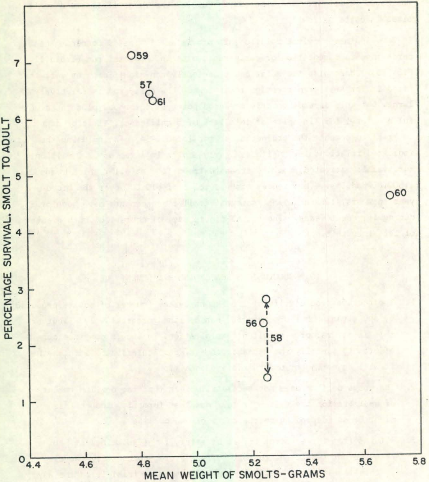

Fig. 12. Percentage survival, to the adult stage, of Babine smolts of different average sizes. Dates indicate year-classes (year of spawning). See Table II regarding the two points shown for 1958.

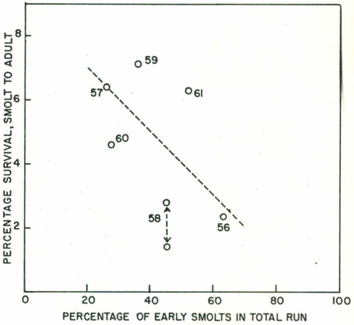

Fig. 13. Percentage survival of Babine smolts to adult stage, related to the percentage of early-run individuals in the total run. The dates indicate year of spawning.

earlier years' data suggest as likely. One or two additional spawnings near the estimated optimum should settle the point conclusively if they give poor returns; however if they give good returns, spawnings of this size should be explored further.

4. At the moment, since there are some theoretical and observational grounds for the possibility that maximum surpluses will be obtained at average spawnings of about 600,000, it is unwise to aim for the apparent optimum of 850,000 in every year.

5. When spawnings fall below 400,000 they have produced decreasing surpluses (on the average) during every period of the fishery, so every effort should be made to keep them above that figure.

6. The decline of the smaller Skeena runs should be watched closely, and efforts made to prevent any becoming extinct, using fish cultural methods if necessary, because of the potential value of their genetic material. However, if they all, or nearly all, produce a smaller surplus per spawner than the Babine stocks do, it will not be economic to maintain them at a high level.

7. Since there is some reason to suppose that the natural productivity of the Skeena environment-plus-sockeye system may have decreased permanently, for one or more of several causes, the need for artificial measures to increase productivity becomes more compelling.

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