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Stock Status and Lake Based Production Relationships for Wild Skeena River Sockeye Salmon

État des stocks de saumon rouge sauvage de la rivière Skeena et relations avec la production en lac

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ABSTRACT

This paper outlines stock status for wild Skeena River sockeye salmon based on updated assessments of freshwater production in nursery lakes, available catch and escapement data, and modelled exploitation rates. The aggregate stock is dominated by sockeye returning to the Babine Lake spawning channels at Pinkut and Fulton Creeks. In addition to Babine Lake, wild sockeye spawn in at least 28 other nursery lakes throughout the Skeena River drainage. Skeena River sockeye are harvested in mixed-stock marine commercial fisheries in south-southeast Alaska and northern British Columbia, in Skeena River First Nations food, social, and ceremonial fisheries, and in recreational fisheries within the Skeena River drainage. The fisheries primarily target the enhanced Babine Lake component which can withstand higher exploitation rates compared to the un-enhanced wild stocks.

Recent analyses of limnological, acoustical fall fry, and spawning ground survey data indicate that, in most cases, wild stock escapements are much too low to fully utilize lake rearing habitat and maximize smolt production. Although many lakes still require evaluation and production parameter estimates are still under review, our findings re-enforce previous assessments (Shortreed et al. 1998, 2001) concluding that the majority of Skeena nursery lakes that have been surveyed are oligotrophic, appear to be largely fry-recruitment limited (not enough spawners) and producing sockeye below potential production. In addition to recruitment limitation, some lakes are also being limited by factors such as low spawning ground capacity or quality, low in-lake growth and/or survival, nutrient limitation, glacial turbidity, and species competition. All of these factors act to reduce sockeye productivity and limit sustainable exploitation rates. Increased fry recruitment through increased escapements, combined with lake-specific restorative and/or enhancement techniques, has been suggested for improving sockeye production from non-Babine nursery lakes (Shortreed et al. 1998, 2001).

RÉSUMÉ

Ce document décrit l'état du stock de saumon rouge sauvage de la rivière Skeena selon les évaluations à jour de la production en eau douce dans les lacs de séjour, les données de capture et d'échappée et les taux d'exploitation modélisés. Le stock combiné est dominé par le saumon rouge qui remonte aux frayères du lac Babine, dans les ruisseaux Pinkut et Fulton, mais le saumon rouge sauvage fraie aussi dans au moins 28 autres lacs de séjour du réseau hydrographique de la rivière Skeena. Le saumon rouge de la rivière Skeena fait l'objet de pêches commerciales visant des stocks mélangés en mer dans le sud-est de l'Alaska et le nord de la Colombie-Britannique, de pêches autochtones à des fins alimentaires, sociales et rituelles et de pêches récréatives dans le bassin de la rivière Skeena. Ces pêches visent principalement le stock mis en valeur du lac Babine qui peut supporter des taux d'exploitation plus élevés que les stocks sauvages non mis en valeur.

Selon des analyses récentes de données de relevés limnologiques, de relevés acoustiques des alevins à l'automne et de relevés sur les frayères, les échappées des stocks sauvages sont pour la plupart bien trop faibles pour permettre la pleine utilisation de l'habitat d'alevinage et la production maximale de smolts. Bien que de nombreux lacs doivent encore être évalués et que les estimations des paramètres de production sont en train d'être examinées, nos résultats renforcent les conclusions des évaluations antérieures (Shortreed *et al.*, 1998 et 2001) selon lesquelles la plupart des lacs de séjour du bassin de la Skeena ayant fait l'objet d'un relevé sont oligotrophes, semblent largement limités par le recrutement des alevins (pas assez de géniteurs) et présentent une production inférieure à la production potentielle. En plus d'être limitée par le recrutement, la production dans certains lacs l'est aussi par des facteurs comme une faible capacité ou qualité des frayères, une faible croissance et/ou survie lacustre, des concentrations peu élevées d'éléments nutritifs, la turbidité glaciaire et la concurrence d'autres espèces. Tous ces facteurs réduisent la productivité du saumon rouge et restreignent les taux d'exploitation durable. Pour améliorer la production de saumon rouge des lacs de séjour autres que le lac Babine, Shortreed *et al.* (1998 et 2001) ont suggéré une augmentation du recrutement des alevins par des échappées accrues associées à des techniques de restauration et/ou de mise en valeur propres à chaque lac.

INTRODUCTION

This paper outlines stock status for wild Skeena River sockeye salmon based on updated assessments of freshwater production in the nursery lakes, available catch and escapement data, and modelled exploitation rates. The aggregate stock is dominated by enhanced sockeye returning to the Babine Lake spawning channels at Pinkut and Fulton Creeks. At least 90% of Skeena sockeye now originate from the Babine Lake system compared with less than 80% prior to 1970 (Wood et al.. 1998). In addition to Babine Lake, wild sockeye return to approximately 28 other nursery lakes throughout the Skeena River drainage (McKinnell and Rutherford 1994; Shortreed et al.. 1998).

In recent years, concern for wild Skeena River sockeye stocks has lead Fisheries and Oceans Canada to begin evaluating their stock status, production dynamics, and exploitation in fisheries targeting the more productive enhanced Babine Lake component. Catch and escapement data for wild Skeena sockeye are of variable quality and cannot be used to develop adult production relationships or to assess stock status beyond general impressions. An alternative approach is to estimate sockeye rearing capacity of the nursery lakes from limnological data and to determine current stock status from juvenile sockeye acoustic and trawl surveys (Hume et al.. 1996; Shortreed et al.. 1998; Shortreed et al.. 2000; Shortreed et al.. 2001).

Shortreed et al.. (1998) reported limnological and juvenile sockeye data for 10 Skeena nursery lakes. Using these data they produced estimates of the maximum number of juveniles (smolts) each lake could produce and the number of adult spawners required to produce these smolts. The estimates were generated with a habitat-based photosynthetic rate (PR) model described by Hume et al.. (1996) and updated by Shortreed et al.. (2000). Shortreed et al.. (1998) showed most Skeena nursery lakes to be oligotrophic, fry-recruitment limited, and producing sockeye below potential production. Besides recruitment limitation, a wide range of other factors were identified as limiting sockeye production from non-Babine lakes ranging from glacial turbidity (Kitsumkalum Lake) to extremely low nutrient levels (Morice Lake) to potential spawning ground limitation (Shortreed et al.. 1998, 2001).

In this paper, we provide background to the PR model and update stock status for Skeena Lakes based on PR model predictions and available adult catch and escapement data. We also present a possible method for determining stock and recruitment relationships between smolt biomass and spawning escapement using PR-model output. The production relationships developed in this paper are being used in risk assessment simulations for predicting future escapements to Skeena nursery lakes under different fishing regimes (Cox-Rogers 2003).

Overview of Skeena River Sockeye Lakes

Skeena River sockeye lakes are distributed from the coast to the high interior regions and vary in size and productivity (**Fig. 1**). The Skeena system has one very large sockeye rearing lake (Babine-Nilkitkwa) and approximately 28 smaller ones (**Table 1**). Babine Lake comprises about 67% of the total Skeena sockeye rearing area (Shortreed et al.. 1998). Babine Lake was enhanced in the late 1960's and early 1970's with the development of the Pinkut Creek and Fulton River spawning channels (West and Mason 1987). Both wild and enhanced sockeye populations rear in Babine Lake and production dynamics for both components have been extensively studied (Levy and Hall 1985; Wood et al.. 1998). Tagging studies (Smith and Jordan 1973) identified three distinct runs of sockeye into Babine Lake (early, mid, and late-timing). Wood et al.. (1998) concluded that these runs were sub-populations rather than distinct populations because they are connected by relatively high rates of gene flow. Wood et al.. (1998) provide the most recent assessment of sockeye production dynamics for Babine Lake.

In addition to Babine Lake, 10 other Skeena nursery lakes are considered important sockeye producers: Alastair, Bear, Johanson, Kitsumkalum, Kitwanga, Lakelse, Morice, Morrison, Sustut, and Swan (Shortreed et al.. 1998). These 10 lakes comprise about 29% of the total Skeena sockeye rearing area (Shortreed et al.. 1998). There are also 18 other smaller Skeena lakes that are utilised by juvenile sockeye: Aldrich, Asitka, Atna, Azuklotz, Club, Damshilgwit, Dennis, Johnston, Kluatantan, Kluayaz, McDonell, Motase, Sicintine, Stephens, Slamgeesh, Spawning, Maxan, and Bulkley. These smaller lakes comprise about 4% of the total Skeena nursery area. Several of the smaller lakes are part of larger lake systems within the same drainage watershed. The level of gene flow between the sockeye populations homing to each of these lakes is not known. Co-joined lake systems include Aldrich-Dennis-McDonnell in the Zymoetz River drainage, Azuklotz-Bear in the Bear River drainage, Atna-Morice in the Morice River drainage, Club-Stephens-Swan in the Kispiox River drainage, the Damshilgwit-Slamgeesh in the Slamgeesh River drainage, and the Morrison-Babine-Nilkitkwa in the Babine River drainage.

Skeena sockeye salmon migrate seaward from April through June predominantly as age-1 smolts having spent one full summer in the rearing lakes. Some populations have significant proportions of age-2 and some age-3 smolts (e.g. Morice Lake). Most returning adults are age-4 or age-5 and pass through southern southeast Alaska waters and into the terminal Skeena fishing areas from mid-June through late August. The stocks do not share the same migration timing and are therefore differentially impacted by fisheries primarily directed on the productive mid-late timed Babine enhanced component (peaking in the third week of July). Spawning takes place in lake tributary streams and along lake shorelines from late August through early October.

Skeena River sockeye are caught in a complex array of mixed-stock fisheries in southern southeast Alaska, northern British Columbia (Statistical Areas 1 through 5), and in First Nations food, social, and ceremonial fisheries (FSC) and escapement surplus to spawning requirement fisheries (ESSR) within the Skeena River itself. Sprout and Kadowaki (1987) provide a historical review of the marine commercial fishery and its management. The aggregate escapement goal for Skeena River sockeye salmon is 900,000 plus 150,000 for native food, social, and ceremonial purposes, although management has typically aimed to increase both escapement and exploitation when abundance is high. A daily in-season management model (Cox-Rogers 1994) is used to develop fishing plans and to manage the Area 3/4/5 fishery. In-season sockeye escapement into the Skeena River is estimated by a gillnet test fishery located at Tyee near the escapement boundary (Cox-Rogers and Jantz 1993).

METHODS AND BACKGROUND

Data Sources

All data used to generate and evaluate stock dynamics for Skeena River sockeye salmon in this working paper are either referenced in this report or come from unpublished records on file with the primary author (Steve Cox-Rogers, DFO Stock Assessment, Prince Rupert, B.C.). Catch and escapement data for Skeena River sockeye from 1951-2002 were compiled by the responsible manager (M. Potyrela, DFO, Prince Rupert, B.C. pers. comm). These data include reconstructed catches of Skeena sockeye salmon in mixed-stock fisheries in Alaska and northern British Columbia, based on updated stock reconstructions for 1982-1996 using methodology summarized by Gazey and English (1996) with updates and revisions in press (Bill Gazey, Gazey Research, pers. comm.) Reconstructed catches of Skeena sockeye from 1951-1981 are approximate and were based on application of 1982-1983 tagging data (English et al.. 1985) to annual catch estimates.

Sub-stock escapement records (e.g. B.C. 16's) for Skeena sockeye nursery lakes come from electronic files maintained by FOC stock assessment staff in Prince Rupert. Limnological and limnetic data for Skeena River nursery lakes come from published and unpublished records provided by FOC's Lake Research Unit (Ken Shortreed and Jeremy Hume, Cultus Lake, B.C.).

PHOTOSYNTHETIC RATE (PR) MODEL FOR ESTIMATING LAKE REARING CAPACITY

Predicting the production capacity for fish in a particular body of water has long been an objective of freshwater research in North America (see Leach et al.. 1987 for a review). It has relevance to management of recreational and commercial fisheries (sustainable yield) and to enhancement (amount that recruitment to a lake can be increased). There have been numerous attempts to develop empirical relationships between lake productivity and fish yield. Since a direct measure of productivity (i.e., photosynthetic rate) was not usually available, investigators used a number of other limnological variables as surrogates for PR. These included mean depth and total dissolved solids (Ryder 1965), summer average chlorophyll concentration (Oglesby 1977; Jones and Hoyer 1982), lake area (Youngs and Heimbuch 1982), euphotic zone depth (Koenings and Burkett 1987), and total phosphorus concentration (Stockner 1987; Downing et al.. 1990).

Fee (1985) and Downing et al.. (1990) reported that PR measurements were positively correlated to fish yield. Further, Downing et al.. (1990) found that PR was more closely correlated to fish yield than other variables commonly used as indices of lake productivity (chlorophyll, total phosphorus). While surrogates may be correlated to PR, using abiotic or biomass variables instead of PR in empirical relationships with fish yield will introduce additional scatter. Further, an improved understanding of energy flow between lake trophic levels is more likely when rate measurements at each trophic level are used.

The PR model (Hume et al.. 1996) was derived from the euphotic volume (EV) model (Koenings and Burkett 1987; Koenings and Kyle 1997), which was developed using data from a number of Alaskan lakes. Both models provide predictions of optimum escapement, optimum spring fry recruitment, and maximum smolt output. The EV model uses euphotic zone depth as a surrogate for productivity. In B.C. lakes euphotic zone depth is not an appropriate surrogate for productivity (Hume et al.. 1996). The PR model uses a direct measure of lake productivity (photosynthetic rate), and so is applicable to a wider range of lakes. Shortreed et al.. (2000) revised the PR model, tested the model predictions, discussed model assumptions, and presented model predictions for many B.C. lakes, including lakes of the Skeena drainage system. Shortreed et al.. (2001) reported predictions for additional Skeena River lakes.

<u>Data collection</u>

PR data used in this paper were collected from 16 lakes of the Skeena River system. Data were collected in 1978 (Stockner and Shortreed 1979), in 1994-1995 (Shortreed et al.. 1998), and in 2001-2002 (K. Shortreed and J. Hume, unpublished data). In 10 of the lakes, data were collected once monthly from May-June to October (n=5 to 6) and in the remaining six lakes PR was measured on only one occasion in late August or early September. PR data were collected using *in situ* incubations and the standard ^{14}C technique using and light and dark bottles. A detailed description of the methods used is available in Shortreed et al.. (1998). When seasonal data were available, seasonal average daily PR (PR_{mean}) in mg $C \cdot m^{-2} \cdot d^{-1}$ for each lake was computed by integrating daily PR and dividing by the length of the growing season, which we defined as May 1-October 31. Since the PR model requires an estimate of PR_{mean}, an adjustment was required when data were available for only one sampling date. Using data from a wide range of B.C. lakes, daily PR collected in late summer is related to PR_{mean} (PR_{mean} = PR x 0.748, r^2=0.60, n=113) (**Figure 2**). We applied this adjustment to estimate PR_{mean}

when data from only one sampling date were available. We calculated total seasonal PR in tonnes C/lake (PR_{total}) by multiplying PR_{mean} by the length of the growing season and by lake area.

PR Variability

Variability in annual estimates of PR_{mean} from any particular lake, or location within a lake, could be a combination of measurement error and annual variability in a number of factors such as sunlight, temperature, nutrient loading, and turbidity. In a lake in Michigan for which data are available for 14 consecutive years, annual variability in PR_{mean} was ±9% 2SE (Wetzel 2001). To calculate annual variability in PR_{mean} for B.C. lakes, we compiled data for all B.C. lakes where 3 or more years of PR_{mean} were available. There were multiple years of data for 6 lakes and a total of 24 locations within the lakes. There were 3 to 5 years of data for each location. We determined the variance in PR_{mean} for each location and the weighted mean variance for all locations (variance was weighted by years) and then calculated 2 SE's. Two SE's ranged from 3 to 44% for the individual locations while the weighted mean SE was 8.0% of the weighted mean of 123 mg $C \cdot m^{-2} \cdot d^{-1}$. In lakes where we have a full season's sampling (5-6 monthly sampling dates) we used this estimate of variability in the fishery model.

In lakes where we have only collected PR data from a single late summer sampling trip there are two sources of variance. The first is the previously mentioned variability associated with the relationship between the late summer estimate and the seasonal mean estimate. Secondly, seasonal mean PR, as shown above, also has an associated variability of 8.0% (2SE's). We are examining appropriate methods for combining these two sources of variability. As a first estimate for the purposes of this paper we used +/- 2SE’s of 20%.

Model equations

The revised PR model in Shortreed et al.. (2000) uses the following forms:

Maximum smolt biomass (kg) = 45.5 x PR_{total}
Optimum escapement (N) = 187 x PR_{total}
Maximum smolts (N) = 10,120 x PR_{total}

where:

Maximum smolt biomass (R_{max}) = Maximum number of smolts times a mean smolt weight of 4.5 g. The weight of 4.5 g was chosen because in Alaskan lakes maximum adult production occurred when smolts were 4-5 g in weight (Koenings and Burkett 1987).

Optimum escapement (S_{max}) = Number of spawners needed to maximize smolt production.

Maximum smolts = Maximum number of 4.5 g smolts a lake can produce. This was based on observed maximum production in Alaskan lakes (Koenings and Burkett 1987)

PR_{total} = Total seasonal (May-October) carbon production (metric tons).

Adjustments to model predictions

Littoral productivity *Implicit* in PR model predictions is the assumption that sockeye fry do not benefit from littoral (benthic) PR. The majority of B.C. sockeye nursery lakes are deep and steep-sided, so the littoral zone makes up a small proportion of total lake area. In these lakes, this assumption is likely to be valid, as littoral PR is insignificant compared to limnetic PR. However, a number of Skeena system sockeye lakes (e.g. Kitwanga, Lakelse, Slamgeesh) are relatively shallow, so the littoral zone comprises a substantial proportion of lake surface area. In these lakes, littoral PR may not be insignificant relative to limnetic PR. Sockeye could benefit from littoral PR in two ways: first, directly by grazing on zoobenthos; and second, limnetic zooplankton could be grazing food items originating in the littoral zone (e.g. dislodged periphyton or bacteria). If littoral PR is of benefit to sockeye, then PR_{total} and PR model predictions would increase. While sockeye fry are often shore-oriented for part of their lake residence, even at these times their diet consists of limnetic zooplankton (Morton and Williams 1990). France (1995) compiled published data on littoral and pelagic food webs from a wide range of (non-sockeye) lakes from around the world and concluded that "With the exception of a few transzonal migrating species such as lake trout, littoral benthic food webs appear to be largely uncoupled from planktonic carbon flow". However, in a large and relatively deep Alaskan lake (Iliamna), Kline et al.. (1993) used biota □^{15}N and □^{13}C to estimate the relative importance of littoral and limnetic diet items to juvenile sockeye. They reported that the littoral zone contributed 14% of the diet of age-0 *O. nerka* and 5% of the diet of age-1 *O. nerka*. The contribution of littoral PR to juvenile sockeye rearing capacity needs to be better documented in all types of sockeye lakes and particularly in shallow lakes. Until such data are available, we have applied no littoral component to PR_{total}.

Limnetic competitors In many sockeye rearing lakes there is often competition with sockeye for the zooplankton food source. Actual or potential competitors include fish such as kokanee (*O. nerka*) or stickleback (*Gasterosteus* spp.) and invertebrates such as mysids, *Chaoborus*, and *Leptodora*. Since the PR model predicts the capacity of the limnetic zone to produce total tertiary biomass, model predictions need to be adjusted when competitors are present. Data on the abundance, biomass, diet, and temporal variability of juvenile sockeye competitors is often limited. In the lakes reported here, we have made preliminary estimates of the biomass of competitors, but considerably more work is required to improve these preliminary estimates.

In Skeena system lakes, there are a variety of species which have the potential to compete with sockeye fry. In most of these lakes, little is known about the sockeye competitors. In most cases, we have sampled the limnetic region with a midwater trawl on one occasion only. We estimated the biomass of potential competitors in each lake from a number of data sources including midwater trawls, acoustic counts and target strength, limnetic gill net sets, and reports by others. We assumed that the abundance, biomass, and type of competitor species present during our trawl surveys was constant and would not change if sockeye fry biomass increased to capacity. We also assumed (sometimes with literature confirmation) that the diet of the competitor was the same as age-0 sockeye and that competitor biomass used the same proportion of available food as an equivalent amount of sockeye biomass. This is the most conservative approach as we know from sampling that these species occupy the lake's limnetic zone and that they are planktivorous. To account for competition, we adjusted PR_{total} by the proportion (by biomass) of PR_{total} utilized by a competitor with the following formula:

$$\text{Adjusted } PR_{total} = PR_{total} - PR_{total} \times (C_{max} / R_{max})$$

where C_{max} = observed competitor biomass (kg) in the lake.

Smolt weights at S_{max} Koenings and Burkett (1987) reported that maximum adult returns occurred when juvenile sockeye densities were sufficiently high to produce 4-5 g smolts. Obviously, average smolt size strongly affects the numbers of smolts produced by a predicted maximum smolt biomass. The PR model uses this Alaskan average of 4.5 g in its predictions for B.C. lakes. In order to test the validity of this average smolt size, we collated age-1 smolt size data from eight sockeye rearing lakes in B.C. and compared it to the total escapement 2 years earlier. These included seven sample years from Quesnel Lake, five from Shuswap Lake (Hume et al.. 1996), 36 sample years from Babine Lake (Wood et al.. 1998; Hume and MacLellan 2000), 48 sample years from Chilko Lake, 6 from Morice Lake, three from Sustut Lake (DFO, data on file), nine from Meziadin Lake

(Bocking et al. 2001), and 22 sample years from Cultus Lake (Schubert et al.. 2002).

With data from all these lakes combined, there was a weak but significant negative logarithmic relationship between age-1 smolt size and total escapement ($P<0.001$, $R^2_{adj} = 0.087$) **(Figure 3)**. Little of the variation in smolt size was explained by the logarithmic relationship but it did explain more than did a linear relationship ($P<0.01$, $R^2_{adj} = 0.067$). However, at higher spawner densities (20-165 spawners/ha), average smolt size was 4.6 g ($\pm$2SE = 12%). These empirical data support the PR model's use of 4.5 g as a maximum smolt size when maximum smolt biomass is being produced.

Lakes which produce small smolts Some B.C. lakes (e.g. Morice, Owikeno) do not produce age-1 smolts as large as 4.5 g even at low escapements. In these lakes, we assumed that PR model predictions of maximum smolt biomass were still valid. Consequently, maximum smolt numbers needed to be increased to account for their smaller size. Also, predicted optimum escapements needed to be increased to account for the higher fry recruitment necessary to increase smolt numbers. To make these adjustments, we increased predictions of both maximum smolt numbers and optimum escapement by the ratio of 4.5 g to observed smolt size at the highest observed escapement:

> Adjusted maximum smolt numbers = R_{max} x (4.5/observed smolt size)
> Adjusted S_{max} = S_{max} x (4.5/observed smolt size)

Presence of age-2 smolts In some lakes, a proportion (sometimes the majority) of sockeye fry from each brood year reside in the lake for more than one year, leaving as age-2 or occasionally age-3 smolts. These older fish compete directly with age-0 sockeye, but they also contribute to smolt production, so they cannot be treated as simple competitors. While the presence of older smolts will not affect the predicted maximum smolt biomass a lake can produce, it can have a substantial effect on the numbers of smolts that make up this biomass. We accounted for older smolts by weighting the mean size of each age class by its proportion in the smolt run of each brood year.

Significant numbers of age 2 smolts are known to occur in Morice and Kitwanga lakes. We used available age-1 and age-2 smolt catch data from these lakes to determine the mean proportion and size of age-2 smolts (data on file). In five brood years from 1958 to 1963, the proportion of age-2 smolts in Morice Lake ranged from 36 to 75% and averaged 46%. Mean size of age-1 and age-2 smolts was 3.7 (range = 2.8 - 4.8 g) and 7.8 g (range = 6.6 - 9.5 g), respectively. We used these means in the model. Kitwanga smolts were enumerated and measured in 2000 and 2001(Mark Cleveland, Gitanyow Fishery Authority, personal communication). Scale ageing found 97% were age-2 smolts with an average weight of 9 g. As very little data were available on the size of the age-1 smolts, we used 4.5 g. While escapements were well below the PR estimate of S_{max}, we have no data on smolt size or age at higher escapements, and so assumed sizes would not change at higher densities.

PR Model and the Ricker Model

In Skeena system sockeye nursery lakes where no stock recruit data exist, the PR model provides a basis for generating theoretical stock recruit relationships. The model makes predictions of both the maximum sockeye smolt biomass produced by a lake and the total (optimum) escapement needed to produce that biomass. Equivalent parameters are generated by stock and recruit models for semelparous species such as sockeye salmon (Ricker 1975; Hilborn and Walters 1992). For the Ricker stock recruit model in the form:

$$R = aSe^{-bS}e^{w} \qquad (1)$$

R is smolt recruitment (biomass) measured in tonnes, *S* is spawning escapement, a is the theoretical recruits per spawner at very low stock sizes (productivity), b describes how quickly recruits per spawner drops as *S* increases (capacity parameter), and e^{w} is the residual error term. The peak of the curve, R_{max}, is the maximum predicted recruits (smolt biomass) generated by S_{max}, the predicted escapement required to produce R_{max}. After Hilborn and Walters (1992):

$$R_{\max} = (a/b)e^{-1} \qquad (2)$$

and

$$S_{\max} = 1/b\,. \qquad (3)$$

Consequently, where suitable PR data are available, we can use PR model predictions of optimum escapement and maximum smolt biomass (S_{max} and R_{max}) to estimate the Ricker model parameters *a* and *b* for generating theoretical Ricker models for each lake.

Comparison of the PR and Ricker models using data from Fraser system lakes to examine the validity of the PR-derived stock-recruit model, we compared it to the Ricker model fitted to available data on adult escapement and juvenile biomass from four sockeye lakes (Chilko, Cultus, Quesnel, Shuswap) in the Fraser River system. Sockeye escapement data are available for most Fraser River lakes (Schubert 1998; NuSEDS). Many Fraser River sockeye stocks have highly variable female spawning success, so to better reflect actual escapements we used estimates of effective female escapement for Chilko, Quesnel, and Shuswap Lake sockeye. Cultus Lake effective females have rarely been enumerated, so for that lake we used estimated total female escapement. We modified the PR model

S_{max} by the weighted mean proportion of effective females from 1938 to 2002 (we weighted the proportion of females by total escapement in each year). Average female spawners were 51% EFS in Chilko Lake, 49% EFS in Shuswap Lake, 48% EFS in Quesnel Lake, and 55% FS in Cultus Lake.

Smolt numbers and size data are available from fences on Chilko and Cultus lakes (Hume et al.. 1996; Bradford et al.. 2000; Schubert et al.. 2002; data on file). On average, 95% of Chilko sockeye smolt in their second spring (age-1), but on occasion age-2 smolts comprise up to 26% of the total and are 2-4 times the size of age-1 smolts. PR model predictions of S_{max} and R_{max} for Chilko Lake were adjusted by the average proportion of age-2 smolts. Age-2 smolts are rare in Cultus Lake (Schubert et al.. 2002). Smolt numbers are not available for Quesnel and Shuswap lakes, but fall fry numbers and size are available from acoustic and trawl surveys (Hume et al.. 1996; Shortreed et al.. 2000; data on file). To convert fall fry biomass to smolt biomass, we made the assumption that sockeye biomass lost to overwinter mortality would be counteracted by winter and spring growth. Consequently, we assumed that observed fall fry biomass was equal to smolt biomass. However, these fall estimates of juvenile *O. nerka* biomass needed to be adjusted for kokanee abundance.

Kokanee are present in both Shuswap and Quesnel lakes and can be a significant proportion of the limnetic fish community in years of low sockeye escapement (Hume et al.. 1996). Age-0 juvenile kokanee are difficult to separate from age-0 sockeye and estimates have only been made occasionally. In Shuswap Lake, Hume et al.. (1996) reported that in the non-dominant brood year (1989), kokanee comprised 73% of the *O. nerka* population or 0.67 kg/ha. In Quesnel Lake, in the nondominant 1999 brood year, the population of age-0 kokanee was estimated at 4% (0.08 kg/ha) using marine Sr in the otolith core (data on file). We assumed these estimates were the same in all years and corrected for kokanee biomass in the manner described above for limnetic competitors. To facilitate comparisons between lakes, we normalized both the juvenile and adult data with lake surface area.

Although significant Ricker curves were fitted to all four sets of juvenile biomass data ($P<0.05$, based on log R/S vs S), less than 50% of the variance in juvenile biomass was explained by spawner density. Given the variance in the Ricker juvenile biomass/spawner model and in the PR model, the predictions for S_{max} from the two models are reasonably similar, except in Cultus Lake where PR S_{max} is considerably higher (**Figure 4**). In Chilko and Quesnel lakes, the juvenile and PR R_{max} are also close but R_{max} estimates from the PR model in Shuswap and Cultus lakes are considerably higher than the estimates from the Ricker juvenile model. This may indicate other constraints on production in Cultus and Shuswap lakes, such as limited spawning ground capacity or high juvenile mortality from fish predation. Fish predators have been documented as major sources of juvenile mortality in both Cultus (summarized in Schubert et al.. 2002) and Shuswap lakes (Williams et al. 1989).

The productivity parameter, Ricker *a*, estimated from the PR model was similar in all 4 lakes, varying from 1.38 in Quesnel Lake to 1.20 in Cultus Lake (**Figure 5**). There was a bigger difference between lakes for the Ricker *a* estimate from the juvenile model than from the PR model. Shuswap sockeye were much more productive with a juvenile Ricker *a* estimate of 1.12. This was at least 1.3 times higher than the other stocks, indicating a much higher stock productivity than that estimated for the other 3 stocks (Ricker *a* = 0.77 - 0.84). The higher values of Ricker *a* from the PR model than from the juvenile model may indicate the presence of factors other than primary productivity that controls the productivity of the sockeye stocks. However, at least some of the discrepancy (possibly most of it) may be due to errors in estimating the parameters from inherently highly variable data.

The capacity parameter, Ricker *b*, from both models varied more than did Ricker *a* ranging from 0.01 - 0.07 for the PR model and from 0.02 - 0.05 for the juvenile model. Unlike the productivity parameter, there was no consistent difference between *Ricker b* for the two models. The estimate of Ricker *b* from the PR model was higher in Quesnel and Chilko lakes. This may indicate that food supply (as measured by PR) is not the limiting factor but that other factors (e.g. spawning ground capacity) are limiting the capacity of these lakes to rear juvenile sockeye. As above, parameter estimate error may also explain much of the differences.

Further adjustments to PR-derived stock and recruitment relationships for Skeena Lakes

For Skeena nursery lakes, only in Babine Lake is it possible to compare PR-derived stock and recruitment relationships against empirical data (**Figure 6**). The Ricker curve from the PR model is very similar to the Ricker fit to the smolt data. Both curves generate essentially the same estimates for S_{max} but the PR-derived $R_{max.}$ is about double the fitted curve R_{max}. Initial simulations using the PR-derived stock-recruit curves for other Skeena lakes suggested high sustainable exploitation at maximum sustained yield (MSY) for many lakes and higher predicted smolt biomass and escapements, under recent patterns of estimated exploitation, than has actually been observed from juvenile surveys. As for some Fraser system lakes, we suspect our PR-derived stock and recruitment model may overestimate productivity for some Skeena sockeye lakes. Reasons for this may be both parameter estimation error and/or the presence of factors other than lake rearing which limit sockeye production. Bodker (2001) made similar observations in her comparison of optimal escapements and maximum recruitment based on Bayesian PR methods and empirical data.

The Ricker parameters from the PR-derived stock and recruitment curves for Skeena lakes can be manipulated to account for possible parameter estimation error and/or other factors affecting lake productivity. For example, factors affecting the quality of the incubation habitat can be modelled by changing Ricker *a* while factors affecting the extent of incubation habitat can be modelled by changing Ricker *b*. The difficulty lies in knowing how much to adjust each parameter in order to generate SR curves that might best approximate current productivity regimes in each Skeena nursery lake?

One option is to first adjust S_{max} for suspected spawning limitation in some lakes (see Shortreed et al.. 1998) (note this also revises R_{max} for those lakes), and then sequentially adjust Ricker *a* (productivity) until predicted future escapements stabilize or “go flat” under estimated recent exploitation rates and estimated escapement levels for each lake. Average exploitation on Skeena sockeye has been relatively stable since the early 1970’s (Cox-Rogers 2003) and so the observed juvenile densities in the lakes today should (we assume) reflect the cumulative affects of historic exploitation patterns. Currently, unadjusted Ricker parameters (when used in the simulation model) generate increasing escapement trends and smolt biomass levels for most Skeena nursery lakes under recent levels of estimated exploitation. Adjusting Ricker *a* downwards too much eventually generates decreasing escapement trends and smolt biomass levels for each lake under recent levels of estimated exploitation. The adjustment procedure does not specifically identify the causal mechanisms generating production “bottlenecks” in each nursery lake (parameter estimation error or biotic factors affecting sockeye productivity) but it does account for their probable effects.

Sub-stock exploitation can be estimated for each stock (see Results section on wild stock exploitation) by applying reconstructed sockeye Area 3/4/5 weekly harvest rates to the estimated weekly run-timing proportions for each stock through the Area 3/4/5 fishery and adding additional estimates for Alaska and in-river FSC/ESSR exploitation. The adjustment procedure provides revised estimates of smolt biomass, $R_{max,}$ for each lake. Ricker *a* values for Skeena lakes were all > 1.32 prior to the adjustment process. Our revised Ricker *a* values range from 0.45-0.98, or slightly less than has been empirically observed for Fraser Lakes. The adjustment procedure is approximate and assumes stock-specific exploitation rates are being estimated within some reasonable range of accuracy. Empirical stock-recruit data from some Skeena sockeye lakes is required to allow comparison of our adjusted PR-derived stock and recruit relationships with known data.

RESULTS

STOCK STATUS FROM ADULTS

Stock status for Skeena nursery lakes is estimated from available adult catch and escapement records and from juvenile densities in the rearing lakes expressed as a proportion of maximum rearing capacity. Only 17 of the 29 Skeena nursery lakes have been surveyed to date. Lake trophic status and juvenile densities have been interpolated for the missing lakes until lake surveys can be conducted (Ken Shortreed, FOC, pers. comm.).

Stock-specific run-timing

Run-timing for Skeena River sockeye stocks is estimated from historical sockeye tagging studies conducted in Area 4 from 1944 to 1959 (Aro and McDonald 1968, Smith and Jordan 1973), the north coast sockeye tagging project conducted in 1982 and 1983 (English et al.. 1985), parasite and electrophoretic variation at the Tyee test fishery from 1987 to 1996 (Rutherford et al.. 1999) and, most recently, DNA variation at the Tyee test fishery for 1996, 1998, 1999 (Beacham et al.. 2000) and 2000, 2001, and 2002 (Terry Beacham, FOC, pers comm.). These studies generally indicate the earliest stocks to be the Lakelse and Alastair components in late June, followed by the Morice, Swan, Motase, Sustut, McDonnell, early Babine Lake and Pinkut Creek stocks in early-mid July, the mid-timed Morrison (Babine Lake) and Fulton Creek stocks in mid-late July, and the late-timed upper and lower Babine River, Kitsumkalum, Kitwanga, Bear, and stocks in later July-early August.

Figure 7 shows historical Area 4 tag distributions for Alastair, Lakelse, Kitsumkalum, Kitwanga, Morice (Bulkley) Kispiox, Babine, Bear, and Johanson lakes as summarized by Aro and McDonald (1968). **Appendix Tables 1, 2, and 3** summarize weekly proportions for the “baseline” DNA sockeye stocks entering Area 3/4/5 in 2000, 2001, and 2002 initially estimated in Tyee test fishery escapement samples and subsequently reconstructed back into the commercial fishery. Both the tagging data and the DNA analyses suggest there is considerable run-timing overlap for Skeena sockeye sub-stocks. The DNA data also suggests possible annual variation in run-timing and/or more than one timing peak or population component for some stocks. While this may be true, some of this variability could also be related to sampling issues (e.g. problems of estimating very small stocks in mixtures dominated by the Babine Lake component) and/or missing stocks in the baseline causing mis-assignment. Analyses are ongoing to try and resolve some of these issues.

Table 2 summarizes currently estimated “peak” week run-timing into Area 3/4/5 for Skeena River sockeye sub-stocks. For stocks lacking run-timing data, interim peak timing dates have been assigned based on geographical proximity to stocks where run-timing data exist.

Aggregate-stock catch, escapement, and exploitation

Total stock and escapement trends for the Skeena aggregate stock from 1951-2001 (source Cox-Rogers 2003, data on file) are plotted in **Figure 8**. Skeena River sockeye returns have steadily increased since enhancement began in the early 1970's. Average total returns were 2.0 million from 1970-79, 2.9 million from 1980-89, and 3.5 million from 1990-1999. During the 1990's, the range of returns has been quite broad (6.9 million in 1996 to a low of 0.91 million in 1998). Very strong returns were seen in 2000 (4.7 million) and 2001 (4.6 million), but they declined to 1.5 million in 2002 as a result of expected reduced production of age 4 (1998 BY) and age 5 (1997 BY) sockeye (Cox-Rogers 2003). Since 1970, escapements have exceeded or met escapement targets (1.05 million) in all years except 1998, 1999, and 2002. Annual exploitation for the Skeena sockeye aggregate has increased over the time series and has averaged 0.60-0.65 since enhancement began (**Figure 9**).

Wild-stock catch and escapement

Historic catch records for non-Babine sockeye do not exist except for terminal FSC and ESSR fisheries in-river and so reconstructed returns for the wild stocks cannot be compiled. Stock-specific FSC catch data exist for Morice Lake sockeye captured in the Bulkley River at Hagwilget Canyon (1930-1964) and at Moricetown Falls (1930-present) (Cox-Rogers 2000). Historic First Nations catches in the Bulkley River appear abundance driven in any given year. Stock-specific FSC catch records also exist for jack and adult harvests taken at the Babine River counting fence (1956-present) and in Kitsegass canyon on the lower Babine River (1982-present). A detailed accounting of in-river Skeena catches of sockeye in native FSC and ESSR fisheries from 1982-2000 have been summarized from the many diverse records available and have been summarized by Gazey (2001).

Visual escapement data for Skeena sockeye lakes (B.C. 16's) have been collected since the late 1920's. McKinnell and Rutherford (1994) carried out an extensive review of methods of estimating non-Babine sockeye. Visual sockeye escapement data to the smaller Skeena River sockeye lakes is variable and of unknown accuracy because of the wide variety of methods used (Shortreed et al.. 1998). Escapement estimates to most of the smaller Skeena lakes have been conducted either by foot or air and have not been done consistently, especially in recent years. Fence counts are (or have been) available for some lake systems: from 1962-1967 in Williams and Scully Creeks (tributaries to Lakelse Lake), from 1992-present in the Sustut River below Sustut and Johanson lakes, from 2000-present in the Kitwanga River below Kitwanga Lake, from 2001-present in Slamgeesh Lake, in 2001 in Swan Lake, and in the Babine River below Babine-Nilkitkwa Lake from 1946-present. A sockeye mark-recapture tagging program at Moricetown Canyon on the Bulkley River was initiated in 2001 to try and improve sockeye escapements estimates into Morice Lake.

Appendix Table 4 summarizes 1950-2002 escapement records for the major Skeena sockeye nursery lakes where surveys have been conducted, as well as 1950-2002 sockeye fence counts Babine Lake. The available data suggest escapements to the non-Babine lakes have declined and stabilized at lower levels, relative to Babine Lake, since the 1950's (**Figure 10).** There is evidence of an increasing trend after the mid-1980's and into the 1990's for some of the lakes despite the sustained high harvest rates on the Skeena run as whole (**Figure 11**). Wood et al.. (1998) presumed this to be a direct result of continuing efforts to harvest the mid-timing Babine sockeye as selectively as possible, but higher freshwater/marine survivals have played a role. However, Wood (2001) pointed to evidence that Babine smolt-to-adult (presumably marine) survival had in fact increased until 1995, then stabilized, whereas exploitation rate on the Skeena aggregate continued to increase. He argued that this exploitation became excessive and may have become even more intense on the early run Skeena populations, contributing to the decline in their escapements through 2001.

It is unclear how escapement survey error may affect interpretation of escapement trends for non-Babine sockeye lakes. The time series is not complete for all lakes and less effort now goes into surveying escapements than in past years. For wild stocks where fences are in place, recent escapements are actually quite concerning. In Kitwanga Lake for example, fence count escapements were just 320, 231, 198, and 998 sockeye in 1999, 2000, 2001, and 2002 respectively. For Slamgeesh Lake, fence count escapements were 1350 and 324 in 2001 and 2002 respectively. For Sustut and Johanson lakes enumerated at the Sustut River fence from 1992-2002, actual escapements to both lakes combined have trended downward since 1992 (**Figure 12**). Sustut fence counts were just 221, 476, 1258, and 674 sockeye in 1999, 2000, 2001, and 2002 respectively. The calculated decline rate from 1992 to 2002 is estimated at 75% (**Figure 12**).

A more detailed analysis of sub-stock escapements into Babine Lake was conducted by Wood et al.. (1998). Their analysis indicated a decline in some Babine lake wild stocks shortly after the first enhanced sockeye returned (**Figure 13**). They attributed the decline to increased exploitation during fisheries targeting the enhanced stocks. Early timing escapements have been the least affected whereas wild mid-timing escapements (Morrison Lake) have been most affected (Wood et al.. 1998). Late-timing escapements increased following implementation of more conservative management policies and continue to do so today whereas mid-timing escapements have averaged less than half of pre-enhancement levels (Wood et al.. 1998).

Wild-stock exploitation

Annual catch and escapement data do not exist for sockeye originating from non-Babine nursery lakes and so exploitation rates cannot be calculated directly. An alternative approach is to calculate annual exploitation rates using historic weekly harvest rates in Area 4 applied to the normal-curve timing proportions for each individual stock. This was done for the years 1970-2002. Reconstructed (annual) Alaskan and in-river FSC exploitation rates for the aggregate stock can be used to approximate additional marine and FSC exploitation on each of the sub-stocks. While this method may overestimate exploitation for some stocks and under-estimate for others, we feel the general trends resulting from this approach are realistic.

Appendix Table 5 summarizes weekly sockeye *harvest rates* in Area 4 (catch/(catch+escape) for the aggregate stock from 1956-2002. Weekly harvest rates have been highest during mid-late July and lowest during early July and early-mid August. They have also varied within weeks over the time series (**Figure 14**). From Appendix table 5, decadal mean weekly Area 4 harvest rates are shown below:

Week	Jn 25-1	Jl 1-7	Jl 8-14	Jl 15-21	Jl 22-28	Jl 29-04	Au 5-11
1956-59	0.000	0.000	0.148	0.423	0.367	0.414	0.272
1960-69	0.227	0.380	0.394	0.485	0.476	0.503	0.418
1970-79	0.160	0.331	0.426	0.414	0.568	0.404	0.495
1980-89	0.022	0.108	0.331	0.406	0.498	0.397	0.321
1990-99	0.106	0.318	0.410	0.457	0.415	0.373	0.276
2000-09	0.155	0.383	0.596	0.570	0.550	0.516	0.309

Appendix Table 6 summarizes estimated 1970-2002 *marine exploitation* (Alaska+Canada) for Skeena sockeye sub-stocks peaking in Area 4 **during** each specified week. Marine exploitation by timing group is plotted in **Figure 15**. We estimate that marine exploitation rates have been lowest for sub-stocks peaking in late June/early July and late July/early August and have been highest for stocks peaking in mid-late July. Exploitation rates on the specific sub-stocks are primarily driven by the pattern of weekly harvest rates in Area 3/4/5. From Appendix Table 6, decadal mean marine exploitation rates for stocks peaking in each week are shown below:

Week	Peaking Jn 25-1	Peaking Jl 1-7	Peaking Jl 8-14	Peaking Jl 15-21	Peaking Jl 22-28	Peaking Jl 29-04	Peaking Au 5-11
1970-79	0.212	0.311	0.396	0.452	0.480	0.481	0.456
1980-89	0.185	0.261	0.352	0.426	0.460	0.454	0.421
1990-99	0.278	0.366	0.438	0.474	0.471	0.439	0.392
2000-09	0.256	0.382	0.487	0.537	0.525	0.463	0.368

Decadal mean *total exploitation* (marine + FSC) for each timing group is shown below. ESSR exploitation for certain years primarily affects the mid-timed enhanced component and would represent an add-on for some stocks to the calculations presented here. We suspect our estimates of total exploitation may actually under-estimate exploitation in some fisheries, especially for some in-river FSC fisheries.

Week	Peaking Jn 25-1	Peaking Jl 1-7	Peaking Jl 8-14	Peaking Jl 15-21	Peaking Jl 22-28	Peaking Jl 29-04	Peaking Au 5-11
1970-79	0.262	0.361	0.446	0.502	0.530	0.531	0.506
1980-89	0.245	0.321	0.412	0.486	0.520	0.514	0.481
1990-99	0.338	0.426	0.498	0.534	0.531	0.499	0.452
2000-09	0.279	0.405	0.510	0.560	0.548	0.486	0.391

STOCK STATUS FROM JUVENILES

Tables 3 and 4 outline the current status of limnological and juvenile surveys conducted for Skeena River sockeye lakes. Our understanding of trophic status and rearing capacity of Skeena Lakes is still evolving and there is some discrepancy among lakes with respect to the quality of the data we are using to make our assessments**.** We anticipate better resolution of trophic status and rearing capacity as further studies and/or updates to past evaluations becomes available.

Table 5 summarizes current (e.g. at the time the surveys were done) estimates of optimum escapement, maximum smolt biomass, observed smolt biomass, and factors limiting production for Skeena sockeye nursery lakes based the PR-model assessments. **Table 6** summarizes calculated production parameters for the un-adjusted and adjusted-PR model stock and recruit relationships. Some of the data in Table 5 differ from previously published or distributed values and reflect updates to the PR model

Appendix Table 7 summarizes predicted and observed smolt biomass levels in Skeena nursery lakes, PR model calculated escapements producing observed smolt biomass levels, and estimates of MSY escapement and sustainable exploitation at MSY for each nursery lake. **Figures 16** and **17** compare the percentages of rearing capacity currently being achieved for each lake for the un-adjusted PR model estimates of rearing capacity and the adjusted PR model estimates of rearing capacity. The unadjusted PR model suggests that smolt biomass levels are at less than 25% of capacity for 21 of the 26 Skeena nursery lakes where data are available. Six of the lakes are estimated to be below 10% of capacity (Kitwanga, Club, Bear, Atna, Johanson, and Kalum). The adjusted PR model suggests that smolt biomass levels are at less than 25% of capacity for 6 of the 26 Skeena nursery lakes where data are available while 2 (Kitwanga and Club) are estimated to be below 10% of capacity. For the adjusted PR model estimates, the majority of the lakes for are estimated to be below 50% of capacity (17/26).

Comment on PR-model derived production estimates

It is unclear at this time if the juvenile stock status of each lake is being accurately portrayed by either the un-adjusted PR model data or our adjusted PR model data. As noted, the unadjusted PR model may overestimate rearing capacity in some nursery lakes and thus result in very pessimistic estimates of current stock status. Our adjustments to the PR model estimates (calibrating to estimated exploitation) attempt to account for possible over-estimation of rearing capacity and this results in more optimistic estimates of current stock status. Another option we are exploring is to simply use un-adjusted PR derived estimates of intrinsic productivity (Ricker *a)* for those Skeena rearing lakes where lake rearing capacity alone is thought to be the **major** or only factor limiting production. For other lakes, importing plausible Ricker "*a*" values from other comparable, well studied systems may prove to be a better approach. We anticipate that updated assessments and further analytical refinements will help to finalize stock status and of Skeena nursery lakes estimated from juvenile data. As such, the results presented in this working paper should be considered preliminary.

Sustainable exploitation at MSY

Using our approach for determining lake-specific production parameters from the PR-model data, it is possible to calculate sustainable exploitation at MSY for Skeena sockeye lakes (**Appendix Table 7**). Our analysis suggests the majority of stocks require exploitation below 0.45, under currently estimated productivity regimes, in order to achieve MSY escapement levels or higher. **Figure 18** shows the distribution of estimated sustainable exploitation at MSY for Skeena sockeye nursery lakes. There does not appear to be wide variation in our estimates of MSY exploitation among lakes which could reflect parameter estimation error. However, while they are low, the estimates of sustainable exploitation at MSY are not un-reasonable considering that most non-Babine nursery lakes are very oligotrophic (Shortreed et al. 1998). For the Babine Lake composite stock which rears both wild and enhanced sockeye, sustainable exploitation at MSY is estimated to be about 0.62, although this rate is likely too high for the wild stocks and too low for the enhanced Pinkut and Fulton components. As with the stock status analyses presented above, updated assessments and further analytical refinements should help to finalize our estimates of sustainable exploitation for Skeena sockeye lakes.

Under current and historic rates of fishery exploitation, our analysis indicates the majority of non-Babine Lake sockeye stocks are probably over-exploited by combined marine and in-river mixed-stock fishing. Shortreed et al. (1998) and Wood et al. (1998) reached the same conclusion.

SUMMARY CONCLUSIONS

Table 5 perhaps best summarizes and re-enforces our impressions of overall stock status of Skeena sockeye nursery lakes. Although many lakes still require evaluation and production parameter estimates are still under review, our findings re-enforce previous assessments (Shortreed et al. 1998, 2001) concluding that the majority of Skeena nursery lakes that have been surveyed are oligotrophic, appear to be largely fry-recruitment limited (not enough spawners) and producing sockeye below potential production. In addition to recruitment limitation, some lakes are also being limited by factors such as low spawning ground capacity or quality, low in-lake growth and/or survival, nutrient limitation, glacial turbidity, and species competition. All of these factors act to reduce sockeye productivity and limit sustainable exploitation rates. Increased fry recruitment through increased escapements, combined with lake-specific restorative and/or enhancement techniques, have been suggested for improving sockeye production from non-Babine nursery lakes (Shortreed et al. 1998, 2001).

Rearing capacity estimates from the PR model were modified to account for other limnetic competitors, variations between lakes in smolt size at rearing capacity, and multiple ages of smolts. Further adjustments were made through the use of the simulation model to account for other limiting factors (e.g. spawning grounds, predation). These modifications and adjustments resulted in reduced estimates of rearing capacity for each stock. From the limnetic and juvenile surveys of the nursery lakes, estimated juvenile densities (at the time of sampling) are estimated to be at less than 15% of adjusted capacity for 4 lakes, at less than 25% of adjusted capacity for 6 lakes, at less than 50% of adjusted capacity for 18 lakes, and at less than 75% of capacity 23 lakes. Juvenile densities in just 4 Skeena nursery lakes (Babine, Alastair, Lakelse, and Slamgeesh) are estimated to be at more than 75% of adjusted capacity.

From the exploitation rate assessments, recent average decadal exploitation rates have been higher than estimated sustainable exploitation at MSY for approximately 19 Skeena sockeye nursery lakes.

From the escapement assessments of non-Babine lakes where fences have been in place for several years, adult escapement counts have either been very low (Kitwanga), or have been declining (Sustut/Johanson).

From the visual escapement assessments of most non-Babine lakes, escapement trends have either been declining or have stabilized to lower than historic levels. The only Skeena sockeye nursery lake showing strong evidence of increasing escapements and production appears to be Babine Lake where early wild, late wild, and enhanced Pinkut and Fulton stocks appear to be doing well.

Three Skeena sockeye nursery lakes warrant special mention either because of observed low juvenile abundances, observed low or declining adult escapements, or both (Kitwanga Lake, Sustut Lake, and Johanson Lake). Two other Skeena sockeye nursery lakes are also of concern because of probable habitat issues restricting sockeye access (Maxan and Bulkey Lakes), although data are lacking for making a through assessment of these two lakes at this time.

RECOMMENDATIONS

1) Data on many Skeena lakes are either very limited or non-existent and are needed to improve both empirical knowledge of these systems and model predictions. Obtaining additional data on current sockeye stock status and factors affecting stock status should be a priority. These factors include juvenile sockeye abundance and growth rates, lake productivity, factors limiting lake productivity, and other factors which could be constraining sockeye production (e.g. access to the lakes, spawning ground capacity/quality, predators, competitors, temperature ranges, and seasonal oxygen depletion).

2) A schedule of rotational assessment surveys should be developed for updating stock status of Skeena lakes in future years. Juvenile surveys provide estimates of lake capacity utilization and are best suited to assessing stock status in sockeye nursery lakes where accurate adult escapement (and associated catch) is difficult or logistically impossible to collect.

3) For all non-Babine sockeye nursery lakes, examining options for increasing fry recruitment through increased escapements, combined with lake-specific restorative and/or enhancement techniques, should be evaluated as a means of improving sockeye production from non-Babine nursery lakes. Recovery plans for addressing low or declining sockeye escapements to several Skeena nursery lakes should be an immediate priority. These lakes include Kitwanga, Sustut, and Johanson lakes.

4) Fishing plans for marine and in-river mixed-stock Skeena sockeye fisheries should be developed with strong consideration of the effects of exploitation on sockeye from all Skeena sockeye lakes where the probabilities of generating or maintaining low escapements and associated juvenile production is high.

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Table 1. Skeena sockeye nursery lakes, associated river drainages, and surface areas.

Lake	Geographical Location	Associated River Drainage	Surface Area (km^2)	% of Total
Alastair	Lower Skeena	Gitnadoix	6.9	1.0%
Aldrich	Middle Skeena	Zymoetz (Copper)	0.5	0.1%
Asitka	Upper Skeena	Sustut	0.4	0.1%
Atna	Middle Skeena	Morice	5.1	0.7%
Azuklotz	Upper Skeena	Bear	2.2	0.3%
Babine-Nilkitkwa	Upper Skeena	Babine	461.0	67.4%
Bear	Upper Skeena	Bear	19.0	2.8%
Bulkley	Middle Skeena	Morice	0.5	0.1%
Club	Middle Skeena	Kispiox	0.4	0.1%
Damshilgwit	Upper Skeena	Slamgeesh	0.3	0.0%
Dennis	Middle Skeena	Zymoetz (Copper)	0.5	0.1%
Johanson	Upper Skeena	Sustut	1.4	0.2%
Johnston	Lower Skeena	Ecstall	1.9	0.3%
Kitsumkalum	Middle Skeena	Kalum	19.0	2.8%
Kitwanga	Middle Skeena	Kitwanga	7.8	1.1%
Kluatantan Lks	Upper Skeena	Kluatantan	0.2	0.0%
Kluayaz	Upper Skeena	Kluatantan	1.4	0.2%
Lakelse	Lower Skeena	Lakelse	13.0	1.9%
Maxan	Middle Skeena	Morice	0.6	0.1%
McDonell	Middle Skeena	Zymoetz (Copper)	2.2	0.3%
Morice	Middle Skeena	Morice	96.0	14.0%
Morrison	Upper Skeena	Babine	13.0	1.9%
Motase	Upper Skeena	Motase	14.0	2.1%
Sicintine	Upper Skeena	Sicintine	0.7	0.1%
Slamgeesh	Upper Skeena	Slamgeesh	0.4	0.1%
Spawning	Upper Skeena	Sustut	0.2	0.0%
Stephens	Middle Skeena	Kispiox	1.9	0.3%
Sustut	Upper Skeena	Sustut	2.5	0.4%
Swan	Middle Skeena	Kispiox	18.0	2.6%
		Total	684.1	100.0%

Table 2. Estimated Area 3/4/5 run-timing peaks for Skeena sockeye stocks and assumed variability

Lake	Estimated Peak Timing	Peak Week	Management Group	Allowed Range	Standard Deviation	Allowed Range
Alastair	June 24-30	64	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
Aldrich	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Asitka	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Atna	July 1-7	71	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
Azuklotz	July 22-28	74	LNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Babine-Nilkitkwa	July 8-Aug 4	72-75	BAB	+/- 1 week	1.5 weeks	+/- 1/2 week
Bear	July 22-28	74	LNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Bulkley	July 1-7	71	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
Club	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Damshilgwit	July 15-22	73	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Dennis	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Johanson	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Johnston	June 24-30	64	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
Kitsumkalum	July 22-28	74	LNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Kitwanga	July 22-28	74	LNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Kluatantan Lks	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Kluayaz	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Lakelse	June 24-30	64	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
Maxan	July 1-7	71	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
McDonell	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Morice	July 1-7	71	ENB	+/- 1 week	1.5 weeks	+/- 1/2 week
Morrison	July 15-22	73	BAB	+/- 1 week	1.5 weeks	+/- 1/2 week
Motase	July 15-22	73	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Sicintine	July 15-22	73	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Slamgeesh	July 15-22	73	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Spawning	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Stephens	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Sustut	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week
Swan	July 8-15	72	MNB	+/- 1 week	1.5 weeks	+/- 1/2 week

(1) Run-timing variability for each stock assumes a triangular distribution for the peak and its s.d.:
e.g. for Alastair, the peak week is set to 64 (June 24-30) with a minimum of week 63 and a maximum of week 71
-the standard deviation about the peak week is set to 1.5 weeks (Cox-Rogers 1994) with a minimum of 1 week and a maximum of 2 weeks.

Table 3. Quality of lake trophic data and juvenile data used in arriving at estimates in in Appendix Table 7.

Lake	Date of Last Limnological Assessment	Date of Last Juvenile Assessment	Bathymetric charts	PR Data	Current biomass	Smolt size at capacity	Competitors	Age at smolting	Mean data Quality	"Good" & "OK" data
Babine	1995	annually	1	1	1	1	1	1	1.0	6
Morice	2002	2002	3	1	2	2	3	2	2.2	4
Slamgeesh	2001	2001	1	3	1	2	3	2	2.0	4
Sustut	1996	1993	2	2	3	2	3	2	2.3	4
Kitsumkalum	1996	1993	2	2	2	3	3	3	2.5	3
Alastair	1996	1994	2	2	3	4	3	3	2.8	2
Lakelse	1996	1993	2	2	3	3	3	3	2.7	2
Swan	1996	2002	2	2	3	4	3	3	2.8	2
Kitwanga	1996	1994	2	2	3	4	3	3	2.8	2
Johanson	1996	1993	2	2	3	4	3	3	2.8	2
Bear	1996	1994	2	2	3	4	3	3	2.8	2
Morrison	1996	1994	3	2	3	3	3	2	2.7	2
Stephens	2002	2002	2	3	3	4	3	3	3.0	1
Club	2002	2002	2	3	3	4	3	3	3.0	1
Maxan	no	no	2	4	4	4	4	4	3.7	1
McDonell	2001	2002	2	3	3	4	3	3	3.0	1
Dennis	2001	no	2	3	4	4	3	4	3.3	1
Aldrich	2001	2001	2	3	3	4	3	3	3.0	1
Azuklotz	no	no	2	4	4	4	4	4	3.7	1
Johnston	no	no	2	4	4	4	4	4	3.7	1
Sicintine	no	no	2	4	4	4	4	4	3.7	1
Motase	no	no	2	4	4	4	4	4	3.7	1
Atna	no	no	4	4	4	4	4	4	4.0	0
Asitka	no	no	4	4	4	4	4	4	4.0	0
Damshilgwit	no	no	4	4	4	4	4	4	4.0	0
Kluatantan	no	no	4	4	4	4	4	4	4.0	0
Kluayaz	no	no	4	4	4	4	4	4	4.0	0
Spawning	no	no	4	4	4	4	4	4	4.0	0

Good =1
OK=2
Poor=3
Very poor=4

Table 4. Explanation of data quality characteristics used in Table 3

	Data Quality			
Data Type	1 Good	2 OK	3 Poor	4 Very poor, None
Bathymetric charts	CHS Charts or charts of simple lakes based on multiple acoustic transects.	more complex lakes with multiple acoustic transects, not done by CHS.	Data source unknown known errors, poor coverage.	none used surface area from Fish Wizard
PR Data	Two or more years of seasonal data.	One year of seasonal data.	One sampling period only.	Never sampled, used a similar, nearby lake if needed.
Current biomass	Measured smolt abundance and size.	Fall acoustic/trawl estimate, using 3x7 trawl and a simple midwater fish (& competitor community).	Fall acoustic/trawl estimate, using 2x2 trawl, often with a complex midwater fish (& competitor community).	Never sampled, guessed at by multiplying Rmax by mean % currently utilized in other lakes.
Smolt size at capacity	Measured smolts when lake is at estimated capacity.	Measured smolts over a wide range of escapements but probably not at capacity.	smolts or fall fry sampled using 3X7 trawl on only a few occasions.	Fall fry sampled using 2x2 trawl or never sampled.
Competitors	Good seasonal acoustic and 3x7 trawl estimates of simple limnetic communities.	Good single acoustic and 3x7 trawl estimates of simple limnetic communities.	Potential competitors detected in non-quantitative sampling, possibly only in other lake in watershed.	Never sampled.
age @ smolting	Scale aged smolts when lake is at estimated capacity.	Scaled aged smolts or fall fry from a 3x7 trawl over a wide range of escapements but probably not at capacity.	Scale ages from smolts or fall fry on only a few occasions.	Never sampled, assumed to be all age-1.

Table 5. Pr data for Skeena sockeye nursery lakes (April 03 revisions, source J.Hume FOC) and adjusted Smax and Rmax as described in the text.

		PR Model			Observed Age-0 fall fry/smolt biomass											
Lake	Area (km²)	S_{max} optimum escapement	R_{max} Smolt biomass (t/lake)	R_{maxN} Smolt number	Age-0 size (g)	Density (n/ha)	Biomass (kg/ha)	Biomass (t/lake)	Proportion of potential smolt biomass production (%)	Adjusted S_{max} optimum escape (1)	Adjusted R_{max} Smolt biomass (t/lake) (2)	Adjusted Proportion of potential smolt biomass production (%)	Limiting Factors	Restoration Required	Rationale	Information needed
Alastair	6.9	32,811	7.99	1,775,648	1.7	1,994	3.39	2.34	29	33000	3.20	73	3,5,6	11	13	15,16
Lakelse	13.5	26,233	6.39	1,419,646	6.12	311	1.90	2.57	40	26000	2.88	89	1	7,8	13	15,16,19
Swan	17.5	24,227	5.90	1,311,120	2.0	193	0.39	0.68	11	24000	2.36	29	1,3,4	?	13	15,16,17
Stephens	2.0	6,967	1.7	377,043	2.5	897	2.24	0.44	26	7000	0.71	62	?	?		15,16,17
Club	0.4	581	0.142	31,457	2.0	56	0.11	0.00	3	600	0.10	4	?	?		15,16,17
Morice	96.1	204,053	61.7	11,042,891	3.3	160	0.53	5.07	8				1,3,4	7,10	12	15,16,17
Morice (3)	96.1	120,000	21.4	6,492,000	3.3	160	0.53	5.07	24	120000	10.70	47				
Atna	5.1	13,786	3.35	745,434	No data available		0.27	0.14	4	14000	1.17	12	?	?		15,16,17
Maxan	6.4	17,338	4.22	937,454	No access		0.00	0.00	0	?	?	?	?	?		15,16,17
Slamgeesh	0.4	789	0.192	42,695	10	436	4.36	0.18	92	800	0.19	92	?	?	13	15,16,17
Kitwanga	7.8	18,117	9.59	980,476	2.36	77	0.18	0.14	1	18000	1.53	9	1,2,6	7,8,9	13	15,16,18,19
Kitsumkalu	18.5	20,531	5.00	1,111,110	1.61	125	0.20	0.37	7	20500	2.20	17	1,2,3,6	7	13	15,16
McDonell	2.3	3,566	0.869	193,001	1.5	595	0.89	0.21	24	3600	0.36	58	1?	7,?	13	15,16,17
Dennis	0.9	546	0.133	29,532	No data available				12	550	0.07	29	1?	7,?	13	15,16,17
Aldrich[f]	0.6	1,116	0.272	60,391	No sockeye in catch					1100	0.12		1?	7,?	13	15,16,17
Johanson	1.4	3,107	0.757	168,168	0.88	321	0.28	0.04	5	3100	0.34	12	1,3,4	7,10	13	15,16
Sustut	2.5	2,750	0.670	148,828	0.89	1,779	1.58	0.08	12	2800	0.34	24	1,3,4	7,10	13	15,16
Bear	18.8	103,064	25.1	5,577,584	3.89	132	0.51	0.97	4				1,2	7,8	13	15
Bear (3)	18.8	30,000	7.3	1,623,529	3.89	132	0.51	0.97	13	30000	3.26	30				
Asitka	0.4	1,099	0.27	59,444	No data available		1.44	0.05	20	1100	0.11	49	?	?		15,16,17
Morrison	13.2	43,960	10.7	2,378,992	4.29	377	1.62	2.13	20	44000	3.96	54	1	7,8	13	15,16
Babine	461.0	2,170,508	529	117,462,800	4.5	1,600	7.20	332	63	2200000	396.00	84	?	?		15,16,17
Azuklotz	2.2	12,815	3.12	692,896	No data available		2.89	0.62	20	13000	1.28	49	?	?		15,16,17
Damshilgw	0.3	995	0.24	53,809	No data available		1.54	0.05	20	1000	0.10	48	?	?		15,16,17
Johnston	1.9	6,685	1.63	361,437	No data available		1.78	0.33	20	6700	0.68	48	?	?		15,16,17
Kluatantan	0.5	1,611	0.39	87,089	No data available		1.46	0.08	20	1600	0.17	46	?	?		15,16,17
Kluayaz	1.4	4,067	0.99	219,879	No data available		1.46	0.20	20	4100	0.42	47	?	?		15,16,17
Sicintine	0.7	2,122	0.52	114,734	No data available		1.46	0.10	20	2100	0.21	49	?	?		15,16,17
Spawning	0.2	582	0.14	31,480	No data available		1.46	0.03	20	600	0.06	47	?	?		15,16,17
Motase	14.0	82,201	20.00	4,444,604	No data available		2.89	4.00	20	82000	8.00	50	?	?		15,16,17

Notes
(1) after Shortreed et al (1998) Table 11 based on consideration of available spawning area. Recommended Smax escapement based on the PR model or estimated spawning ground capcity, whichever is less.
(2) adjusted Rmax obtained from calibration using estimated historic exploitation rates for each stock, see text for methodology
(3) with Spawning Capacity Limit

Limiting factors
1 Low escapements and fry recruitment
2 Low spawning ground capacity or quality
3 Low in-lake growth and/or survival
4 Nutrient limitation
5 Rearing capacity reached or exceeed in some years
6 Other

Rationale for restoration
12 Enhancement larger stock with probable short-term economic benefit
13 Resortaion conservation of small or weak stock- possible long-term economic benefit
14 Creation of new run

Restoration Type
7 Increased escapement through harvest reduction
8 Increased fry recruitment (outplants)
9 Increased fry recruitment (spawning channel/grounds))
10 Lake fertlisation
11 Predator/competitor control

Information needs
15 Escapement
16 Limnetic fish abundance and growth rates
17 Limnology or updated limnology
18 Spawning ground capacity
19 Other

Table 6. Calculated Ricker parameters for Skeena sockeye nursery lakes (standardized by lake area)

Lake	Area (hec)	Optimum Escape Smax	Unadjusted Smolt Biomass Rmax (t/lake)	Adjusted Smolt Biomass Rmax (t/lake)	Smax (1) females/hec	Unadjusted Rmax kg/hec	Ricker a	Ricker b	Adjusted Rmax kg/hec	Ricker a	Ricker b
Alastair	690	33000	7.99	3.20	24	11.58	1.32	0.04	4.64	0.53	0.04
Lakelse	1350	26000	6.39	2.88	10	4.73	1.34	0.10	2.13	0.60	0.10
Swan	1750	24000	5.90	2.36	7	3.37	1.34	0.15	1.35	0.53	0.15
Stephens	197	7000	1.70	0.71	18	8.63	1.32	0.06	3.61	0.55	0.06
Club	39	600	0.14	0.10	8	3.61	1.29	0.13	2.54	0.91	0.13
Morice	9610	120000	21.40	10.70	6	2.23	0.97	0.16	1.11	0.48	0.16
Atna	513	14000	3.35	1.17	14	6.54	1.30	0.07	2.28	0.45	0.07
Maxan	640	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Slamgeesh	41	800	0.19	0.19	10	4.73	1.30	0.10	4.73	1.30	0.10
Kitwanga	780	18000	9.59	1.53	12	12.29	2.90	0.09	1.96	0.46	0.09
Kitsumkalum	1850	20500	5.00	2.20	6	2.70	1.33	0.18	1.19	0.58	0.18
McDonell	232	3600	0.87	0.36	8	3.74	1.31	0.13	1.55	0.54	0.13
Dennis	90	550	0.13	0.07	3	1.47	1.31	0.33	0.77	0.69	0.33
Aldrichf	64	1100	0.27	0.12	9	4.23	1.34	0.12	1.87	0.59	0.12
Johanson	140	3100	0.76	0.34	11	5.41	1.33	0.09	2.43	0.60	0.09
Sustut	250	2800	0.67	0.34	6	2.68	1.30	0.18	1.36	0.66	0.18
Bear	1880	30000	7.30	3.26	8	3.88	1.32	0.13	1.73	0.59	0.13
Asitka	37	1100	0.27	0.11	15	7.19	1.32	0.07	2.96	0.54	0.07
Morrison	1320	44000	10.7	3.96	17	8.11	1.32	0.06	3.00	0.49	0.06
Babine	46100	2200000	528.58	396.00	24	11.47	1.31	0.04	8.59	0.98	0.04
Azuklotz	219	13000	3.12	1.28	30	14.25	1.30	0.03	5.85	0.54	0.03
Damshilgwit	32	1000	0.24	0.10	16	7.57	1.32	0.06	3.13	0.54	0.06
Johnston	186	6700	1.63	0.68	18	8.76	1.32	0.06	3.66	0.55	0.06
Kluatantan	55	1600	0.39	0.17	15	7.19	1.33	0.07	3.12	0.58	0.07
Kluayaz	138	4100	0.99	0.42	15	7.19	1.31	0.07	3.05	0.56	0.07
Sicintine	72	2100	0.52	0.21	15	7.19	1.34	0.07	2.92	0.54	0.07
Spawning	20	600	0.14	0.06	15	7.19	1.28	0.07	3.05	0.54	0.07
Motase	1404	82000	20.00	8.00	29	14.25	1.33	0.03	5.70	0.53	0.03

(1) assuming 50% females, 50% males

Appendix Table 1. Estimated run-timing (weekly proportions) for Skeena River sockeye into Area 3/4/5 in 2000 based on DNA analysis (1,2)

Baseline	Associated	62	63	64	71	72	73	74	75	81	82	83	
Stock	Lake		Jun14-24	Jun25-Jul1	Jul2-8	Jul9-15	Jul16-22	Jul23-29	Jul30-Aug5	Aug6-12	Aug13-25		Total
McDonnell	McDonnell	0.000	0.167	0.334	0.250	0.166	0.083	0.000	0.000	0.000	0.000	0.000	1.000
Motase	Motase	0.000	0.001	0.000	0.000	0.000	0.250	0.499	0.250	0.000	0.000	0.000	1.000
Grizzly	Babine	0.001	0.001	0.007	0.109	0.268	0.276	0.171	0.076	0.036	0.037	0.018	1.000
Swan	Swan	0.000	0.103	0.353	0.397	0.147	0.000	0.000	0.000	0.000	0.000	0.000	1.000
UpperBabine	Babine	0.000	0.007	0.022	0.049	0.158	0.246	0.199	0.154	0.113	0.044	0.008	1.000
Pinkut	Babine	0.002	0.038	0.115	0.171	0.210	0.218	0.145	0.063	0.028	0.010	0.000	1.000
FultonLate	Babine	0.000	0.000	0.008	0.041	0.136	0.240	0.257	0.195	0.093	0.024	0.005	1.000
LowerBabine	Babine	0.000	0.020	0.052	0.057	0.039	0.092	0.231	0.280	0.178	0.051	0.000	1.000
Nanika	Morice	0.049	0.098	0.145	0.296	0.306	0.105	0.000	0.000	0.000	0.000	0.000	1.000
Morrison	Morrison	0.011	0.037	0.042	0.017	0.002	0.085	0.267	0.302	0.158	0.060	0.020	1.000
Williams	Lakelse	0.250	0.500	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Schulbuckhand	Lakelse	0.000	0.250	0.500	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Pierre	Babine	0.010	0.052	0.085	0.055	0.101	0.195	0.214	0.198	0.090	0.000	0.000	1.000
SalixBear	Bear	0.011	0.064	0.158	0.168	0.154	0.210	0.150	0.030	0.014	0.027	0.014	1.000
Alastair	Alastair	0.036	0.152	0.195	0.080	0.000	0.040	0.153	0.185	0.094	0.044	0.022	1.000
Kitwanga	Kitwanga	0.250	0.500	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Kalum	Kalum	0.039	0.079	0.095	0.110	0.121	0.132	0.155	0.178	0.089	0.000	0.000	1.000
Twain_Cr	Babine	0.174	0.348	0.174	0.020	0.039	0.020	0.000	0.056	0.113	0.056	0.000	1.000
Four Mile	Babine	0.006	0.011	0.006	0.000	0.108	0.292	0.262	0.137	0.119	0.060	0.000	1.000
Tahlo	Babine	0.000	0.022	0.052	0.077	0.114	0.136	0.200	0.242	0.130	0.023	0.003	1.000
Lakelse	Lakelse	0.134	0.384	0.366	0.116	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
lower Skeena	combin.	0.030	0.141	0.203	0.118	0.055	0.066	0.124	0.148	0.075	0.027	0.014	1.000
upper Skeena	combin.	0.009	0.069	0.185	0.201	0.148	0.176	0.136	0.032	0.011	0.022	0.011	1.000
Bulkley	Morice	0.049	0.098	0.145	0.296	0.306	0.105	0.000	0.000	0.000	0.000	0.000	1.000
Babine	Babine	0.002	0.017	0.043	0.070	0.138	0.208	0.217	0.179	0.096	0.026	0.005	1.000

(1) Estimated from mDNA analysis (Source T. Beacham, FOC, Nanaimo) of weekly Tyee Test Fishery escapement samples and subsequent weekly reconstruction of stock-specific abundance entering Area 3/4/5 B7using known Area 3/4/5 weekly harvest rates.

e.g. Weekly abundance by stock= (4 day lagged weekly escapement by stock)/(1-weekly harvest rate)
Weekly harvest rate = (weekly total catch)/(weekly total catch+ 4 day lagged weekly total escapement)

(2) The weekly proportions have been smoothed using (a+(2b)+c)/4)

Appendix Table 2. Estimated run-timing (weekly proportions) for Skeena River sockeye into Area 3/4/5 in 2001 based on DNA analysis (1,2)

Baseline Stock	Associated Lake	61	62 June 12-16	63 June 17-21	64 June 27-28	71 July 2-7	72 July 8-14	73 July 15-22	74 July 22-28	75 July 29- Aug 4	81 Aug 5-11	82 Aug 12-18	83 Aug 19-25	84 Aug 26-01	91 Sep 2-22	92
Alastair	Alastair	0.015	0.044	0.085	0.150	0.180	0.120	0.105	0.142	0.071	0.012	0.032	0.029	0.011	0.003	0.001
Kalum	Kalum	0.000	0.000	0.000	0.000	0.000	0.000	0.141	0.357	0.291	0.087	0.036	0.046	0.030	0.010	0.001
Kitwanga	Kitwanga	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.247	0.493	0.247	0.000	0.003	0.007	0.003
McDonnell	McDonell	0.000	0.000	0.055	0.304	0.443	0.194	0.000	0.000	0.001	0.002	0.001	0.000	0.000	0.000	0.000
Motase	Motase	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.247	0.493	0.247	0.000	0.003	0.007	0.003
SalixBear	Bear	0.008	0.018	0.012	0.038	0.072	0.119	0.167	0.174	0.203	0.141	0.037	0.008	0.001	0.002	0.001
Sustut	Sustut	0.000	0.000	0.000	0.240	0.480	0.240	0.000	0.000	0.003	0.007	0.003	0.000	0.007	0.013	0.007
Swan	Swan	0.009	0.018	0.009	0.021	0.082	0.281	0.399	0.179	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Nanika	Morice	0.008	0.022	0.067	0.111	0.127	0.202	0.256	0.164	0.043	0.000	0.000	0.000	0.000	0.000	0.000
Four_Mile	Babine	0.010	0.033	0.080	0.122	0.124	0.143	0.189	0.181	0.092	0.019	0.004	0.001	0.001	0.000	0.000
FultonLate	Babine	0.000	0.003	0.006	0.029	0.067	0.134	0.222	0.243	0.177	0.078	0.022	0.012	0.005	0.002	0.000
Grizzly	Babine	0.024	0.053	0.095	0.197	0.236	0.139	0.035	0.054	0.109	0.055	0.001	0.002	0.001	0.000	0.000
Lower_Babine	Babine	0.000	0.003	0.012	0.017	0.010	0.040	0.175	0.294	0.243	0.119	0.046	0.023	0.013	0.003	0.001
Morrison	Morrison	0.006	0.015	0.029	0.075	0.101	0.058	0.143	0.297	0.207	0.053	0.013	0.003	0.000	0.000	0.000
Pierre	Babine	0.010	0.048	0.112	0.161	0.197	0.203	0.146	0.078	0.028	0.005	0.008	0.003	0.000	0.000	0.000
Pinkut	Babine	0.004	0.013	0.027	0.043	0.102	0.216	0.244	0.177	0.116	0.047	0.005	0.003	0.002	0.001	0.000
Tahlo	Babine	0.002	0.008	0.013	0.011	0.005	0.080	0.258	0.323	0.200	0.072	0.019	0.005	0.003	0.001	0.000
Twain_Cr	Babine	0.002	0.004	0.094	0.185	0.093	0.144	0.288	0.144	0.007	0.019	0.017	0.005	0.000	0.000	0.000
Upper_Babine	Babine	0.000	0.001	0.006	0.010	0.006	0.098	0.256	0.252	0.151	0.107	0.076	0.030	0.005	0.001	0.000
Schulbuckhand	Lakelse	0.006	0.012	0.006	0.241	0.481	0.241	0.000	0.000	0.003	0.007	0.003	0.000	0.000	0.000	0.000
Williams	Lakelse	0.080	0.226	0.288	0.218	0.076	0.000	0.000	0.000	0.026	0.053	0.026	0.002	0.003	0.002	0.000
Lower Skeena	combin.	0.008	0.022	0.054	0.138	0.181	0.101	0.096	0.175	0.120	0.032	0.027	0.028	0.014	0.004	0.001
Upper Skeena	combin.	0.008	0.017	0.010	0.042	0.099	0.199	0.262	0.166	0.100	0.071	0.019	0.004	0.001	0.002	0.001
Bulkley	Morice	0.008	0.022	0.067	0.111	0.127	0.202	0.256	0.164	0.043	0.000	0.000	0.000	0.000	0.000	0.000
Babine	Babine	0.004	0.014	0.034	0.057	0.078	0.133	0.210	0.222	0.148	0.063	0.022	0.010	0.004	0.001	0.000
Lakelse	Lakelse	0.071	0.201	0.256	0.220	0.121	0.028	0.001	0.001	0.024	0.047	0.024	0.001	0.003	0.001	0.000
Total		0.005	0.016	0.036	0.060	0.081	0.134	0.208	0.218	0.144	0.062	0.022	0.010	0.004	0.001	0.000

(1) Estimated from mDNA analysis (Source T. Beacham, FOC, Nanaimo) of weekly Tyee Test Fishery escapement samples and subsequent weekly reconstruction of stock-specific abundance entering Area 3/4/5 using known Area 3/4/5 weekly harvest rates.

e.g. Weekly abundance by stock= (4 day lagged weekly escapement by stock)/(1-weekly harvest rate)
Weekly harvest rate = (weekly total catch)/(weekly total catch+ 4 day lagged weekly total escapement)

(2) The weekly proportions have been smoothed using (a+(2b)+c)/4)

Appendix Table 3. Estimated run-timing (weekly proportions) for Skeena River sockeye into Area 3/4/5 in 2002 based on DNA analysis (1,2)

Baseline	Associated	63	64	71	72	73	74	75	81	82	83	84	
Stock	Lake		June 22-30	July 1-6	July 7-13	July 14-20	July 21-27	July 28- Aug 3	Aug 4-10	Aug 11-17	Aug 18-24		Total
Alastair	Alastair	0.040	0.081	0.040	0.000	0.062	0.182	0.254	0.225	0.103	0.013	0.000	1.000
Kalum	Kalum	0.002	0.094	0.281	0.286	0.098	0.000	0.003	0.029	0.083	0.090	0.034	1.000
Kitwanga	Kitwanga	0.070	0.141	0.070	0.000	0.000	0.000	0.152	0.329	0.205	0.030	0.003	1.000
McDonnell	McDonell	0.066	0.245	0.361	0.249	0.068	0.000	0.002	0.005	0.003	0.000	0.000	1.000
Motase	Motase	0.078	0.157	0.078	0.000	0.000	0.000	0.145	0.314	0.195	0.029	0.003	1.000
SalixBear	Bear	0.109	0.315	0.302	0.131	0.069	0.035	0.000	0.000	0.010	0.019	0.009	1.000
Sustut	Sustut	0.002	0.184	0.362	0.180	0.063	0.127	0.067	0.008	0.005	0.001	0.000	1.000
Swan	Swan	0.001	0.096	0.273	0.331	0.224	0.071	0.001	0.002	0.001	0.000	0.000	1.000
Nanika	Morice	0.103	0.233	0.274	0.265	0.120	0.000	0.001	0.002	0.001	0.000	0.000	1.000
Four_Mile	Babine	0.041	0.119	0.190	0.227	0.179	0.118	0.088	0.036	0.002	0.000	0.000	1.000
FultonLate	Babine	0.001	0.022	0.083	0.164	0.227	0.233	0.164	0.073	0.022	0.008	0.003	1.000
Grizzly	Babine	0.015	0.155	0.267	0.127	0.005	0.095	0.184	0.112	0.029	0.011	0.000	1.000
Lower_Babine	Babine	0.000	0.005	0.078	0.150	0.120	0.142	0.211	0.172	0.082	0.031	0.009	1.000
Morrison	Morrison	0.007	0.056	0.179	0.219	0.106	0.109	0.179	0.109	0.028	0.008	0.001	1.000
Pierre	Babine	0.015	0.082	0.195	0.298	0.274	0.112	0.009	0.001	0.004	0.007	0.004	1.000
Pinkut	Babine	0.010	0.062	0.158	0.248	0.221	0.105	0.074	0.076	0.038	0.009	0.000	1.000
Tahlo	Babine	0.018	0.076	0.150	0.212	0.229	0.152	0.062	0.047	0.037	0.014	0.004	1.000
Twain_Cr	Babine	0.000	0.232	0.481	0.267	0.018	0.000	0.000	0.001	0.001	0.000	0.000	1.000
Upper_Babine	Babine	0.000	0.049	0.101	0.057	0.137	0.289	0.216	0.101	0.046	0.005	0.000	1.000
Schulbuckhand	Lakelse	0.070	0.141	0.070	0.000	0.000	0.000	0.152	0.329	0.205	0.030	0.003	1.000
Williams	Lakelse	0.240	0.479	0.240	0.000	0.000	0.000	0.009	0.019	0.012	0.002	0.000	1.000
Lower Skeena	combin.	0.040	0.139	0.204	0.150	0.072	0.077	0.111	0.106	0.065	0.027	0.008	1.000
Upper Skeena	combin.	0.050	0.206	0.296	0.222	0.135	0.060	0.008	0.003	0.006	0.009	0.004	1.000
Bulkley	Morice	0.103	0.233	0.274	0.265	0.120	0.000	0.001	0.002	0.001	0.000	0.000	1.000
Babine	Babine	0.008	0.047	0.122	0.188	0.203	0.179	0.136	0.076	0.029	0.010	0.003	1.000
Lakelse	Lakelse	0.228	0.456	0.231	0.006	0.003	0.000	0.016	0.035	0.022	0.003	0.000	1.000
Total		0.011	0.057	0.132	0.189	0.196	0.170	0.129	0.073	0.029	0.010	0.003	1.000

(1) Estimated from mDNA analysis (Source T. Beacham, FOC, Nanaimo) of weekly Tyee Test Fishery escapement samples and subsequent weekly reconstruction of stock-specific abundance entering Area 3/4/5 using known Area 3/4/5 weekly harvest rates.

e.g. Weekly abundance by stock= (4 day lagged weekly escapement by stock)/(1-weekly harvest rate)
Weekly harvest rate = (weekly total catch)/(weekly total catch+ 4 day lagged weekly total escapement)

(2) The weekly proportions have been smoothed using (a+(2b)+c)/4)

Appendix Table 4. Available escapement records for non-Babine and Babine sockeye lakes: 1950-2002 (1)

Year	Alastair	Bear	Kalum	Kitwanga	Lakelse	Morice	Morrison	Sustut	Johanson	Sustut Fence (2)	Swan	McDonnel	Slamgeesh	All non-Babine	Babine Lake (3)
1950	11000	16200	3000		2200	42750					700	4500		80350	364356
1951	13000	1700	4000		5700	55400	3138				1700	4000		88638	141415
1952	17000	15000	4400		13140		1254				3250	3500		57544	349011
1953	16000	9375	2500		9250	35700	12626				600	5000		91051	686586
1954	20000	10200	5000		8250		12724				225	1000		57399	493677
1955	19250	5000	1500		3700	4000	1184				950	1000		36584	71352
1956	26000	8475	5000		3575	6000	12385				8275	750		70460	355345
1957	42900	7525	950		7700	400	9995	750	75		4250	3500		78045	433149
1958	44000	7700	3750		8250	25	13605	400	200		4250	1500		83680	812050
1959	22500	5000	2250		8250	750	18617		25		825	750		58967	782868
1960	3900	1700	1000	400	4500	3500	5590	75	25		3250	750		24690	262719
1961	14250	1345	1550	200	5900	5000	11219	250	250		2250	750		42964	941711
1962	10395	2100	1900	200	7925	3000	5630	250	250		18	850		32518	547995
1963	9000	8700	3400		7900	2000	24268	200	300		3775	800		60343	588000
1964	1900	3650	4800	200	20991	8000	14650	750	200		3075	750		58966	827437
1965	7900	1000	2650	400	40528	10500	4568	2000	100		1575	6000		77221	580000
1966	8400	625	2650	200	18431	6400	3303	50			3400	4350		47809	389000
1967	12500	900	2250		13711	3400	2343	50	50		4500	400		40104	602807
1968	15000	1200	2650	200	11825	3300	13250	500	600		3500	6000		58025	552000
1969	3000		1975		6600	3300	14800	1500	300		5750	2472		39697	634000
1970	2250	600	1975		5300	4700		2000	500		4300	3000		24625	662000
1971	1150	200	2650		3050	3300	2095	500			5400	2800		21145	816000
1972	4000	9500	3400		2700	1800	717	400	800		5400	2100		30817	680145
1973	4000	7600	3400		1850	1000	11134	3000	300		4650	4500		41434	797461
1974	1750		2650		2450	1200	21382	25	50		4650	3800		37957	726990
1975	600	1350	1700		2700	325	8730	12			4450	500		20367	820795
1976	3000	100	1000		3050	100	3509				625	400		11784	580597
1977	7000	800	2650	25	2375	600	4449		40		4300	2100		24339	937992
1978	9000	1550	825	75	5450	550	1965		2		1700	7500		28617	401318
1979	9000	800	400		5760	700	8070	100	100		5000	1500		31430	1160966
1980	15000	900	375	100	13767	400	6203	500	100		3850	540		41735	526259
1981	900	420	250		7555	1000	881	300			5000	1600		17906	1432734
1982	4750		1150		17507	3000	495				8000	1100		36002	1136835
1983	6500		850		9335	4000	3180					5150		29015	886393
1984	4000	300	625		4660	3000	4963				6000	575		24123	1052385
1985	4000	1200	3650	2200	16785	2000	8736				7700	600		46871	2148044
1986	10500	1000	2600		4400	3000	750				6250	5000		33500	701507
1987	5000	5000	1200		2550	4000	4686	500	400		9000	3000		35336	1307852
1988	6500	3300	600		5050	1000	8682	500	50		9000	2000		36682	1408879
1989	5500	774	1000		3720	5600	3914	N/O			5500			26008	1132316
1990	5000	1260	1700	500	1380	6000	1802	100	70		6000	1500		25312	978646
1991	11000	3850	1800		6350	40000	9139				7500	600		80239	1176318
1992	8000	2300	4450		4890	27000	3035	2600	2600	2590	11250	5000		73715	1142916
1993	7500	2600	3700		6400	22000	14672	2169	1021	2169	13050	7500		82781	1737426
1994	6500		5500		1629			2308	1429	3737		2000		23103	1052905
1995	8500	4800	4875		12550	35000	1626	802	328	523	5900			74904	1737009
1996	12500	2850	1900		10825	41000				3368	7800			80243	1900591
1997	12000	1810	3650		1575	24000				965	2000			46000	995147
1998	5500	740	4900		1075	6000				2777				20992	510246
1999	1000	4500		320		15000				221	7000			28041	606136
2000	3100	1600	5000	231		3000				476				13407	1831613
2001	1400	1150	2500	198	1225	5047				1258	10109		1350	24237	1984260
2002	1000	300	3300	998	160	8900	20000			674	4208	3536	324	43400	590012

(1) From Area 4 Escapement Database (Source B. Spilsted, FOC, Prince Rupert)
(2) The Sustut fence enumerates sockeye destined for both Sustut and Johanson Lakes combined
(2) Total counts at the Babine Lake counting fence. FSC or ESSR catches have not been removed.

Appendix Table 5: Estimated Weekly Area 4 sockeye harvest rates:1956-2002 (outer Area 3+5 included starting in 1997).

Week	Jn 25-1	Jl 1-7	Jl 8-14	Jl 15-21	Jl 22-28	Jl 29-04	Au 5-11	Au 12-19	Au 20-27	Au 28-04	Se 05-11
1956	0.000	0.000	0.000	0.585	0.393	0.374	0.207	0.377	0.108	0.065	0.000
1957	0.000	0.000	0.000	0.362	0.443	0.617	0.465	0.250	0.117	0.154	0.260
1958	0.000	0.000	0.315	0.577	0.477	0.664	0.415	0.351	0.169	0.153	0.052
1959	0.000	0.000	0.276	0.168	0.154	0.000	0.000	0.633	0.643	0.592	0.356
1960	0.000	0.000	0.000	0.543	0.410	0.517	0.397	0.305	0.322	0.000	0.188
1961	0.144	0.240	0.235	0.440	0.745	0.531	0.517	0.483	0.289	0.193	0.000
1962	0.830	0.498	0.652	0.623	0.306	0.392	0.551	0.260	0.410	0.422	0.000
1963	0.239	0.395	0.303	0.000	0.040	0.149	0.690	0.398	0.648	0.000	0.000
1964	0.000	0.421	0.611	0.318	0.454	0.555	0.532	0.216	0.709	0.271	0.000
1965	0.000	0.316	0.293	0.550	0.327	0.405	0.000	0.385	0.000	0.270	0.000
1966	0.000	0.385	0.377	0.637	0.530	0.740	0.285	0.726	0.436	0.589	0.000
1967	0.305	0.477	0.442	0.712	0.698	0.732	0.547	0.000	0.873	0.000	0.000
1968	0.380	0.652	0.607	0.605	0.595	0.525	0.311	0.415	0.000	0.000	0.000
1969	0.372	0.416	0.415	0.429	0.656	0.490	0.348	0.280	0.000	0.600	0.000
1970	0.509	0.460	0.275	0.249	0.783	0.000	0.382	0.686	0.301	0.578	0.000
1971	0.000	0.206	0.094	0.183	0.368	0.641	0.471	0.696	0.478	0.617	0.000
1972	0.588	0.707	0.597	0.280	0.730	0.391	0.631	0.822	0.565	0.000	0.000
1973	0.504	0.391	0.230	0.843	0.690	0.574	0.578	0.390	0.000	0.000	0.000
1974	0.000	0.251	0.679	0.657	0.722	0.792	0.541	0.000	0.270	0.000	0.000
1975	0.000	0.755	0.683	0.000	0.585	0.315	0.310	0.189	0.132	0.222	0.000
1976	0.000	0.000	0.000	0.441	0.108	0.486	0.690	0.672	0.417	0.000	0.000
1977	0.000	0.211	0.559	0.458	0.538	0.475	0.396	0.452	0.600	0.000	0.000
1978	0.000	0.332	0.730	0.459	0.551	0.000	0.315	0.398	0.000	0.000	0.000
1979	0.000	0.000	0.412	0.571	0.599	0.366	0.633	0.369	0.000	0.000	0.000
1980	0.000	0.000	0.490	0.587	0.400	0.381	0.000	0.000	0.000	0.000	0.000
1981	0.000	0.000	0.469	0.753	0.606	0.325	0.259	0.398	0.481	0.000	0.000
1982	0.000	0.000	0.580	0.547	0.748	0.696	0.494	0.346	0.000	0.000	0.000
1983	0.000	0.000	0.000	0.074	0.337	0.204	0.216	0.524	0.515	0.106	0.000
1984	0.000	0.000	0.000	0.546	0.536	0.428	0.232	0.353	0.182	0.000	0.000
1985	0.000	0.647	0.492	0.365	0.558	0.612	0.402	0.375	0.385	0.000	0.000
1986	0.000	0.000	0.238	0.134	0.579	0.483	0.124	0.383	0.515	0.000	0.000
1987	0.000	0.000	0.133	0.147	0.360	0.273	0.498	0.436	0.385	0.147	0.000
1988	0.000	0.240	0.421	0.512	0.667	0.277	0.720	0.347	0.518	0.156	0.000
1989	0.223	0.192	0.488	0.395	0.193	0.292	0.269	0.242	0.130	0.104	0.000
1990	0.250	0.235	0.158	0.421	0.555	0.409	0.451	0.453	0.124	0.084	0.155
1991	0.000	0.232	0.349	0.525	0.458	0.530	0.355	0.345	0.329	0.049	0.000
1992	0.000	0.738	0.461	0.329	0.541	0.581	0.543	0.468	0.547	0.052	0.000
1993	0.000	0.407	0.557	0.649	0.529	0.463	0.308	0.251	0.316	0.228	0.000
1994	0.000	0.221	0.442	0.449	0.283	0.428	0.317	0.243	0.269	0.000	0.000
1995	0.091	0.323	0.576	0.635	0.517	0.451	0.237	0.458	0.223	0.000	0.000
1996	0.208	0.401	0.644	0.701	0.718	0.505	0.474	0.215	0.000	0.000	0.000
1997	0.512	0.357	0.618	0.610	0.546	0.364	0.076	0.068	0.000	0.000	0.000
1998	0.000	0.261	0.293	0.251	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.409	0.603	0.586	0.667	0.455	0.377	0.268	0.011	0.000	0.000	0.000
2001	0.051	0.342	0.549	0.556	0.603	0.487	0.381	0.343	0.021	0.000	0.000
2002	0.005	0.203	0.652	0.487	0.591	0.683	0.277	0.303	0.272	0.000	0.000
1956-59	0.000	0.000	0.148	0.423	0.367	0.414	0.272	0.403	0.259	0.241	0.167
1960-69	0.227	0.380	0.394	0.485	0.476	0.503	0.418	0.347	0.369	0.235	0.019
1970-79	0.160	0.331	0.426	0.414	0.568	0.404	0.495	0.467	0.276	0.142	0.000
1980-89	0.022	0.108	0.331	0.406	0.498	0.397	0.321	0.340	0.311	0.051	0.000
1990-99	0.106	0.318	0.410	0.457	0.415	0.373	0.276	0.250	0.181	0.041	0.016
2000-20	0.155	0.383	0.596	0.570	0.550	0.516	0.309	0.219	0.098	0.000	0.000

Appendix Table 6. Exploitation rates for Skeena sockeye stocks peaking in each week (Marine = Alaska+Canada)

Computed Marine Exploitation for different Sx Run-Timing Components from 1970-2002.

Week	Jn 25-1	Jl 1-7	Jl 8-14	Jl 15-21	Jl 22-28	Jl 29-04	Au 5-11
1970	0.307	0.371	0.394	0.404	0.406	0.404	0.422
1971	0.102	0.149	0.208	0.292	0.397	0.493	0.551
1972	0.413	0.521	0.551	0.547	0.554	0.580	0.600
1973	0.307	0.407	0.501	0.585	0.622	0.587	0.488
1974	0.191	0.343	0.506	0.623	0.659	0.604	0.472
1975	0.271	0.395	0.443	0.424	0.392	0.358	0.311
1976	0.057	0.094	0.164	0.255	0.356	0.458	0.523
1977	0.162	0.279	0.396	0.471	0.496	0.489	0.470
1978	0.204	0.342	0.449	0.468	0.409	0.335	0.281
1979	0.108	0.208	0.343	0.456	0.507	0.498	0.437
1980	0.180	0.275	0.388	0.455	0.436	0.349	0.243
1981	0.184	0.294	0.435	0.535	0.544	0.493	0.441
1982	0.190	0.302	0.450	0.577	0.638	0.615	0.518
1983	0.115	0.130	0.165	0.222	0.284	0.338	0.387
1984	0.132	0.183	0.281	0.392	0.457	0.450	0.400
1985	0.297	0.414	0.495	0.534	0.549	0.541	0.499
1986	0.142	0.190	0.265	0.351	0.415	0.432	0.416
1987	0.130	0.163	0.217	0.284	0.353	0.412	0.445
1988	0.218	0.320	0.431	0.514	0.551	0.555	0.538
1989	0.261	0.337	0.389	0.397	0.376	0.351	0.326
1990	0.272	0.328	0.388	0.452	0.500	0.511	0.483
1991	0.235	0.324	0.421	0.493	0.524	0.515	0.476
1992	0.333	0.445	0.514	0.543	0.566	0.583	0.574
1993	0.291	0.416	0.527	0.580	0.568	0.515	0.452
1994	0.238	0.326	0.406	0.448	0.453	0.436	0.404
1995	0.298	0.415	0.520	0.571	0.560	0.511	0.454
1996	0.348	0.480	0.595	0.658	0.651	0.583	0.474
1997	0.403	0.505	0.570	0.579	0.525	0.423	0.311
1998	0.223	0.277	0.301	0.276	0.222	0.174	0.150
1999	0.140	0.140	0.140	0.140	0.140	0.140	0.140
2000	0.367	0.494	0.560	0.554	0.489	0.387	0.271
2001	0.217	0.342	0.459	0.527	0.534	0.487	0.402
2002	0.183	0.311	0.442	0.529	0.552	0.513	0.431
70-79 Avg	0.212	0.311	0.396	0.452	0.480	0.481	0.456
80-89 Avg	0.185	0.261	0.352	0.426	0.460	0.454	0.421
90-99 Avg	0.278	0.366	0.438	0.474	0.471	0.439	0.392
00-09 Avg	0.256	0.382	0.487	0.537	0.525	0.463	0.368

Computed Marine +FSC Exploitation for different Sx Run-Timing Components from 1970-2002

Week	Jn 25-1	Jl 1-7	Jl 8-14	Jl 15-21	Jl 22-28	Jl 29-04	Au 5-11
1970	0.357	0.421	0.444	0.454	0.456	0.454	0.472
1971	0.152	0.199	0.258	0.342	0.447	0.543	0.601
1972	0.463	0.571	0.601	0.597	0.604	0.630	0.650
1973	0.357	0.457	0.551	0.635	0.672	0.637	0.538
1974	0.241	0.393	0.556	0.673	0.709	0.654	0.522
1975	0.321	0.445	0.493	0.474	0.442	0.408	0.361
1976	0.107	0.144	0.214	0.305	0.406	0.508	0.573
1977	0.212	0.329	0.446	0.521	0.546	0.539	0.520
1978	0.254	0.392	0.499	0.518	0.459	0.385	0.331
1979	0.158	0.258	0.393	0.506	0.557	0.548	0.487
1980	0.240	0.335	0.448	0.515	0.496	0.409	0.303
1981	0.244	0.354	0.495	0.595	0.604	0.553	0.501
1982	0.250	0.362	0.510	0.637	0.698	0.675	0.578
1983	0.175	0.190	0.225	0.282	0.344	0.398	0.447
1984	0.192	0.243	0.341	0.452	0.517	0.510	0.460
1985	0.357	0.474	0.555	0.594	0.609	0.601	0.559
1986	0.202	0.250	0.325	0.411	0.475	0.492	0.476
1987	0.190	0.223	0.277	0.344	0.413	0.472	0.505
1988	0.278	0.380	0.491	0.574	0.611	0.615	0.598
1989	0.321	0.397	0.449	0.457	0.436	0.411	0.386
1990	0.332	0.388	0.448	0.512	0.560	0.571	0.543
1991	0.295	0.384	0.481	0.553	0.584	0.575	0.536
1992	0.393	0.505	0.574	0.603	0.626	0.643	0.634
1993	0.351	0.476	0.587	0.640	0.628	0.575	0.512
1994	0.298	0.386	0.466	0.508	0.513	0.496	0.464
1995	0.358	0.475	0.580	0.631	0.620	0.571	0.514
1996	0.408	0.540	0.655	0.718	0.711	0.643	0.534
1997	0.463	0.565	0.630	0.639	0.585	0.483	0.371
1998	0.283	0.337	0.361	0.336	0.282	0.234	0.210
1999	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2000	0.407	0.534	0.600	0.594	0.529	0.427	0.311
2001	0.227	0.352	0.469	0.537	0.544	0.497	0.412
2002	0.203	0.331	0.462	0.549	0.572	0.533	0.451
70-79 Avg	0.262	0.361	0.446	0.502	0.530	0.531	0.506
80-89 Avg	0.245	0.321	0.412	0.486	0.520	0.514	0.481
90-99 Avg	0.338	0.426	0.498	0.534	0.531	0.499	0.452
00-09 Avg	0.279	0.405	0.510	0.560	0.548	0.486	0.391

Appendix Table 7. Predicted and Observed production data for Skeena sockeye nursery lakes (April 03 revisions)

Lake	Optimum Escape. Smax (n)	Observed Smolt Bio. (t/lake)	PR Max. Smolt Bio. (t/lake)	% Obs of PR Max. Smolt Bio.	Adj. PR Max Smolt Bio. (t/lake)	% Obs of Adj. PR Max. Smolt Bio.	PR Estimated Spawning Escape (2)	Visual/Fence 1990-2002 Escape (3)	Possible PRP (7)	Estimated MSY Escapement	Estimated MSY Recruits	Estimated MSY Equil. Exploit.	Estimated 90-99 Mean Exploit.(6)
Alastair	33000	2.34	7.99	29	3.20	73	13200	6385	3300	13575	23233	0.42	0.34
Lakelse	26000	2.57	6.39	40	2.88	89	15500	4369	2600	11301	20149	0.44	0.34
Swan	24000	0.68	5.90	11	2.36	29	2800	7482	2400	9162	14919	0.39	0.50
Stephens	7000	0.44	1.70	26	0.71	62	2200	w/Swan	700	2958	5163	0.43	0.50
Club	600	0.00	0.14	3	0.10	4	260	w/Swan	60	290	568	0.49	0.50
Morice	120000	5.07	21.40	24	10.70	47	26000	19412	12000	40866	62631	0.35	0.43
Atna	14000	0.14	3.35	4	1.17	12	650	w/Morice	1400	4750	7229	0.34	0.43
Maxan (1)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Slamgeesh	800	0.18	0.19	92	0.19	92	560	837	80	536	1639	0.67	0.50
Kitwanga	18000	0.14	9.59	1	1.53	9	600	449	1800	6137	9364	0.34	0.53
Kalum	20500	0.37	5.00	7	2.20	17	1300	3606	2050	8374	14263	0.41	0.53
McDonnel	3600	0.21	0.87	24	0.36	58	1000	3356	360	1426	2378	0.40	0.50
Dennis	550	n/a	0.13	n/a	0.07	n/a	n/a	w/McDonnel	55	240	428	0.44	0.50
Aldrich	1100	n/a	0.27	n/a	0.12	n/a	n/a	w/McDonnel	110	478	852	0.44	0.50
Johanson	3100	0.04	0.76	5	0.34	12	500	1705	310	1349	2407	0.44	0.50
Sustut	2800	0.08	0.67	12	0.34	24	500	w/Johanson	280	1252	2285	0.45	0.50
Bear	30000	0.97	7.30	13	3.26	30	3600	2313	3000	12666	22092	0.43	0.53
Asitka	1100	0.05	0.27	20	0.11	49	270	w/Johanson	110	463	805	0.42	0.43
Morrison	44000	2.13	10.7	20	3.96	54	13575	8379	4400	19657	35826	0.45	0.50
Babine (all)	2200000	331.92	528.58	63	396.00	84	1400000	1249479	220000	1347548	3511335	0.62	0.53
Azuklotz	13000	0.63	3.12	20	1.28	49	3700	w/Bear	1300	5507	9630	0.43	0.53
Damshilgwit	1000	0.05	0.24	20	0.10	49	80	w/Slamgeesh	100	414	710	0.42	0.50
Johnston	6700	0.33	1.63	20	0.68	49	1800	1090	670	2832	4943	0.43	0.34
Kluatantan	1600	0.08	0.39	20	0.17	47	400	no data	160	695	1238	0.44	0.43
Kluayaz	4100	0.20	0.99	20	0.42	48	1100	no data	410	1699	2923	0.42	0.50
Sicintine	2100	0.10	0.52	20	0.21	50	570	no data	210	870	1496	0.42	0.50
Spawning	600	0.03	0.14	20	0.06	48	130	w/Johanson	60	252	437	0.42	0.50
Motase	82000	4.06	20.00	20	8.00	51	23500	no data	8200	34442	59842	0.42	0.53
Non-Bab.	461250	20.89	109.65	19	44.52	47	113795	59383	46125	182191	307450	0.41	
Babine	2200000	331.92	528.58	63	396.00	84	1400000	1249479	220000	1347548	3511335	0.62	

(1) Maxan+Bulkley Lakes, no PR or juvenile data available, restricted access due to habitat degredation, low flows. Past evidence of Sx in both lakes.

(2) The spawning escapement required to produce observed smolt biomass levels. Estimated from the adjusted PR stock-recruit curves for each lake.

(3) Visual escapement data are of unknown accuracy but are considered underestimates. Fence counts are for Sustut/Johanson, Babine, and Slamgeesh Lakes.

(4) Morrison Lake is included with Babine Lake

(5) Recruits (kg/hec) vs Spawners (females/hec) assuming 50:50 sex comp.

(6) Does not include ESSR exploitation, which would represent an add-on 1990-1999 average of about 0.05 for some stocks (e.g. Babine)

(7) Prudent Reference Point = 10% of optimum spawning escapement Smax: simulations show this is roughly equivalent to escapement level required to achieve MSY within 3 generations.
under no exploitaion with 90% probability. Rules for determining PRP's are still evolving and have not yet been finalised. PRP's less than 100 fish are not considered realistic

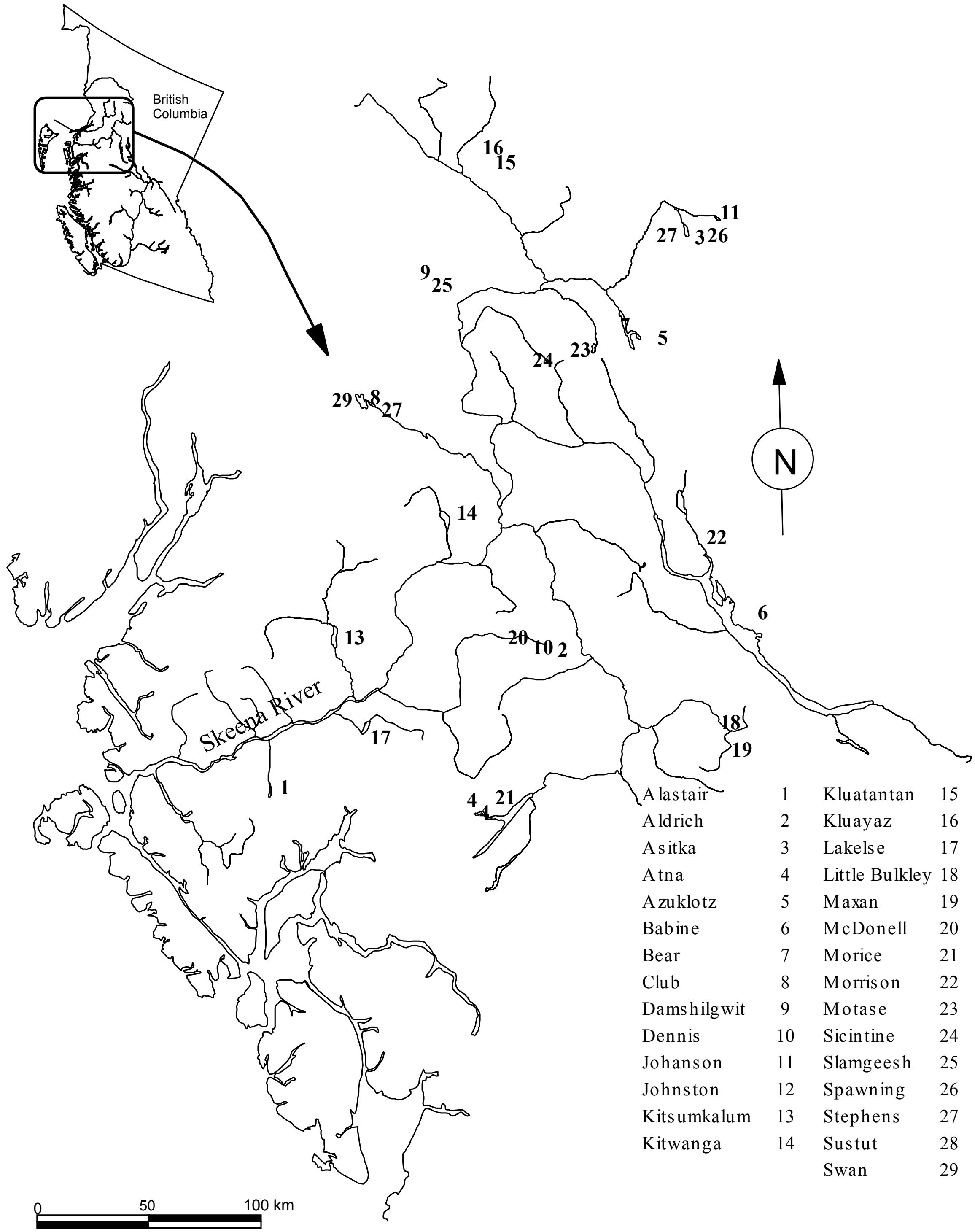


Figure 1. Skeena River sockeye salmon nursery lakes.

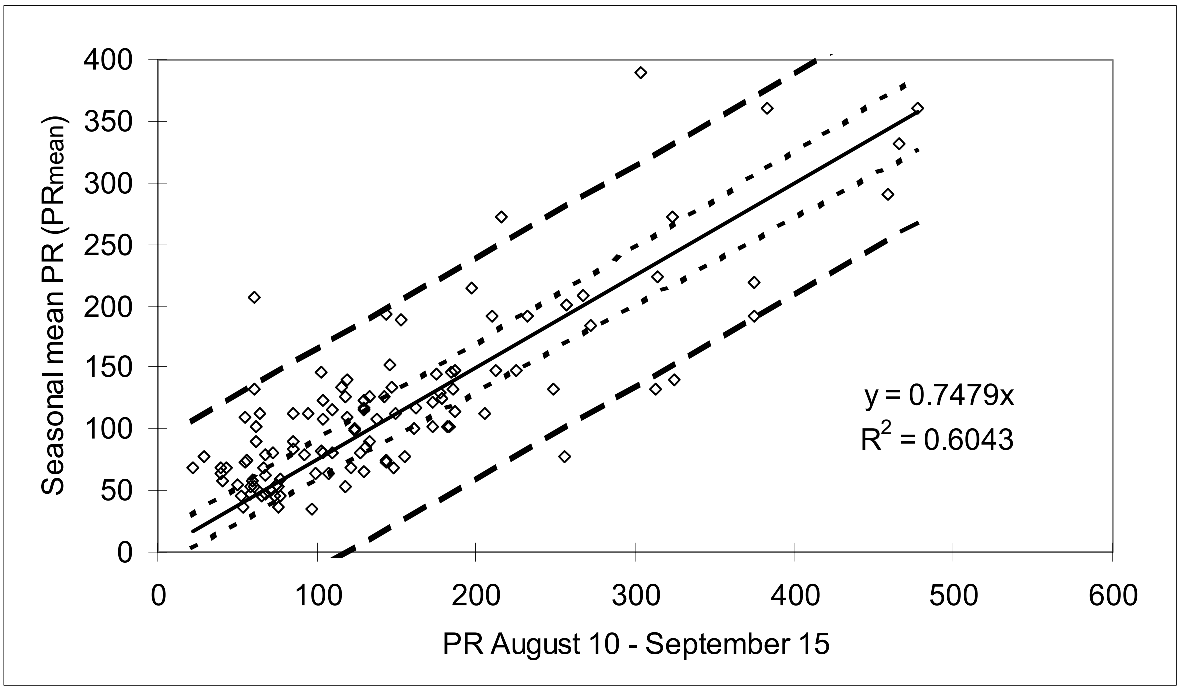


Figure 2. Relationship between seasonal mean PR (PR_{mean}) and PR from the fall of the same year. Inner dashed lines are the 95% CI and the outer lines are the 95% prediction interval from one fall sample.

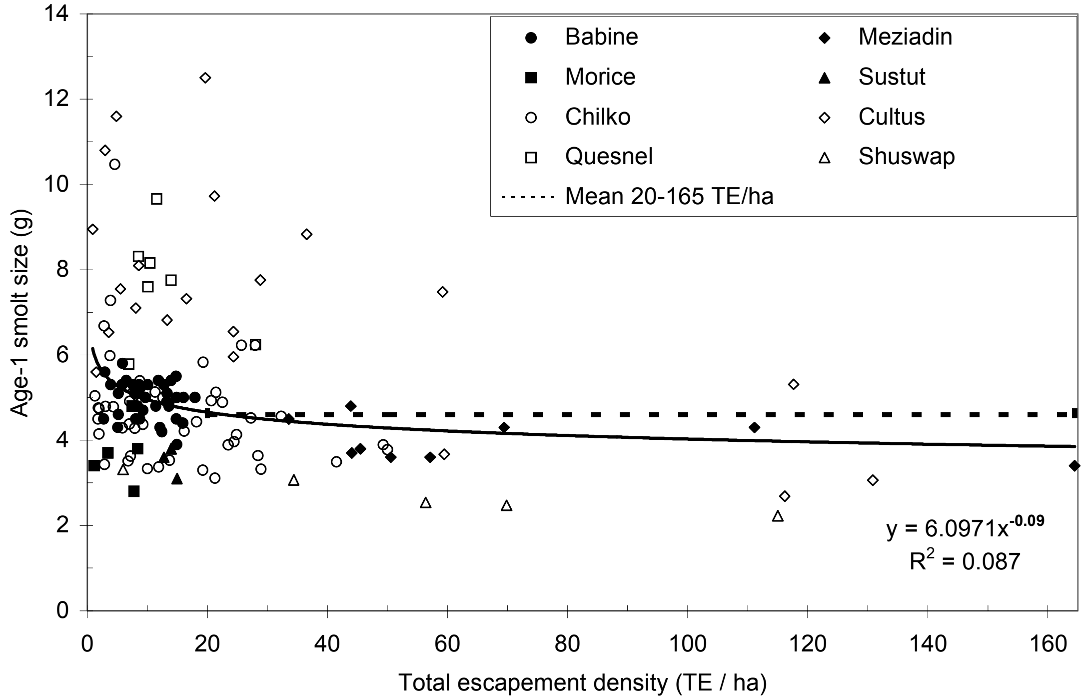


Figure 3. Weight of age-1 sockeye smolts from eight rearing lakes in British Columbia. The solid line is fitted to all data. The mean size from all escapements greater than 20TE/ha is shown (dotted line).

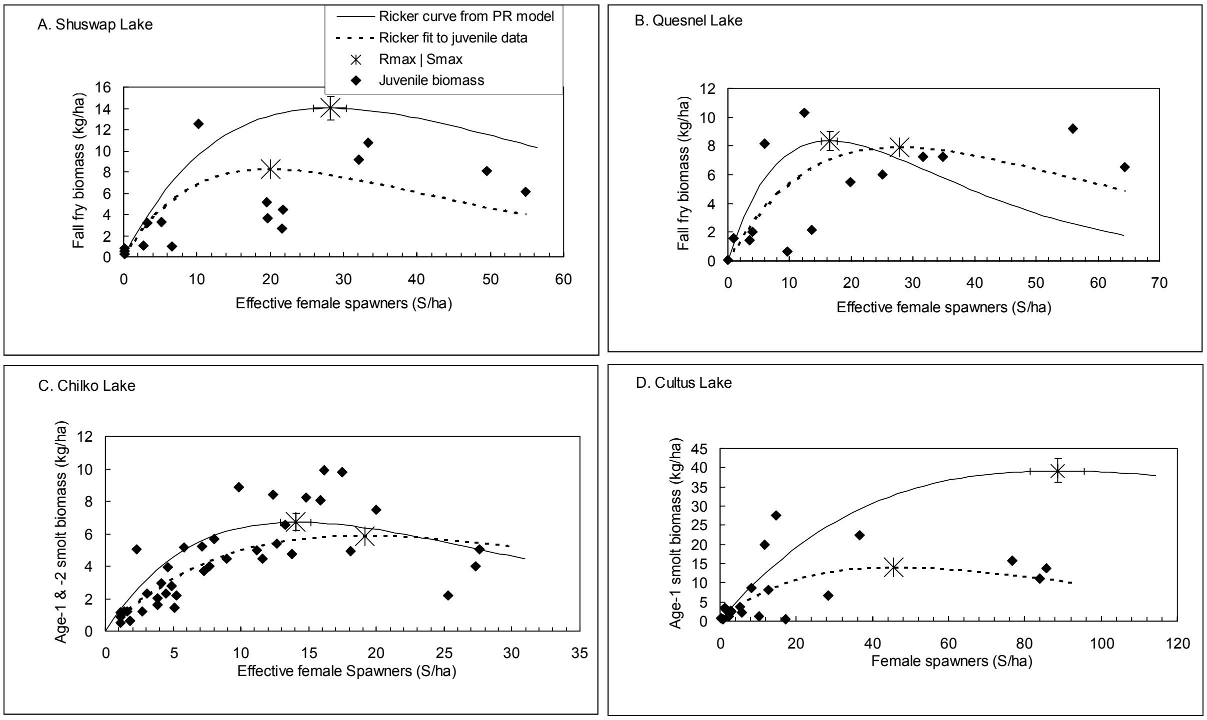


Figure 4. Comparisons of Ricker curves generated from the PR model with Ricker curves fitted to the observed juvenile biomass from four Fraser system lakes. Two standard errors of the PR estimate for S_{max} and R_{max} are shown.

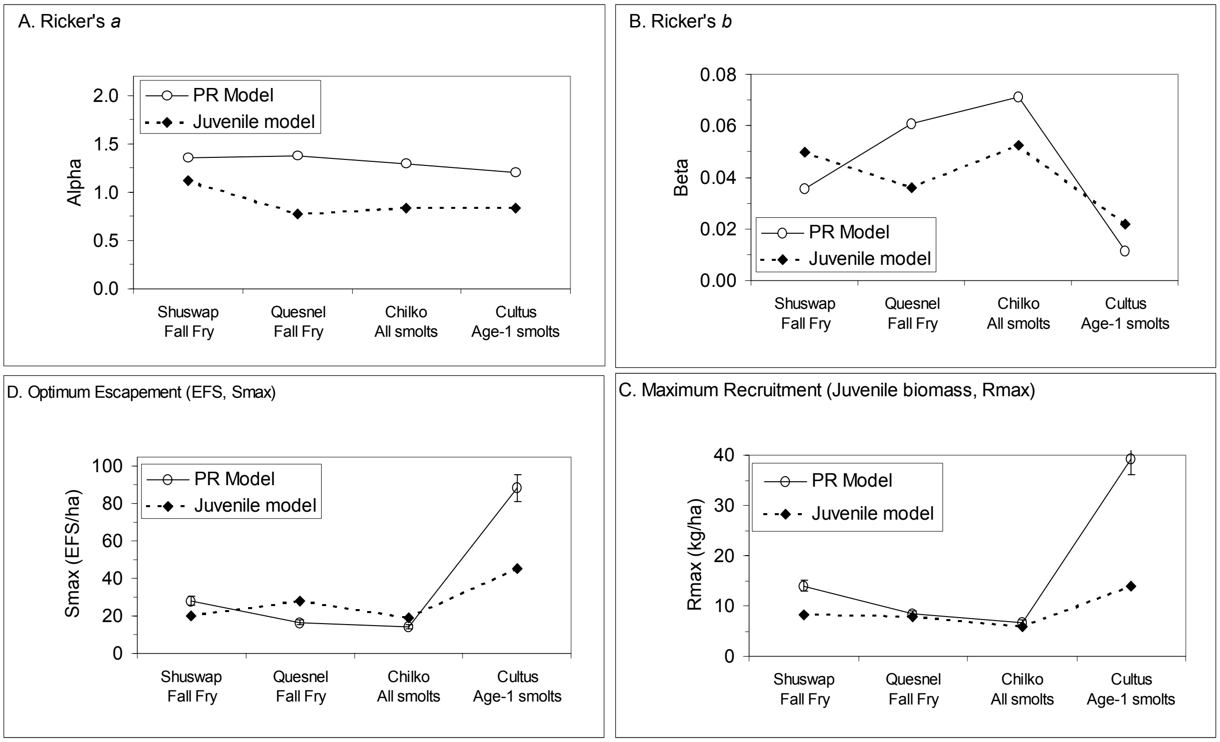


Figure 5. Comparison of model and management parameters from the Ricker curves shown in Fig. 4.

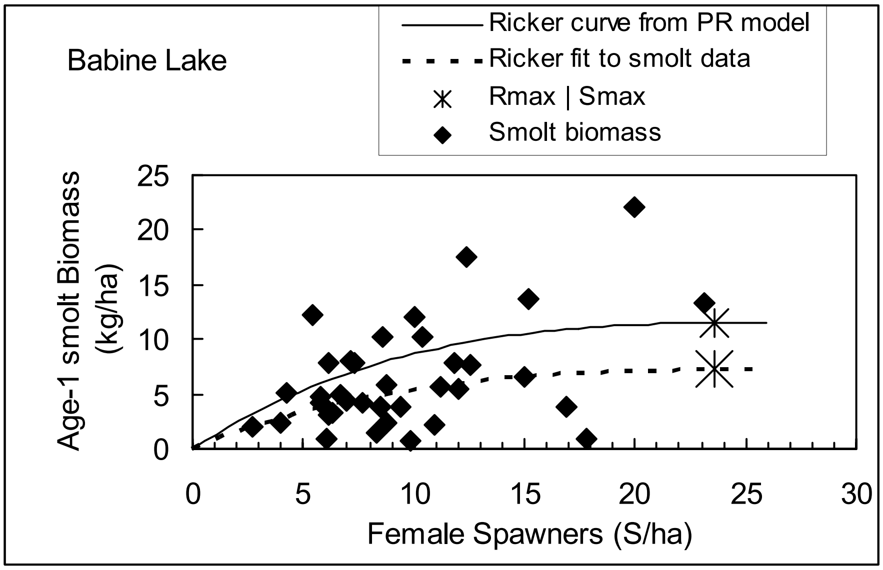


Figure 6. Comparison of the Ricker curve generated from the PR model with the Ricker curve fitted to the observed juvenile biomass for Babine Lake (1960-1995).

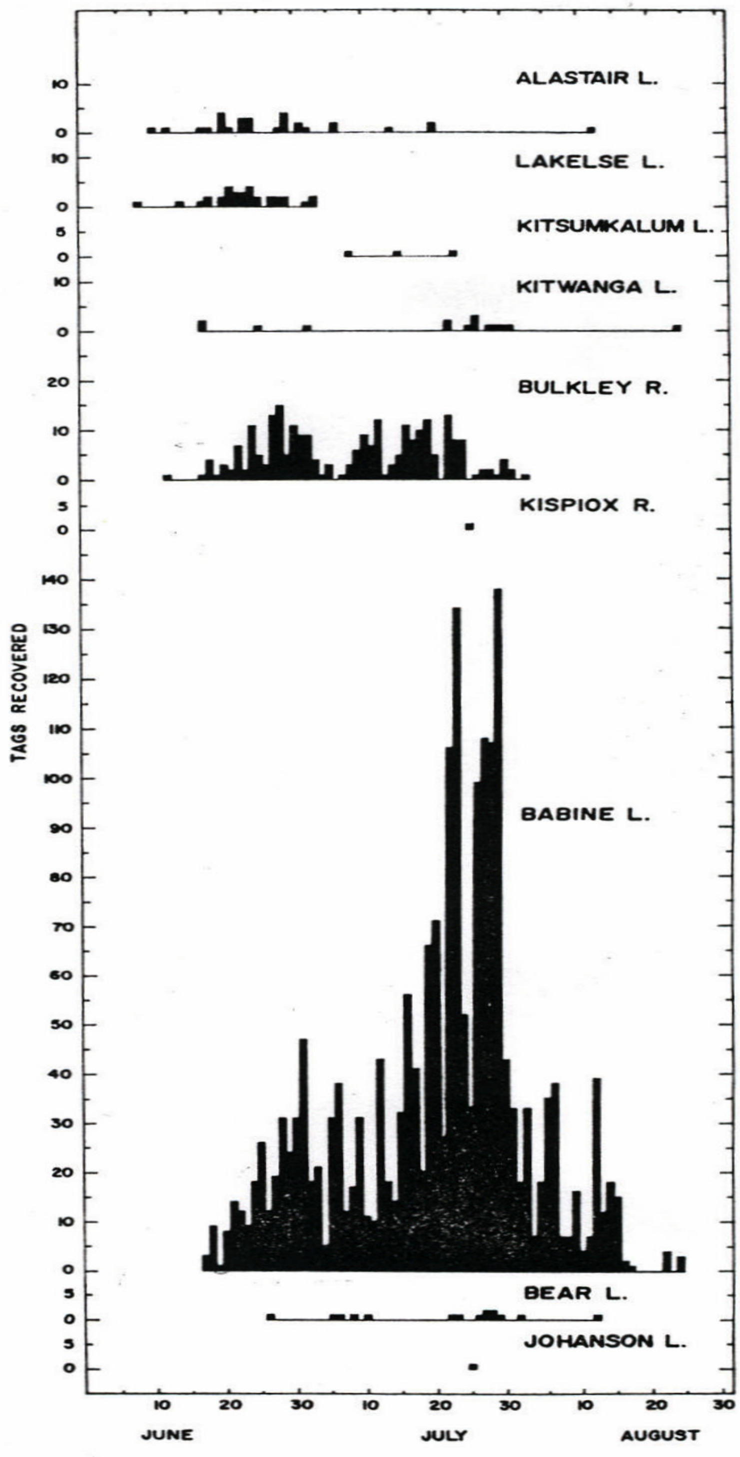


Figure 7. Comparsion of sockeye tag recoveries at various Skeena River spawning areas plotted by the dates when the fish were estimated to have passed the river boundary (source Aro and McDonald 1968).

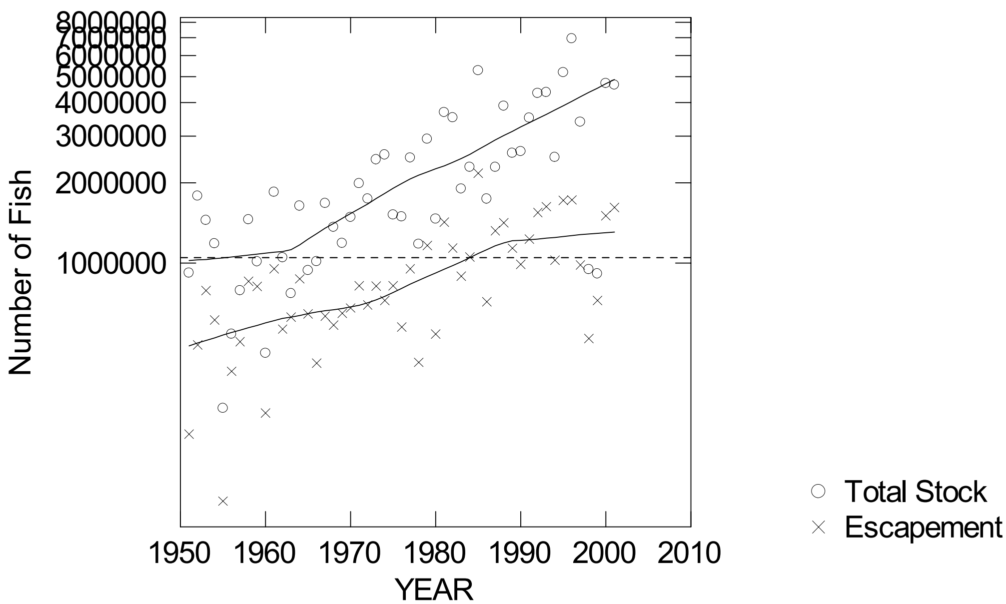


Figure 8. Skeena River sockeye salmon aggregate total stock and escapement 1951-2001. The dashed line is the aggregate-stock escapement goal past the Tyee test fishery of 900,000 + 150,000 for FSC allocations. Note the y-axis is plotted on a logarithmic scale. The smoothed trend line is a LOWESS fit. Data prior to 1970 are not reconstructed through all fisheries and therefore may underestimate total stock.

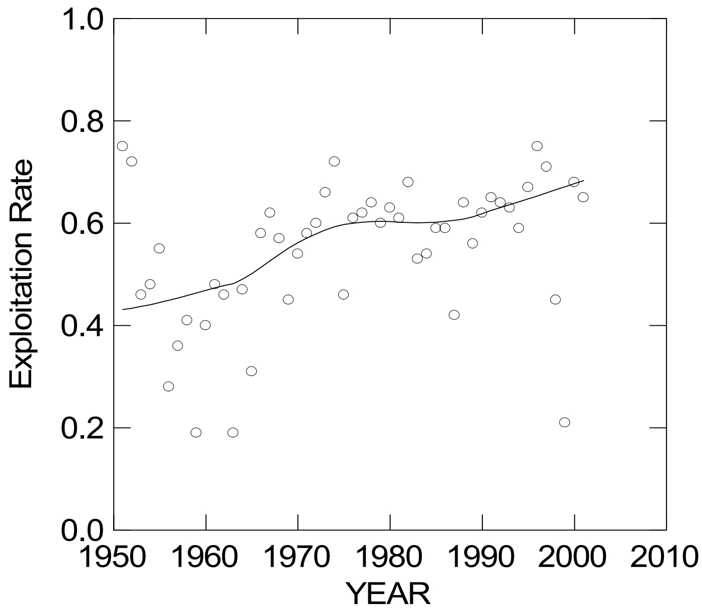


Figure 9. Skeena River sockeye salmon exploitation rates for the aggregate stock: 1951-2001. The smoothed trend line is a LOWESS fit. Data prior to 1970 are not reconstructed through all fisheries and may therefore underestimate total exploitation. Average exploitation (all fisheries) since enhancement of Babine Lake began in the late 1960’s has been in the 0.60-0.65 range.

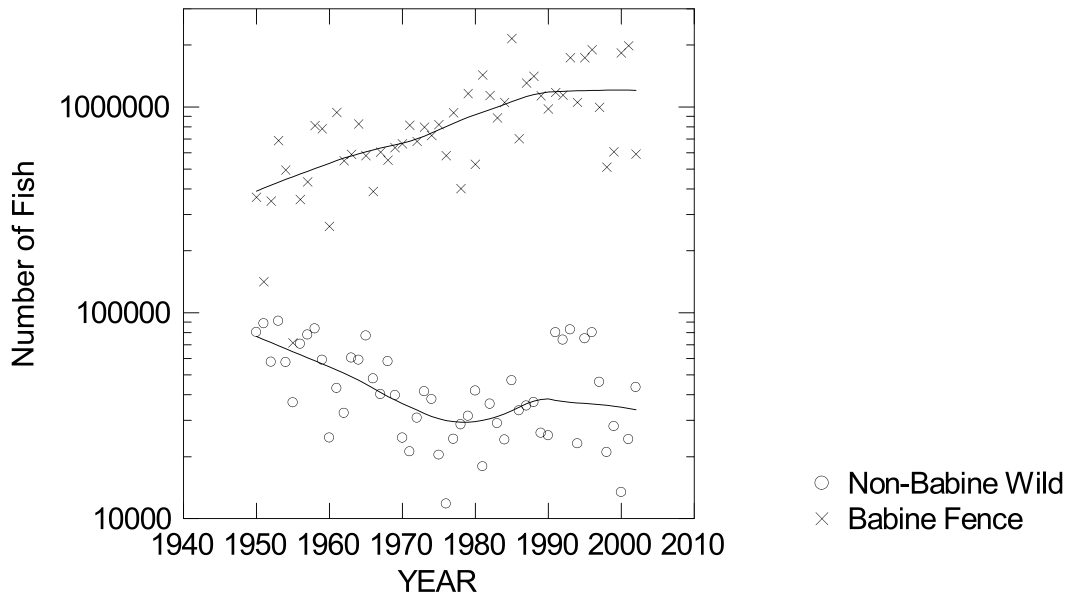


Figure 10. Sockeye salmon counts through the Babine River counting fence at Babine Lake and estimated sockeye escapements for aggregated non-Babine nursery lakes: 1950-2002. Note the y-axis is plotted on a logarithmic scale. The smoothed trend line is a LOWESS fit. Note that under-estimate error and/or missing survey data for some lakes in some years has not been incorporated into the estimated escapements for the aggregated non-Babine nursery lakes.

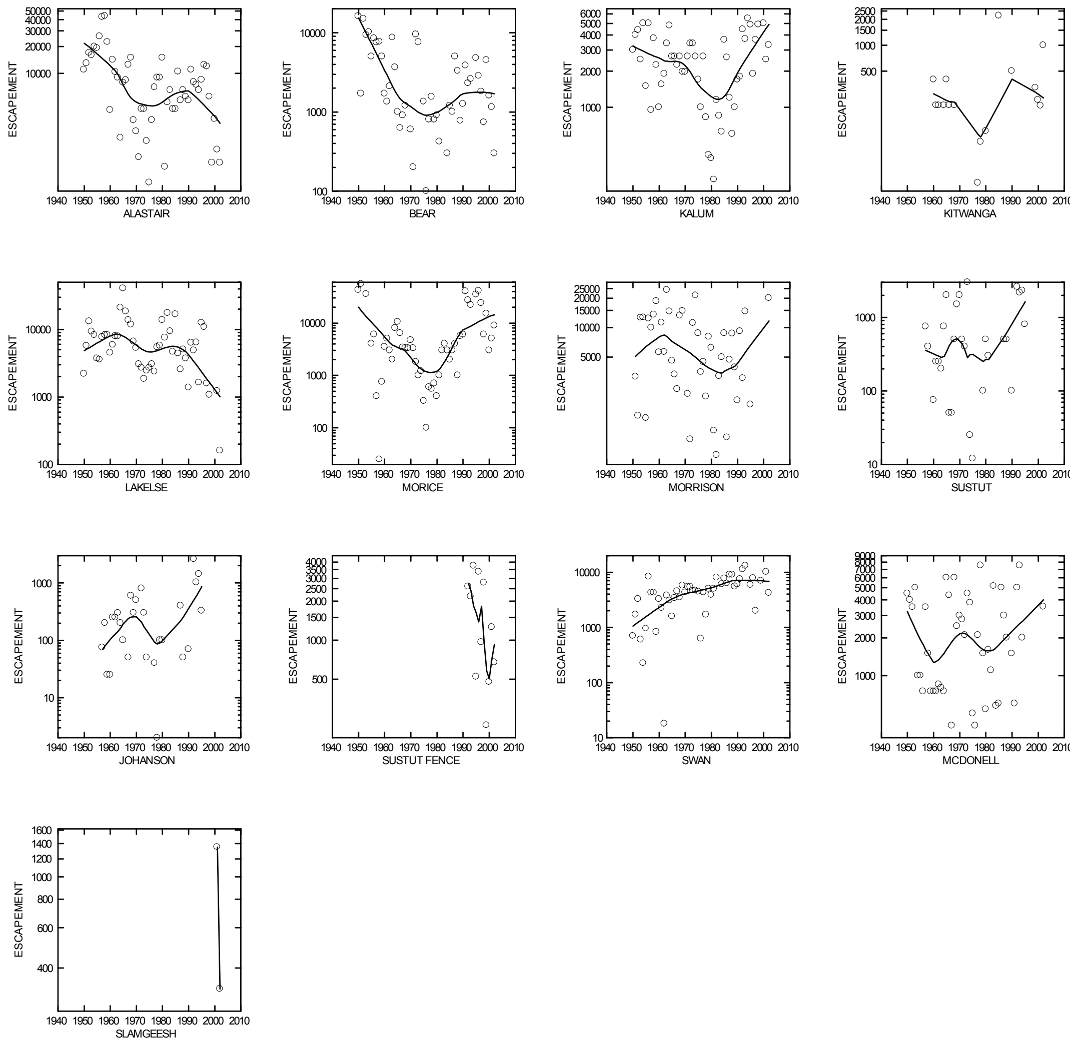
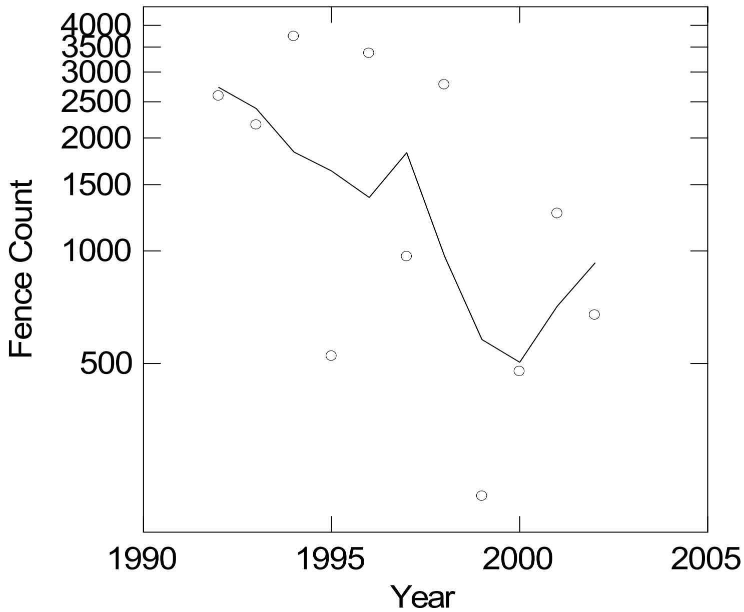


Figure 11. Available escapement records for non-Babine sockeye nursery lakes: 1950-2002. All except Kitwanga Lake 1999-2002, the Sustut Fence 1992-2002, and Slamgeesh Lake 2000-2001 are visual estimates. Note the y-axis is plotted on a logarithmic scale. The smoothed trend lines are LOWESS fits.



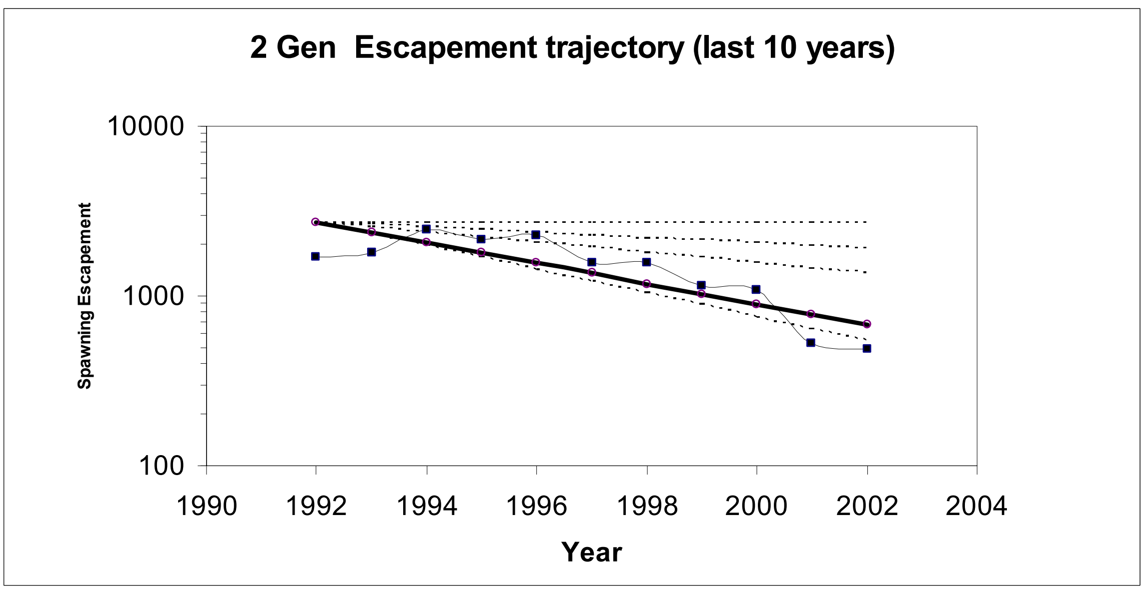


Figure 12. Sockeye salmon escapement counts through the Sustut River counting fence (1992-2002) and the estimated decline rate (about 75%) from 1992-2002. The Sustut fence is located on the upper Sustut River and enumerates sockeye escapements into both Sustut and Johanson Lakes. Note the y-axis is plotted on a logarithmic scale. The smoothed trend line in the upper graph is a LOWESS fit. The decline rate is calculated from the linear regression of smoothed fence count escapement (5yr running avg) over the past 10 years. The dashed lines show the zero, 30%, 50%, and 80% decline lines.

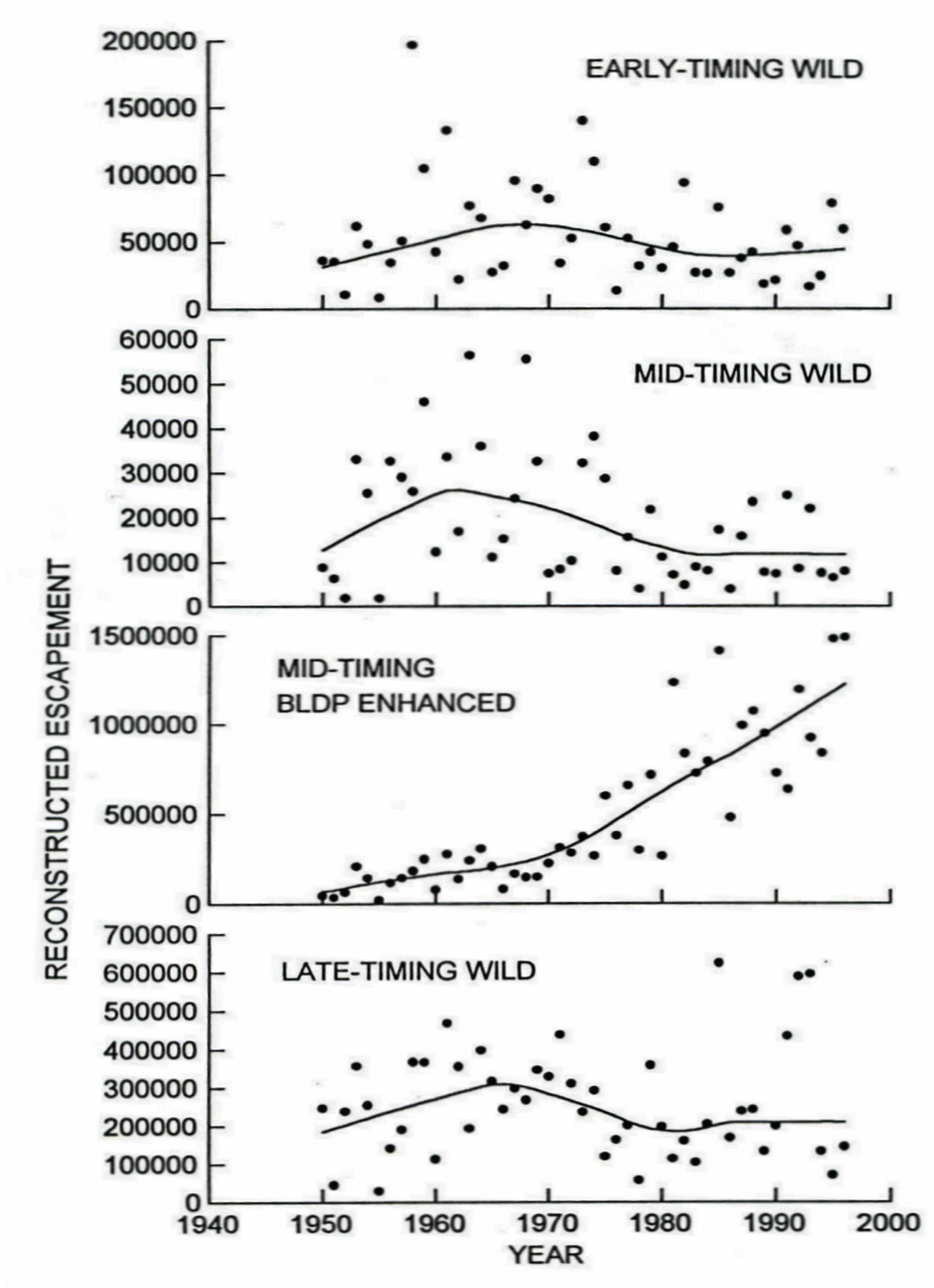


Figure 13. Trends in reconstructed escapements to Babine Lake by run-timing group. 1950-1996. The smoothed trend line is a LOWESS fit. Source. Wood et al. (1998).

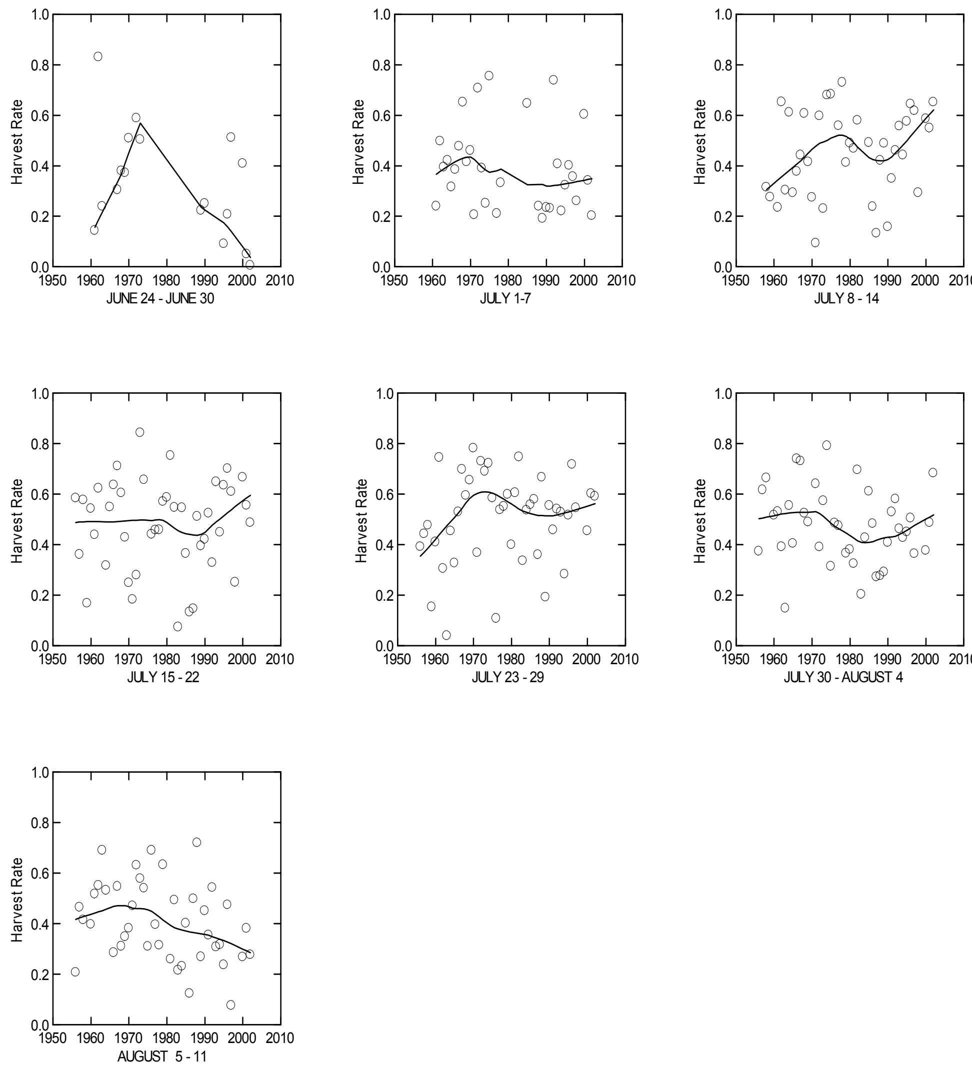


Figure. 14. Computed Area 4 weekly harvest rates (catch/ (catch+escapement) for the Skeena River aggregate sockeye salmon stock: 1956-2002. The smoothed trend line is a LOWESS fit. Data points for 1997-2002 include outer Area 3 and Area 5.

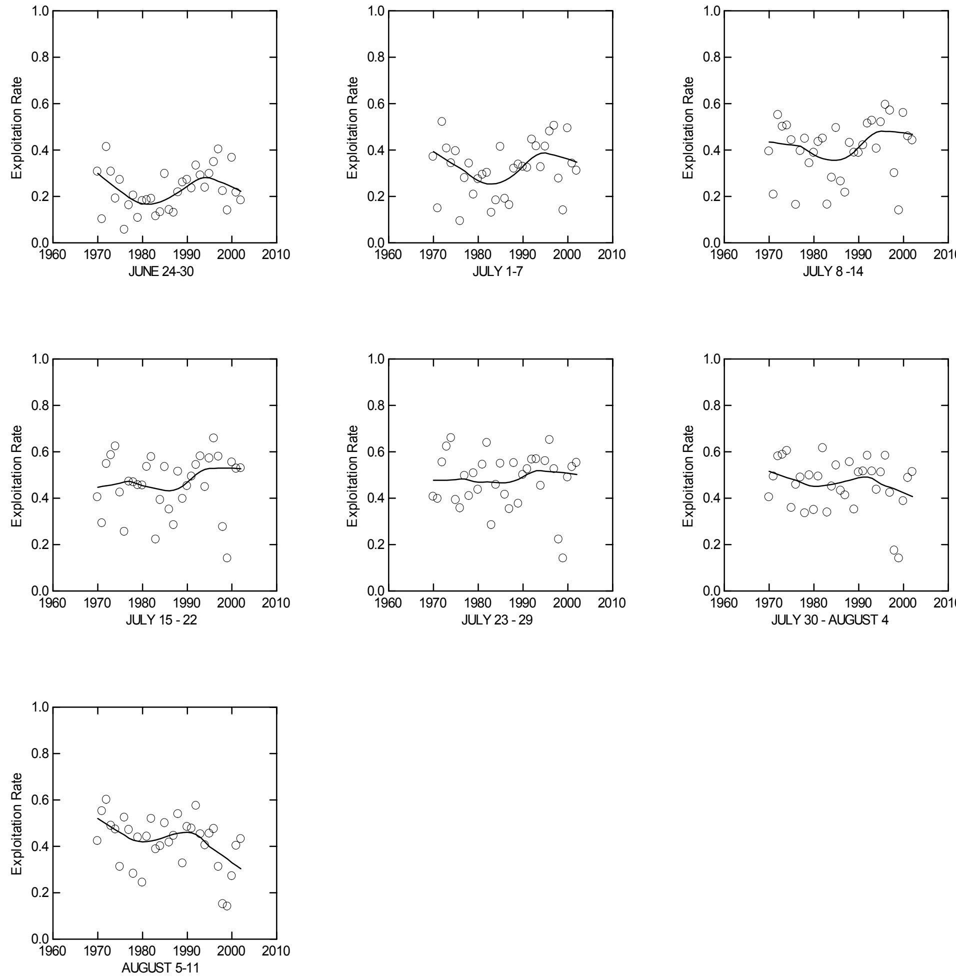


Figure 15. Estimated marine exploitation rates (Alaska+Canada) on Skeena River sockeye sub-stocks peaking in Area 4 during specific weeks: 1970-2002. The smoothed trend line is a LOWESS fit.

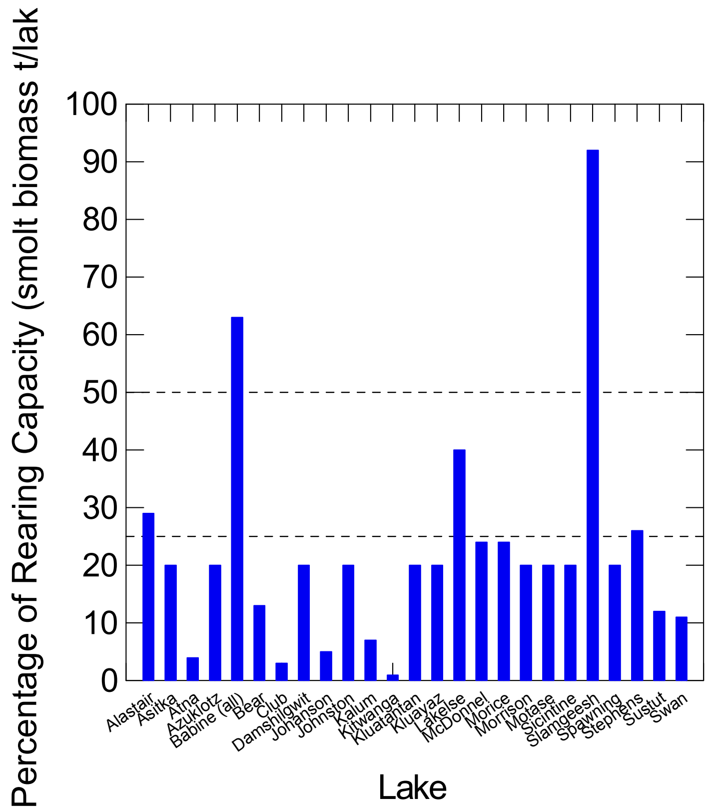


Figure 16. Estimated percentage of juvenile rearing capacity being achieved for each Skeena sockeye rearing lake based upon **un-adjusted** PR model data (see text). The percentage of juvenile rearing capacity being achieved = observed smolt biomass/estimated maximum smolt biomass at capacity*100.

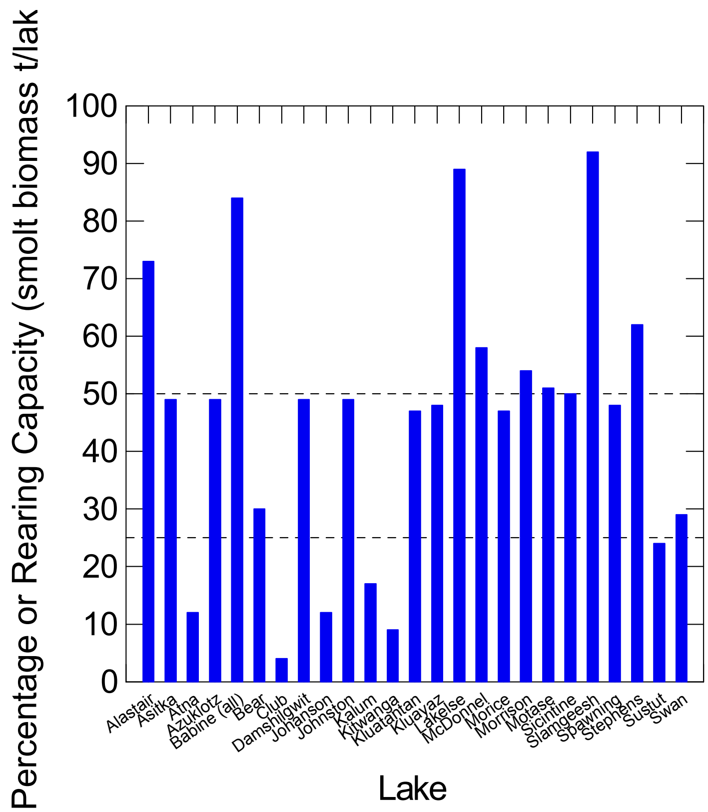


Figure 17. Estimated percentage of juvenile rearing capacity being achieved for each Skeena sockeye rearing lake based upon **adjusted** PR model data (see text). The percentage of juvenile capacity being achieved = observed smolt biomass/maximum smolt biomass at capacity*100. The adjusted PR model data reflect reductions in estimated juvenile rearing capacity as a result of suspected parameter over-estimation error and/or the presence of factors other lake rearing capacity limiting sockeye productivity in the nursery lakes.

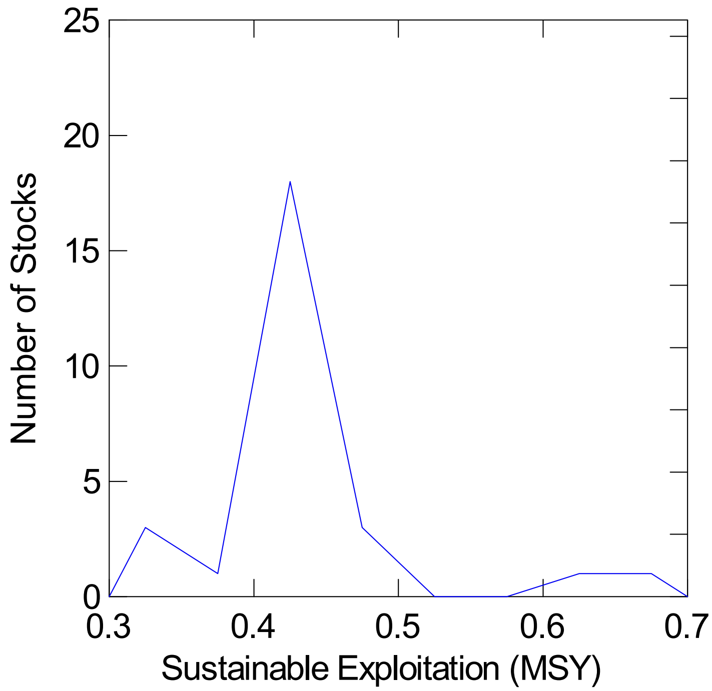


Figure 18. The estimated distribution of sustainable exploitation at MSY for Skeena sockeye stocks (nursery lakes).