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Babine Lake sockeye salmon: Stock status and forecasts for 1998

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Abstract

The Babine-Nilkitkwa lake system is the largest natural lake in British Columbia (500 km^2). It also supports the largest sockeye salmon population in Canada, a total adult stock that has averaged over 4 million annually since 1990. This working paper provides a comprehensive assessment of sockeye production from the Babine-Nilkitkwa system in that it brings together, for the first time in many years, recently compiled information on trends in spawning escapements by run timing group, fry recruitment, smolt production, adult returns, harvest rate, and surplus production from Babine Lake Development Project (BLDP) facilities. Exploitation rate on Skeena River sockeye has increased over the last decade, averaging 68% since 1990, and exceeding 70% in 1996 and 1997. Recent escapements to enhanced sites in Babine Lake have exceeded spawning requirements such that over a third of the Babine fence count has been surplus produced by the BLDP. Enhanced fry now account for about 90% of fry recruitment to the main basin. As expected, increased fry and smolt production has increased adult returns although the relationship between adult returns and smolt abundance is non-linear. Available data indicate that further increases in adult returns could be expected by increasing smolt production, and that fry recruitment is still below levels required to yield maximum smolt biomass. However, prespawning mortality at the BLDP sites in 1994 and 1995 caused by parasitic infections has significantly reduced fry recruitment and smolt production. Near record low smolt production and jack returns from the 1993 brood, together with near record low smolt production and age 4 returns from the 1994 brood, provide clear signals that adult returns in 1998 and 1999 will be much lower than in recent years. The smolt forecast model indicates a 75% chance that adult returns to the Skeena River in 1998 will exceed 820, 000 sockeye, and a 50% chance that returns will exceed 1,420,000 sockeye.

Résumé

Le bassin Babine-Nilkitkwa est le plus grand lac naturel de la Colombie-Britannique (500 km^2). Il abrite la plus importante population de saumon rouge du Canada avec un stock d'adultes dont l'effectif annuel moyen est supérieur à 4 millions de poissons depuis 1990. Le présent document de travail constitue une évaluation détaillée de la production de saumon rouge du réseau Babine-Nilkitkwa et regroupe, pour la première fois depuis plusieurs années, des renseignements récemment compilés sur les tendances des échappées de géniteurs en fonction du moment des remontées, du recrutement d'alevins, de la production de saumoneaux, des remontées d'adultes, du taux de récolte et de la production excédentaire des installations du projet de mise en valeur du lac Babine. Le taux d'exploitation du saumon rouge de la rivière Skeena a augmenté au cours de la dernière décennie pour atteindre en moyenne 68 % depuis 1990 et dépasser 70 % en 1996 et 1997. Les échappées récentes vers les sites mis en valeur du lac Babine ont été supérieures aux besoins du frai de sorte que plus du tiers des poissons dénombrés à la barrière de comptage du lac étaient des excédents produits par les installations du projet. Des alevins des travaux de mise en valeur représentent maintenant 90 % environ du recrutement en alevins du bassin principal. Comme prévu, l'augmentation de la production d'alevins et de saumoneaux a donné lieu à une augmentation des remontées d'adultes mais la relation entre les remontées d'adultes et l'abondance des saumoneaux n'est pas linéaire. Les données montrent que l'on peut escompter d'autres augmentations des remontées d'adultes d'une augmentation de la production de saumoneaux et que le recrutement d'alevins est encore inférieur au niveau donnant lieu à l'atteinte de la biomasse de saumoneaux maximale. Mais une mortalité d'avant le frai aux sites du projet en 1994 et 1995, due au parasitisme, a réduit de façon appréciable le recrutement en alevins et la production de saumoneaux. Les valeurs faibles presque records de la production de saumoneaux et du retour de saumons mâles des géniteurs de 1993 de même que de la production de saumoneaux et des retours de poissons d'âge 4 (géniteurs de 1994) sont des indices clairs que les remontées d'adultes de 1998 et 1999 seront de beaucoup inférieures à celles des années antérieures. Le modèle de prévision des saumoneaux fait état, pour 1998, d'une probabilité de 75 % d'une remontée de saumons rouges supérieure à 820 000 poissons et d'une probabilité de 50 % d'une remontée supérieure à 1 420 000 saumons dans la Skeena.

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1.0 INTRODUCTION

The Babine-Nilkitkwa lake system is the largest natural lake in British Columbia with a surface area of 500 km^2 (Figure 1). It also supports the largest sockeye salmon population in Canada. The total stock is estimated to have averaged over 4 million adults annually since 1990.

The Fisheries Research Board of Canada began investigations of sockeye salmon in the Babine system in the 1940s and extensive data have been gathered to date (e.g., McDonald and Hume 1984 and references therein). Three distinct runs (early-, mid-, and late-timing) have been identified by tagging studies (Smith and Jordan 1973). We consider these runs to be subpopulations, rather than distinct populations, because they are connected by relatively high levels of gene flow as estimated from surveys of genetic variation in allozymes (Varnavskaya et al. 1994), mitochondrial DNA and microsatellite DNA (C.C. Wood, J.W. Bickham, and J.C. Patton, unpubl. data). Early investigations also revealed that sockeye salmon production from Babine Lake was limited by the availability of suitable spawning habitat (Johnson 1958). These conclusions led directly to the Babine Lake Development Project in the 1960s, an ambitious enhancement project involving the construction of flow control structures and large spawning channels in Pinkut Creek and Fulton River (West and Mason 1987).

Sockeye salmon production from Babine Lake increased significantly as a result of the Babine Lake Development Project (BLDP). At least 90% of Skeena sockeye salmon now originate from the Babine-Nilkitkwa system (West and Mason 1987; McKinnell and Rutherford 1994) compared with less than 80% prior to 1970 (Brett 1952). Unfortunately, the resulting mixture of enhanced and wild stocks in commercial fishing areas has created conflict among user groups and an awkward situation for managers who must choose between maximizing the catch of enhanced Babine sockeye salmon with concomitant loss of production from other wild, less productive stocks, or ensuring the conservation and continued production from non-enhanced sockeye salmon stocks and other salmonid species by foregoing harvest opportunities on enhanced sockeye salmon in the mixed-stock fishing areas. Sprout and Kadowaki (1987) provide an historical account of the management of Skeena River sockeye salmon fisheries.

Stock assessment of Babine sockeye salmon has been complicated by several factors: First, Babine sockeye salmon are harvested in numerous mixed-stock fisheries in Southeast Alaska and northern British Columbia, so that the total catch cannot be known with certainty. However, recently revised, best estimates of total Skeena River sockeye salmon returns based on a sophisticated run reconstruction analysis by Gazey and English (1996) are now available. Second, overall escapements to Babine Lake are known accurately from fence counts in the Lower Babine River since the 1940s, but these data require careful interpretation because of surplus production returning to the enhanced sites. In the past, puzzling discrepancies between the overall fence count and summed estimates of escapement to individual spawning sites were attributed to an uncensused "lake spawning" population. However, Wood et al. (1995) demonstrated that opportunities for lake spawning are extremely limited within Babine Lake; they also suggested a parsimonious approach for estimating the uncensused (surplus) production returning to the enhancement facilities after correcting visual escapement estimates for the early-, mid-, and late-timing runs for obvious bias.

Finally, annual smolt production from Babine Lake has been estimated since the 1950s, but interpretation of these data has been complicated by the existence of both early- and late-migrant smolts and by enhancement. Macdonald et al. (1987) analyzed smolt production data for brood years 1959-1983, and Wood et al. (1995) compiled additional data for brood years 1984-1993.

This working paper provides a comprehensive assessment of sockeye salmon production from the Babine-Nilkitkwa lake system in that it brings together, for the first time in many years, recently compiled information on trends in spawning escapements, fry recruitment, smolt production, adult returns, harvest rate, and surplus production from BLDP facilities. We use these data to assess whether the total production of smolts and adults from Babine Lake is close to the maximum level that can be expected, and whether current management targets and policy have had any undesirable impacts on wild sockeye salmon production within Babine Lake. We also derive forecasts expressed as cumulative probability distributions for adult sockeye salmon returns to the Skeena River in 1998. Prespawning mortality at the BLDP sites in 1994 and 1995 caused by parasitic infections, and abnormally low fry-to-smolt survival, have significantly reduced fry recruitment and smolt production for brood years 1993-1995. Consequently, we are advising that adult returns may decline dramatically until the year 2001.

2.0 METHODS

2.1 DATA SOURCES

2.1.1 Spawning Escapements

Since 1949, all sockeye salmon returning to Babine Lake have been counted at the Babine River fence situated 1 km below the outlet of Nilkitkwa Lake. Escapement data in Appendix 1 are from the Area 4 spreadsheet tables maintained by DFO staff in Prince Rupert (file: 4esc.xls). Entries are generally consistent with data in the regional Salmon Escapement Database System but they allow for finer spatial resolution of spawning sites. Visual estimates of sockeye salmon abundance have been documented for most early-timing and mid-timing lake tributary spawning sites since 1950. Since 1966, spawning escapements to Fulton River and Pinkut Creek and associated spawning channels have been counted through fences maintained as part of the Babine Lake Development Project. Once target escapements for these rivers and spawning channels have been met, the fences are closed and escapements below the fences are estimated by systematic visual surveys (Appendix 1) but an unknown proportion also remains uncounted in Babine Lake. Late-timing runs to the Upper and Lower Babine rivers were enumerated by mark-recapture techniques from 1976 to 1992 and by visual surveys in other years.

2.1.2 Escapements By Run Timing Group

In most years, the sum of escapements to individual spawning sites is significantly less than the Babine fence count, and fish unaccounted for are referred to here as "uncounted" (Appendix 1). Previously, uncounted fish were recorded as "lake spawners" although there was no evidence that spawning occurred to any significant extent within Babine Lake itself. In fact, recent studies indicate that lake spawning accounts for a negligible proportion of the uncounted escapement (see Wood et al. 1995).

The visual estimates of "surplus" enhanced fish shut below fences in the Fulton and Pinkut systems account for most but not all of the uncounted fish in recent years. However uncounted fish also existed prior to the earliest measurable return of enhanced fish in 1970, which suggests that spawning escapements to the various tributaries were generally underestimated by visual survey and/or mark-recapture techniques. Wood et al. (1995) used a simple but parsimonious algorithm to correct estimates of escapement to unenhanced streams, grouped according to their run timing as early-, mid-, or late-timing streams, and considered that any remaining uncounted fish were surplus enhanced fish. We followed this approach to update the adjusted escapement data series in Wood et al. (1995).

2.1.3 Fry Recruitment

Following McDonald and Hume (1984) and Wood et al. (1995), we assumed that an average of 233 fry were produced by each sockeye salmon spawning in natural streams. In this context, natural streams include all spawning sites except those in Fulton River and Pinkut Creek after the initiation of the Babine Lake Development Project in 1966.

From 1966 to 1993, Habitat and Enhancement Branch staff have enumerated sockeye salmon fry originating from spawning sites above the adult counting fences in Fulton River and Pinkut Creek using fixed-position, converging throat traps or fan traps (West and Mason 1987). The total migration is estimated by weighting catches in index traps by time and cross-sectional area fished (details in Ginetz 1977). Egg-to-fry survival was calculated by dividing the estimate of fry production by an estimate of potential egg deposition based on adult counts, sex ratio, fecundity and egg retention data (D. Bailey unpubl. data).

Fry production from spawning sites below the adult counting fences was estimated very approximately from visual estimates of the number of spawners below the fence (Appendix 2) and sex ratio, fecundity and egg retention data, and egg-to-fry survival rates observed for fish spawning upstream of the fences. However, spawning habitat below the fences was considered sufficient for successful spawning by a maximum of only 50,000 spawners in Fulton River and 5,000 spawners in Pinkut Creek; additional spawners were assumed to produce no additional fry because of overcrowding and superimposition of redds, and thus were considered surplus (as in Wood et al. 1995).

2.1.4 Smolt Production

Smolt migrations out of Babine Lake have been sampled and enumerated by mark-recapture near the outlet of Nilkitkwa Lake annually since 1951 except for 1989 when the program was not funded. We recomputed mark-recapture estimates of abundance data (with estimates of variance) using a new (1996) implementation of the parsimonious model of Macdonald and Smith (1980) provided by P.D.M. Macdonald (Department of Mathematics and Statistics, McMaster

University, Hamilton, Ont., L8S 4K1). The smolt estimate for the 1984 brood year was excluded from our analyses because the parsimonious model did not fit the mark-recapture data adequately, suggesting that assumptions of the analysis were inappropriate; smolt estimates based on the conventional "constant sampling fraction" model which makes different (but also questionable) assumptions are presented in Table 2, but not used. In addition, the smolt estimate for the 1995 brood year should be regarded as a minimum estimate because flooding conditions in 1997 required that the mark-recapture program be aborted before the normal termination date, although after the normal date of peak migration.

Smolt size data for brood years 1959 to 1983 were taken from Macdonald et al. (1987). Smolt data for brood years 1949-1959 are from the unpublished records of H.D. Smith (available from C. Wood); abundance estimates for these years are considered less reliable than in later years because tagging procedures were still being developed and estimates were based on the constant sampling fraction model (see Macdonald and Smith 1980).

Tagging studies have confirmed that fry originating from the Upper and Lower Babine rivers and a few small tributaries to Nilkitkwa Lake and the North Arm of Babine Lake rear primarily within Nilkitkwa Lake and the North Arm; these juveniles emigrate as "early-migrant" smolts (Macdonald and Smith, unpublished MS, Department of Mathematics and Statistics, McMaster University, Hamilton, Ont., L8S 4K1). In contrast, fry emerging from other tributaries to the main basin of Babine Lake rear primarily within the main basin and emigrate one to two weeks later as "late-migrant" smolts. The parsimonious model estimates a transition day that best separates the early and late smolt migrations based on observed differences in the time lag between release and recapture. In years when distinct modes in abundance are evident for the early and late migrants, the transition day can also be obtained by inspection (see Figure 2). However, estimates from the parsimonious model almost invariably concur with those based on trends in daily abundance, and are considered to be more objective and precise. Estimates of transition day only affect conclusions about the relative magnitude of the early- and late-migrant subpopulations. Estimates of the early-migrant subpopulation are considered to be less reliable than for the late-migrant subpopulation because in some years it was obvious that an unknown, but significant proportion of the early migrants had migrated before the mark-recapture program began.

Following Wood et al. (1995), we assumed that early-migrant smolts originated only from late-timing adults spawning in the Upper and Lower Babine rivers, thus ignoring the minor contributions of smolts from early-timing adults spawning in tributaries to Nilkitkwa Lake and the North Arm. Similarly, we assumed that late-migrant smolts originated only from the early-timing and mid-timing adults whose fry rear in the main basin of Babine Lake (including Morrison Arm).

2.1.5 Adult Returns

Skeena River sockeye salmon are caught in a complex array of mixed-stock fisheries in southern Southeast Alaska and throughout northern British Columbia. Catch data by major stock have recently been revised for 1970-1996 based on run reconstructions by Gazey and English (1996) for 1982-1992 and stock composition estimates for 1982-1983 from a joint Canada-U.S. tagging study. Despite the many assumptions involved, the revised estimates of total returns to the

Skeena River are probably satisfactory for most assessment purposes, given that Skeena sockeye salmon are predominant in the mixed-stock catches. In this report, we have used the revised total stock (by calendar year) and total return (by brood year) data reported by Wood et al. (1997) for years 1970-1996. We extended the time series of returns by brood year back to 1950 by including estimates of returns from brood years 1950-1969 reported by Macdonald et al. (1987). The estimates prior to 1970 do not include Alaskan catches, but these were relatively small.

To estimate adult returns to Babine Lake, we have assumed that 90% of all age 1.2 and 1.3 Skeena sockeye salmon originated from Babine Lake. This approximation is based on data in McKinnell and Rutherford (1994) and probably overestimates Babine returns prior to 1970; it may also underestimate Babine returns in some years after 1970. Age 1.1 or "jack" sockeye salmon are not caught to any significant extent in fisheries until after they are enumerated at the Babine fence. Thus, we used the Babine fence count of jack sockeye salmon as the best estimate of age 1.1 returns to Babine Lake (see Appendices 3 and 4). Elsewhere the Babine fence count of jacks is reported as the (minimum) estimate of age 1.1 returns to the entire Skeena system (e.g., Wood et al. 1997).

2.2 FORECASTING MODELS

Three models were used to forecast Skeena sockeye salmon returns in 1998:
(1) the 5-yr mean model used in previous years (Wood et al. 1997)

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

where N_i is the total stock size in year i;

(2) a non-linear stock-recruitment relationship based on observed smolt production

$$\ln(R_t) = a + b\ln(J_t) + \varepsilon$$

where R_t is the adult return and J_t is the smolt abundance for brood year t. Parameter estimates based on the entire data series are a= 5.615 and b=0.502 for R_t and J_t in millions of fish..

(3) and a non-linear sibling age-class model (Bocking and Peterman 1988) based on observed returns of a younger age class from the same brood year

$$\ln(R_{t,k+1}) = a + b\ln(R_{t,k}) + \varepsilon$$

where $R_{t,k}$ is the adult return at age k in brood year t. Parameter estimates based on the entire data series are a= 5.617 and b=0.691 for predicting $R_{1994,4}$ and a= 5.785 and b=0.599 for predicting $R_{1993,5}$ (in millions of fish).

Probability distributions for the forecasts were computed by assuming that residuals in the log-transformed domain are normally distributed. Forecasted run sizes corresponding to risk averse probability reference points of 75% and 50% were then transformed back to the arithmetic scale. The modal (most likely) run size in the log-transformed domain corresponds to the median (50%) value in the original (arithmetic) scale. Cumulative probability distribution plots were generated from the student's *t* distribution function (tcf) in SYSTAT using estimated means and standard deviations in the log-transformed domain. For the 5-yr mean model, the standard deviation was computed from the series used to compute the forecasts (i.e., the most recent five years). For the regression models, means and standard deviations for the forecasted log-transformed stock sizes were computed as:

(4) $$E[\ln(R_t)] = a + b\,X_{1998}$$

(5) $$SD[\ln(R_t)] = s_{y.x}\{1 + 1/n + (X_{1997} - X_{mean})^2 / \Sigma(X_i - X_{mean})^2\}^{0.5}$$

where *a* and *b* are the regression parameters, $s_{y.x}$ is the standard error of the estimate, X_{1998} is the independent variable (number of smolts or returns for a sibling age class for the brood returning in 1998), X_{mean} is the average value of the independent variable, and n is the number of data points in the regression (Draper and Smith, 1966).

For models (2) and (3), we computed total stock size for 1998 by combining forecasts of returns from the 1993 and 1994 brood years. For the smolt model, we assumed the long-term average proportion of returns at age 4 (q_4= 0.45) within each forecasted brood year, so that $N_{1998} = q_4R_{1994} + (1-q_4)R_{1993}$. As a simple but conservative approximation, ignoring bias from transformation, we assumed

(4) $$E[\ln(N_{1998})] \approx \ln\{q_4\exp(E[R_{1994}]) + (1-q_4)\exp(E[R_{1993}])\}$$

(5) $$SD[\ln(N_{1998})] \approx \max\{SD[\ln(R_{1994}), SD[\ln(R_{1993})]\}$$

The latter assumption seems reasonable because the forecasted contributions from each brood year are very similar.

For the sibling model, $N_{1998} = R_{1994,4} + R_{1993,5}$ and we assumed

(6) $$E[\ln(N_{1998})] \approx \ln\{\exp(E[R_{1994,4}]) + \exp(E[R_{1993,5}])\}$$

(7) $$SD[\ln(N_{1998})] \approx SD[\ln(R_{1993})]$$

because the forecasted contributions from the 1993 brood year accounted for over 90% of N_{1998}.

3.0 RESULTS AND DISCUSSION

3.1 TRENDS IN ABUNDANCE

3.1.1 Spawning Escapements

Spawning escapements to Fulton River and Pinkut Creek increased dramatically following the first significant return of enhanced sockeye salmon in 1970 (Figure 3). Escapements exceeded requirements for the first time in 1975 in Fulton River and in 1981 in Pinkut Creek (Appendix 1). These fish are considered surplus under the assumption that they cannot contribute to fry production given the overcrowded conditions in the streams below the fences and the limited occurrence and poor reproductive success of surplus fish spawning in Babine Lake or neighbouring streams (see Wood et al. 1995). Since 1981, surpluses have returned to Pinkut Creek in every year except 1983, and to Fulton River in 10 of 16 years. Best estimates of total enhanced surplus over the same period have averaged 46% (range 31-63%) of the total enhanced run counted through the Babine fence or 36% (range 24-55%) of the total fence count (Table 1).

Total escapements to unenhanced spawning sites declined between 1970 and 1985 but have since rebuilt to their former abundance . However, trends differ among run timing groups (Figure 3). The early-timing run appears to have declined since exploitation of BLDP returns began in 1970, although average escapements are not statistically different before and after enhancement ($p>0.36$, Wilcoxin-Mann-Whitney test). In contrast, the unenhanced component of the mid-timing run decreased significantly after 1970 ($p<0.003$) and has not recovered since 1985 ($p>0.77$). The relatively large late-timing run drives the total pattern and appears to have declined between 1970 and 1985, and to have increased slightly thereafter (Figure 3); however, average escapements in these three periods (pre-1970, 1970-1985, and 1986-1987) were not statistically different ($p=0.39$) because of high variability in escapements during the first and last period.

3.1.2 Fry and Smolt Production

Main Basin: Average fry recruitment to the main basin has increased over threefold following enhancement, from an average of 55.1 million (1260 fry/ha) to an average of 172.3 million fish (3940 fry/ha) (Table 2, Figure 4). Smolts from the main basin showed a corresponding increase in average abundance from 19.6 million (449 smolts/ha) to 72.4 million (1660 smolts/ha) annually (Figure 5). Smolt production from the main basin in 1994 (1992 brood year) set a new record at 188.7 million (SE= 8.8 million, 4320 smolts/ha). Wood et al. (1995) suspected that this estimate was biased high because it implied "an improbable emergent fry-to-smolt survival rate of 83%, and was over three times larger than the hydroacoustic estimate of fry abundance (56 million) from surveys the previous fall (K. Shortreed and J. Hume, DFO, pers. comm.)". However, this brood year has subsequently produced record numbers of adults within each age class. In retrospect, it appears that the estimates of fry abundance for the 1992 brood were likely too low.

The BLDP has accounted for the vast majority of fry recruitment to the main basin of Babine Lake (mean=89%, range=63-98%) and most from the entire Babine-Nilkitkwa system (mean=67%, range=33-85%). Infection by the "ich" parasite (white spot disease) caused high prespawning mortality at both enhancement sites in 1994 and 1995 (Traxler et al. in press). As a result, BLDP fry production from the 1994 and 1995 broods was <60% of the 1984-93 average. Observations in 1994 also confirmed the presence of the parasite in other locations within the watershed (Morrison River, Pierre Creek and Babine River). Consistent with these observations, total smolt production from the 1994 and 1995 brood years has fallen to the lowest level observed since production from the BLDP began (<20 million). The parasite was present during spawning in 1996, but at low levels, and fry recruitment from the BLDP returned to above average levels. However, moderate levels of parasite-induced prespawning mortality were again reported at both enhancement sites in 1997, so that fry production is expected to be 20 - 30% below target levels (M. Higgins and M. Kent, DFO, Pacific Biological Station, unpubl. report).

It is important to recognize, however, that prespawning mortality cannot have been solely responsible for the recent decline in smolt production. Smolt production was unusually low for the 1993 brood year before any prespawning mortality due to ich infection had been observed. Moreover, fry-to-smolt survival, estimated after prespawning mortality, has been below average and declining since the 1993 brood year (Table 2). These facts suggest that some other agent of mortality may also be responsible. IHN disease has been detected at low titres in sockeye salmon fry from the BLDP facilities in some years, including the recent years of poor survival (G. Traxler DFO, Pacific Biological Station, unpubl. data). However, it is not known whether the IHN virus poses a threat to wild juvenile sockeye salmon when present at such low titres.

Nilkitkwa Lake: Prior to brood year 1966, over 35% of sockeye salmon smolt production from the Babine system were early-migrant smolts, attributed to Nilkitkwa Lake and the north arm of Babine Lake (Table 3). Early-migrant smolt production has declined dramatically from an average of 11.9 million smolts from brood years prior to 1970, the year enhanced returns were first exploited, to an average of only 2.7 million during the most recent decade (brood years 1985-1994) ($p<0.001$, Figure 6). This trend generally follows the trend of decreasing escapements to the Upper and Lower Babine River over the same period, except that the unusually large spawning escapements recorded in brood years 1985, 1992 and 1993 apparently failed to produce commensurate numbers of smolts (see Figure 7 and discussion in the next section).

3.1.3 Adult Returns

Adult returns to Babine Lake averaged 1.0 million sockeye salmon per brood year before 1966 (the first enhanced brood), and 2.7 million thereafter. In fact, adult returns have increased more or less steadily such that adult returns from the last five complete brood years (1988-1992) have averaged 4.3 million of which 86% is attributable to the BLDP (Figure 8). Adult returns for the most recent complete brood (1992) set a new record at 6.08 million (Table 3).

3.2 PRODUCTIVITY

3.2.1 Factors Limiting Fry Recruitment

Egg-to-fry survival and overall incubation capacity at the enhanced sites are the main factors affecting fry recruitment from the BLDP sites and the entire Babine system. BLDP fry have accounted for as much as 98% of the estimated fry recruitment to the main basin, and 85% of the estimated fry recruitment to the entire Babine-Nilkitkwa system. Egg-to-fry survival at the two major BLDP spawning channels has averaged about 50% in normal (disease-free) years, although it has varied by an order of magnitude from 7-76% in the large Fulton spawning channel, and 9-83% in the Pinkut channel. At present, parasitic infections causing prespawning mortality, and the unidentified factor causing abnormally low fry-to-smolt survival, have emerged as potentially serious limitations to future fry production from BLDP. Further research is recommended to determine how these sources of mortality may be ameliorated as soon as possible.

Recent surveys were undertaken (with Skeena Green Plan funding) to assess the feasibility of enhancing Morrison River sockeye salmon, both to increase fry recruitment to Morrison Arm, and to increase the productivity of the run to ensure its conservation while permitting increased harvest rates on Pinkut-Fulton sockeye salmon with the same run-timing. The surveys confirmed that fry densities are typically lower in Morrison Arm than in the main basin of Babine Lake (K. Shortreed and J. Hume, Cultus Lake Laboratory, Science Branch, unpubl. data), despite unused and apparently suitable spawning habitat in the Morrison River and its tributaries (D. Lofthouse, DFO, Vancouver, pers. comm.). This suggests that wild spawning escapements to the Morrison River system currently limit, and given selective fisheries on mid-timing sockeye salmon, will likely continue to limit fry recruitment to Morrison Arm. No decision regarding enhancement has been made for the Morrison system, and current activities focus on improving opportunities for wild spawning through beaver dam control.

Spawning escapements to the Upper and Lower Babine rivers appear to be limiting fry recruitment to Nilkitkwa Lake. Late-timing escapements and early-migrant smolt abundances remain below average levels recorded before 1970. This implies that current escapements are not adequate to fully seed Nilkitkwa Lake, assuming that the quality of incubation or rearing habitat has not changed. However, the poor levels of early-migrant smolt production resulting from apparently very large late-timing escapements in brood years 1985, 1992, and 1993 is puzzling because it appears inconsistent with previous levels of smolt production from moderate to high escapements (Figure 7). The early-migrant smolt migration was seriously underestimated for the 1991 brood because of unusually early migration in 1993, so this estimate was omitted from Figure 7. However, nothing abnormal was reported for the smolt enumeration of brood years 1985, 1992, and 1993. We are uncertain whether to attribute the discrepancy to errors in fitting transition dates to separate the early- and late-migrant smolts, unreliable escapement estimates, prespawning mortality at high density, or unusually poor egg-to-smolt survival. This uncertainty can only be resolved by research to assess potential egg deposition and subsequent fry-to-smolt survival.

3.2.2 Factors Limiting Smolt Production

Increased fry recruitment from the BLDP has not caused a detectable reduction in fry-to-smolt survival in the main basin of Babine Lake. Calculated emergent fry-to-smolt survival has been highly variable but without trend, and it is uncorrelated with fry density (Figure 9). The high variation in calculated survival is at least partly due to imprecision in the estimates of fry and smolt abundance as evidenced by several years of unbelievably high survival (e.g., >100% for brood year 1962, and >80% for brood years 1979 and 1992). Even after excluding these improbable values, fry-to-smolt survival in the main basin appears to have increased following enhancement from an average of 28% (range 6-55%) to 42% (range 17-71%) ($p<0.03$, *t* test). However, this may simply indicate that fry production from unenhanced sites was less than has been assumed (here and in previous reports, McDonald and Hume 1984; Macdonald et al. 1987). Record high adult returns from the 1992 brood also suggest that the smolt abundance estimate for that year was more reliable than the fry recruitment estimate.

Smolts emigrating from Babine Lake are predominantly (>98%) yearlings (McDonald and Hume 1984). Until recently the trend of increasing juvenile density in the main basin was associated with a steady decrease in average smolt size (Figure 10) because smolt size is negatively correlated both with fry (Figure 11) and smolt (Figure 12) abundance for the corresponding brood year. Even so, the average weight of yearling smolts resulting from brood years of maximum fry recruitment or smolt abundance remains between 4 and 5 g, This is still large in comparison to other productive, interior sockeye salmon lakes such as Shuswap Lake where smolts average <3.5 g on the dominant year cycle (Hume et al. 1995).

Smolt weights achieved in the last four years exceed, or are among the highest of those observed at comparable fry recruitments (or smolt densities) in any previous years. These observations are compelling given that recent smolt densities span the entire range of historical values and they suggest that Babine Lake has become more productive. This inference is corroborated by direct measurements of primary productivity (PR) which was estimated at 111.5 mg C $m^{-2}d^{-1}$ in 1973 compared with 132.8 mg C $m^{-2}d^{-1}$ in 1994 and 144 mg C $m^{-2}d^{-1}$ in 1995 (K. Shortreed and J. Hume, DFO, Cultus Lake Laboratory, unpubl. data). Increased nutrient loading from the large surplus escapements in recent years may be responsible for this increase in primary productivity (see Schmidt et al. in press).

In any case, it is obvious that maximum smolt biomass has not yet been achieved within the range of fry recruitments achieved to date (Figures 11 and 12). The predicted maximum smolt biomass for the main basin of Babine Lake based on PR values for 1994-95 and a PR-sockeye salmon production model calibrated to empirical data for Alaskan sockeye salmon lakes was just under 600,000 kg or about 120,000,000 smolts. This is close to actual production levels that have been sustained over the last two decades. The comparison provides further evidence that the PR model as calibrated to Alaskan sockeye salmon lakes underestimates the production potential of interior Canadian lakes (see Shortreed et al. 1997).

3.2.3 Factors Affecting Smolt-to-Adult Survival

Smolt-to-adult survival has averaged 3.8% since smolt enumeration began in brood year 1959 but has varied considerably from year to year (range 0.8-8.1%), especially when smolt abundance was high (Figure 13). Returns from the 1992 brood were 4.2 times greater than those from the 1979 brood year, even though similar (record high) numbers of smolts were counted past the Babine fence. The 1979 brood set the record for poor survival at 0.8% whereas the 1992 brood survived just slightly below the long-term average at 3.1%. Overall, the relationship between adult returns to Babine Lake (R_t) and total Babine smolt abundance (J_t) is non-linear:

$$(8) \quad \ln(R_t) = 5.87 + 0.481 \ln(J_t) \qquad r^2 = 0.28,\ p<0.002$$

It seems possible that the density-dependence in equation (8) is associated with competition in freshwater that affects smolt size. Smolts from the 1992 brood were 20% heavier than those from the 1979 brood. However, in general, smolt size is very poorly correlated with smolt-to-adult survival ($p>0.08$, Figure 14). Similarly, the proportion of smolts returning as jacks (age 1.1) is only weakly positively correlated with smolt weight ($p<0.03$, Figure 14).

In previous analyses, Peterman (1982) and McDonald and Hume (1984) pointed out that smolts survived better, on average, in odd years than in even years. Peterman (1982) and Ricker (1982) explored several possible explanations involving negative interactions with pink salmon which were then typically more abundant in even years in northern B.C. This relationship is no longer evident in time series of residuals from the common relationship fitted to all years (Figure 15). Brood years 1979 and 1992 are extreme examples where the even-odd year pattern of previous years no longer holds. However, it should be noted that since 1979, odd-year pink salmon have become more abundant than even-year pink salmon in the Skeena River. In fact, pink salmon abundance (PS_t) is a statistically-significant variable in the following regression:

$$(9) \ \ln(R_t) = 1.457 + 0.478 \ln(J_t) + 0.321 \ln(PS_t)$$

Note that the coefficient for the pink salmon term is positive, and thus at odds with Peterman's original (1982) hypothesis. More likely, common environmental conditions have favoured the survival of both sockeye salmon and pink salmon in the Skeena River. Sockeye salmon smolt size was excluded from equation (9) by a step-wise fitting procedure because it had no statistically significant effect ($p>0.15$).

To look for evidence that sockeye salmon smolt-to-adult survival has changed systematically over time, we used "regime" as a categorical variable. Following the hypothesis of Welch et al. (1997), we defined regime = 1 for sea entry years 1952-1976 (brood years 1950-1974), 2 for sea-entry years 1977-1989 (brood years 1975-1987), and 3 for sea-entry years 1990-1994 (brood years 1988-1992). Smolt-to-adult survival (i.e., R_t/J_t) was not statistically different between regimes ($p>0.75$, Wilcoxin-Mann-Whitney test). However, regime was statistically significant ($p<0.02$) as a categorical variable in the regression of $\ln(R_t)$ on $\ln(J_t)$, primarily because of the strong positive residuals during the last three brood years. Pink salmon abundance was no longer significant as an independent variable if regime was included in the analysis, supporting our speculation that the correlation between sockeye salmon and pink salmon arises indirectly through another shared effect here labelled regime. A deficiency of this analysis is that smolt abundance has generally increased over time, and is thus somewhat confounded with regime. However, smolt abundance declined to near record low levels in brood years 1993-96. Adult returns over the next few years will provide important data for testing our assumptions about the relative magnitude of density-dependent versus climatic effects on smolt-to-adult survival.

In conclusion, we attribute the record returns from the 1992 brood year primarily to the record level of freshwater production. In addition, smolts from the 1992 brood, and other recent brood years, experienced higher smolt-to-adult survival than would typically be expected *at such high smolt densities*. This is the same as stating that competition between smolts has been relaxed in recent years. The regression of $\ln(R_t)$ on $\ln(J_t)$ using data for all years (see Figure 13) indicates that, on average, and particularly under recent conditions, increased adult returns can be expected from increased smolt production. Thus, efforts to maximize smolt production in Babine Lake and other Skeena lakes are warranted if the goal is to increase adult returns. However, the diminishing returns associated with density-dependent survival will affect the cost-effectiveness of such efforts.

3.3 HARVEST RATE

3.3.1 Trends in Harvest Rate Relative to Target

Prior to 1983, Skeena sockeye salmon were managed to a fixed escapement target of 1,003,976 sockeye salmon for Babine sub-area and 1,163,111 sockeye salmon for the entire Skeena system. Between 1983 and 1993, additional restrictions were placed on the timing of fishing effort in response to concerns about the status of steelhead trout and coho salmon. Actual escapements and exploitation rates are plotted in comparison to the Skeena target in Figure 16. In practice, the management appears to have been a compromise between a fixed escapement policy and a fixed harvest rate policy. Since 1994, the official management policy has been based on an inseason model of abundance that implies a variable exploitation rate policy (D. Peacock, DFO, Prince Rupert, pers. comm.).

Both total catch and exploitation rate on Skeena River sockeye salmon have increased over the last decade (Figure 17). Total exploitation rate for the entire Skeena sockeye salmon run (including Alaskan catches) has averaged 68% since 1990 and exceeded 70% in 1996 and 1997 (preliminary). No reliable data are available to compute exploitation rates for the Babine and non-Babine runs separately. However, managers use an in-season management model based on differences in run-timing to direct commercial fishing effort towards the mostly enhanced, mid-timing Babine run. The percentage of the total catch (excluding jacks) taken in terminal fisheries at or above the Babine fence has also increased from 1.6% before 1990, to 5.4% in the last three years. Thus, harvest rates on unenhanced Skeena sockeye salmon may have been considerably lower than the total exploitation rate.

The escapement target for Babine Lake cannot be based on conventional considerations of stock productivity because adult returns to Babine Lake originate from both wild and enhanced sites with very different productivities. The total escapement required to maximize production from the BLDP is less than 500,000 spawners, and yet in normal (disease-free) years the BLDP accounts for about 90% of the fry recruitment to the main basin. In contrast, an escapement of about 300,000 late-timing spawners to the Upper and Lower Babine rivers appears necessary to fully seed Nilkitkwa Lake (Figure 7). Any escapement target chosen for the aggregate of early-, mid-, and late-timing subpopulations reflects a deliberate trade-off between maximizing harvestable surplus and maintaining adequate levels of production from the diversity of unenhanced sites.

3.3.2 Impact on Wild Skeena Sockeye salmon

Escapements to non-Babine sockeye salmon populations have been increasing, despite the sustained high harvest rates on the Skeena run as a whole (Figure 18). Presumably this is a direct result of continuing efforts to harvest the mid-timing Babine sockeye salmon as selectively as possible. Even so, recent analyses of limnological and spawning ground survey data for other (non-Babine) Skeena lakes indicate that in most cases, these escapements are much too low if the objective is to fully utilize lake rearing habitat, and maximize smolt production (Shortreed et al. 1997).

Within Babine Lake, escapements to the unenhanced streams began to decline shortly after the first enhanced sockeye salmon returned which suggests that increased exploitation rates on enhanced returns caused the decline (Wood et al. 1995). This conclusion is supported by the fact that early-timing escapements were least affected whereas wild mid-timing escapements were most affected. Furthermore, late-timing escapements increased following the implementation of more conservative management policies (Henderson and Diewert 1989) whereas mid-timing runs that overlap the enhanced runs completely, have not. Since 1985, the wild mid-timing escapements have averaged less than half of pre-enhancement levels. Similarly, since 1985, smolt production from the late-timing runs (Nilkitkwa Lake) has averaged less than a quarter of levels observed before exploitation of enhanced returns began in 1970.

Analyses in this and a companion working paper (Shortreed et al. 1997) provide compelling evidence that the Skeena River system has the lake rearing capacity to produce significantly larger adult returns than realized to date. The enhancement techniques required to harness this potential are already well developed -- some were pioneered in the Skeena system. However, from the perspective of biological production and conservation, the present pattern of utilization, with most fish being harvested in mixed-stock fisheries in Alaska and northern British Columbia is a poor compromise between the dual objectives of maximizing catch from a single productive stock (enhanced Babine sockeye salmon) and conserving the diversity of less productive salmon populations. The result is that over the last ten years, an average of over half a million enhanced sockeye salmon surplus to escapement goals has gone unharvested annually, whereas unenhanced Skeena sockeye salmon populations have been maintained at the lowest levels deemed acceptable. Managers appear to have done a commendable job in achieving these goals considering the complex and irrational nature of this policy.

3.4 FORECASTS

3.4.1 Forecast for 1998

Forecasts of Skeena River sockeye salmon returns in 1998 are summarized in Figures 19-21 based on three alternative models. As expected, the 5-yr mean forecast used in previous years predicts continued above average adult returns. The 5-yr mean model has performed as well or better than other models under typical situations because variation in the independent variables used by other models has been small, and their effects have been obscured by other factors. In the present case, the independent variables in the alternative models are at or near the extreme low end of their historical ranges. Therefore, we recommend that the 5-yr mean model be rejected in favour of the smolt and sibling age-class models that utilize our knowledge of the alarmingly poor smolt production, and returns at age 3 and age 4 from the 1993 and 1994 brood years. Moreover, because forecasts from the smolt and sibling models are lower than from the 5-yr mean model, their use is more consistent with the precautionary principle.

The smolt and sibling models produce almost identical forecasts for 1998 with a 75% chance that adult returns to the Skeena River will exceed 820 thousand sockeye salmon, and a 50% chance that returns will exceed either 1.22 million sockeye salmon (sibling model) or 1.42 million sockeye salmon (smolt model). The congruence of these models provides a clear signal that adult returns in 1998 will be much lower than in recent years.

3.4.2 Considerations for 1999 To 2001

Because smolt production has continued to decline to 1997, forecasts for 1999 and 2000 based on the smolt model will be even lower than for 1998. Forecasts from the sibling age class models cannot be generated more than one year in advance. It is imperative that the smolt migration be enumerated in 1998 because continued low smolt abundance in 1998 would indicate that prespawning mortality is not the principal factor causing reduced smolt production from Babine Lake.

Fry recruitment to Babine Lake returned to normal levels last spring, and it is hoped that smolt production will return to normal in 1998 (the 1996 brood year). Unfortunately, both Pinkut Creek and Fulton River facilities experienced a moderate level of parasite-induced prespawning mortality in 1997, and fry production is expected to be 20 - 30% below target levels. Until the sporadic problems arising from parasite infection can be addressed, the prognosis for future fry recruitment remains uncertain.

4.0 CONCLUSIONS

1. Escapements within Babine Lake: Escapements to enhanced sites in Babine Lake continue to exceed spawning requirements such that on average, over a third of the Babine fence count is surplus produced by the Babine Lake Development Project. In contrast, escapements to the unenhanced Morrison River continue to be low relative to pre-enhancement levels, and stated

escapement objectives. Recent escapements to the unenhanced early-timing and late-timing subpopulations are not statistically different from pre-enhancement levels.

2. Smolt production from Babine Lake (main basin): Smolt production from the main basin of Babine Lake has increased dramatically as a result of enhancement. BLDP fry now account for about 90% of fry recruitment to the main basin. Even so, all the available data suggest that fry recruitment is still below levels required to yield maximum smolt biomass and maximum adult returns.

3. Smolt production from Nilkitkwa Lake and the North Arm of Babine Lake: Smolt production from Nilkitkwa Lake, as inferred from enumeration of early-migrant smolts, has declined to less than a quarter of the level observed before exploitation of enhanced returns began in 1970. Data for Nilkitkwa Lake are less reliable than for Babine Lake, and further investigation seems warranted.

4. Adult returns: Increased smolt production from the Babine-Nilkitkwa lake system has led to dramatic increases in adult returns. However, the relationship between adult returns and smolt abundance is non-linear. presumably reflecting competition among smolts. Recent returns have been higher than expected based on the density-dependent model, suggesting that favourable conditions have led to relaxed density-dependence after emigration. The disparity between smolt-to-adult survival in even and odd years noted previously by Peterman (1982) is no longer evident. Despite density-dependence, increased adult production could be expected from increased smolt production, especially if current conditions continue.

5. Harvest Management: Exploitation rate on Skeena River sockeye salmon has increased over the last decade, averaging 68% since 1990, and exceeding 70% since 1996. Despite the increased exploitation, spawning escapements to non-Babine sockeye salmon populations have been increasing, presumably because of continuing efforts to harvest the mid-timing Babine sockeye salmon as selectively as possible. Even so, recent analyses of limnological and spawning ground survey data for other (non-Babine) Skeena lakes indicate that in most cases, these escapements are much too low if the objective is to fully utilize lake rearing habitat and maximize smolt production (Shortreed et al. 1997). Thus, from the perspective of biological production and conservation, the present pattern of utilization, with most fish being harvested in mixed-stock fisheries in Alaska and northern British Columbia is a poor compromise between the dual objectives of maximizing catch from a single productive stock (enhanced Babine sockeye salmon) and maintaining production from the diversity of less productive salmon populations.

6. Outlook for 1998-2000: The smolt and sibling forecasting models produced almost identical forecasts for 1998 with a 75% chance that adult returns to the Skeena River will exceed 820 thousand sockeye salmon, and a 50% chance that returns will exceed either 1.22 million sockeye salmon (sibling model) or 1.42 million sockeye salmon (smolt model). The congruence of these models provides a clear signal that adult returns in 1998 will be much lower than in recent years. Because smolt production has continued to decline to 1997, forecasts for 1999 and 2000 based on the smolt model will be even lower than for 1998. Fry recruitment to Babine Lake returned to normal levels last spring, but is expected to be 20 - 30% below

target levels next spring. It is imperative that the smolt migration be enumerated in 1998 because continued low smolt abundance in 1998 would indicate that prespawning mortality is not the principal factor causing reduced smolt production from Babine Lake. Until the cause of abnormally low fry-to-smolt survival is understood, the prognosis for future smolt production remains uncertain.

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7.0 FIGURES, TABLES AND APPENDICES

Table 1. Reconstructed Babine Lake escapements by run-timing group.

	Fence		BLDP as	Early	Middle				Late	Total
Year	Count	Catch[a]	% of fence[b]	Total	Pinkut-Fulton	Surplus	Morrison	Total	Total	Escapement[c]
1950	364356	27449	0.0	35844	44962	0	8812	53774	247289	336907
1951	141415	19007	0.0	35149	35342	0	6276	41618	45641	122408
1952	349011	34404	0.0	10486	62820	0	1848	64667	239454	314607
1953	686586	26913	0.0	61547	208708	0	33088	241796	356330	659673
1954	493677	21847	0.0	48107	143365	0	25487	168852	254871	471830
1955	71352	10423	0.0	8338	20721	0	1776	22497	30094	60929
1956	355345	30582	0.0	34283	117093	0	32651	149743	140736	324763
1957	433149	20434	0.0	50518	142785	0	29033	171817	190379	412715
1958	812050	38580	0.0	196599	183674	0	25850	209524	367347	773470
1959	782868	16727	0.0	104474	248747	0	46018	294765	366902	766141
1960	262719	16754	0.0	42485	78262	0	12298	90560	112920	245965
1961	941711	30856	0.0	133007	276734	0	33657	310391	467457	910855
1962	547995	18122	0.0	21587	136862	0	16828	153690	354597	529873
1963	588000	20021	0.0	76661	241228	0	56319	297548	193770	567979
1964	827437	19855	0.0	67738	306602	0	35992	342595	397250	807582
1965	580000	18540	0.0	27278	207236	0	11094	218330	315852	561460
1966	389000	18652	0.0	31918	80044	0	15199	95243	243187	370348
1967	602807	18992	0.0	95242	167718	0	24201	191919	296655	583815
1968	552000	19146	0.0	62457	147571	0	55410	202981	267415	532854
1969	634000	17293	0.0	89318	148885	0	32626	181511	345878	616707
1970	662000	20048	36.8	81749	224536	0	7432	231968	328235	641952
1971	816000	23450	41.2	34049	313244	0	8381	321625	436876	792550
1972	680145	24283	45.1	52692	283389	0	10277	293666	309504	655862
1973	797461	17015	46.3	140253	337492	34382	32179	404053	236140	780446
1974	726990	22318	36.5	109851	235408	29780	38189	303377	291444	704672
1975	820795	13896	69.6	60353	464933	134442	28686	628061	118485	806899
1976	580597	18157	65.8	13336	338263	39683	8022	385967	163137	562440
1977	937992	10777	69.2	52713	591788	67384	15577	674748	199754	927215
1978	401318	10920	66.0	32024	171267	125774	3931	300972	57402	390398
1979	1160966	21500	57.6	42455	552632	165164	21765	739562	357449	1139466
1980	526259	22635	45.5	30437	178863	86093	11168	276123	197064	503624
1981	1432734	30300	78.7	46093	586207	649611	7178	1242997	113344	1402434
1982	1136835	42000	67.9	93630	505550	331233	4827	841610	159595	1094835
1983	886393	20000	78.0	26965	472789	254708	8904	736401	103027	866393
1984	1052385	20500	67.9	26503	486395	306475	8065	800935	204447	1031885
1985	2148044	17500	42.7	75649	517259	896769	17229	1431257	623637	2130544
1986	701507	23500	61.8	26865	298412	181419	3874	483705	167437	678007
1987	1307852	20296	61.8	37960	452629	543775	15786	1012190	237406	1287556
1988	1408879	25000	62.7	42373	495753	580318	23459	1099530	241976	1383879
1989	1132316	22000	74.1	18412	434467	517173	7701	959341	132563	1110316
1990	978646	22000	67.8	21328	457633	271425	7395	736454	198864	956646
1991	1176318	20800	40.2	58719	328999	310238	24980	664217	432582	1155518
1992	1915149[c]	73879	47.7	47075	515297	681364	8515	1205176	589020	1841270
1993	1737426	177590	51.5	16646	511120	414730	21962	947812	595377	1559836
1994	1052905	48465	78.7	24636	563623	276301	7561	847485	132318	1004440
1995	1737009	98592	82.4	78739	636049	846928	6556	1489533	70145	1638417
1996	2056205	352234	81.1	59502	581946	910598	7976	1500520	143948	1703971
1997	1086610	156000								

[a] harvest after enumeration at Babine fence

[b] includes Pinkut-Fulton (after 1969), surplus, and prorated catch

[c] Babine fence count - catch - surplus

[d] reconstructed fence count, actual count not credible, see PSARC s95-06

Table 2. Babine Lake freshwater production, main basin only.

Brood	Estimated Abundance			Smolt Weight		Smolt	Fry-to-smolt
Year	Fry*10^6	Smolts	SE	Mean	(SD)	Biomass (kg)	Survival (%)
1950	20.9	0	0	4.9			
1951	17.9	0	0	6.2			
1952	17.5	0	0	6.3			
1953	70.7	0	0	5.4			
1954	50.6	0	0	5.1			
1955	7.2	0	0	5.9			
1956	42.9	0	0	6.1			
1957	51.8	0	0	5.5			
1958	94.6	0	0	6.2			
1959	93.0	13216226	547152	5.2		68724	14.2
1960	31.0	17140050	1087906	5.6		95984	55.3
1961	103.3	6645905	285134	5.3		35223	6.4
1962	40.8	41741112	5433752	5.3		221228	102.2
1963	87.2	28334963	1399898	5.1		144508	32.5
1964	95.6	22768048	730334	4.7		107010	23.8
1965	57.2	7415431	382854	5.3		39302	13.0
1966	64.2	23677175	778924	4.5		106547	36.9
1967	75.3	28093879	1649028	5.4		151707	37.3
1968	103.2	38431464	916012	5.1		196000	37.3
1969	87.9	38753163	1106440	5.8		224768	44.1
1970	135.7	37325167	1340116	5.3		197823	27.5
1971	162.0	88690671	4257584	5.3		470061	54.8
1972	173.2	77854348	2615787	4.8	1.3	373701	45.0
1973	190.9	33248302	1135680	5.4	1.3	179541	17.4
1974	141.6	38590631	947016	5.1	1.0	196812	27.3
1975	175.3	54481971	1974869	4.9	1.3	266962	31.1
1976	233.8	80398367	4269472	4.5	1.3	361793	34.4
1977	207.4	110424296	4785295	5.0	0.7	552121	53.2
1978	131.7	55128796	2483147	4.3	0.9	237054	41.9
1979	212.0	179427612	16855600	4.5	1.2	807424	84.7
1980	171.4	122067466	5993841	4.6	1.2	561510	71.2
1981	229.8	142594834	16709866	4.4	1.2	627417	62.0
1982	217.8	93464694	10791980	3.9	1.2	364512	42.9
1983	124.4	42796531	2181594	4.2	0.3	179745	34.4
1984[a]	228.2	49387722		5.3	1.7	261755	21.6
1985	212.9	122873389	6321951	5.0	1.3	614367	57.7
1986	226.4	80536904	3266217	4.5	1.1	362416	35.6
1987	117.0	no smolt program					
1988	212.2	61049322	2034479	5.0	1.2	305247	28.8
1989	164.7	51809312	1430708	4.8	1.3	248685	31.5
1990	247.0	97523387	3561698	4.8	1.1	468112	39.5
1991	192.1	83095829	16576996	4.3		357312	43.3
1992	228.1	188667005	8762382	5.4	1.2	1020688	82.7
1993	181.7	30887461	4066305	5.6	1.3	165248	17.0
1994	131.9	17310854	405299	5.6		96941	13.1
1995[b]	114.2	7747408	506990	5.3		41371	6.8
1996	248.0						0.0

[a] Smolt abundance estimates are questionable and were excluded from analyses in this report. Values reported here are from the constant sampling fractioon model because the parsimonious model fitted poorly, presumably because of a failure in the assumptions of the mark/recapture model

[b] Minimum estimate. Flooding conditions resulted in early termination of the program, but after normal peak of migration.

Table 3. Summary of total sockeye production from the Babine-Nilkitkwa lake system.

Brood Year	Estimated Abundance			Adult Returns			Marine Survival (%)
	$Fry*10^6$	Smolts	SE	Total[a]	% Age 4	% Age 5	
1950	78.5			645479	72.7	23.0	
1951	28.5			123665	37.6	54.3	
1952	73.3			665850	65.2	30.1	
1953	153.7			1323932	38.2	60.4	
1954	109.9			1348990	44.7	51.6	
1955	14.2			371950	57.7	33.9	
1956	75.7			659561	46.9	48.3	
1957	96.2			2026471	69.6	28.0	
1958	180.2			639729	72.4	23.2	
1959	178.5	21398560	962885	1658321	33.0	64.2	7.7
1960	57.3	20921978	1825103	870970	47.8	32.4	4.2
1961	212.2	13385010	461711	1081387	54.0	40.4	8.1
1962	123.5	61940522	5637487	1401038	35.0	60.4	2.3
1963	132.3	31640521	1548164	2203229	39.8	51.9	7.0
1964	188.2	36109063	1709064	667969	26.8	68.8	1.8
1965	130.8	18002144	721345	1087229	61.8	33.3	6.0
1966	120.8	33068152	1974697	1528244	48.5	41.5	4.6
1967	144.5	52026755	3165728	2062906	45.4	46.6	4.0
1968	165.5	52335617	2225504	1235187	26.9	68.7	2.4
1969	168.5	56580032	1400349	2647773	39.1	51.2	4.7
1970	212.2	50811124	1758704	1284709	58.3	25.5	2.5
1971	263.8	105240328	4421657	2103481	48.2	39.6	2.0
1972	245.3	106200662	2948216	1795703	27.5	64.8	1.7
1973	245.9	38098370	1150471	2052224	49.6	37.9	5.4
1974	209.5	45617761	964075	567185	41.9	49.7	1.2
1975	203.0	64724487	2093195	3528455	63.7	27.9	5.5
1976	271.8	90374023	4858829	719784	36.0	51.4	0.8
1977	254.0	121540385	4856565	5828662	49.1	46.9	4.8
1978	145.1	57504845	2530794	1894137	29.5	62.3	3.3
1979	295.2	192043404	16893631	1450254	46.9	49.0	0.8
1980	217.3	136566225	6760934	4650624	28.1	64.3	3.4
1981	256.2	146245251	16711858	2685514	58.1	37.4	1.8
1982	255.0	94608919	10818521	1765995	31.2	65.1	1.9
1983	148.4	49837031	2308173	1931329	45.6	49.9	3.9
1984[b]	275.8	159047767		4470372	52.9	32.8	2.8
1985	358.2	125634259	6334902	2327093	33.7	62.9	1.9
1986	265.4	82336836	3276923	3090707	23.8	72.2	3.8
1987	172.3	no smolt program		2706902	29.5	67.2	
1988	268.6	68835118	2761881	4526592	33.2	57.6	6.6
1989	195.6	53385373	1459025	3383310	42.5	49.8	6.3
1990	293.3	99650699	3563086	2561993	22.7	73.8	2.6
1991	292.9	83095829	16576996	4845080	42.5	50.9	5.8
1992	365.3	194134277	8764720				
1993	320.4	34796643	4076434				
1994	162.7	18090918	408931				
1995[c]	130.5	8266703	514660				
1996	281.6						
1997							

[a] includes jack sockeye

[b] questionable smolt estimate, not used in analyses (see Table 2)

[c] minimum smolt estimate (see Table 2)

Table 4. Skeena sockeye run size forecasts for 1998

	Probability Reference Points[a]	
Model	0.5	0.75
5-yr Mean	4550000	3550000
Smolt (Y=aXb)	1420000	820000
Sibling (Y=aXb)	1220000	820000
Recommended	1220000	820000

[a] see Figures 19-21 for full cumulative probability

FIGURE CAPTIONS

1. Map of the Babine-Nilkitkwa lake system showing principal tributaries, location of the Babine counting fence and the Babine Lake Development Project sites at Fulton River and Pinkut Creek (from Ginetz 1977)

2. Rearing areas and typical timing of early- and late-migrant smolts from the Babine-Nilkitkwa lake system (from Macdonald et al. 1987).

3. Trends in reconstructed escapements by run timing group. Lines fitted by LOWESS (F=0.5).

4. Trends in estimated fry recruitment to the main basin of Babine Lake (upper) and to the entire Babine-Nilkitkwa system (lower). Lightly hatched portions represent contributions from the BLDP.

5. Trends in smolt abundance from the main basin of Babine Lake (late-migrant smolts) and from the entire Babine-Nilkitkwa system (lower). Error bars represent one standard error.

6. Trends in smolt abundance from Nilkitkwa Lake (early-migrant smolts). Error bars represent one standard error.

7. Stock-recruitment relationship for Nilkitkwa Lake as inferred from late-timing spawning escapements and subsequent early-migrant smolt abundance. Solid circles and upper curve, brood years prior to 1985; open circles and lower curve, brood years since 1985. Curves are fitted as a power function ($Y=aX^b$).

8. Trends in adult returns to Babine Lake by brood year. Line is fitted by LOWESS (F=0.5).

9. Relationship between fry-to-smolt survival (upper panel), late-migrant smolt abundance (lower panel) and estimated fry recruitment to the main basin of Babine Lake. Curves fitted by LOWESS (F=0.5) and as a power function, respectively.

10. Trends in mean smolt weight for late-migrant smolts rearing in the main basin of Babine Lake. Line is fitted by LOWESS (F=0.5).

11. Relationships between smolt weight (upper) and smolt biomass (lower) and fry recruitment to the main basin of Babine Lake. Lines fitted as power functions.

12. Relationships between smolt weight (upper) and smolt biomass (lower) and late-migrant smolt abundance from main basin of Babine Lake. Lines fitted as power functions.

13. Relationship between smolt-to-adult survival (upper panel), subsequent adult returns to Babine Lake (lower panel) and the total number of smolts leaving Babine Lake. Curves fitted as power functions.

14. Linear regressions (with 95% confidence bounds) of smolt-to-adult survival (upper) and proportion of smolts returning as jacks (at age 3) on the mean weight of late-migrant smolts leaving Babine Lake.

15. Trends in residuals from the adult returns-smolt abundance relationship in Figure 13, distinguished by even (open circles, dashed line) and odd (solid circles, solid line) years. Lines fitted by LOWESS (F=0.5).

16. Total exploitation rates (excluding jacks) and resulting escapements of Skeena sockeye salmon for 1970-1996 compared with target (solid line). The dashed line is the average exploitation rate since 1990.

17. Trends in total exploitation rate (upper) and total catch (lower) of Skeena sockeye salmon. Age 3 (jack) sockeye salmon have been excluded. Curved line fitted by LOWESS (F=0.5).

18. Trends in Skeena sockeye salmon escapement to non-Babine subareas (upper) and the Babine subarea (lower). Note logarithmic scale on y-axis; curves fitted by LOWESS (F=0.5).

19. The 5-yr mean-based forecast for total Skeena sockeye salmon stock size in 1998. The cumulative probability distribution is shown in relation to the distribution of historical stock sizes. This forecast is not recommended for 1998.

20. The smolt-based forecast for total Skeena sockeye salmon stock size in 1998. The cumulative probability distribution is shown in relation to the distribution of historical stock sizes.

21. The recommended forecast for total Skeena sockeye salmon stock size in 1998 based on the observed return of sibling age classes (jacks in 1996 and age 4 sockeye salmon in 1997). The cumulative probability distribution is shown in relation to the distribution of historical stock sizes.

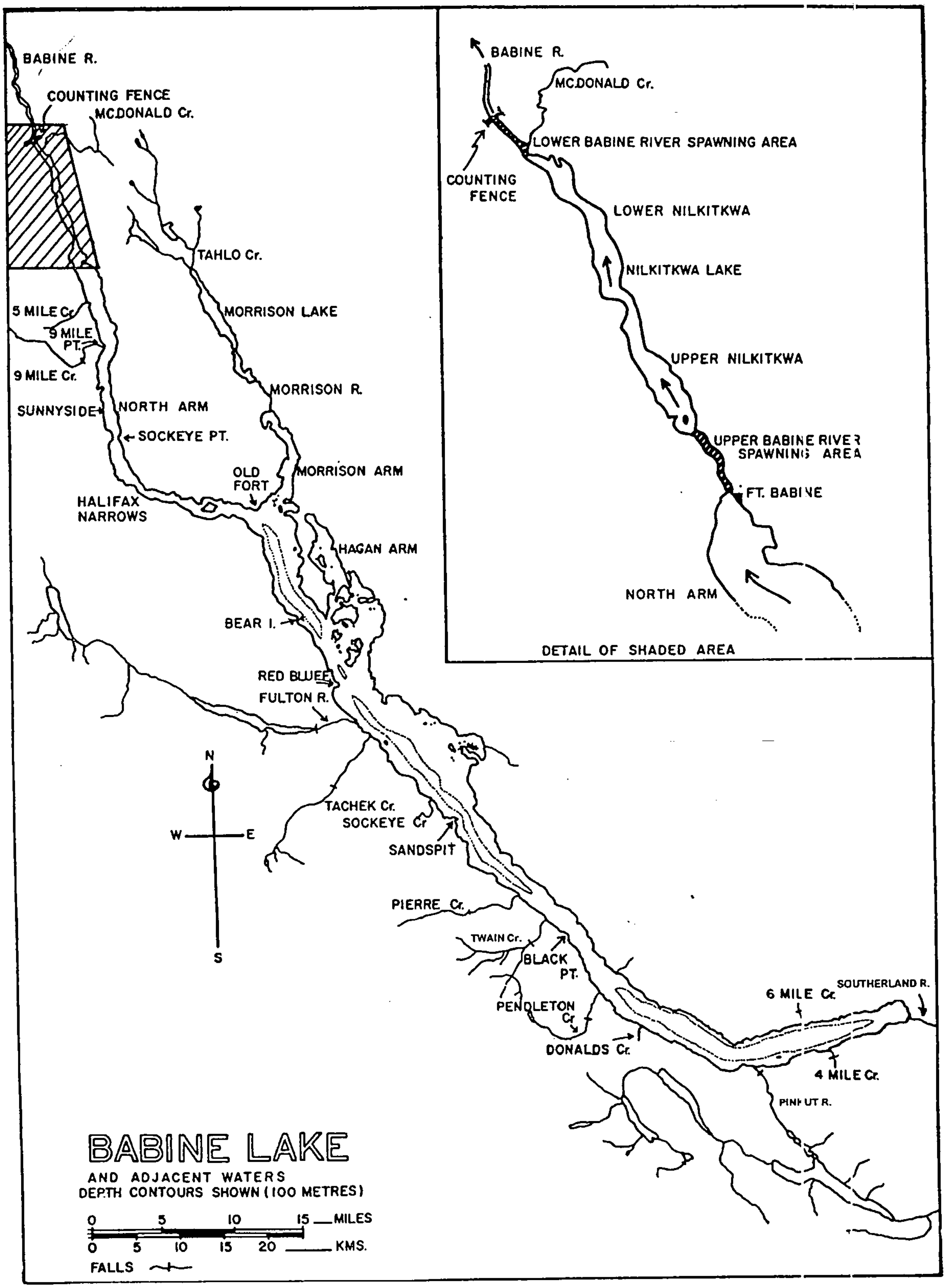

BABINE R.
COUNTING FENCE
MCDONALD Cr.
TAHLO Cr.
MORRISON LAKE
5 MILE Cr.
9 MILE PT.
9 MILE Cr.
MORRISON R.
SUNNYSIDE
NORTH ARM
SOCKEYE PT.
OLD FORT
MORRISON ARM
HALIFAX NARROWS
HAGAN ARM
BEAR I.
RED BLUFF
FULTON R.
TACHEK Cr.
SOCKEYE Cr
SANDSPIT
PIERRE Cr.
TWAIN Cr.
BLACK PT.
PENDLETON Cr
DONALDS Cr.
6 MILE Cr.
SOUTHERLAND R.
4 MILE Cr.
PINKUT R.
N
W
E
S
BABINE R.
MCDONALD Cr.
LOWER BABINE RIVER SPAWNING AREA
COUNTING FENCE
LOWER NILKITKWA
NILKITKWA LAKE
UPPER NILKITKWA
UPPER BABINE RIVER SPAWNING AREA
FT. BABINE
NORTH ARM
DETAIL OF SHADED AREA
BABINE LAKE
AND ADJACENT WATERS
DEPTH CONTOURS SHOWN (100 METRES)
0 5 10 15 MILES
0 5 10 15 20 KMS.
FALLS

Figure 1

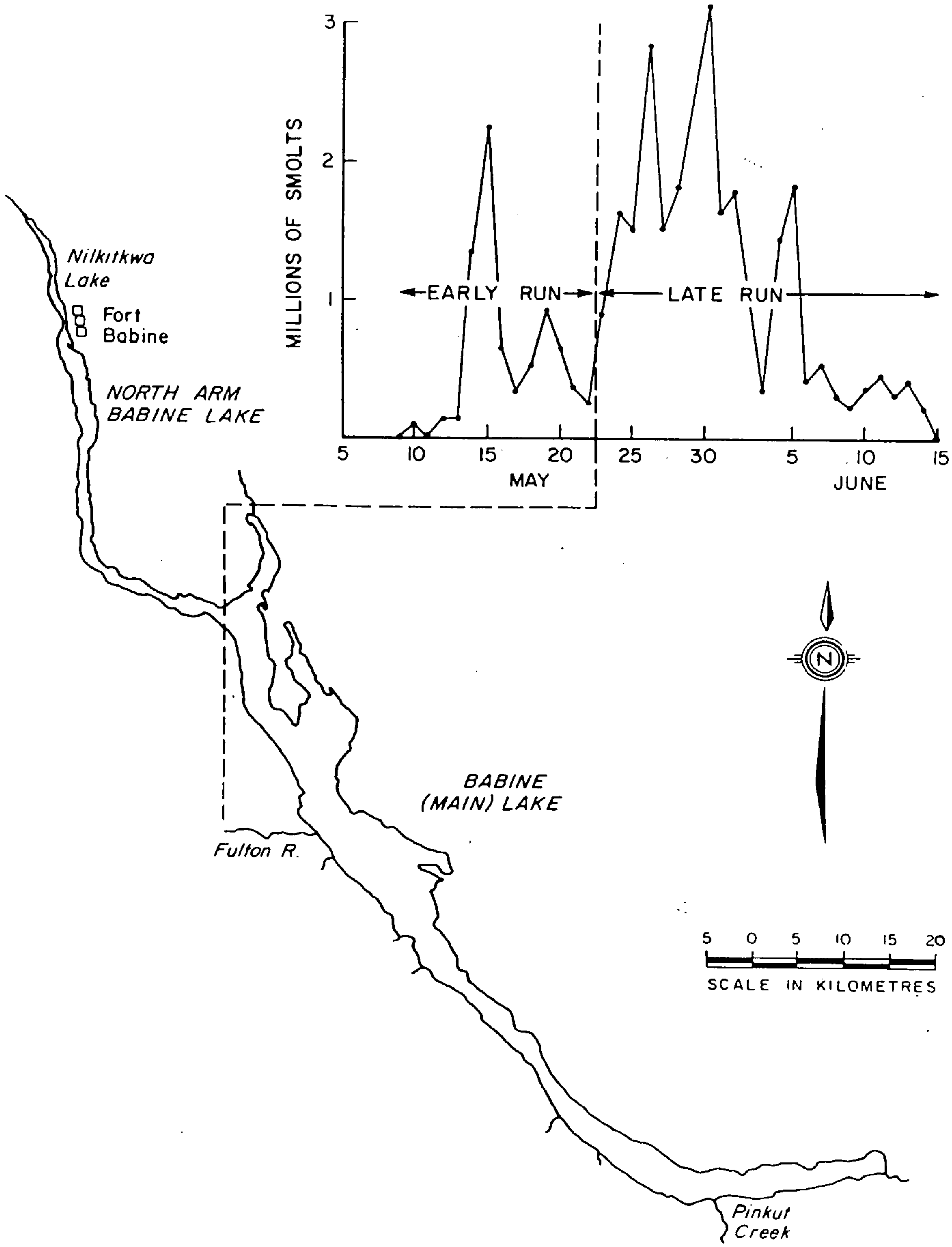

3
2
1
MILLIONS OF SMOLTS
←EARLY RUN→
←LATE RUN→
5
10
15
20
25
30
5
10
15
MAY
JUNE
Nilkitkwa
Lake
Fort
Babine
NORTH ARM
BABINE LAKE
BABINE
(MAIN) LAKE
Fulton R.
Pinkut
Creek
N
5
0
5
10
15
20
SCALE IN KILOMETRES

Figure 2.

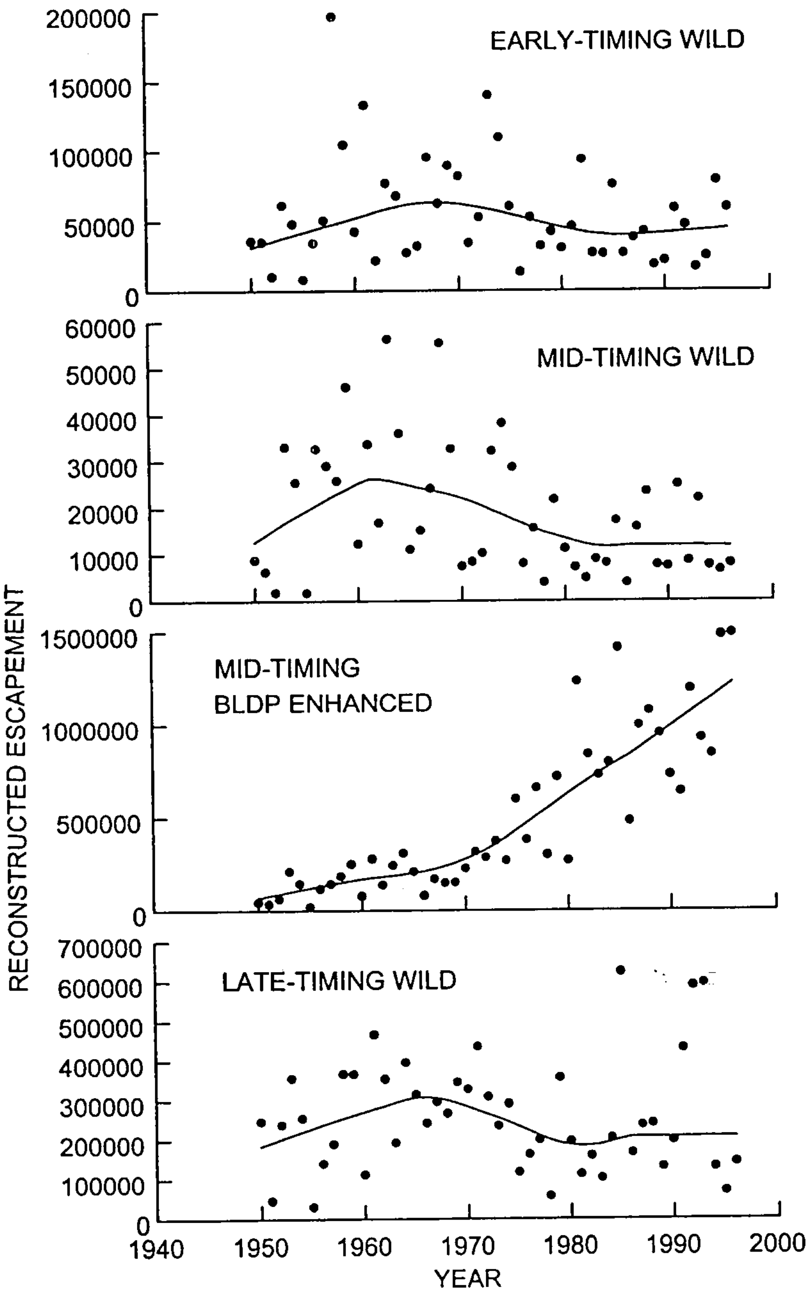

EARLY-TIMING WILD
MID-TIMING WILD
MID-TIMING
BLDP ENHANCED
LATE-TIMING WILD
RECONSTRUCTED ESCAPEMENT
YEAR
200000
150000
100000
50000
0
60000
50000
40000
30000
20000
10000
1500000
1000000
500000
700000
600000
500000
400000
300000
200000
100000
1940
1950
1960
1970
1980
1990
2000

Figure 3.

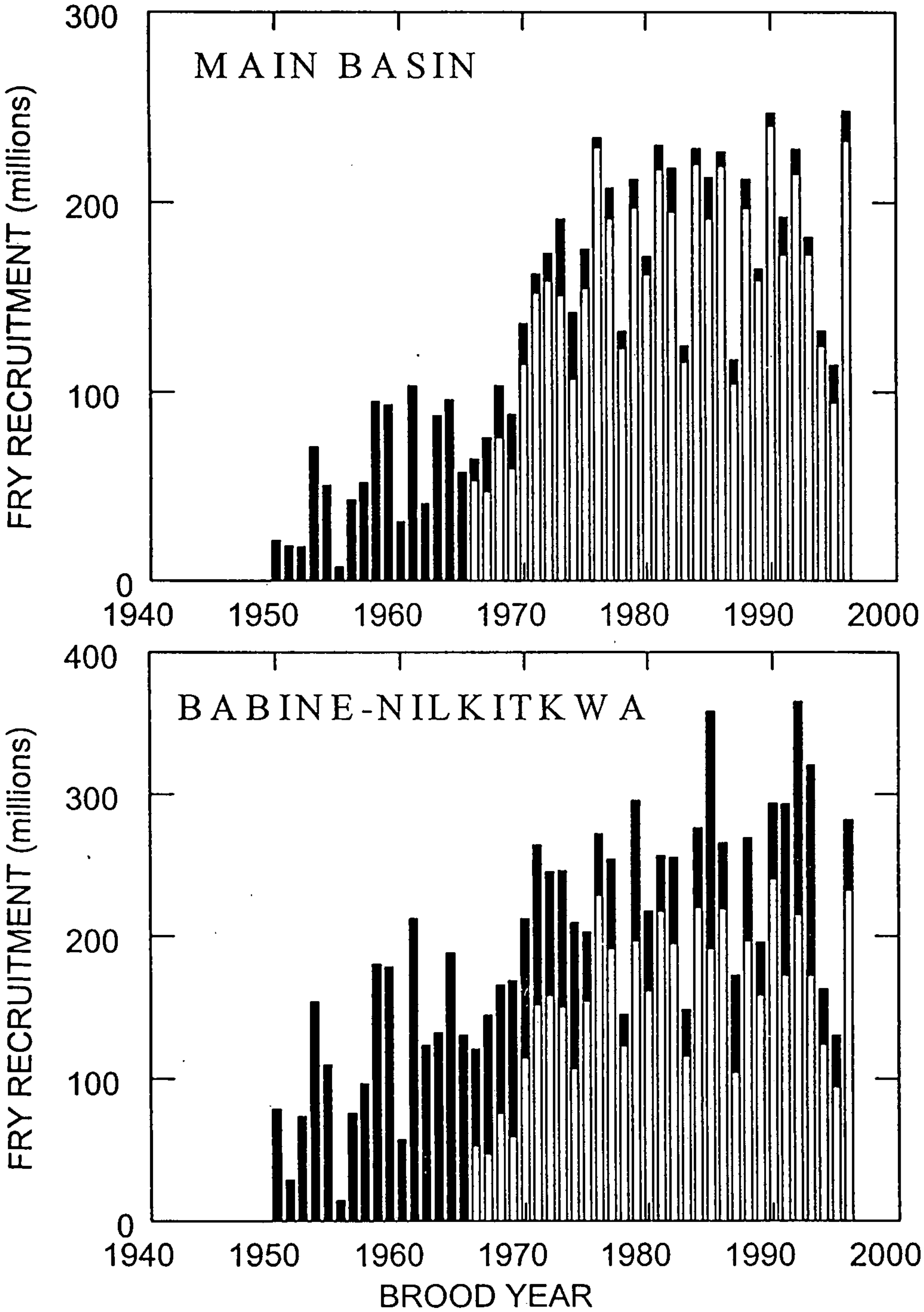

MAIN BASIN
FRY RECRUITMENT (millions)
300
200
100
0
1940
1950
1960
1970
1980
1990
2000
BABINE-NILKITKWA
FRY RECRUITMENT (millions)
400
300
200
100
0
1940
1950
1960
1970
1980
1990
2000
BROOD YEAR

Figure 4.

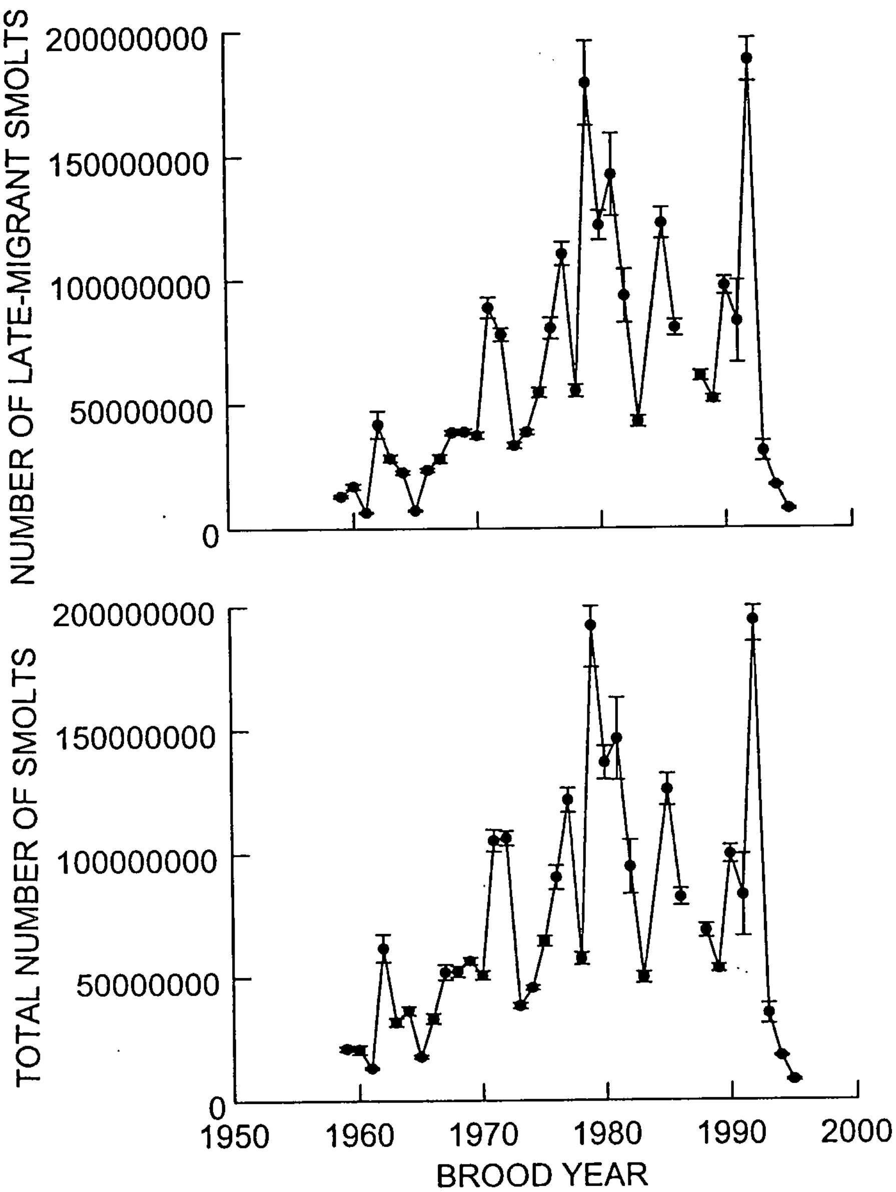


Figure 5. Note that values of brood year 1995 are minimum estimates due to flooding.

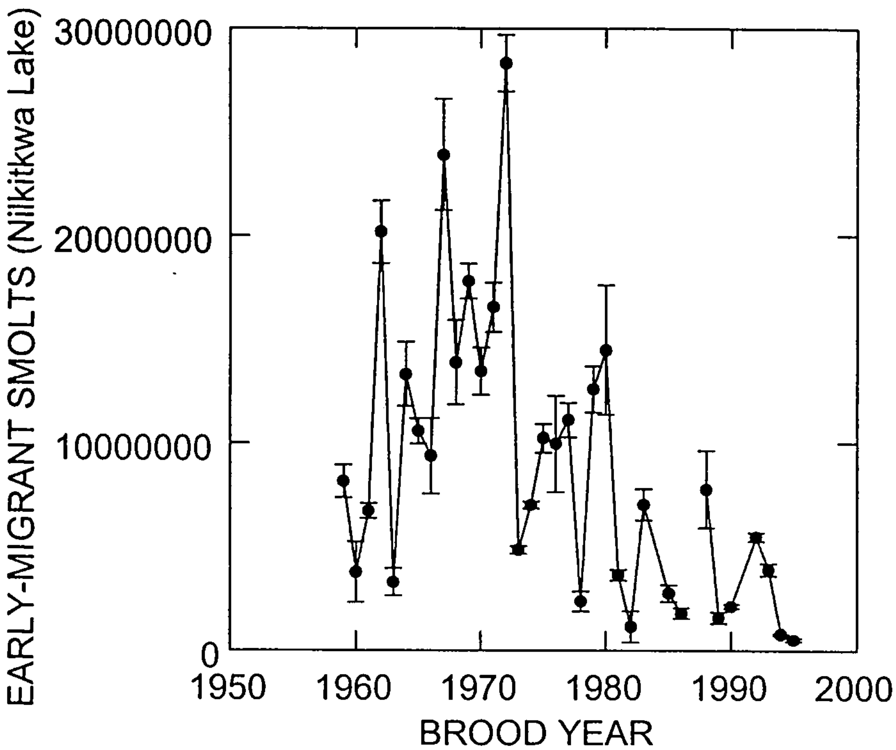

EARLY-MIGRANT SMOLTS (Nilkitkwa Lake)
30000000
20000000
10000000
0
1950
1960
1970
1980
1990
2000
BROOD YEAR

Figure 6.

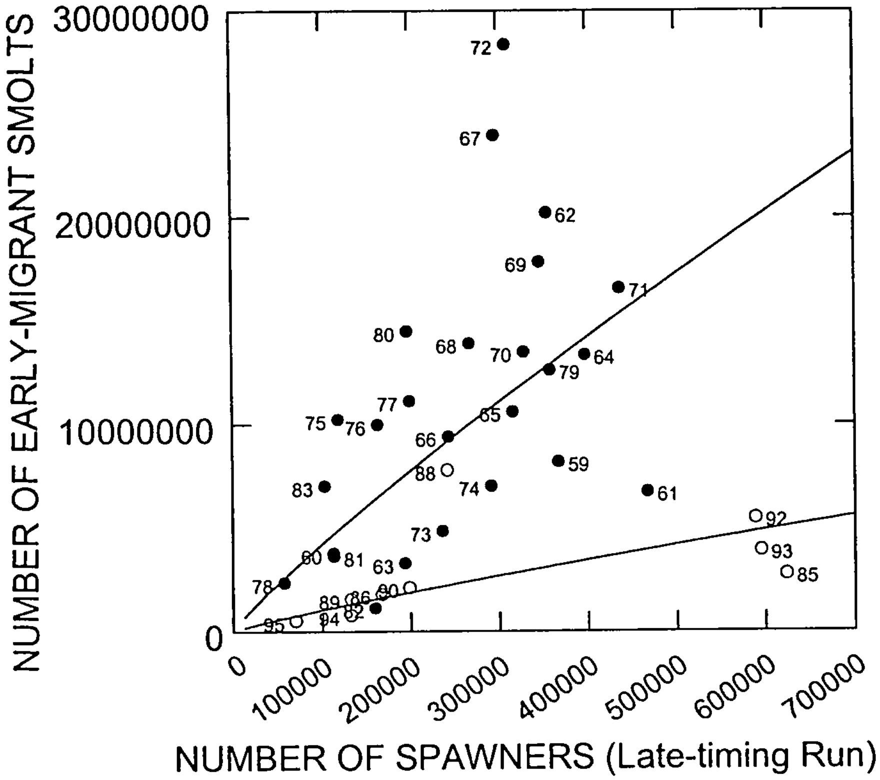

NUMBER OF EARLY-MIGRANT SMOLTS
30000000
20000000
10000000
0
0
100000
200000
300000
400000
500000
600000
700000
NUMBER OF SPAWNERS (Late-timing Run)

Figure 7.

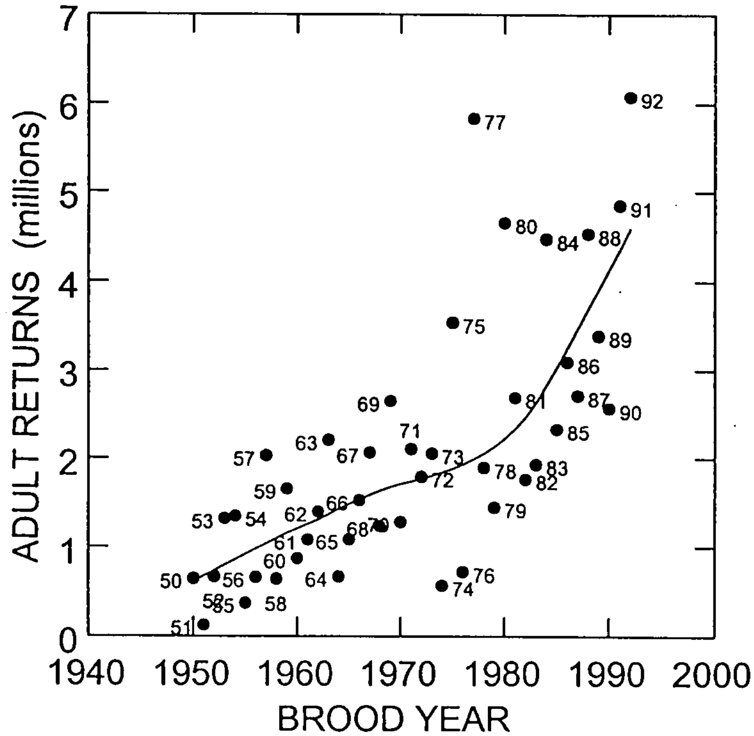

ADULT RETURNS (millions)
0
1
2
3
4
5
6
7
1940
1950
1960
1970
1980
1990
2000
BROOD YEAR
50
51
53
54
56
57
58
59
60
61
62
63
64
65
66
67
69
71
72
73
74
75
76
77
78
79
80
82
83
84
85
86
88
89
90
91
92

Figure 8.

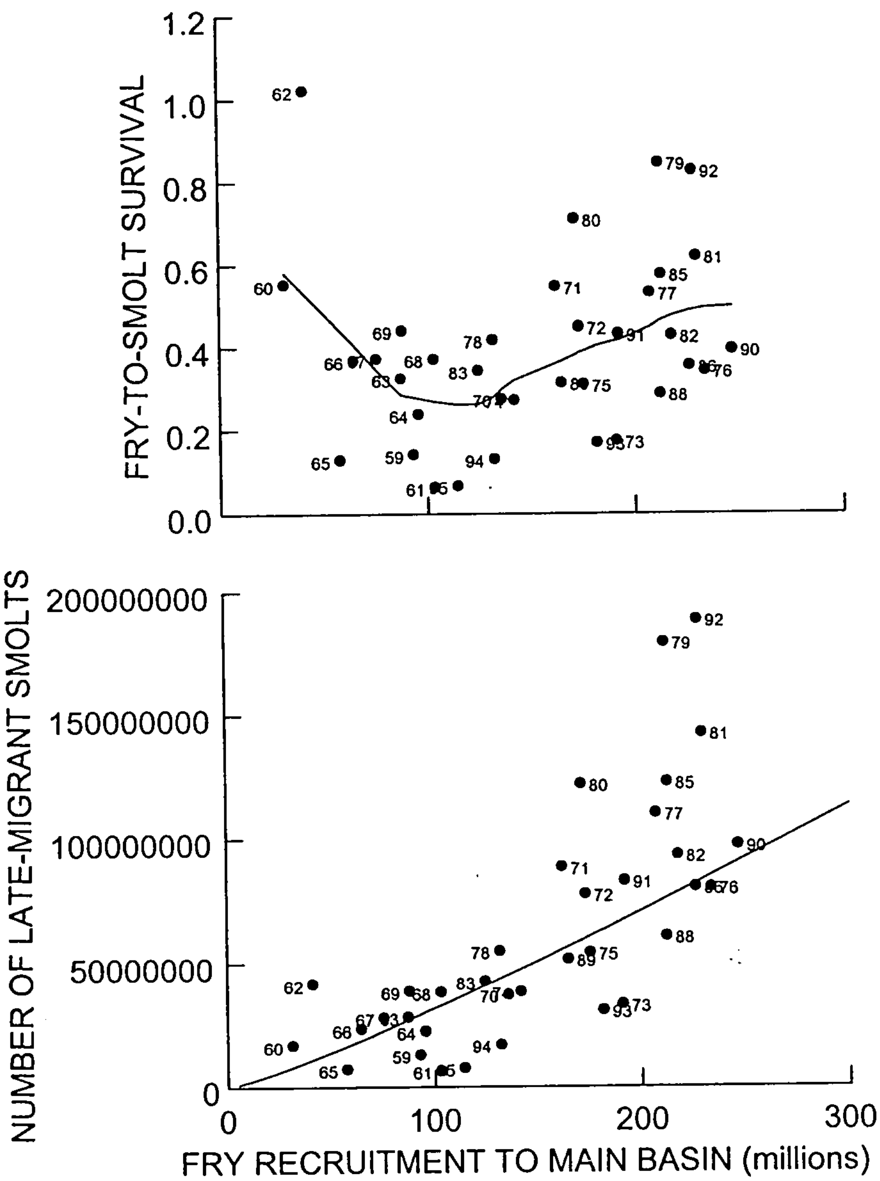

FRY-TO-SMOLT SURVIVAL
1.2
1.0
0.8
0.6
0.4
0.2
0.0
NUMBER OF LATE-MIGRANT SMOLTS
200000000
150000000
100000000
50000000
0
0
100
200
300
FRY RECRUITMENT TO MAIN BASIN (millions)

Figure 9.

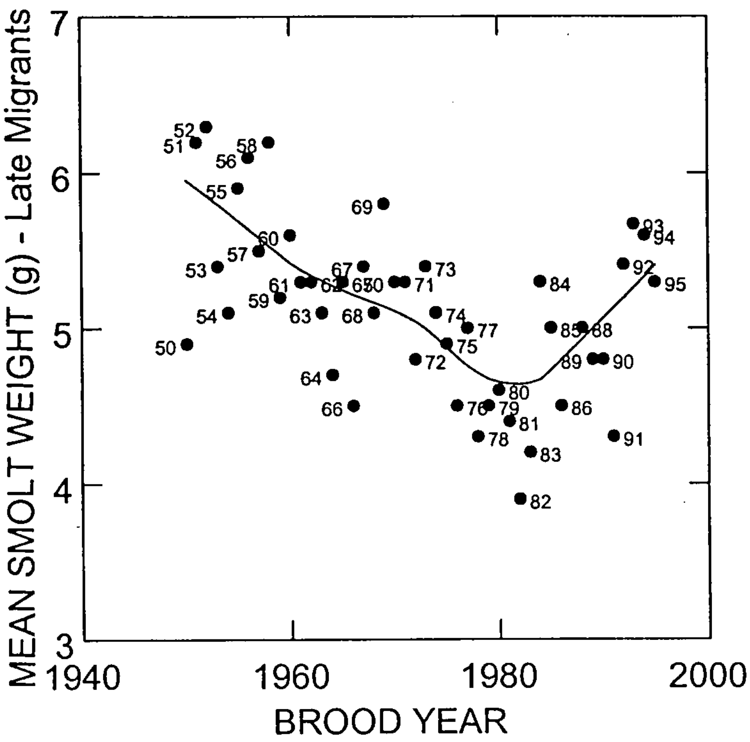
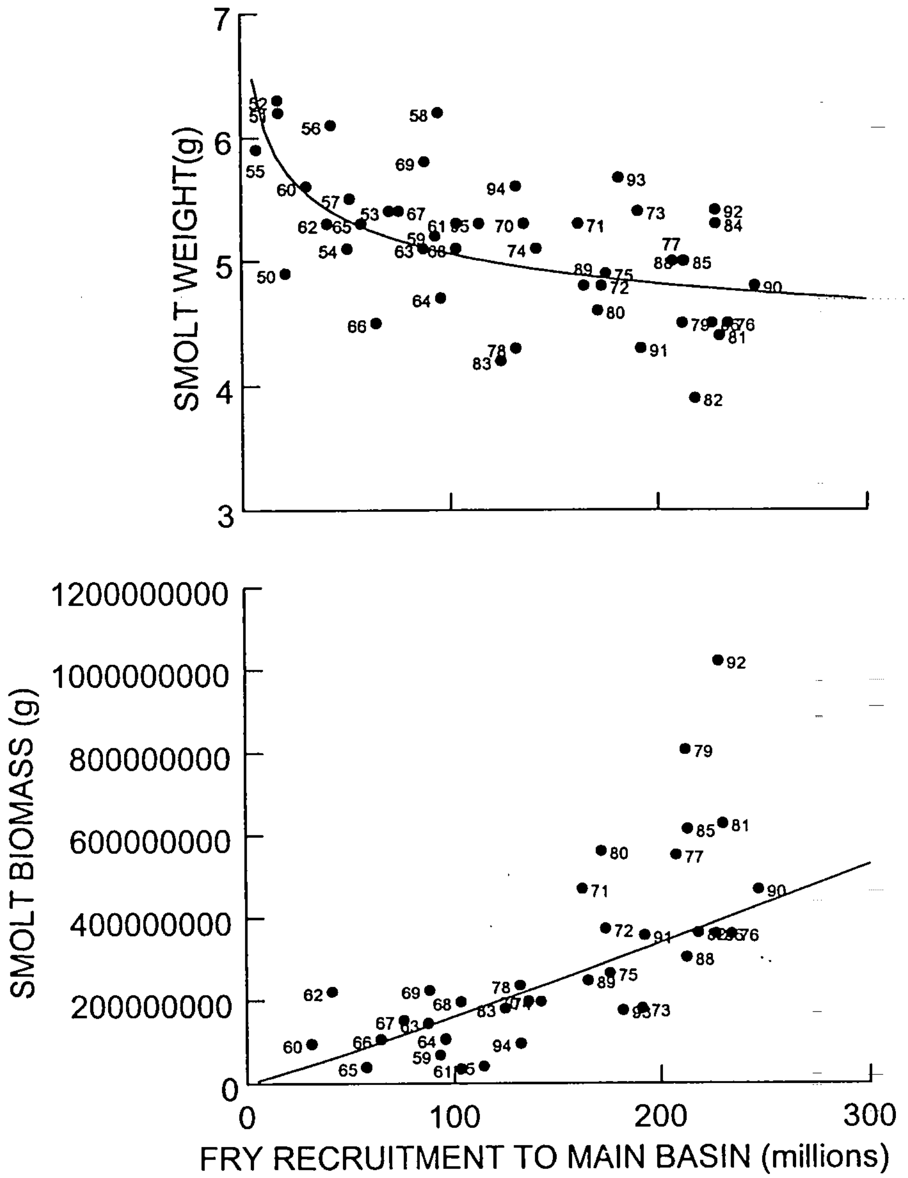

MEAN SMOLT WEIGHT (g) - Late Migrants
BROOD YEAR
7
6
5
4
3
1940
1960
1980
2000

Figure 10.



SMOLT WEIGHT(g)
7
6
5
4
3
SMOLT BIOMASS (g)
1200000000
1000000000
800000000
600000000
400000000
200000000
0
0
100
200
300
FRY RECRUITMENT TO MAIN BASIN (millions)

Figure 11.

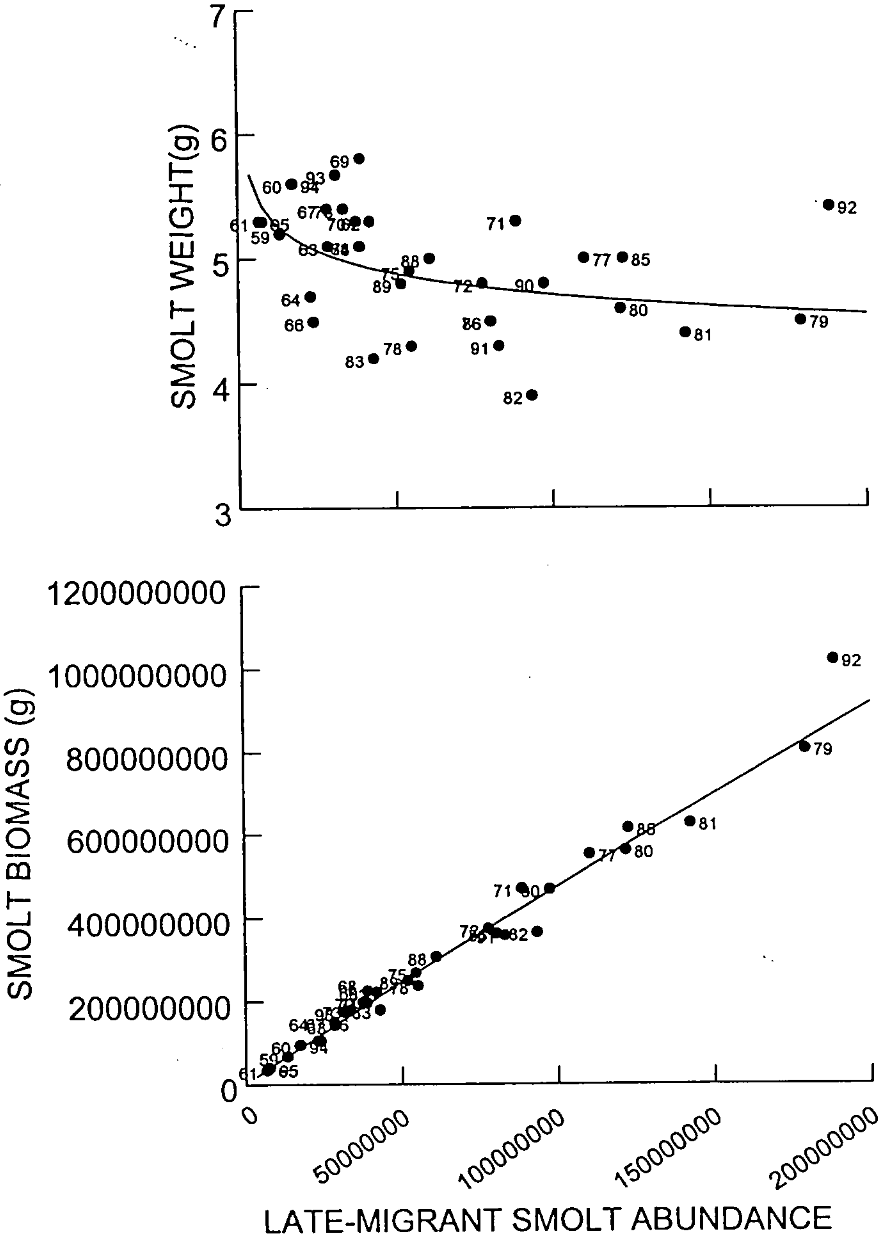
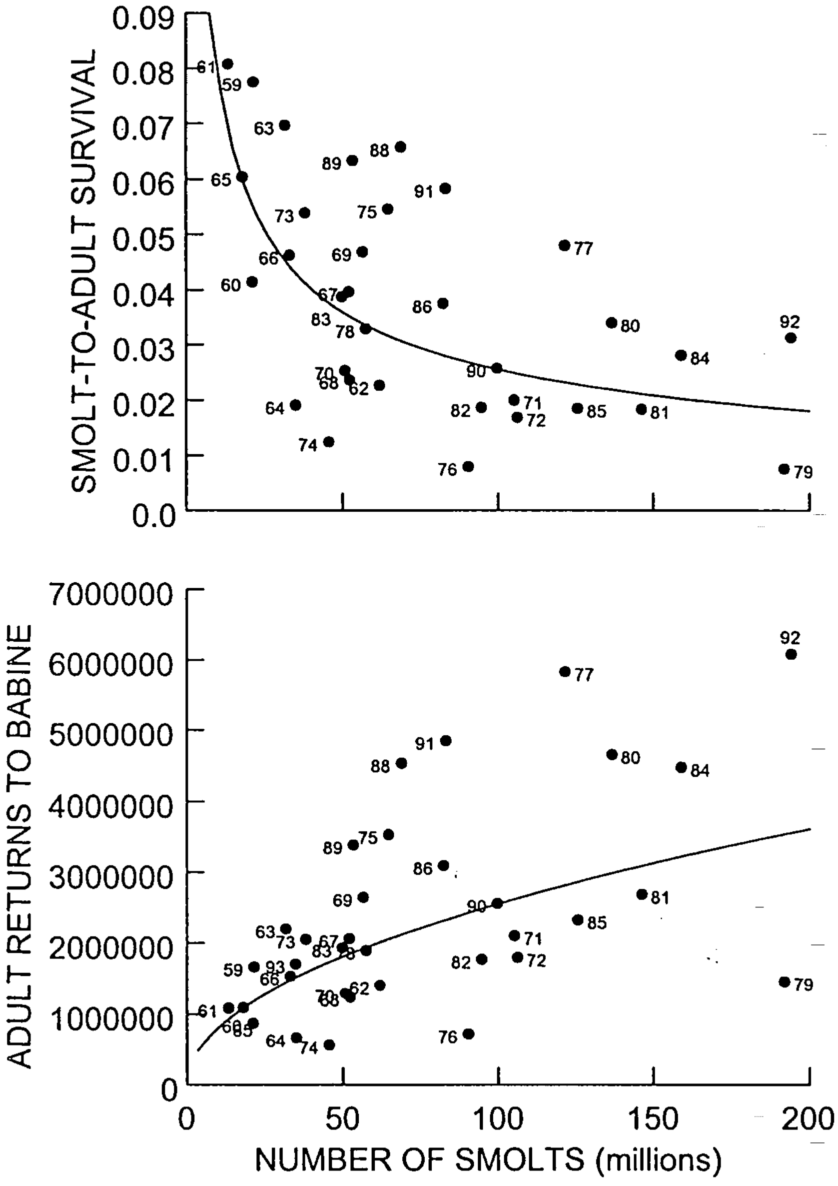

SMOLT WEIGHT(g)
SMOLT BIOMASS (g)
LATE-MIGRANT SMOLT ABUNDANCE
0
50000000
100000000
150000000
200000000
1200000000
1000000000
800000000
600000000
400000000
200000000
3
4
5
6
7

Figure 12.



SMOLT-TO-ADULT SURVIVAL
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.0
ADULT RETURNS TO BABINE
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
50
100
150
200
NUMBER OF SMOLTS (millions)

Figure 13.

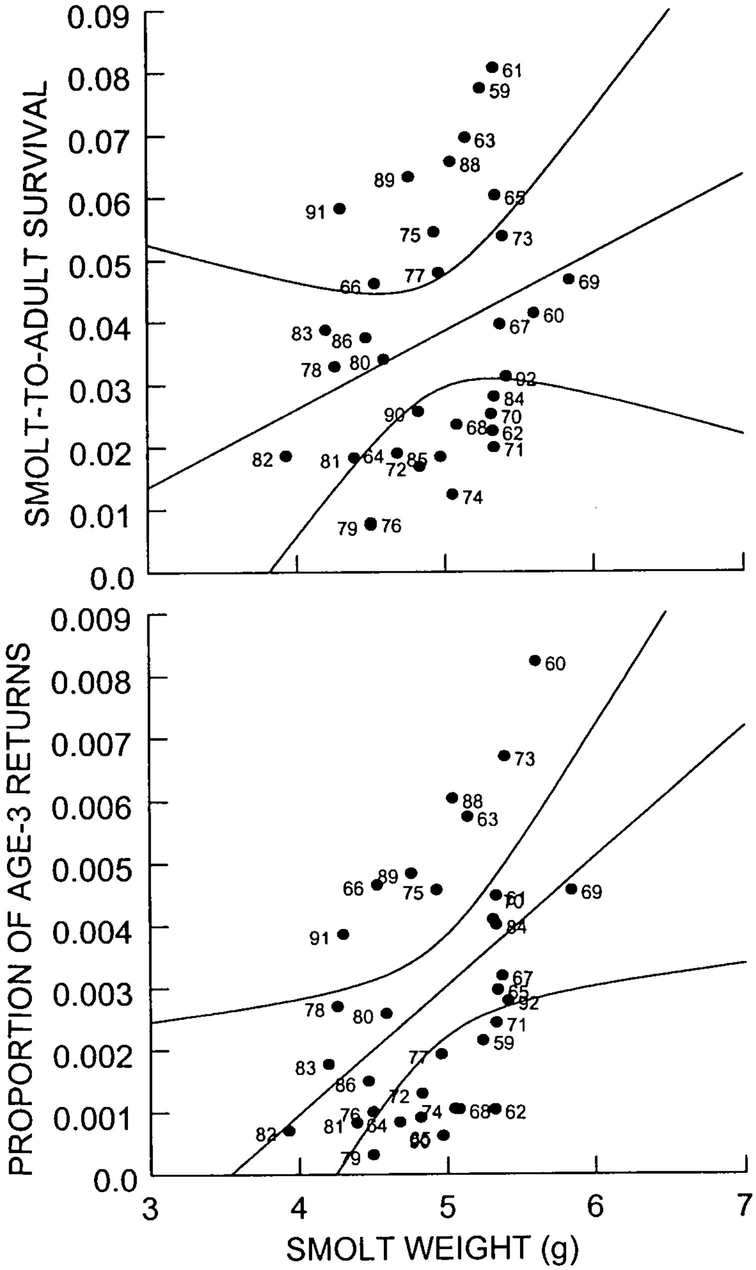

SMOLT-TO-ADULT SURVIVAL
PROPORTION OF AGE-3 RETURNS
SMOLT WEIGHT (g)

Figure 14.

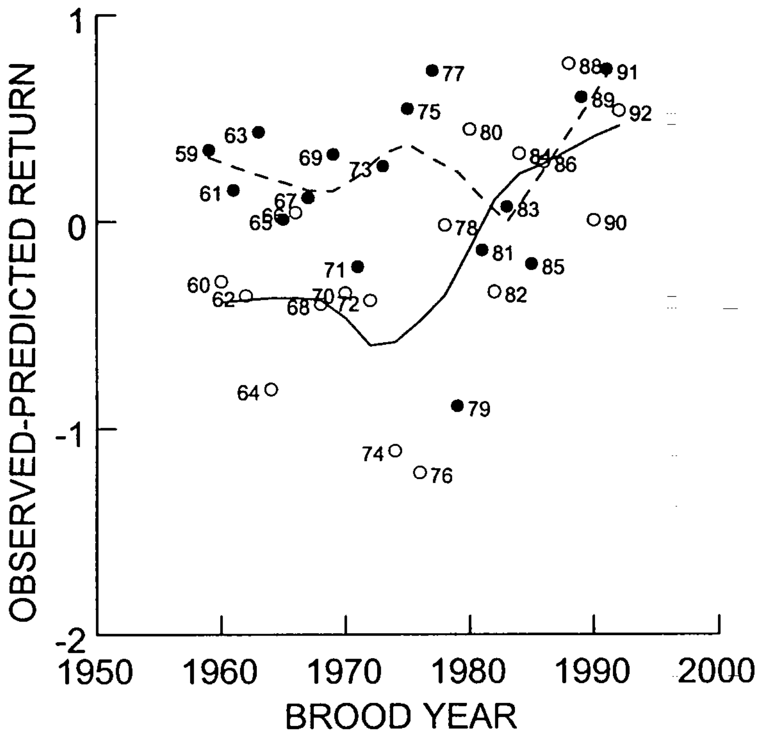

OBSERVED-PREDICTED RETURN
BROOD YEAR
1
0
-1
-2
1950
1960
1970
1980
1990
2000
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
88
89
90
91
92

Figure 15.

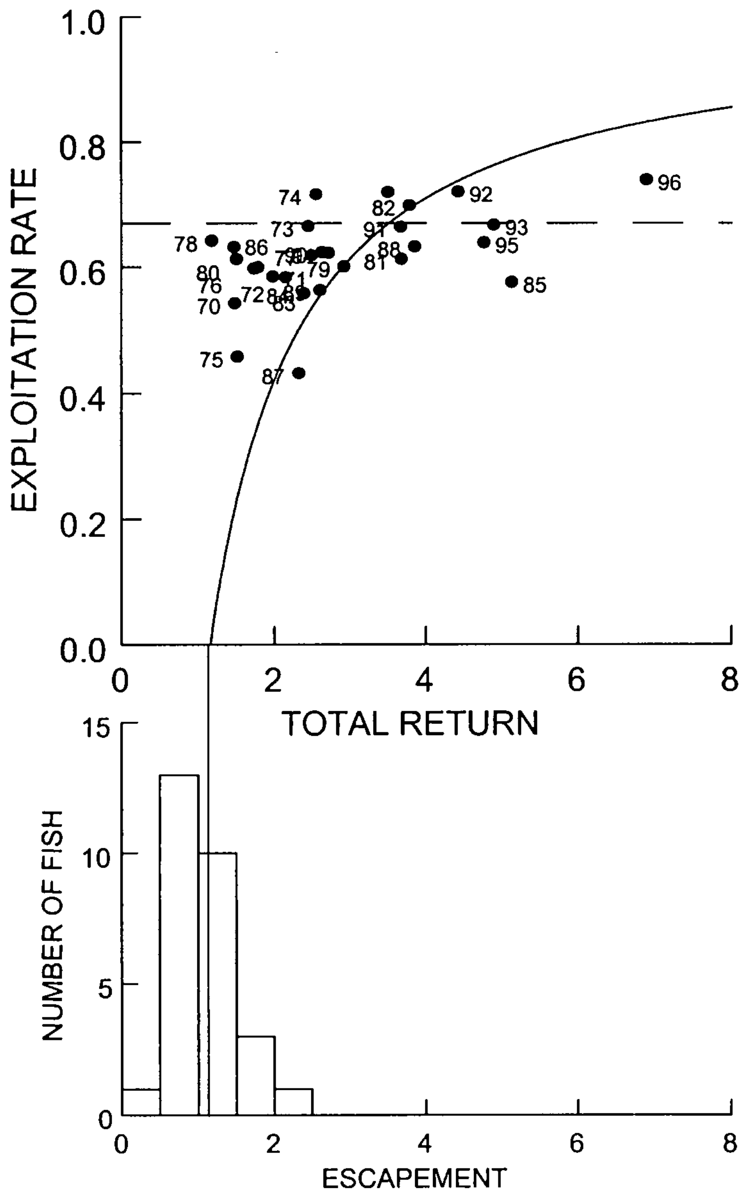
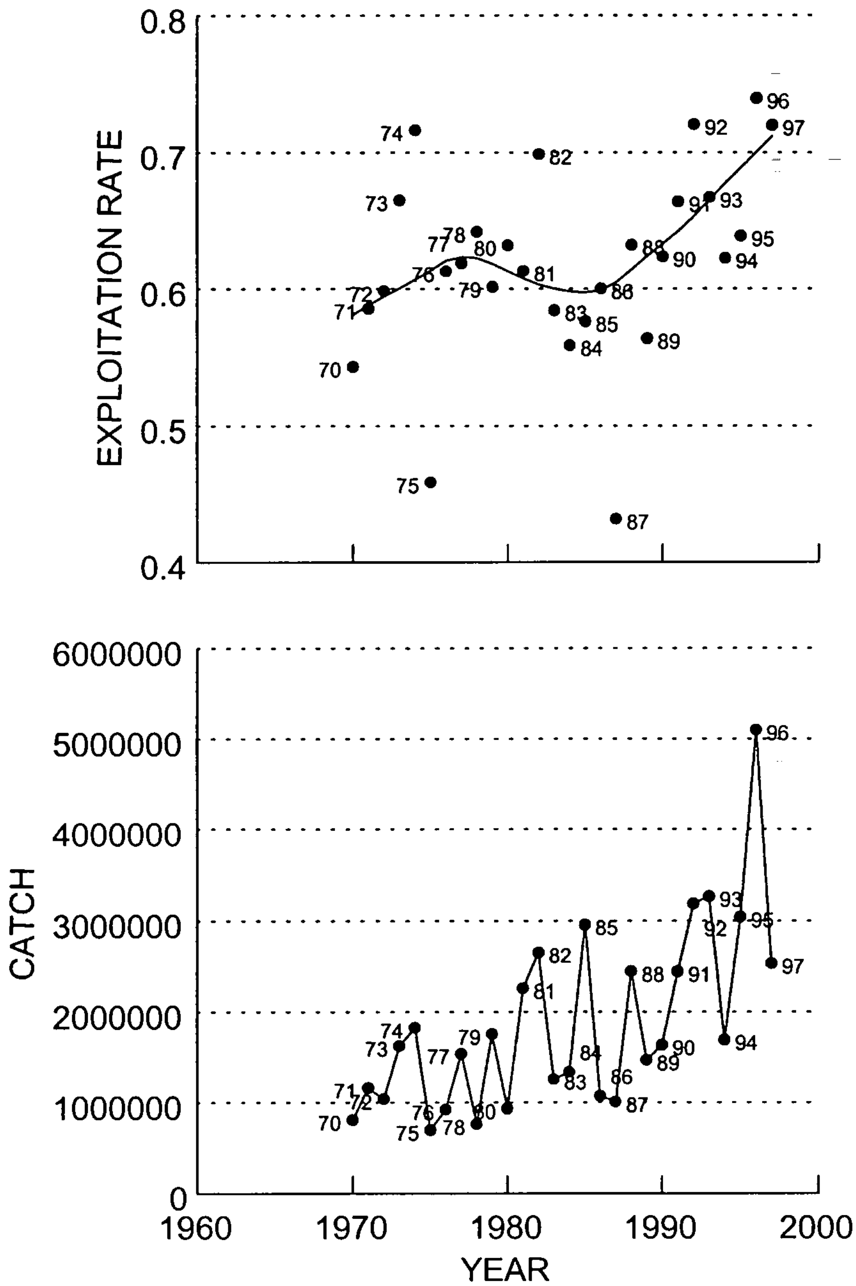

1.0
0.8
0.6
0.4
0.2
0.0
EXPLOITATION RATE
0
2
4
6
8
TOTAL RETURN
74
82
92
96
73
97
93
78
86
88
95
80
79
81
76
70
85
75
87
15
10
5
0
NUMBER OF FISH
ESCAPEMENT

Figure 16.



EXPLOITATION RATE
0.8
0.7
0.6
0.5
0.4
CATCH
6000000
5000000
4000000
3000000
2000000
1000000
0
1960
1970
1980
1990
2000
YEAR

Figure 17.

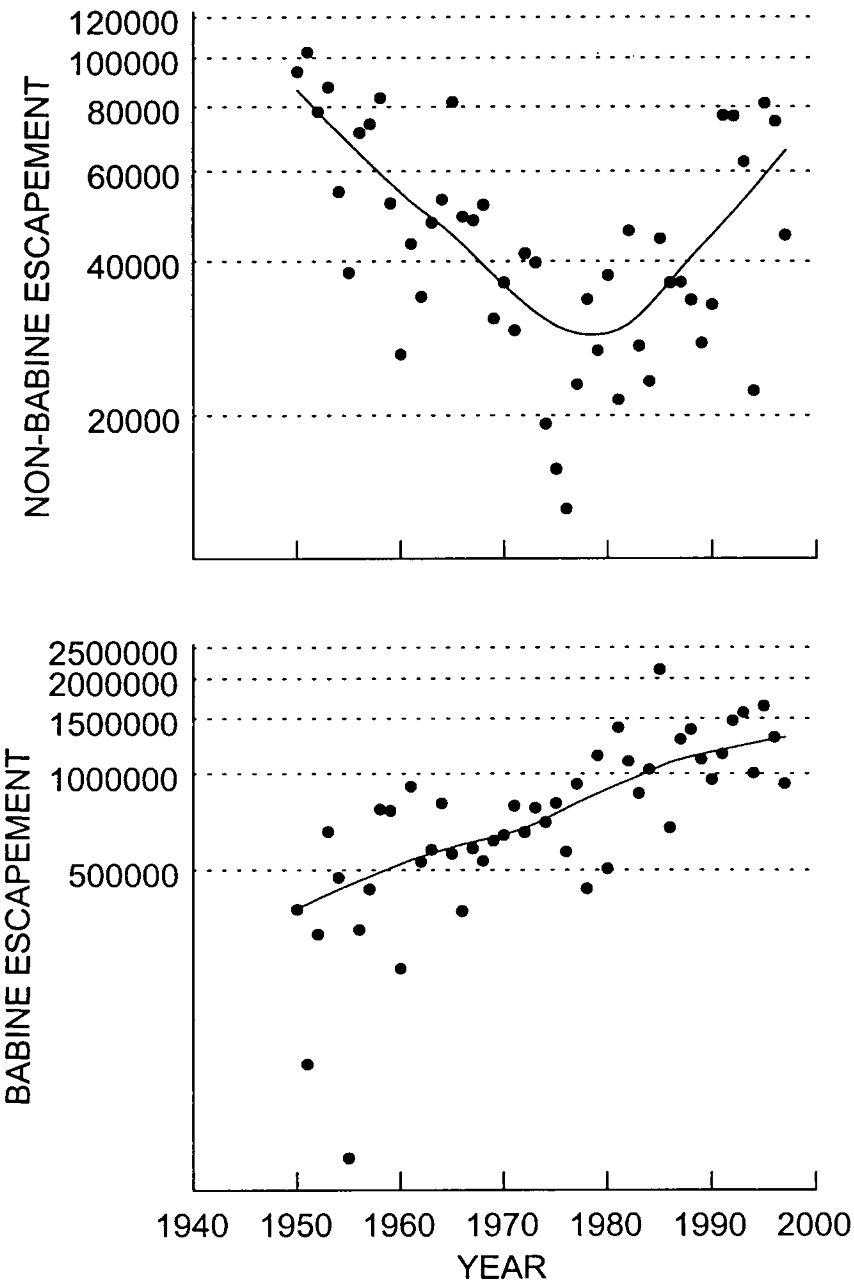

120000
100000
80000
60000
40000
20000
NON-BABINE ESCAPEMENT
2500000
2000000
1500000
1000000
500000
BABINE ESCAPEMENT
1940
1950
1960
1970
1980
1990
2000
YEAR

Figure 18.

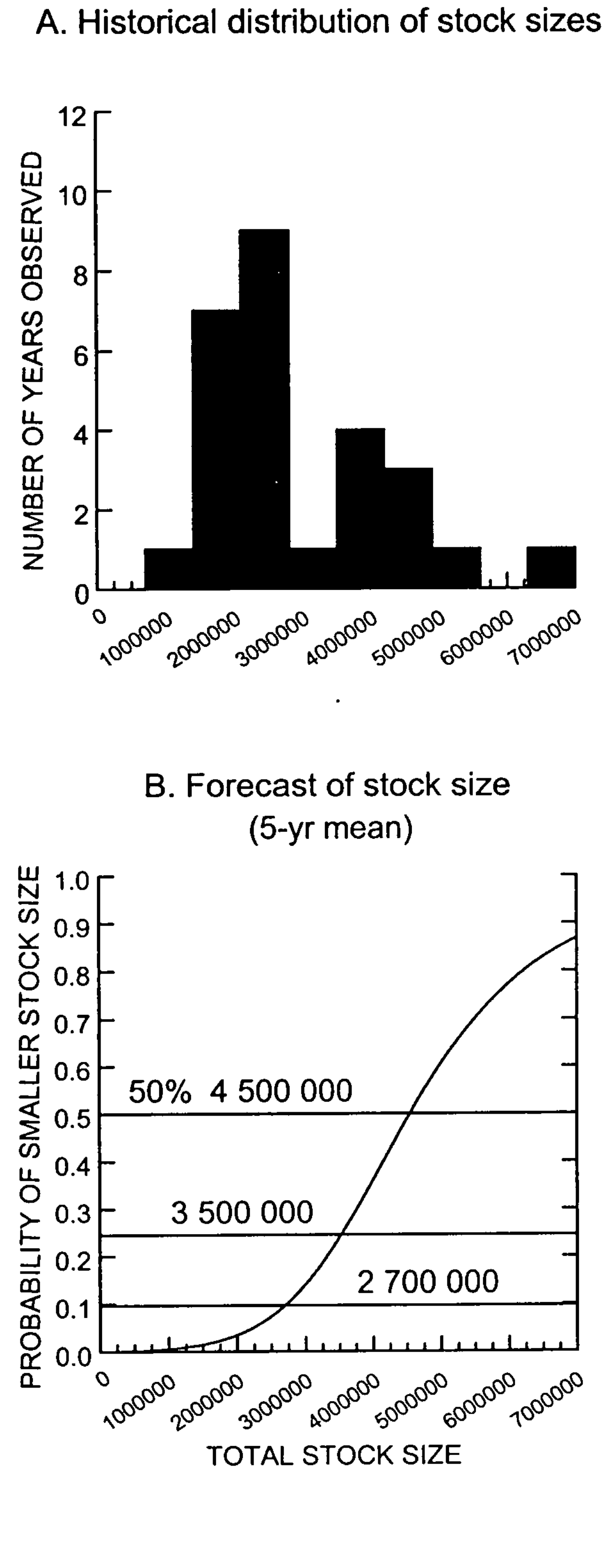

A. Historical distribution of stock sizes
NUMBER OF YEARS OBSERVED
12
10
8
6
4
2
0
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
B. Forecast of stock size
(5-yr mean)
PROBABILITY OF SMALLER STOCK SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
50% 4 500 000
3 500 000
2 700 000
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
TOTAL STOCK SIZE

Figure 19.

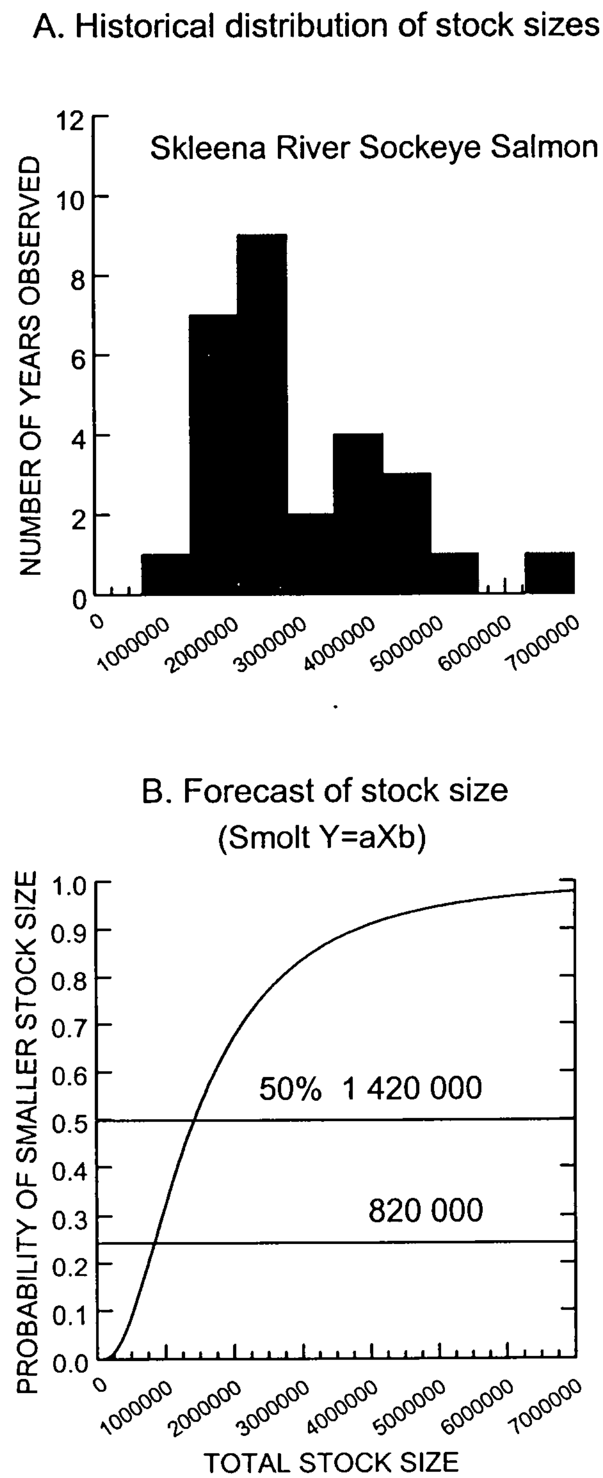

A. Historical distribution of stock sizes
Skleena River Sockeye Salmon
NUMBER OF YEARS OBSERVED
12
10
8
6
4
2
0
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
B. Forecast of stock size
(Smolt Y=aXb)
PROBABILITY OF SMALLER STOCK SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
50% 1 420 000
820 000
TOTAL STOCK SIZE

Figure 20.

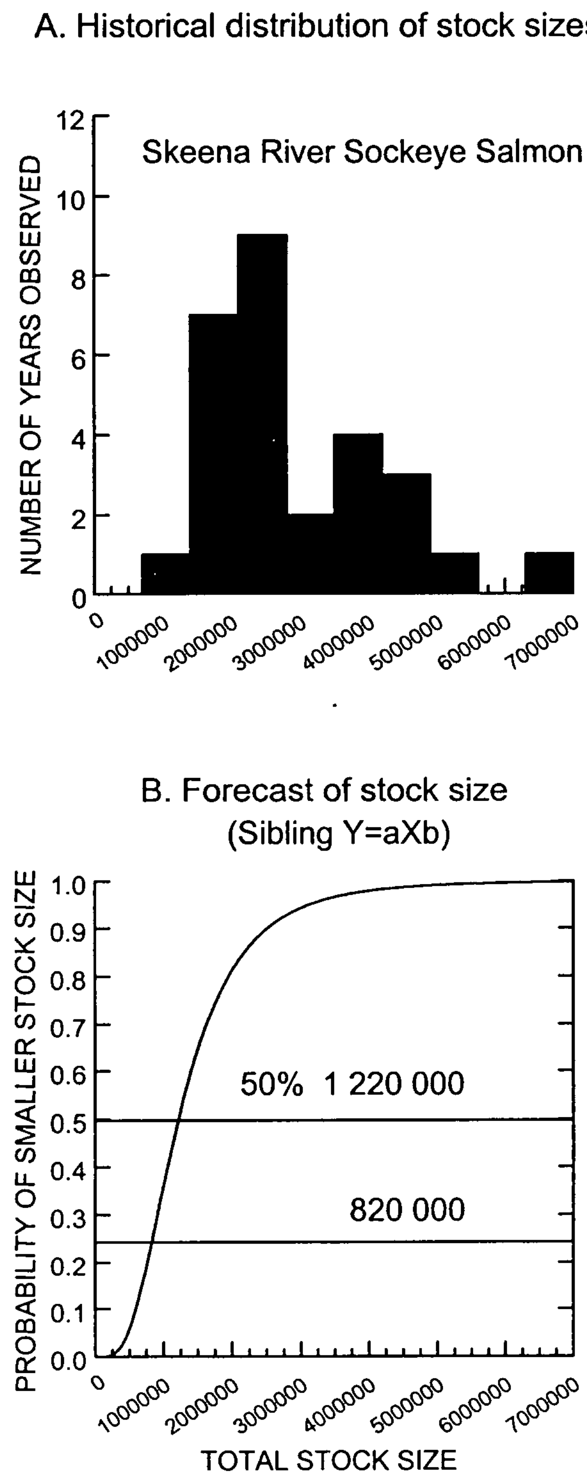

A. Historical distribution of stock sizes
Skeena River Sockeye Salmon
NUMBER OF YEARS OBSERVED
0
2
4
6
8
10
12
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
B. Forecast of stock size
(Sibling Y=aXb)
PROBABILITY OF SMALLER STOCK SIZE
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
50% 1 220 000
820 000
TOTAL STOCK SIZE

Figure 21.

Appendix 1. Babine Lake sockeye escapements (unadjusted) 1950-1996 with averages by decade (source: B. Spilsted DFO, Prince Rupert)

Stream	Timing	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	Average
Babine Fence Count		364,356	141,415	349,011	686,586	493,677	71,352	355,345	433,149	812,050	782,868	448,981
Unenhanced Spawning Sites												
Babine R. (Sec 1-3)	late	130,000	20,000	62,000	150,000	140,000	15,500	70,000	130,000	160,000	165,000	104,250
Babine R. (Sec 4)	late	145,000	12,000	100,000	130,000	100,000	15,000	55,000	70,000	110,000	130,000	86,700
Babine R. (Sec 5)	early											
Babine Lake	early											
Boucher Creek	early			400	4,000	400						1,600
Donalds Creek	early				300	300			200		800	400
Five-Mile Creek	early		111		300	2,000	100		200		600	552
Fork Creek	early										600	600
Four-Mile Creek	early	4,664	927	192	2,000	2,200	400	400	2,500	7,000	5,400	2,568
Hazelwood Creek	early											
Kew Creek	early				100	300					400	267
Morrison Creek	mid	9,800	2,200	400	16,000	12,000	600	18,000	20,000	9,000	22,000	11,000
Nichyeskwa R	early											
Nilkwitka R.	early											
Nine-Mile Creek	early	978	407	75	2,500	1,000	50		4,000		2,400	1,426
Pendelton Creek	early	1,341			1,500	1,100			300		2,500	1,348
Pierre Creek	early	17,920	12,460	3,500	20,000	17,000	4,000	20,000	23,000	80,000	34,000	23,188
Shass Creek	early	2,697	2,333	2,500	6,000	3,100	500	5,000	7,000	30,000	14,000	7,313
Six-Mile Creek	early	1,225			2,663	1,800	100	50	600	2,500	3,500	1,555
Sockeye Creek	early	900	786		600	900	500		2,500	2,000	4,000	1,523
Sutherland Creek	early											
Tachek Creek	early	2,055	2,600		2,500	1,900	300		6,771	3,000	6,000	3,141
Tahlo Creek	mid		1,000	450	10,000	12,000	1,200	11,000	9,000	10,000	12,500	7,461
Tahlo Creek (upper)	mid		1,200	400					1,500		2,500	1,400
Telzato Creek	early										900	900
Tsezakwa Creek	early										400	400
Twain Creek	early	8,081	5,020	827	10,000	14,000	2,500	5,000	6,000	20,000	9,000	8,043
Wright Creek	early										800	800
Total Wild		324,661	61,044	170,744	358,463	310,000	40,750	184,450	283,571	433,500	417,300	258,448
Enhanced Spawning Sites												
Fulton Channel #1	mid											
Fulton Channel #2	mid											
Fulton Above Weir	mid	50,000	19,000	35,000	140,000	110,000	17,000	80,000	120,000	90,000	120,000	78,100
Fulton Below Weir	mid											
Pinkut Channel	mid											
Pinkut Above Weir	mid		5,779	7,500	24,000	25,000	4,000	24,000	30,000	45,000	80,000	27,253
Pinkut Airlift	mid											
Pinkut Below Weir	mid											
Total Enhanced		50,000	24,779	42,500	164,000	135,000	21,000	104,000	150,000	135,000	200,000	102,628
Harvest at or Above Weir		27,449	19,007	34,404	26,913	21,847	10,423	30,582	20,434	38,580	16,727	24,637
Uncounted			36,585	101,363	137,210	26,830		36,313		204,970	148,841	98,873

Appendix 1. (cont'd)

Stream	Timing	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	Average
Babine Fence Count		262,719	941,711	547,995	588,000	827,437	580,000	389,000	602,807	552,000	634,000	592,567
Unenhanced Spawning Sites												
Babine R. (Sec 1-3)	late	41,000	200,000	210,000	141,450	250,000	120,000	70,000	135,000	185,000	178,000	153,045
Babine R. (Sec 4)	late	60,000	175,000	75,000	55,350	48,000	120,000	114,000	55,000	37,000	60,000	79,935
Babine R. (Sec 5)	early						2,000					2,000
Babine Lake	early											
Boucher Creek	early											
Donalds Creek	early					800						800
Five-Mile Creek	early		500	50		50	150	150	100	50	400	181
Fork Creek	early											
Four-Mile Creek	early	2,000	2,000	3,000	3,690	2,064	1,400	1,500	4,000	4,000	4,500	2,815
Hazelwood Creek	early											
Kew Creek	early											
Morrison Creek	mid	6,000	18,000	9,000	32,500	16,000	5,000	9,000	14,000	35,000	12,250	15,675
Nichyeskwa R	early											
Nilkwitka R.	early				400	200		50			400	263
Nine-Mile Creek	early	2,000	4,000	500	1,230	1,500	500	1,000	1,000	600	1,110	1,344
Pendelton Creek	early			200		1,400						800
Pierre Creek	early	11,000	55,000	4,500	36,900	22,000	10,000	11,000	40,000	25,000	25,000	24,040
Shass Creek	early	12,000	30,000	5,000	14,760	8,000	5,000	6,000	3,000	7,500	9,000	10,026
Six-Mile Creek	early	1,000		1,000	1,845	1,500	100	300	1,200	1,000	300	916
Sockeye Creek	early	2,000		1,100	3,075	1,500	50	1,400	700	1,200	2,140	1,463
Sutherland Creek	early											
Tachek Creek	early	2,000		600	1,600	3,000	700	300	1,000	500	2,350	1,339
Tahlo Creek	mid	5,000	7,000	4,500	24,600	10,000	3,500	2,500	1,500	11,000	10,200	7,980
Tahlo Creek (upper)	mid		2,000	25	100	1,000						781
Telzato Creek	early					350					100	225
Tsezakwa Creek	early		200									200
Twain Creek	early	6,000	15,000	1,400	14,760	9,000	3,000	2,500	10,000	12,000	16,660	9,032
Wright Creek	early											
Total Wild		150,000	508,700	315,875	332,260	376,364	271,400	219,700	266,500	319,850	322,410	308,306
Enhanced Spawning Sites												
Fulton Channel #1	mid							18,186	21,752	26,043	21,034	21,754
Fulton Channel #2	mid										23,770	23,770
Fulton Above Weir	mid	40,000	175,000	80,000	180,000	140,000	135,000	40,395	110,224	99,244	60,555	106,042
Fulton Below Weir	mid								4,000			4,000
Pinkut Channel	mid									13,479	33,745	23,612
Pinkut Above Weir	mid	30,000	47,000	30,000	65,000	90,000	23,780	21,463	31,742	6,633	7,331	35,295
Pinkut Airlift	mid											
Pinkut Below Weir	mid									2,172	2,450	2,311
Total Enhanced		70,000	222,000	110,000	245,000	230,000	158,780	80,044	167,718	147,571	148,885	158,000
Harvest at or Above Weir		16,754	30,856	18,122	20,021	19,855	18,540	18,652	18,992	19,146	17,293	19,823
Uncounted		25,965	180,155	103,998		201,418	133,280	70,654	149,597	65,433	145,812	119,590

Appendix 1. (cont'd)

Stream	Timing	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Average
Babine Fence Count		662,000	816,000	680,145	797,461	726,990	820,795	580,597	937,992	401,318	1,160,966	758,426
Unenhanced Spawning Sites												
Babine R. (Sec 1-3)	late	234,000	321,000	189,000	153,000	203,529	92,000	127,159	121,232	32,915	272,555	174,639
Babine R. (Sec 4)	late	84,000	96,000	70,000	40,000	35,000	3,000	3,000	40,351	10,895	19,770	40,202
Babine R. (Sec 5)	early											
Babine Lake	early											
Boucher Creek	early									6		6
Donalds Creek	early								400			400
Five-Mile Creek	early	300	200	47	90	500	250	60	40	16		167
Fork Creek	early											
Four-Mile Creek	early	2,500	6,000	7,370	11,000	7,256	1,750	800	8,800	6,000	6,800	5,828
Hazelwood Creek	early											
Kew Creek	early											
Morrison Creek	mid	7,200	6,000	8,000	17,200	13,755	16,000	3,600	9,000	1,500	11,200	9,346
Nichyeskwa R	early								1,600			1,600
Nilkwitka R.	early	400										400
Nine-Mile Creek	early	1,200	1,200	802	1,100	950	140	900	900	215	900	831
Pendelton Creek	early					100		1,000	600	300		500
Pierre Creek	early	44,000	14,200	25,075	60,890	42,920	20,100	2,430	10,000	4,000	11,500	23,512
Shass Creek	early	5,400	2,400	750	13,900	12,000	4,500	1,400	6,000	1,200	3,100	5,065
Six-Mile Creek	early	600	350	1,400	4,800	880	100	450	1,500	300	1,400	1,178
Sockeye Creek	early	4,800	650	650	600	3,500	2,600	1,300	1,700	1,500	800	1,810
Sutherland Creek	early				400	400				400		400
Tachek Creek	early	2,400	500	1,200	850	2,900	1,150	500	3,500	1,500	1,200	1,570
Tahlo Creek	mid		2,000	600	9,000	17,200	7,000	1,400	3,600	1,500	6,600	5,433
Tahlo Creek (upper)	mid				100	300		1,400				600
Telzato Creek	early	100										100
Tsezakwa Creek	early								200	10	20	77
Twain Creek	early	18,000	7,000	6,800	21,000	18,500	17,800	1,800	9,000	9,000	9,000	11,790
Wright Creek	early											
Total Wild		404,900	457,500	311,694	333,930	359,690	166,390	147,199	218,423	71,257	344,845	281,583
Enhanced Spawning Sites												
Fulton Channel #1	mid	25,483	24,746	21,600	25,272	12,530	14,874	16,834	19,080	10,613	21,284	19,232
Fulton Channel #2	mid	58,786	115,481	106,491	112,062	62,397	108,199	110,676	127,548	88,648	126,035	101,632
Fulton Above Weir	mid	99,789	125,869	81,387	99,975	46,709	192,670	140,561	345,403	39,042	244,568	141,597
Fulton Below Weir	mid	11,500	16,705			17,575	81,756	20,000	10,000	5,000	25,000	23,442
Pinkut Channel	mid	19,763	21,665	57,083	63,260	51,655	48,083		64,556	23,716	68,411	46,466
Pinkut Above Weir	mid	8,257	7,878	15,828	17,969	17,000	12,000	20,227	20,201	4,248	26,000	14,961
Pinkut Airlift	mid				16,654	25,542	40,107	28,965			36,334	29,520
Pinkut Below Weir	mid	958	900	1,000	2,300	2,000	5,000	1,000	5,000		5,000	2,573
Total Enhanced		224,536	313,244	283,389	337,492	235,408	502,689	338,263	591,788	171,267	552,632	355,071
Harvest at or Above Weir		20,048	23,450	24,283	17,015	22,318	13,896	18,157	10,777	10,920	21,500	18,236
Uncounted		12,916	21,806	60,779	109,024	109,574	137,820	76,978	118,604	147,874	241,989	103,736

Appendix 1. (cont'd)

Stream	Timing	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Average
Babine Fence Count		526,259	1,432,734	1,136,835	886,393	1,052,385	2,148,044	701,507	1,307,852	1,408,879	1,132,316	1,173,320
Unenhanced Spawning Sites												
Babine R. (Sec 1-3)	late	150,640	70,000	94,647	74,000	158,986	500,000	120,000	175,000	185,000	100,000	162,827
Babine R. (Sec 4)	late	8,175	20,000	34,300	7,000	5,787	14,000	14,000	17,500	11,500	5,000	13,726
Babine R. (Sec 5)	early											
Babine Lake	early											
Boucher Creek	early								N/I	N/I	N/I	
Donalds Creek	early				100			0	50	50	N/O	50
Five-Mile Creek	early	4		150	100	20	150	0	30	0	N/I	57
Fork Creek	early											
Four-Mile Creek	early	3,600	6,500	15,000	4,200	2,300	5,000	3,000	2,000	1,200	500	4,330
Hazelwood Creek	early	50						N/I	N/I	N/I	N/I	50
Kew Creek	early											
Morrison Creek	mid	4,000	5,000	3,500	4,500	2,500	7,000	2,500	9,000	12,000	3,000	5,300
Nichyeskwa R	early	1,000	300					N/I	N/I	N/I	N/I	650
Nilkwitka R.	early	6						N/I	200	50	N/O	85
Nine-Mile Creek	early	750	500	1,000	400	1,000	1,850	500	1,500	200	300	800
Pendelton Creek	early	25	600	5,500	150	100	850	550	700	600	80	916
Pierre Creek	early	3,750	10,000	20,000	7,500	12,650	23,000	7,700	11,500	12,500	6,750	11,535
Shass Creek	early	3,000	6,000	4,500	1,500	950	12,000	2,000	5,150	12,000	2,600	4,970
Six-Mile Creek	early	1,300	800	6,000	950	200	700	1,500	300	250	10	1,201
Sockeye Creek	early	3,100	1,500	2,500	500	40	2,000	50	600	600	30	1,092
Sutherland Creek	early	500						N/I	350		N/I	425
Tachek Creek	early	950	700	4,000	400	100	800	600	1,100	500	14	916
Tahlo Creek	mid	5,000	700	400	2,500	4,000	7,200	600	3,800	7,000	3,100	3,430
Tahlo Creek (upper)	mid						N/O	N/I	N/O	50	N/O	50
Telzato Creek	early							N/I				
Tsezakwa Creek	early	UNK	N/I	N/I	N/I	N/I	N/I					
Twain Creek	early	7,500	10,000	17,000	5,400	4,000	16,000	5,600	7,500	6,500	4,300	8,380
Wright Creek	early									10		10
Total Wild		193,350	132,600	208,497	109,200	192,633	590,550	158,600	236,280	250,010	125,684	219,740
Enhanced Spawning Sites												
Fulton Channel #1	mid	8,550	20,795	16,845	21,712	16,655	17,208	13,640	16,438	13,685	16,032	16,156
Fulton Channel #2	mid	64,100	144,969	115,507	164,810	109,803	104,340	85,696	102,471	104,301	115,315	111,131
Fulton Above Weir	mid	42,558	175,302	221,714	156,552	210,022	200,312	86,100	136,239	200,000	150,000	157,880
Fulton Below Weir	mid	6,000	100,000	45,000	5,000	10,000	300,000	5,000	10,000	200,000	100,000	78,100
Pinkut Channel	mid	41,655	79,847	55,085	94,520	69,500	76,377	51,800	74,076	58,382	66,800	66,804
Pinkut Above Weir	mid	15,000	25,541	25,000	25,195	19,566	19,235	20,378	20,266	24,429	24,501	21,911
Pinkut Airlift	mid		90,753	22,399		45,849	50,787	30,798	88,139	45,956	12,819	48,438
Pinkut Below Weir	mid	1,000	60,000	50,000	5,000	150,000	300,000	50,000	350,000	150,000	20,000	113,600
Total Enhanced		178,863	697,207	551,550	472,789	631,395	1,068,259	343,412	797,629	796,753	505,467	604,332
Harvest at or Above Weir		22,635	30,300	42,000	20,000	20,500	17,500	23,500	20,296	25,000	22,000	24,373
Uncounted		132,417	572,927	334,788	284,404	207,857	471,735	175,995	253,847	337,166	479,165	325,030

Appendix 1. (cont'd)

Stream	Timing	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	AVERAGE
Babine Fence Count		978,646	1,176,318	1,233,785	1,737,426	1,052,905	1,737,009	2,056,205				1,424,613
Unenhanced Spawning Sites												
Babine R. (Sec 1-3)	late	150,000	350,000	500,000	475,000	100,000	50,000	100,000				246,429
Babine R. (Sec 4)	late	10,000	5,000	5,000	15,000	5,000	5,000	15,000				8,571
Babine R. (Sec 5)	early		N/I		N/I	UNK	500	500				500
Babine Lake	early			5,000				N/I				5,000
Boucher Creek	early	N/I	N/I	100	UNK	50	50	20				55
Donalds Creek	early	N/O	12	N/O	N/I	0	0	N/O				4
Five-Mile Creek	early	N/I	N/I	60	N/O	30	100	350				135
Fork Creek	early					N/I		N/I				
Four-Mile Creek	early	1,800	3,500	2,500	UNK	2,000	9,300	9,500				4,767
Hazelwood Creek	early	N/I	N/I	N/I	N/I	N/I	N/I	N/I				
Kew Creek	early					N/I		N/I				
Morrison Creek	mid	4,500	13,000	4,800	6,000	6,000	3,900	5,100				6,186
Nichyeskwa R	early	N/I	N/I		N/I	10	N/O	N/I				10
Nilkwitka R.	early	N/O	N/O		N/O	N/I	200	215				208
Nine-Mile Creek	early	N/I	N/I	4,400	200	500	1,800	2,100				1,800
Pendelton Creek	early	200	400	1,100	UNK	100	0	650				408
Pierre Creek	early	4,300	25,000	18,000	UNK	7,000	26,000	16,500				16,133
Shass Creek	early	2,500	8,100	2,000	3,000	2,500	10,000	N/I				4,683
Six-Mile Creek	early	230	300	N/O	UNK	40	700	1,343				523
Sockeye Creek	early	N/O	320	2,700	3,500	30	3,000	3,500				2,175
Sutherland Creek	early	N/I	900	N/I	N/I	UNK	UNK	N/I				900
Tachek Creek	early	130	156	2,500	7,000	300	2,000	2,000				2,012
Tahlo Creek	mid	1,450	7,500	2,500	12,000	N/I	1,287	1,300				4,340
Tahlo Creek (upper)	mid	N/O	N/O	N/O	75	N/I		N/I				75
Telzato Creek	early					N/I		N/I				
Tsezakwa Creek	early				N/I	50	200	800				350
Twain Creek	early	8,000	9,500	7,000	UNK	7,000	9,200	11,000				8,617
Wright Creek	early					N/I		N/I				
Total Wild		183,110	423,688	557,660	521,775	130,610	123,237	169,878				301,423
Enhanced Spawning Sites												
Fulton Channel #1	mid	16,181	12,409	14,577	21,129	18,200	23,144	13,811				17,064
Fulton Channel #2	mid	108,108	97,010	122,021	102,125	188,700	180,004	133,975				133,135
Fulton Above Weir	mid	172,904	52,068	178,144	164,173	164,600	222,749	207,780				166,060
Fulton Below Weir	mid	150,000	20,000	250,000	100,000	125,000	200,000	400,000				177,857
Pinkut Channel	mid	69,715	84,339	79,009	85,243	88,377	91,881	99,320				85,412
Pinkut Above Weir	mid	25,047	25,924	35,221	34,773	27,421	25,050	33,676				29,587
Pinkut Airlift	mid	16,678	32,249	37,325	54,677	27,325	44,221	44,384				36,694
Pinkut Below Weir	mid	60,000	250,000	200,000	200,000	15,151	225,000	250,000				171,450
Total Enhanced		618,633	573,999	916,297	762,120	654,774	1,012,049	1,182,946				817,260
Harvest at or Above Weir		22,000	20,800	73,879	177,590	48,465	98,592	352,234				113,366
Uncounted		154,903	157,831		275,941	219,066	503,831	351,458				277,172

Appendix 2. Enhanced sockeye fry production (millions) from Fulton River and Pinkut Creek Projects by brood year.

	Fulton River Project						Pinkut Creek Project						
Brood Year	Above Fence	Below[a] Fence	River Total	Channel One	Channel Two	Total	Above Fence	Below[b] Fence	River Total	Channel	Airlift	Total	BLDP Total
1966	24.0		24.0	25.5		49.5			3.7			3.7	53.2
1967	27.8	1.0	28.8	16.0		44.8			2.7			2.7	47.5
1968	38.7	0.0	38.7	24.7		63.4	1.4	0.5	1.9	10.4		12.3	75.7
1969	11.2	0.0	11.2	5.9	25.4	42.5	1.3	0.5	1.8	15.2		17.0	59.5
1970	34.9	4.0	38.9	13.4	37.3	89.6	3.0	0.3	3.3	22.0		25.3	114.9
1971	27.4	3.6	31.0	20.0	82.2	133.2	2.0	0.2	2.2	16.7		18.9	152.1
1972	33.4	0.0	33.4	23.2	69.9	126.5	2.8	0.2	3.0	29.0		32.0	158.5
1973	27.5	0.0	27.5	15.0	75.0	117.5	2.7	0.4	3.1	24.1	6.0	33.2	150.7
1974	20.1	7.6	27.7	15.0	48.5	91.2	2.7	0.3	3.0	8.3	4.6	15.9	107.1
1975	31.9	9.9	41.8	12.7	68.6	123.1	1.8	0.8	2.6	22.3	6.6	31.5	154.6
1976	43.9	6.1	50.1	17.9	141.8	209.8	7.7	0.4	8.1		10.9	19.0	228.8
1977	32.1	0.9	33.0	14.3	84.0	131.3	5.3	1.3	6.6	53.6		60.2	191.5
1978	29.8	3.8	33.6	8.3	62.8	104.7	3.5	0.0	3.5	15.1		18.6	123.3
1979	27.9	2.9	30.8	9.0	91.5	131.3	7.3	1.4	8.7	47.5	9.5	65.7	197.0
1980	28.4	3.9	32.3	8.0	68.4	108.7	10.0	0.8	10.8	42.2		53.0	161.7
1981	46.0	18.5	64.5	12.3	53.3	130.1	6.1	1.9	8.0	57.7	21.6	87.3	217.4
1982	35.8	7.3	43.1	9.6	54.0	106.7	9.5	1.9	11.4	68.0	8.8	88.2	194.9
1983	37.4	1.2	38.6	5.9	14.0	58.5	6.3	1.3	7.6	49.9		57.5	116.0
1984	39.4	1.9	41.3	9.3	99.9	150.5	12.8	1.5	14.3	46.6	8.7	69.6	220.1
1985	43.5	10.1	53.6	5.2	83.4	142.2	4.5	0.0	4.5	35.9	8.7	49.1	191.3
1986	38.1	2.2	40.3	7.6	96.9	144.8	11.9	2.5	14.4	44.7	15.4	74.4	219.2
1987	11.6	0.8	12.4	2.8	44.3	59.5	10.7	0.5	11.2	19.1	14.8	45.0	104.5
1988	19.5	7.4	26.9	4.4	121.6	152.9	5.3	0.7	6.0	25.5	12.5	44.0	196.9
1989	23.3	10.1	33.4	12.0	87.1	132.5	5.2	0.5	5.7	11.2	9.2	26.1	158.6
1990	34.0	9.8	43.8	15.8	118.7	178.3	13.9	0.5	14.4	45.1	2.6	62.0	240.3
1991	15.1	5.8	20.9	13.4	82.8	117.1	3.3	1.3	4.6	40.3	10.7	55.6	172.6
1992	26.8	7.5	34.3	4.6	91.5	130.4	4.7	1.3	6.0	62.5	16.2	84.8	215.1
1993	33.7	15.8	49.5	3.7	76.9	130.1	4.2	1.0	5.2	25.1	12.3	42.6	172.7
1994	12.8	12.5	25.3	15.1	36.6	77.0	5.6	0.8	6.4	29.0	5.6	47.4	124.4
1995	21.9	12.5	34.4	4.7	22.1	61.2	3.7	0.8	4.5	17.6	6.5	33.1	94.3
1996	33.6	12.5	46.1	12.0	117.7	175.8	2.1	0.8	2.9	46.8	4.0	56.5	232.3

[a] maximum 12.5 million fry based on 25,000 females at 3080 eggs per female and 16.2 % egg-to-fry survival (data from above fence in 1984-1993)
[b] maximum 0.8 million fry based on 2,500 females at 3080 eggs per female and 10.4% egg-to-fry survival (data from above fence in 1984-1993)

Appendix 3. Escapements, total stock sizes and exploitation rate by calendar year

Year	Skeena Escapement	Skeena Sockeye Stock Size Age 3	Age 4	Age 5	Other	Total	Exploitation Rate	Babine Stock Size
1970	678652	166000	925392	453946	106905	1652243	0.54	1503619
1971	821850	54600	1129289	758599	95334	2037822	0.59	1839500
1972	697237	258700	420678	1231737	83201	1994317	0.60	1820755
1973	820196	208350	1153052	1057572	237767	2656740	0.67	2411901
1974	723898	256772	831757	1628184	92115	2808829	0.72	2553623
1975	822633	137396	1127097	364197	27455	1656145	0.46	1504270
1976	575590	255458	548679	924801	31281	1760219	0.62	1609743
1977	951805	47697	1131537	1293885	71222	2544341	0.62	2294677
1978	424075	296274	263777	864870	55652	1480573	0.64	1362143
1979	1166236	90509	2498508	313432	112656	3015104	0.60	2722645
1980	542164	233886	288034	1092804	92271	1706995	0.63	1559684
1981	1424509	155395	3177365	411161	91119	3835040	0.61	3467076
1982	1140737	60223	621563	3039052	124433	3845271	0.70	3466766
1983	893724	353135	755494	1310373	83927	2502929	0.58	2287950
1984	1055215	120752	1451716	788985	151587	2513040	0.56	2273811
1985	2174806	66714	1733185	3323273	76072	5199244	0.58	4685991
1986	716312	88125	611270	1116550	57854	1873799	0.60	1695232
1987	1324128	638641	977637	1276820	74940	2968038	0.43	2735098
1988	1417543	77631	2627321	1070368	157997	3933317	0.63	3547748
1989	1137994	122711	871807	1630157	107649	2732324	0.56	2471363
1990	989566	89631	817553	1627596	183654	2718434	0.62	2455554
1991	1232568	416049	887664	2480221	300839	4084773	0.66	3717901
1992	1550109	258240	1671873	2020415	731657	4682185	0.65	4239791
1993	1629426	90580	1598624	2895397	400844	4985445	0.67	4495959
1994	1026816	320804	646101	1873677	199919	3040500	0.62	2768530
1995	1720292	542895	2286244	2099914	377430	5306482	0.64	4830123
1996	1782357	43000	3701513	2740730	449405	6934647	0.74	6245482

Appendix 4. Babine sockeye fence counts and adult returns by brood year.

Brood	Fence	Adult Returns			
Year	Count	Age 3	Age 4	Age 5	Total
1950	364356	28000	469257	148222	645479
1951	141415	10000	46463	67201	123665
1952	349011	31000	434217	200633	665850
1953	686586	18000	506219	799712	1323932
1954	493677	50000	603269	695721	1348990
1955	71352	31000	214794	126156	371950
1956	355345	32000	309078	318483	659561
1957	433149	49000	1410864	566607	2026471
1958	812050	28000	463162	148568	639729
1959	782868	46000	547639	1064682	1658321
1960	262719	173000	416160	281810	870970
1961	941711	60000	584313	437073	1081387
1962	547995	64000	490567	846472	1401038
1963	588000	182000	877467	1143762	2203229
1964	827437	29300	179053	459616	667969
1965	580000	53400	671660	362169	1087229
1966	389000	154000	740532	633713	1528244
1967	602807	166000	936606	960300	2062906
1968	552000	54600	332547	848039	1235187
1969	634000	258700	1034572	1354501	2647773
1970	662000	208350	748582	327777	1284709
1971	816000	256772	1014387	832321	2103481
1972	680145	137396	493811	1164496	1795703
1973	797461	255458	1018383	778383	2052224
1974	726990	47697	237400	282088	567185
1975	820795	296274	2248657	983524	3528455
1976	580597	90509	259230	370045	719784
1977	937992	233886	2859629	2735147	5828662
1978	401318	155395	559406	1179336	1894137
1979	1160966	60223	679944	710087	1450254
1980	526259	353135	1306544	2990945	4650624
1981	1432734	120752	1559867	1004895	2685514
1982	1136835	66714	550143	1149138	1765995
1983	886393	88125	879873	963331	1931329
1984	1052385	638641	2364589	1467142	4470372
1985	2148044	77631	784626	1464836	2327093
1986	701507	122711	735798	2232199	3090707
1987	1307852	89631	798898	1818373	2706902
1988	1408879	416049	1504686	2605857	4526592
1989	1132316	258240	1438761	1686309	3383310
1990	978646	90580	581490	1889922	2561993
1991	1176318	320804	2057619	2466657	4845080
1992	1233785	542895	3331361		
1993	1737426	43000			
1994	1052905				
1995	1737009				
1996	2056205				
1997	1086610				