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Rivers Inlet Sockeye Salmon: Stock Status Update

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Abstract

Adult and juvenile data were used to provide an update on the stock status of Rivers Inlet (Owikeno Lake) sockeye salmon. The Rivers Inlet sockeye stock declined to record low levels in 1995 and 1996. Total sockeye returns increased in 1997 such that the minimum target escapement of 200,000 sockeye was exceeded, however the 1997 return was still below average. All available data indicate that the recent decline resulted from poor marine survival, not a failure in freshwater production. Analysis of juvenile data also suggests that the longer-term decline in total stock since the 1970's cannot be attributed to a decline in freshwater production either. The juvenile abundance indices for brood years 1991 and 1994 were above the long term mean suggesting that the freshwater production potential of Owikeno Lake had not declined from historic levels. Future returns to Rivers Inlet are expected to be low through 2001 as a result of very poor escapements in 1994 to 1996.

Résumé

Des données sur les adultes et les juvéniles ont servi à faire le point sur le stock de saumon rouge de Rivers Inlet (lac Owikeno). Ce stock a baissé en 1995 et 1996 à un niveau jamais atteint. L'ensemble des remontées de saumon rouge a augmenté en 1997, de sorte que l'échappée cible minimale de 200 000 saumons rouges a été dépassée, mais la remonte se situait encore au-dessous de la moyenne en 1997. Selon toutes les données disponibles, le déclin récent était lié à la faible survie en mer, et non à l'échec de la production en eau douce. L'analyse des données sur les juvéniles montre aussi qu'on ne peut pas attribuer à la production en eau douce le déclin à long terme de l'ensemble du stock observé depuis les années 70. Les indices de l'abondance des juvéniles pour les pontes de 1991 et 1994 étaient au-dessus de la moyenne à long terme, ce qui permet de penser que le potentiel de production dulcicole du lac Owikeno n'a pas baissé avec le temps. Les retours vers Rivers Inlet devraient rester bas jusqu'en 2001, étant donné la faiblesse des échappées de 1994 à 1996.

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1.0 INTRODUCTION

The Rivers Inlet sockeye stock has recently received much attention because of a dramatic decline in total abundance (since 1994) which culminated in a complete closure of the commercial fishery in 1996 and 1997. This document was prepared in response to requests for an update on the status of the Rivers Inlet sockeye salmon stock. A comprehensive assessment of Rivers Inlet sockeye was last reviewed by PSARC in 1995 (see Rutherford et al. 1995). The present report includes updated information on catch, escapement indices, total stock size indices, age composition, and juvenile sockeye abundance indices collected in 1995-1997.

All sockeye production from Rivers Inlet (Statistical Area 9) originates from spawning areas associated with Owikeno Lake, a deep, cold and typically oligotrophic coastal lake (Ruggles 1965; Narver 1969). Owikeno Lake is large by coastal standards (96 km^2) and comprises four distinct basins, each separated by shallow narrows (Fig. 1). The two lowermost basins (stations 1-3) account for approximately 90% of the total lake area, and these are deep and highly turbid; the two uppermost basins are much smaller, shallower and less turbid. Many streams flow into Owikeno Lake. The two largest, Machmell and Sheemahant, are very turbid and carry the bulk of the silt to the main basins of Owikeno Lake. The 5-km long Wannock River drains Owikeno Lake into Rivers Inlet.

2.0 METHODS

2.1 DATA SOURCES

2.1.1 Spawning Escapements

The glacial turbidity of Owikeno Lake and its major spawning streams preclude reliable estimation of spawning escapements by visual survey (Walters et al. 1993; Rutherford et al. 1995). Nevertheless, estimates of spawning escapement to Area 9 are recorded for years 1948-1997. Escapements for years 1948 to 1951 are from Wood et al. (1970). Escapement for years 1952-1996 are available from the Regional Salmon Escapement Database System (SEDS, Serbic 1991). The SEDS database is missing the estimated escapement to the Wannock River for 1956 and 1960, and missing the estimated escapements to the Sheemahant River for 1958 and 1960. Escapement estimates for these rivers are reported in Wood et al. (1970) and we have added these estimates to the total escapement numbers obtained from the SEDS database.

An escapement index using only the estimated escapement to the clear rivers has been developed to address the reliability problems associated with estimating sockeye escapement to the glacially turbid rivers. This clear stream index has been modified from that reported by Rutherford et al. (1995) to include only those clear water rivers that are easily accessible for visual enumeration of spawning sockeye. The new index is the sum of escapement estimates to the Ashlum, Dallery, Genesee, Inziana and Washwash rivers (Table 1). The previous clear stream index also included the escapement to the Amback and Tzeo rivers. The 1996 and 1997 sockeye salmon escapements to the clear rivers were estimated using an "area under the curve" (AUC) procedure.

An overall sockeye escapement index for Owikeno Lake (Rivers Inlet) in 1997 was calculated and expressed in units comparable to the total escapements reported in previous years. Previous estimates of total escapement (for the period 1948 -1996) were regressed on the clear stream escapement index. The resulting equation, $y=1.76x+139563$, was then used to generate a comparable total escapement index for Owikeno Lake in 1997. (The fisheries manager for Area 9 has also attempted to partition the total escapement index, less the estimated clear stream index, among the remaining unsurveyed streams in Owikeno Lake, but these numbers are considered too unreliable for use in this assessment.)

All escapement values used in this document are reported in Table 1. Escapement data by individual streams listed in Appendix 1 are from the Area 9 spreadsheet tables maintained by DFO staff in Prince Rupert (file:9esc.xls). Entries are generally consistent with data in the regional Salmon Escapement Database System. Methods used to estimate escapement have been previously reported and discussed by Rutherford et al. (1995).

It should be noted that the 1960 estimate of total escapement reported in the SEDS database is 68,800 sockeye. Many authors have mistakenly reported the 1960 estimate of escapement as 688,800 sockeye (Walters et al. 1993; Hilborn and Walters 1992; Routledge 1997; Anonymous 1997a) and stated their data source was Department of Fisheries and Oceans Salmon Escapement Database. This error has lead authors to publish a total stock size of over 1.2 million (1,205,303 sockeye) for 1960 when in fact stock size was only about half that at 655,303 sockeye. The estimate of escapement for 1960 should be 138,800 sockeye (the SEDS estimate of 68,800 plus the estimate of 35,000 each to the Wannock and Sheemahant rivers).

2.1.2 Commercial Catch

Reliable catch data for Area 9 sockeye is reported for 1948 through 1997 in Table 1, and catch estimates are available back to 1882. Catches for years 1882 to 1951 were summarized by Rutherford et al. (1995) and catches for 1952 to 1996 are in the Regional Catch database (Holmes and Whitfield 1991). No commercial or assessment sockeye fisheries occurred in Rivers Inlet in 1996 or 1997.

2.1.3 Age Composition

Age composition data from escapement samples for years 1995 to 1997, and catch samples for 1995 were compiled by the senior author. Age composition data from both catch and escapement samples in previous years were taken from Rutherford et al. (1995). The total updated data series is reported in Table 2.

2.1.4 Total Returns

Total stock size (reported in Table 1) and total returns by brood year (in Table 3) are very unreliable estimates because total escapement to Owikeno Lake is measured as an approximate (and probably unreliable) index whereas actual catch is known reliably. Because the ratio of catch to escapement has changed dramatically through regulation of fishing effort, total stock cannot be used to assess long-term trends or productivity relationships without making an assumption about the multiplier required to convert escapement indices into absolute counts. Even so, following previous authors (e.g., Walters et al. 1993), a Ricker stock recruitment curve was fitted to escapement and total return data updated to include the 1990, 1991 and 1992 brood years by implicitly assuming an escapement index multiplier of one. Lognormal errors were assumed, and Ricker parameters a and b were estimated by linear regression such that $\ln(R_t/S_t) = a + bS_t + \varepsilon_t$ where S_t and R_t are the escapement and total adult returns for brood year t, and ε_t is a normal variate $\sim N(0, \sigma^2)$.

2.1.5 Juvenile Abundance and Size.

In many years, including all recent brood years (1994-1996), juvenile abundance was measured directly by nighttime surface trawling at stations 1-3 during July and August using standardized methods described by Wood and Schutz (1970). The July-August sampling period was selected because the majority of juveniles are vulnerable to the surface trawl gear at this time (Hyatt et al. 1989). Individual trawl catches can vary considerably and appear to be lognormally distributed. For this reason, individual catches are $\log_e$-transformed and averaged within stations. The overall juvenile index is the average across all stations weighted by the lake area corresponding to each station. The size and number of juvenile sockeye caught in standardized trawl surveys provides an index of fry recruitment and smolt production. Late summer trawl surveys began in 1960, were discontinued in 1969, and were reinstated in 1995 with the creation of the Stock Assessment Division

It has also been possible to infer the juvenile abundance index from average pre-smolt weight in years where spring surveys (but no summer surveys) were conducted. The inference is based on a good relationship between the summer juvenile index and subsequent pre-smolt weight (Rutherford et al. 1995). To corroborate this relationship in more recent brood years, pre-smolt weight was obtained by surveys conducted in the spring of 1997 and 1998. All juvenile abundance data and pre-smolt weights used in this document are reported in Table 4.

A very approximate marine survival index was estimated as the ratio of estimated total adult returns to estimated fry recruitment for the corresponding brood year. (i.e., marine survival index=$R_t/\exp^{(\text{juvenile index})}$). The bias associated with back-transformation of the juvenile index is ignored in view of the greater uncertainty associated with total adult returns.

2.2 STOCK SIZE FORECAST MODEL

Following Wood et al. (1997) the following 5-yr mean model was used to forecast sockeye returns in 1998:

$$\ln(N_{1998}) = a = \sum \ln(N_i) / 5 \quad \text{for i=1993 to 1997}$$

where N_i is the total stock size in year i.

3.0 RESULTS AND DISCUSSION

3.1 TRENDS IN ABUNDANCE

3.1.1 Escapement Trends

An overall increasing trend in the total sockeye escapement index for Area 9 occurred from 1948 through 1993 (Fig. 2). A dramatic drop in escapement was observed in 1994 and persisted for three years. Since the writing of the last PSARC Working Paper (Rutherford et al. 1995), annual sockeye escapements for years 1995 to 1997 were 73,000, 65,000, and 285,000, respectively. The 1995 and 1996 escapement estimates are the lowest on record. The 1997 escapement of 285,000 was a considerable improvement over the 1994-1996 escapements, and exceeded the target. However, the 1997 escapement was still slightly below the long-term median escapement of 312,000 sockeye.

The clear stream indices for years 1995 to 1997 were 41,500, 19,555, and 82,767, respectively. The clear stream indices for 1995 and 1996 are below the median index of 92,700 sockeye. However, the 1997 clear stream index of 82,767 is close to the median.

We consider the clear stream escapement index derived from the SEDS database to be a more reliable index of escapement than the SEDS total escapement index. The clear streams have accounted for a large portion (on average 37%) of the total estimated escapement index from SEDS. Individual stream visit logs were available for a limited number of years (1983 to 1996) for which we re-estimated escapements using a standardized AUC procedure; we then compared these systematic estimates with the SEDS escapement for each of the clear rivers. A strong positive correlation was observed between the SEDS escapement and the systematic estimates of all clear rivers (Fig. 3) except the Amback River. For this reason the Amback River was excluded from the clear stream escapement index.

The total Area 9 SEDS sockeye escapement has generally increased over time, but the clear stream index has not shown a corresponding increase (Fig. 4 and 5). This implies that the proportion of the total Area 9 escapement attributed to the glacially-turbid rivers has increased over time (Fig. 5), perhaps reflecting changes in methodology for estimating escapement to glacial streams. Thus, the total Area 9 SEDS sockeye escapement data cannot be considered as a consistent index of escapement over time and this questionable reliability must be considered when interpreting results from analyses that require the use of total return data.

3.1.2 Commercial Catch

Area 9 sockeye catch was variable and without trend for most of the first half of the 20th century although some outstandingly high catches were recorded in 1968 and 1973. Beginning in the early to mid-1970's the average catch declined significantly, driven by poor catches in 1970, 1974 and 1975 (Fig. 6). An adaptive management plan implemented in 1979 restricted commercial catch from 1979 through 1988 (Walters 1993). Commercial catch has continued to decline since the last PSARC assessment. The 1995 catch was 44,379 sockeye and no commercial gillnet fisheries were permitted in Area 9 in 1996 and 1997 due to concern over declining stock size.

3.1.3 Age Composition

Age composition of escapement and commercial catch samples is highly variable and dominated by age 1.2 and 1.3 sockeye. For the last several years age 1.3 (5-yr old) sockeye have dominated calendar year returns (Table 2). Age composition by brood year is less variable with an average age composition of 35% 4-yr old and 65% 5-yr old sockeye (Table 3).

3.1.4 Stock Recruitment

The Ricker stock recruitment model fitted to total return and escapement data suggests an optimum escapement of about 300,000 sockeye (Fig. 7). However, this estimate cannot be considered reliable because the curve fit the data very poorly, and because considerable uncertainty surrounds both the total adult return and the total escapement data used in the analysis (Walters et al. 1993; Rutherford et al. 1995).

3.1.5 Juvenile Abundance and Size

Growth of sockeye in Owikeno Lake is density-dependent; pre-smolts are smaller in years of high abundance than in years of low abundance (Fig. 8). This relationship indicates that food supply is limiting growth in Owikeno Lake, and confirms that late summer trawl catches are a reliable index of juvenile abundance.

No juvenile data are available for brood years 1992 and 1993. The juvenile abundance index for brood year 1994 was slightly above the long term mean of 4.75. Abundance indices of 4.14 and 2.82 for brood years 1995 and 1996, respectively, are below historical levels with 1996 among the lowest on record, consistent with the record low parent escapement (Fig. 9), and their record high average fresh weight of 2.65g. Pre-smolt samples collected from the 1994 through 1996 brood years indicate that the previously documented density-dependent relationship still holds, confirming that trawl catches continue to provide a reliable index of juvenile abundance (Fig. 8).

Plots of the total and clear stream escapement indices versus juvenile recruitment grouped by decade (1970's and 1980's pooled) indicate that there has not been a long term decrease in egg-to-fry survival in Owikeno Lake (Fig. 10). Analysis of covariance (GLM in SYSTAT) indicated that neither "decade" (defined as a categorical variable), nor the decade-escapement interaction term were statistically significant (p=0.70 and p=0.69, respectively using the total escapement index; p=0.96 and p=0.83, respectively using the clear stream index); in contrast, the covariate, escapement, was statistically significant in both cases (p=0.01 and p=0.00 respectively). Of course, statistical power was limited by the number of years of data available, and by the lack of high escapements observed since 1988.

A weak positive relationship exists between juvenile catch and subsequent total returns (Fig. 11). Some indication of an upward trend is evident but this is driven by the outstanding returns from the 1963 and 1968 brood years. The poor relationship between juvenile abundance and subsequent adult returns, and poor recent returns regardless of the juvenile abundance, suggests that marine survival can be highly variable and that it has been poor during recent years. This highly variable and recently poor marine survival is illustrated in Figure 12. Poor marine survival has also been measured at neighbouring Long Lake in recent years (Anonymous 1997b). Strong compensation due to smolt size also appears to be influencing marine survival rates so that increased escapements in the 1980's may have been counterproductive by producing a large number of smaller smolts all experiencing decreased marine survival (Fig. 13). It should be noted, however, that the marine survival index may be unreliable because it is based on the unreliable total return index. Thus, the relationships shown in Figures 12 and 13 will be spurious to the extent that errors in the total escapement index have changed over time, or have increased with increasing escapement which in turn, reduces average pre-smolt size.

3.2 STOCK SIZE FORECAST FOR 1998

The forecasted sockeye returns to Rivers Inlet in 1998 are expected to be low with a 75% chance that returns will exceed 95,000 (Table 5, Fig 14). The median forecast (50% level) of 165,000 is well below the minimum escapement target of 200,000 sockeye. The 1998 returns will comprise fish from the 1993 and 1994 brood years. Juvenile data indicate that fry recruitment from the low 1994 escapement was unexpectedly high, and the 1993 escapement was estimated to have been close to the historical average. Thus, our forecast could be unduly pessimistic if marine survival has improved. Even so, expectations for returns in 1999 through 2001 are low given the record low escapements experienced in 1995 and 1996. Prudence demands that this stock be managed to rebuild escapement, and that management plans be developed assuming poor returns through 2001.

4.0 CONCLUSIONS

Our assessment of factors affecting the status of Area 9 sockeye has not changed since the last PSARC review (Rutherford et al. 1995). Assessment of Area 9 sockeye production is still limited by the unknown precision and reliability of the adult escapement estimates. The reinstatement of the juvenile trawl program has addressed some of the uncertainties of using escapement and total stock data to monitor long term trends in sockeye production for Owikeno Lake. Recent juvenile data has corroborated our earlier conclusion that recent poor returns to Owikeno Lake are the result of poor marine survival.

The juvenile abundance indices for brood years 1991 and 1994 were above the long-term mean suggesting that freshwater production potential had not declined from historic levels. Reduced fry recruitment from the 1995 and 1996 brood years is consistent with the record low parent escapements to Owikeno Lake.

Work is currently underway to infer juvenile abundance from the freshwater growth zone in historical scale collections from adult fish (McKinnell et al. in prep[1]). Preliminary results from this work have been encouraging and we hope to obtain a 46-yr time series of juvenile sockeye abundance in Owikeno Lake by extending and filling in gaps in the time series reported here (Fig. 9).

In summary, the Owikeno Lake sockeye stock declined to record low levels in 1995 and 1996. All available data indicate that this decline resulted from poor marine survival, not a failure in freshwater production. Analyses of juvenile data also suggest that the overall decline in total stock size since the early 1970's cannot (parsimoniously) be attributed to a decline in freshwater production. Total returns increased in 1997 such that the minimum target escapement of 200,000 sockeye was exceeded. However, the 1997 return was still below average, and lacking juvenile data for 1992, we cannot judge whether marine survival has improved. Future returns to Owikeno Lake are expected to be low through to 2001 as a result of very poor escapements in 1994 to 1996. The median forecast of total returns in 1998 is 165,00 sockeye with a 25% chance that the return will be less than 95,000, based on the 5-yr mean model.

5.0 ACKNOWLEDGEMENTS

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Table 1. Commercial catch, escapement, total stock size, and clear stream escapement index for Area 9 sockeye salmon, 1948-1997.

Year	Commercial Catch	Escapement	Total Stock	Clear Stream Index
1948	451727	105273	557000	45000
1949	603120	236880	840000	83500
1950	1549338	444662	1994000	222000
1951	1016495	304500	1320995	164500
1952	938722	582500	1521222	305000
1953	1522285	440000	1962285	280000
1954	575664	103800	679464	91800
1955	584245	132900	717145	118000
1956	1072332	223500	1295832	116000
1957	373976	212900	586876	92900
1958	1017545	296750	1314295	136000
1959	439419	380500	819919	197000
1960	516503	138800	645303	45900
1961	842953	161850	1004803	64500
1962	1035917	413500	1449417	176000
1963	437459	932500	1369959	500000
1964	1053591	573900	1627491	268500
1965	644974	140150	785124	45075
1966	528212	200000	728212	74000
1967	1102838	435250	1538088	145750
1968	2727552	555000	3282552	285000
1969	727330	226000	953330	28250
1970	19019	102250	121269	28250
1971	402538	215900	618438	89800
1972	379006	224000	603006	62000
1973	1760156	985000	2745156	457500
1974	118574	557025	675599	161500
1975	40631	480002	520633	136500
1976	613067	300000	913067	63500
1977	659819	192600	852419	62600
1978	577908	383000	960908	140000
1979	28328	297525	325853	65500
1980	528	313000	313528	70500
1981	98706	753075	851781	148000
1982	39180	823000	862180	233000
1983	35161	636502	671663	160500
1984	53879	214301	268180	99700
1985	184543	500430	684973	217425
1986	337443	825626	1163069	185000
1987	398854	521700	920554	153200
1988	372018	503000	875018	85500
1989	63746	375175	438921	42600
1990	234281	586500	820781	92500
1991	168226	346500	514726	79000
1992	508068	343005	851073	90500
1993	82529	311000	393529	67000
1994	40320	91500	131820	26000
1995	44379	73000	117379	36500
1996	0	65000	65000	15205
1997	0	285000	285000	82767

Table 2. Age composition of Area 9 sockeye salmon sampled from the commercial catch and escapement, 1948-1997.

	Proportion of catch			Proportion of escapement		
Year	Age 1.2	Age 1.3	Other	Age 1.2	Age 1.3	Other
1948	0.55	0.45	0.00			
1949	0.84	0.15	0.00			
1950	0.13	0.89	0.00			
1951	0.38	0.61	0.01			
1952	0.41	0.59	0.02			
1953	0.73	0.27	0.02			
1954	0.60	0.40	0.02			
1955	0.45	0.56	0.01			
1956	0.10	0.92	0.00			
1957	0.65	0.35	0.00			
1958	0.28	0.71	0.00			
1959	0.19	0.79	0.01			
1960	0.38	0.57	0.04	0.43	0.57	0.00
1961	0.49	0.49	0.02	0.31	0.69	0.00
1962	0.90	0.09	0.00	0.53	0.47	0.00
1963	0.37	0.60	0.02	0.47	0.52	0.01
1964	0.13	0.79	0.07	0.12	0.86	0.01
1965	0.69	0.27	0.01	0.36	0.64	0.00
1966	0.34	0.65	0.00	0.42	0.58	0.00
1967	0.78	0.20	0.01	0.40	0.60	0.00
1968	0.07	0.90	0.03			
1969	0.35	0.61	0.02			
1970	0.40	0.49	0.05	0.40	0.50	0.05
1971	0.75	0.23	0.01	0.76	0.22	0.02
1972	0.48	0.45	0.04	0.81	0.14	0.01
1973	0.06	0.94	0.00	0.06	0.94	0.00
1974	0.19	0.78	0.01	0.19	0.78	0.01
1975	0.47	0.52	0.01	0.47	0.52	0.01
1976	0.47	0.51	0.00			
1977	0.44	0.54	0.00			
1978	0.04	0.94	0.02	0.03	0.95	0.02
1979	0.57	0.41	0.02	0.57	0.41	0.02
1980	0.17	0.83	0.00	0.17	0.83	0.00
1981	0.34	0.65	0.00	0.34	0.65	0.00
1982	0.12	0.85	0.00			
1983	0.19	0.80	0.01	0.19	0.80	0.01
1984	0.74	0.26	0.00	0.62	0.38	0.00
1985	0.38	0.62	0.00	0.21	0.79	0.00
1986	0.34	0.66	0.00	0.17	0.83	0.00
1987	0.42	0.58	0.00	0.09	0.87	0.00
1988	0.18	0.82	0.00	0.04	0.96	0.00
1989	0.39	0.61	0.00	0.56	0.44	0.00
1990	0.11	0.86	0.03	0.12	0.88	0.00
1991	0.26	0.71	0.02	0.39	0.61	0.00
1992	0.09	0.90	0.01	0.17	0.76	0.03
1993	0.34	0.63	0.03	0.18	0.82	0.00
1994	0.34	0.63	0.03	0.14	0.84	0.02
1995	0.35	0.65	0.00	0.06	0.94	0.00
1996				0.38	0.59	0.02
1997				0.14	0.84	0.02

Table 3. Area 9 sockeye escapement, total returns, and age composition by brood year.

Brood Year	Escapement	Adult Returns	Proportion returning at Age 4	Age 5
1948	105273	1153518	0.54	0.46
1949	236880	1704254	0.84	0.16
1950	444662	809280	0.50	0.50
1951	304500	1514881	0.21	0.79
1952	582500	334990	0.39	0.61
1953	440000	1314619	0.29	0.71
1954	103800	1015739	0.36	0.64
1955	132900	523607	0.30	0.70
1956	223500	776379	0.32	0.68
1957	212900	750798	0.62	0.38
1958	296750	1898856	0.61	0.39
1959	380500	1926026	0.31	0.69
1960	138800	469674	0.44	0.56
1961	161850	954824	0.52	0.48
1962	413500	745310	0.35	0.65
1963	932500	3988610	0.26	0.74
1964	573900	811310	0.28	0.72
1965	140150	394110	0.85	0.15
1966	200000	188589	0.26	0.74
1967	435250	667900	0.70	0.30
1968	555000	2943810	0.12	0.88
1969	226000	691677	0.24	0.76
1970	102250	399093	0.32	0.68
1971	215900	710362	0.34	0.66
1972	224000	889448	0.48	0.52
1973	985000	1282148	0.29	0.71
1974	557025	168206	0.21	0.79
1975	480002	445964	0.42	0.58
1976	300000	606957	0.09	0.91
1977	192600	1022459	0.28	0.72
1978	383000	640792	0.16	0.84
1979	297525	223059	0.57	0.43
1980	313000	682493	0.25	0.75
1981	753075	1083199	0.16	0.84
1982	823000	940301	0.27	0.73
1983	636502	1002406	0.21	0.79
1984	214301	291045	0.30	0.70
1985	500430	952561	0.25	0.75
1986	825626	426956	0.23	0.77
1987	521700	896819	0.20	0.80
1988	503000	411050	0.25	0.75
1989	375175	186187	0.45	0.55
1990	586500	124604	0.21	0.79
1991	346500	58629	0.35	0.65
1992	343005	255700	0.10	0.90

Table 4. Area 9 sockeye escapement, juvenile abundance index, and pre-smolt weight by brood year. Juvenile abundance indices without SE were inferred from preserved pre-smolt weight (except as noted).

Brood		Juvenile Abundance		Pre-smolt weight (g)	
Year	Escapement	Index	(SE)	Mean	(SD)
1948	105273				
1949	236880				
1950	444662				
1951	304500				
1952	582500				
1953	440000				
1954	103800				
1955	132900				
1956	223500				
1957	212900				
1958	296750	4.90		1.28	0.66
1959	380500	5.27	1.03	1.18	0.44
1960	138800	4.63	1.12	1.44	0.36
1961	161850	4.55	0.92	1.39	0.40
1962	413500	3.92	1.13	1.46	0.44
1963	932500	5.85	0.72	0.85	0.33
1964	573900	6.14	0.74	1.11	0.46
1965	140150	3.28	1.13	1.82	0.51
1966	200000	5.45	1.00	1.03	0.41
1967	435250	3.12	0.98	1.61	
1968	555000	6.14		0.87	
1969	226000	5.60		1.05	
1970	102250	5.57		1.06	
1971	215900	4.45		1.43	
1972	224000	5.21		1.18	
1973	985000	5.96		0.93	
1974	557025	5.66		1.03	
1975	480002	4.87		1.29	
1976	300000				
1977	192600	5.22[a]			
1978	383000				
1979	297525				
1980	313000				
1981	753075				
1982	823000				
1983	636502				
1984	214301				
1985	500430				
1986	825626				
1987	521700				
1988	503000	4.03		1.57	
1989	375175	1.97		2.25	
1990	586500				
1991	346500	4.84		1.30	
1992	343005				
1993	311000				
1994	91500	4.94	0.41	1.41	
1995	73000	3.93	0.98	1.73	0.41
1996	65000	2.08	1.20	2.65[b]	

[a] inferred from sockeye fry weight (Simpson et al. 1981)

[b] preliminary fresh weight

Table 5. Area 9 sockeye pre-season run size forecast for 1998.

Forecast for reference probabilities [a]				
25%	50%	75%	80%	90%
276,000	165,000	95,000	83,000	63,000

[a] probability that the actual run size will exceed the specified forecast

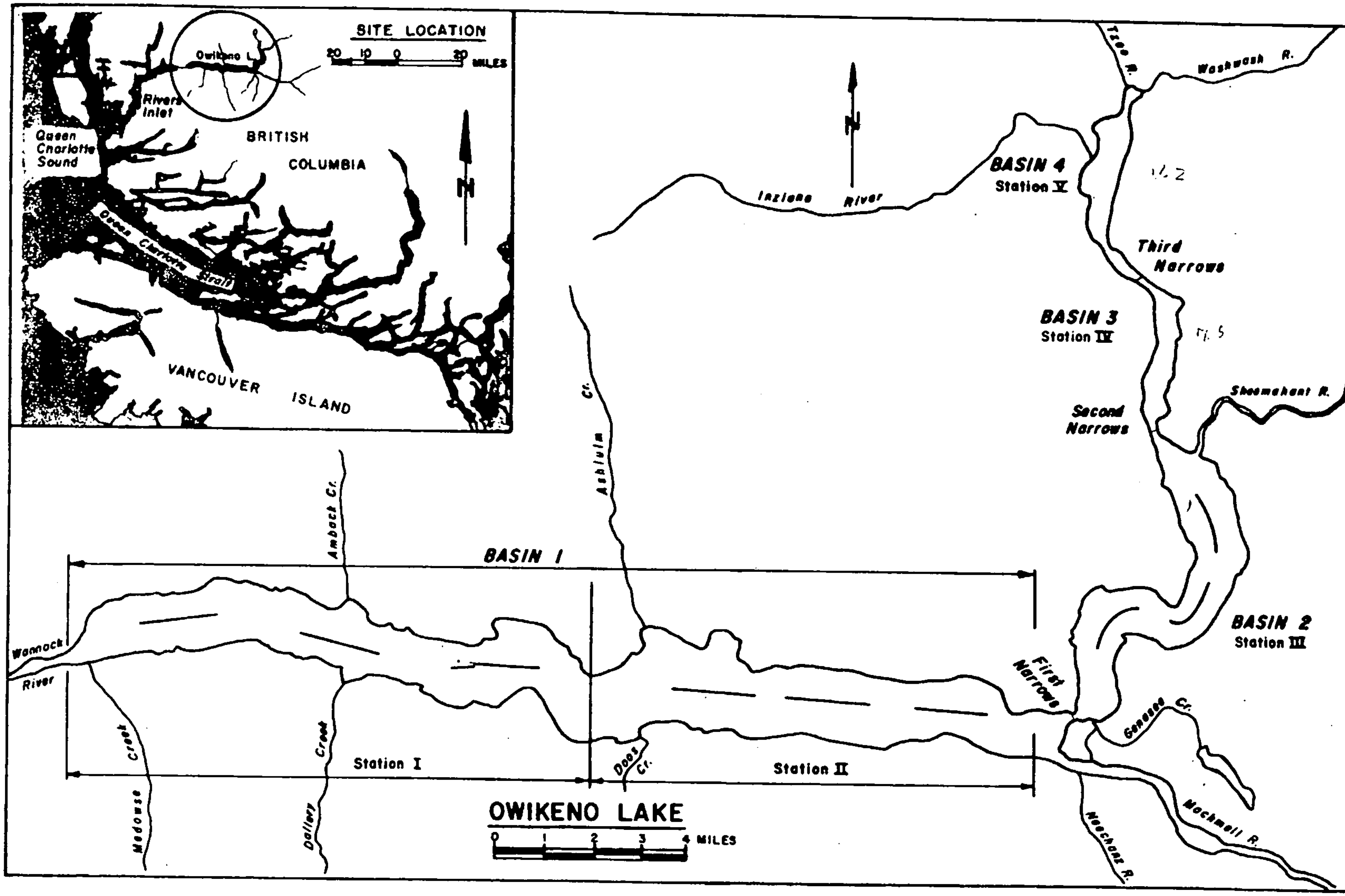


Figure 1. Map showing location of Owikeno Lake, its principal tributaries, and the juvenile survey stations.

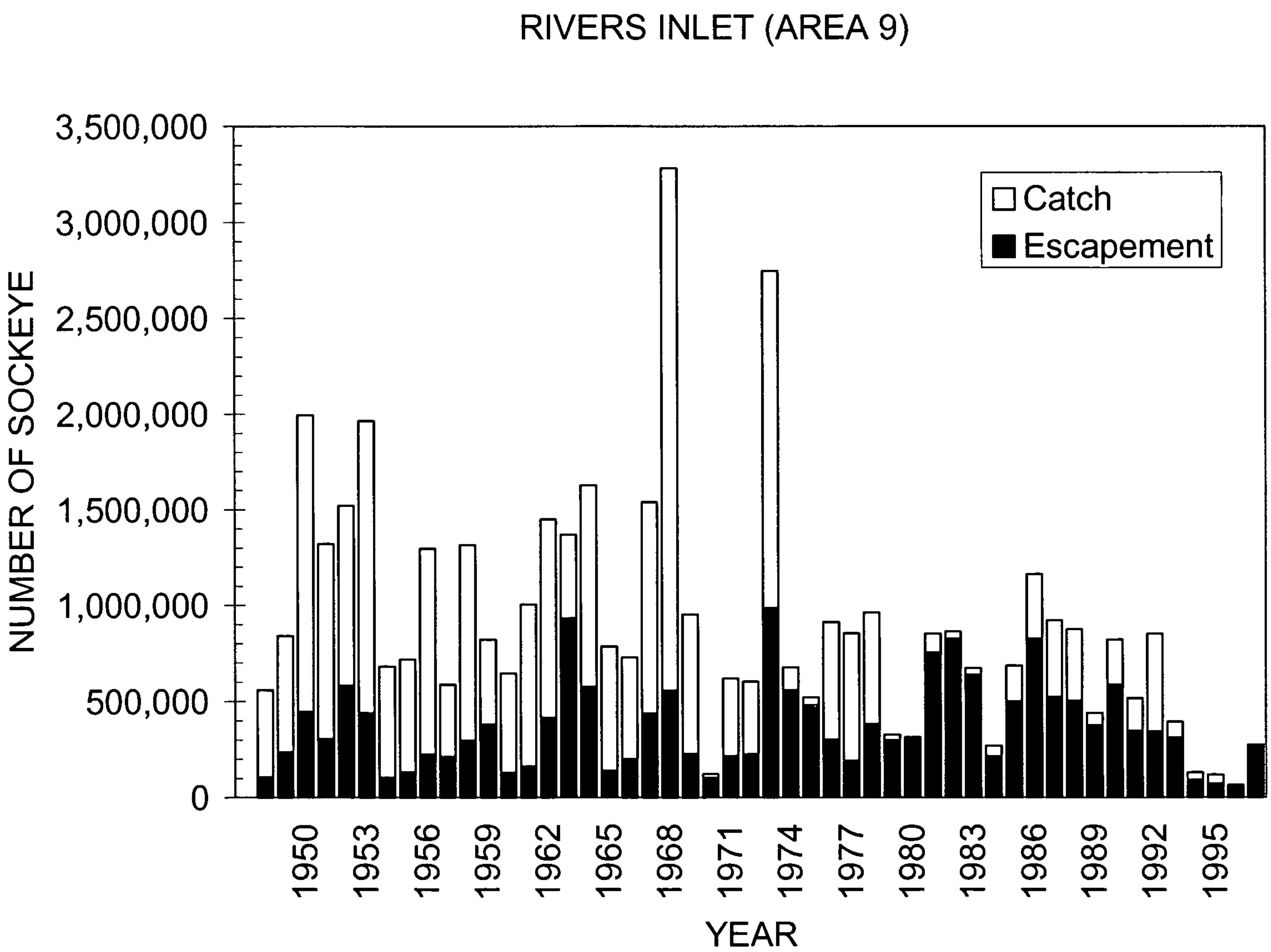


Figure 2. Total stock and escapements for Area 9, 1948-1997.

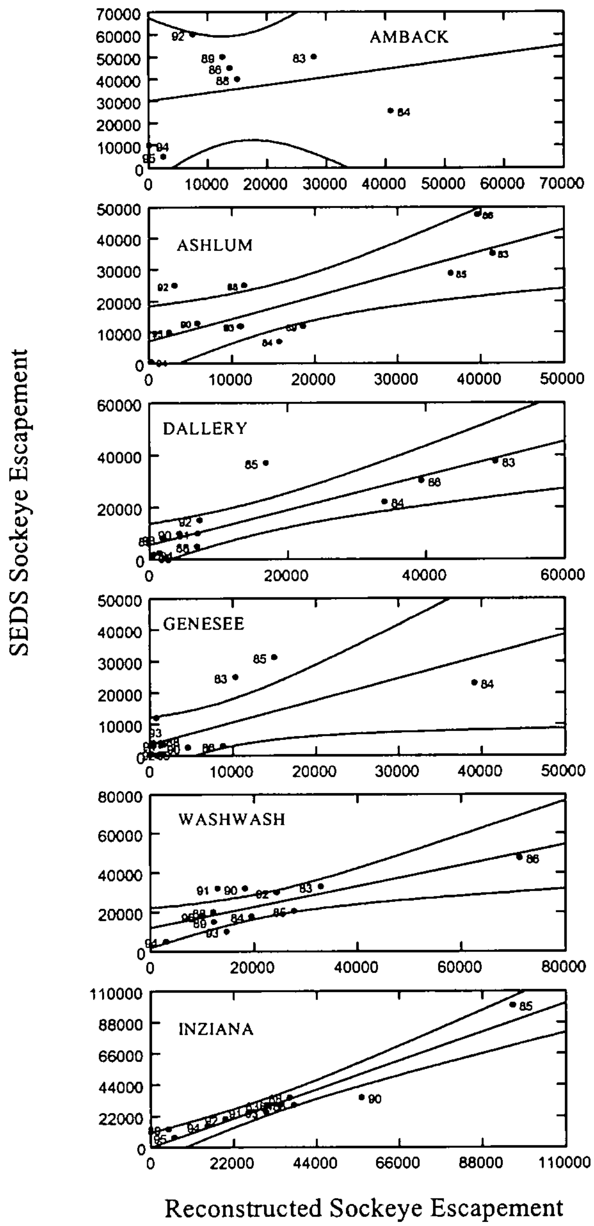


Figure 3. Relationship between SEDS and reconstructed escapement indices to clear water rivers.

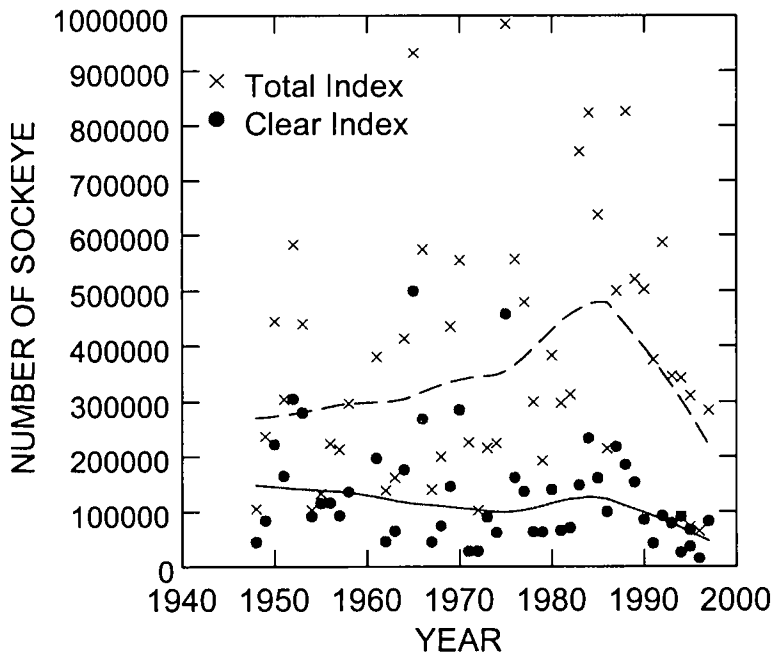


Figure 4. Trend in total and clear stream sockeye escapement indices. Lowess line fitted to data.

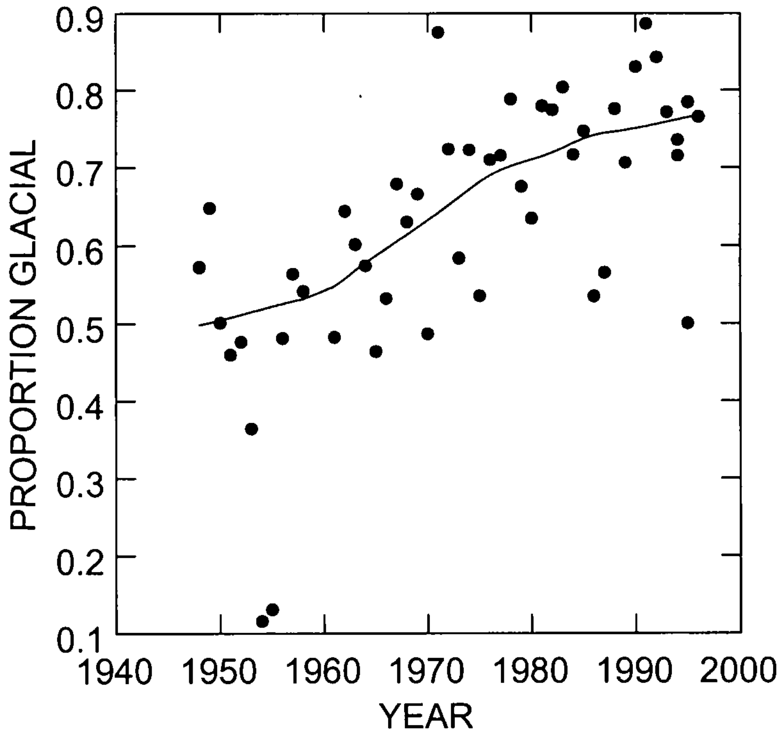


Figure 5. Changes in proportion, over time, of total sockeye escapement estimated to spawn in the glacially turbid rivers of Owikeno Lake. Lowess line fitted to data.

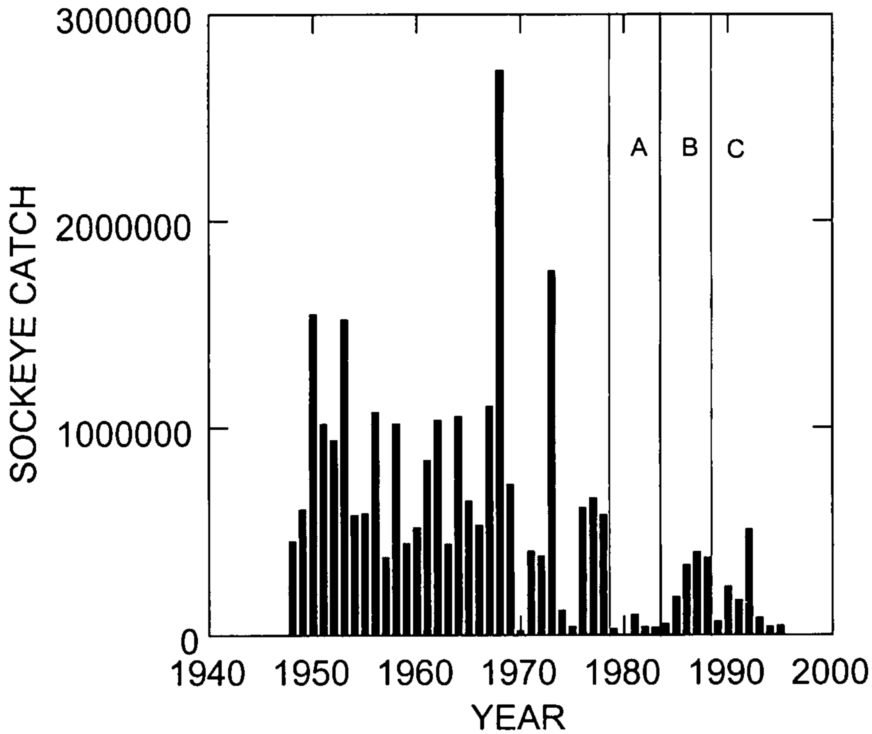


Figure 6. **Trend in Area 9 commercial catch 1948-1997. "A" indicates start of adaptive management plan (Walters et al. 1993), "B" indicates phase two of adaptive management plan, "C" indicates start of variable harvest rate plan (Goruk 1990).**

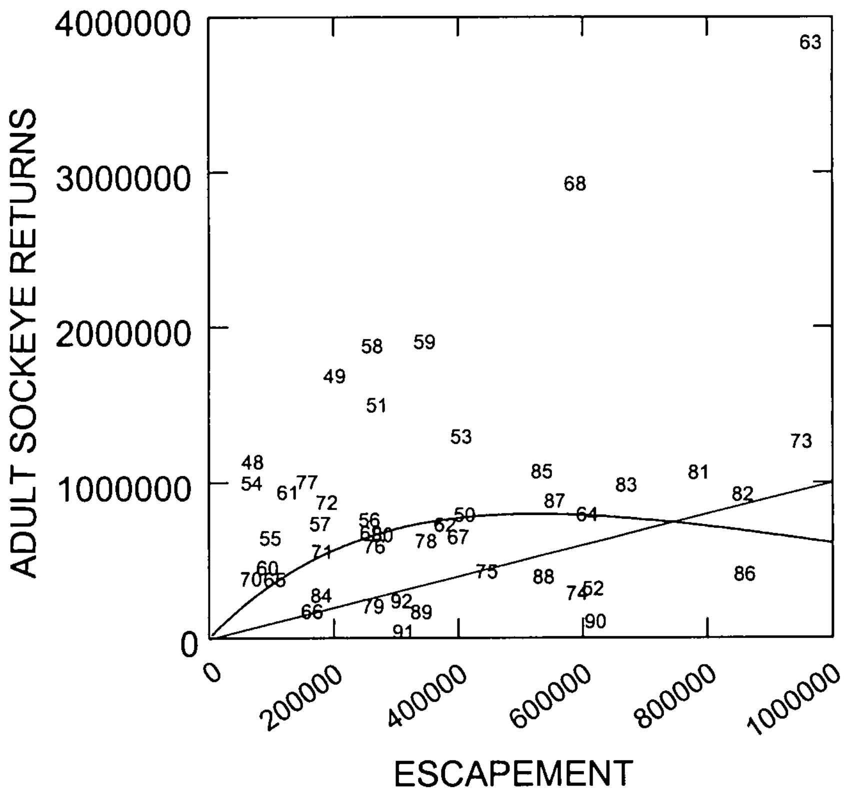


Figure 7. Stock-recruitment pattern for Area 9 sockeye salmon, showing replacement line and Ricker curve fitted to data for 1948-1989.

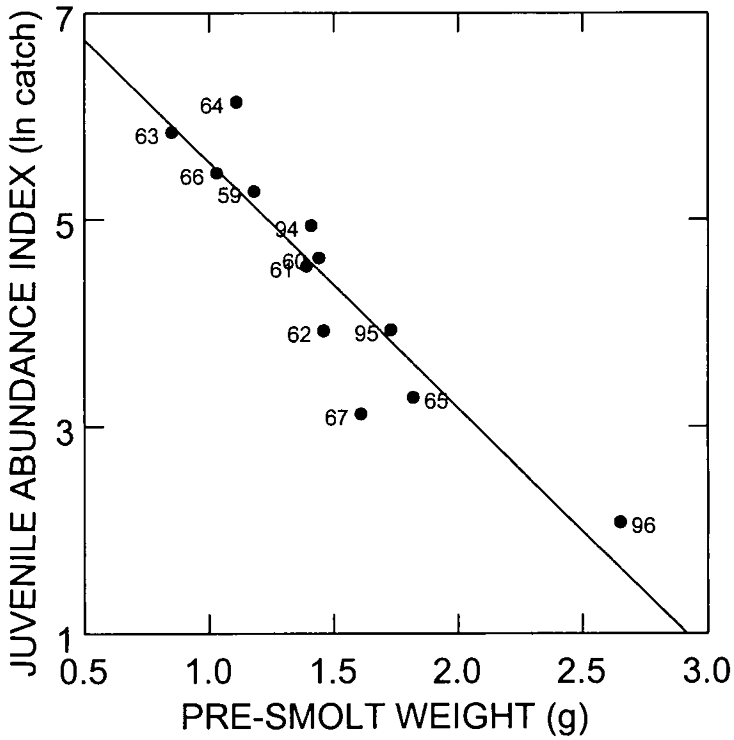


Figure 8. **Juvenile abundance index (mean $\log_e$ catch in summer trawls) versus mean pre-smolt weight (g) for the corresponding brood year (indicated next to data points).**

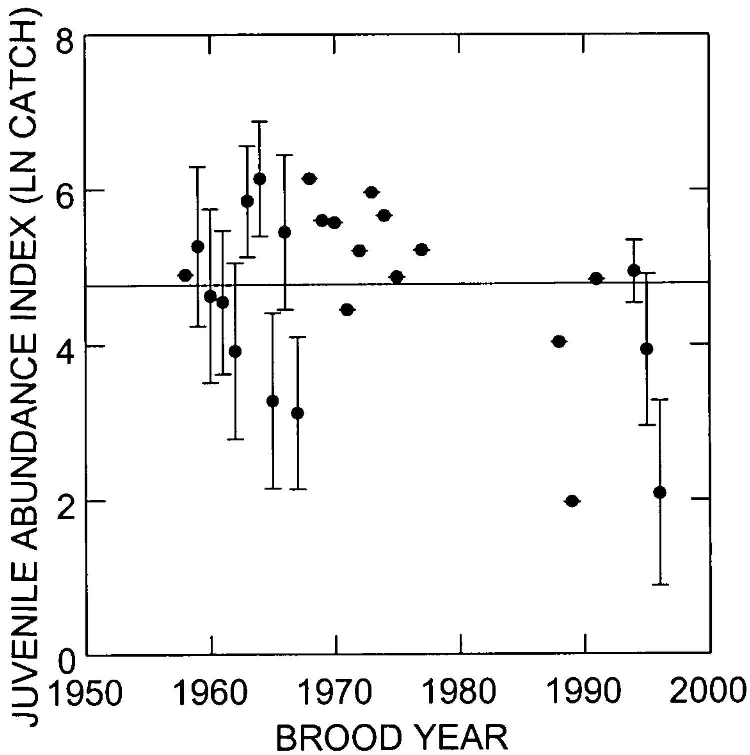
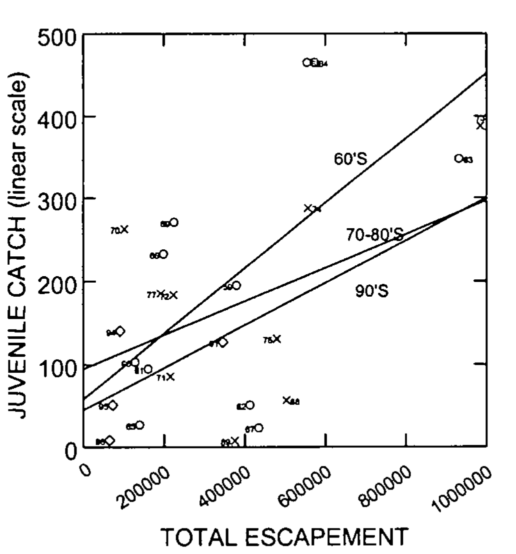


Figure 9. **Variation in juvenile abundance index by year. Average index indicated by horizontal line. Circles with error bars indicate index measured directly, circles only indicate index inferred from pre-smolt size.**



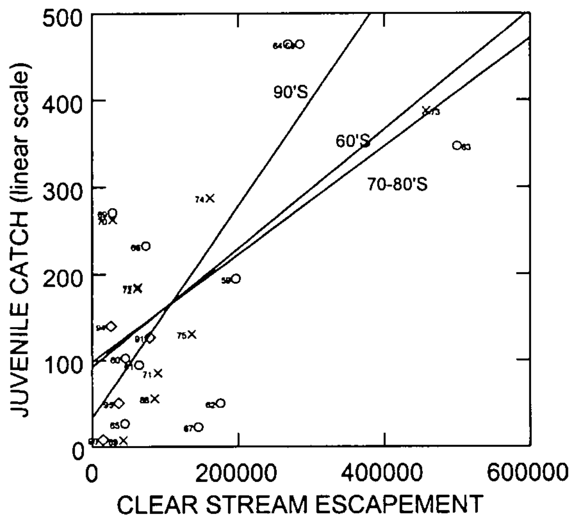


Figure 10. Relationship between sockeye escapement indices and subsequent juvenile recruitment as measured by summer catch (linear scale). Lines indicate relationship by time period by decade(s) as noted on graph. Brood year is indicated for each data point.

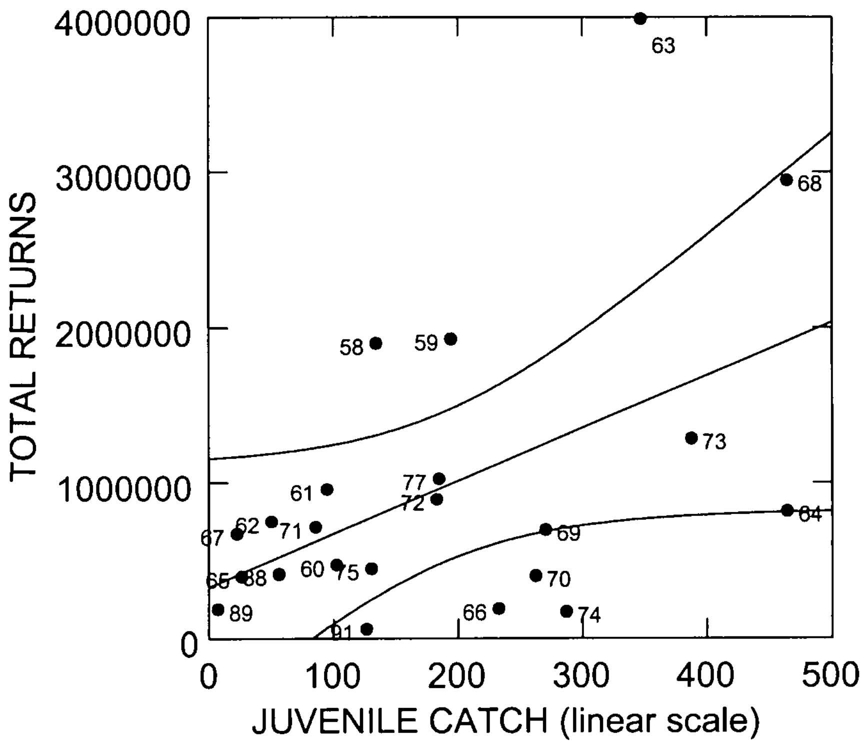


Figure 11. Relationship between juvenile catch and subsequent total returns. Brood year is indicated for each data point; line and 95% confidence interval was fitted by regression.

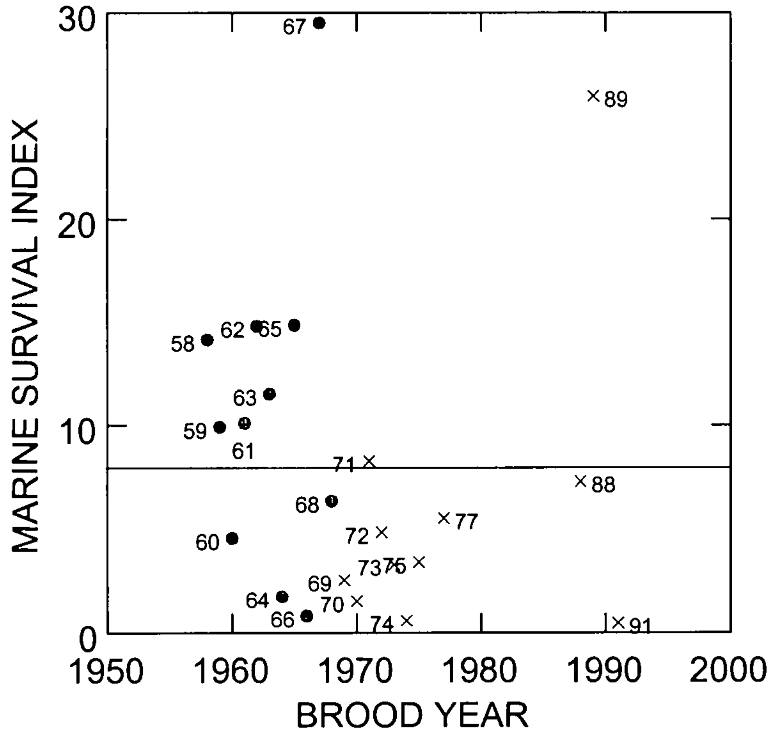


Figure 12. Trend in the approximate marine survival index (see text for caveats). Average survival indicated by horizontal line; brood year indicated for each data point.

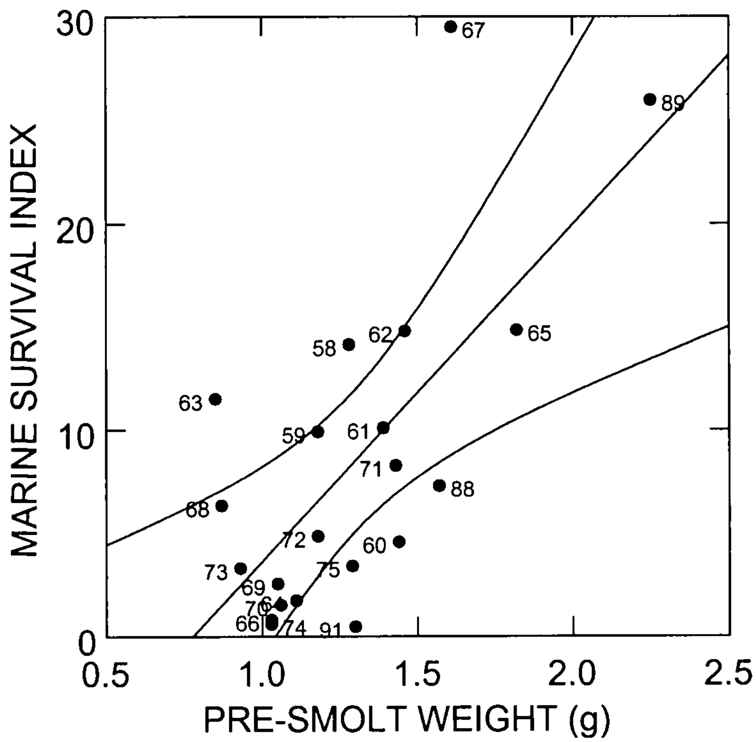
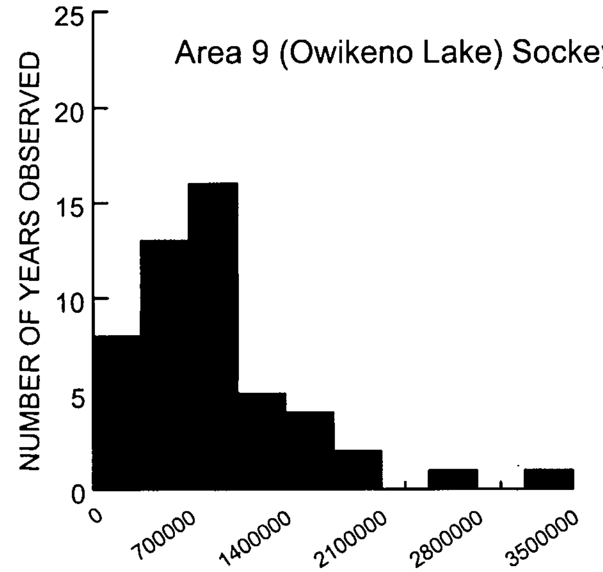
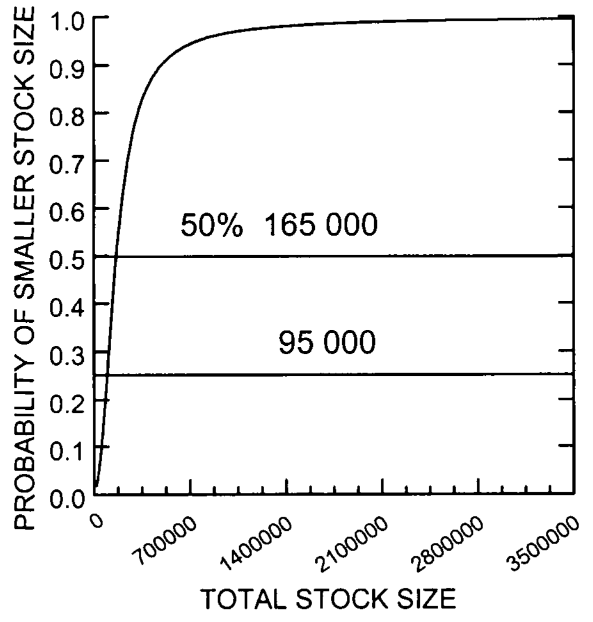


Figure 13. Relationship between pre-smolt weight and an approximate marine survival index (see text for caveats). Brood year indicated for each data point.

A. Historical distribution of stock sizes



B. Forecast of stock size



Figures 14. **The forecasted cumulative probability distribution for total stock size in 1998 for Area 9 sockeye salmon as compared with the historical distribution of total stock size.**

Appendix 1. Area 9 sockeye escapements 1950-1997 with averages by decade (source B. Spilsted DFO, Prince Rupert)

STREAM	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	AVERAGE 1950-59
AREA 9											
ALLARD CREEK											
AMBACK CREEK	76,000	37,500	75,000	35,000	7,500	7,500	15,000	35,000	35,000	75,000	39,850
ASHLULM CREEK	9,000	25,000	40,000	15,000	300	3,500	15,000	15,000	35,000	3,500	16,130
BEAVER CREEK											
CHUCKWALLA RIVER											
CLYAK, YOUNG & NEIL CREEKS											
DALLERY CREEK	67,500	45,000	100,000	75,000	65,000	100,000	75,000	35,000	15,000	100,000	67,750
DRANEY CREEK*											
GENESEE CREEK	10,500	4,500	15,000	15,000	1,000	3,500	3,500	400	3,500	3,500	6,040
INZIANA RIVER	37,500	35,000	50,000	75,000	25,000	3,500	15,000	7,500	7,500	75,000	33,100
JOHNSTON CREEK											
KILBELLA RIVER											
LOCKHART-GORDON CREEK											
MACHMELL RIVER	N/R	N/R	N/R	N/R	N/I	UNK	UNK	UNK	UNK	UNK	
MACNAIR CREEK											
MILTON RIVER											
NEECHANZ RIVER	11,000	15,000	45,000	7,500	2,000	3,500	7,500	7,500	7,500	7,500	11,400
NICKNAQUEET RIVER						N/R					
OATSOALIS CREEK	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	
OWIKENO LAKE SPAWNERS	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	75,000	3,500	39,250
SHEEMAHANT RIVER**	57,500	45,000	75,000	35,000	UNK	UNK	35,000	35,000	UNK	7,500	41,429
TZEO RIVER	15,000	7,500	7,500	UNK	2,500	400	15,000	7,500	7,500	15,000	8,656
WANNOCK RIVER & FLATS	75,000	35,000	75,000	75,000	UNK	3,500	35,000	35,000	75,750	75,000	53,806
WASHWASH CREEK	97,500	55,000	100,000	100,000	500	7,500	7,500	35,000	75,000	15,000	49,300
AREA 9 TOTAL	456,500	304,500	582,500	432,500	103,800	132,900	223,500	212,900	336,750	380,500	316,635

Appendix 1. (cont'd)

STREAM	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	AVERAGE 1960-69
AREA 9											
ALLARD CREEK											
AMBACK CREEK	15,000	15,000	75,000	75,000	75,000	3,500	15,000	3,500	35,000	15,000	32,700
ASHLULM CREEK	400	3,500	3,500	20,000	3,500	75	1,500	750	35,000	750	6,898
BEAVER CREEK		750		3,500	400	75		N/O	N/O	N/O	1,181
CHUCKWALLA RIVER											
CLYAK, YOUNG & NEIL CREEKS											
DALLERY CREEK	35,000	35,000	27,500	125,000	100,000	15,000	15,000	3,500	15,000	7,500	37,850
DRANEY CREEK*											
GENESEE CREEK	3,500	3,500	35,000	55,000	15,000		15,000	15,000	35,000	15,000	21,333
INZIANA RIVER	3,500	7,500	35,000	175,000	75,000	15,000	7,500	1,500	100,000	1,500	42,150
JOHNSTON CREEK											
KILBELLA RIVER											
LOCKHART-GORDON CREEK											
MACHMELL RIVER	UNK	UNK	UNK	UNK	UNK	N/O	UNK	UNK	UNK	UNK	
MACNAIR CREEK											
MILTON RIVER											
NEECHANZ RIVER	7,500	7,500	15,000	35,000	15,000	7,500	15,000	7,500	35,000	3,500	14,850
NICKNAQUEET RIVER											
OATSOALIS CREEK	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	
OWIKENO LAKE SPAWNERS	N/O	200	1,500	1,500	15,000	N/O	3,500	15,000	35,000	3,500	9,400
SHEEMAHANT RIVER**	UNK	35,400	42,500	82,500	110,000	15,000	50,000	135,000	75,000	75,000	68,933
TZEO RIVER	400	3,500	3,500	35,000	15,000	1,500	7,500	3,500	15,000	750	8,565
WANNOCK RIVER & FLATS	UNK	35,000	100,000	200,000	75,000	75,000	35,000	125,000	75,000	100,000	91,111
WASHWASH CREEK	3,500	15,000	75,000	125,000	75,000	7,500	35,000	125,000	100,000	3,500	56,450
AREA 9 TOTAL	68,800	161,850	413,500	932,500	573,900	140,150	200,000	435,250	555,000	226,000	370,695

Appendix 1. (cont'd)

STREAM	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	AVERAGE 1970-79
AREA 9											
ALLARD CREEK											
AMBACK CREEK	15,000	55,000	37,500	62,500	100,000	55,000	65,000	32,500	25,000	45,000	49,250
ASHLULM CREEK	750	1,300	1,500	27,500	9,000	4,500	4,000	3,000	22,500	8,000	8,205
BEAVER CREEK	N/O	N/O	N/O	N/O	25	N/O			UNK	UNK	25
CHUCKWALLA RIVER											
CLYAK, YOUNG & NEIL CREEKS											
DALLERY CREEK	15,000	20,000	9,000	22,500	22,500	45,000	12,000	18,000	15,000	15,000	19,400
DRANEY CREEK*										25	25
GENESEE CREEK	7,500	55,000	27,500	45,000	15,000	14,500	2,500	600	5,000	5,000	17,760
INZIANA RIVER	1,500	3,500	1,500	162,500	40,000	30,000	25,000	6,000	32,500	22,500	32,500
JOHNSTON CREEK						2					2
KILBELLA RIVER											
LOCKHART-GORDON CREEK											
MACHMELL RIVER	N/O	N/O	2,500	12,500	10,000	7,500	7,000	2,000	15,000	35,000	11,438
MACNAIR CREEK											
MILTON RIVER											
NEECHANZ RIVER	15,000	4,000	3,000	50,000	45,000	45,000	25,000	8,000	18,000	42,500	25,550
NICKNAQUEET RIVER							N/I				
OATSOALIS CREEK	N/R	N/R	N/R	N/R	N/R	N/R					
OWIKENO LAKE SPAWNERS	N/R	N/R	5,000	10,000	8,000	102,500	20,000	10,000	5,000	7,500	21,000
SHEEMAHANT RIVER**	7,500	6,000	30,000	250,000	137,500	35,000	20,000	27,500	150,000	65,000	72,850
TZEO RIVER	1,500	1,100	1,500	55,000	32,500	11,000	12,000	4,000	10,000	2,000	13,060
WANNOCK RIVER & FLATS	35,000	60,000	80,000	87,500	62,500	87,500	87,500	45,000	20,000	35,000	60,000
WASHWASH CREEK	3,500	10,000	22,500	200,000	75,000	42,500	20,000	35,000	65,000	15,000	48,850
AREA 9 TOTAL	102,250	215,900	221,500	985,000	557,025	480,002	300,000	191,600	383,000	297,525	373,380

Appendix 1. (cont'd)

STREAM	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	AVERAGE 1980-89
AREA 9											
ALLARD CREEK										N/O	
AMBACK CREEK	75,000	180,000	90,000	50,000	25,500	52,000	45,000	17,000	40,000	50,000	62,450
ASHLULM CREEK	5,000	25,000	15,000	35,000	7,000	28,700	47,500	32,000	25,000	12,000	23,220
BEAVER CREEK		75		1	N/O	185	125	N/O		N/O	97
CHUCKWALLA RIVER						6				N/O	6
CLYAK YOUNG NEIL						2				N/O	2
DALLERY CREEK	25,000	40,000	60,000	37,500	22,000	37,000	30,000	21,500	5,000	2,500	28,050
DRANEY CREEK						1	1			N/O	1
GENESEE CREEK	4,500	15,000	8,000	25,000	23,000	31,300	30,000	200	500	100	13,760
INZIANA RIVER	22,500	18,000	40,000	33,000	17,700	20,425	47,500	44,800	20,000	15,000	27,893
JOHNSTON CREEK						5				N/O	5
KILBELLA RIVER										N/O	
LOCKHART-GORDON CR.				1	1	4				N/O	2
MACHMELL RIVER	17,500	20,000	80,000	37,000	5,000	10,000	5,000	1,500	30,000	5,000	21,100
MACNAIR CREEK										N/O	
MILTON RIVER						2				N/O	2
NEECHANZ RIVER	32,500	40,000	50,000	50,000	11,000	35,800	53,000	37,000	53,000	18,000	38,030
NICKNAQUEET RIVER										N/O	
OATSOALIS CREEK										N/O	
OWIKENO LAKE SPWNS	25,000	10,000	15,000	10,000	1,100	20,000	2,500	2,500	5,000	6,075	9,718
SHEEMAHANT RIVER	61,000	200,000	150,000	125,000	25,000	135,000	325,000	100,000	200,000	125,000	144,600
TZEO RIVER	4,000	5,000	55,000	4,000	2,000	10,000	10,000	10,500	9,500	3,500	11,350
WANNOCK R & FL	27,500	150,000	150,000	200,000	45,000	20,000	200,000	200,000	80,000	125,000	119,750
WASHWASH CREEK	13,500	50,000	110,000	30,000	30,000	100,000	30,000	54,700	35,000	13,000	46,620
AREA 9 TOTAL	313,000	753,075	823,000	636,502	214,301	500,430	825,626	521,700	503,000	375,175	546,581

Appendix 1. (cont'd)

STREAM	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	AVERAGE 1990-99
AREA 9											
ALLARD CREEK											
AMBACK CREEK	30,000	17,000	60,000	30,000	10,000	5,000	4,350	15,000			21,419
ASHLULM CREEK	13,000	12,000	25,000	12,000	500	10,000	650	8,500			10,206
BEAVER CREEK	10	N/O	5	N/O	N/O	N/I		UNK			8
CHUCKWALLA RIVER											
CLYAK, YOUNG & NEIL CREEKS											
DALLERY CREEK	10,000	10,000	15,000	8,000	2,000	1,000	250	4,400			6,331
DRANEY CREEK											
GENESEE CREEK	2,500	0	500	12,000	3,500	500	250	700			2,494
INZIANA RIVER	32,000	32,000	30,000	10,000	5,000	18,000	6,580	42,000			21,948
JOHNSTON CREEK	N/I										
KILBELLA RIVER											
LOCKHART-GORDON CREEK											
MACHMELL RIVER	20,000	0	5,000	5,000	5,000	2,500	3,000	N/I			5,786
MACNAIR CREEK											
MILTON RIVER											
NEECHANZ RIVER	25,000	20,000	30,000	20,000	8,000	10,000	10,645	20,000			17,956
NICKNAQUEET RIVER											
OATSOALIS CREEK				N/O							
OWIKENO LAKE SPAWNERS	5,000	3,000	2,500	4,000	2,000	500	100	UNK			2,443
SHEEMAHANT RIVER	300,000	100,000	50,000	80,000	20,000	10,000	16,000	83,000			82,375
TZEO RIVER	14,000	2,500	5,000	5,000	500	500	700	UNK			4,029
WANNOCK RIVER & FLATS	100,000	125,000	100,000	100,000	20,000	8,000	15,000	75,000			67,875
WASHWASH CREEK	35,000	25,000	20,000	25,000	15,000	7,000	7,475	27,500			20,247
AREA 9 TOTAL	586,510	346,500	343,005	311,000	91,500	73,000	65,000	276,100			261,577