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**Research Document 2001/083**

**Document de recherche 2001/083**

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## **2001 Stock Status Assessment of Coho Salmon from the Interior Fraser River**

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## Abstract

The extreme fishery management measures undertaken in BC since 1998 to conserve coho appear to have stopped the declining trend for interior Fraser coho populations. We evaluated the impacts of continued restrictions in salmon harvest on the status of coho salmon of the interior Fraser River, including the Thompson drainage in 2000. Fishery exploitations in 2000 were the lowest on record, ~3.4% in total, of which half was in British Columbia. Fishery exploitations the last two years were low enough that spawner numbers generally exceeded brood escapements. Productivity measured in recruits per spawner has improved and populations are now above replacement levels.

A mark-recapture program that used fishwheels in the Fraser Canyon as marking platforms provided an independent estimate of spawner numbers in the interior Fraser watershed, as well as useful information on stock composition. Results indicated that spawner surveys may be missing significant numbers of coho, particularly in non-Thompson streams. Additional survey work is required to verify the distribution of coho in the upper Fraser watershed, determine abundance, and collect baseline genetic samples.

We updated our information on the population structure of interior Fraser coho, and present evidence that indicates that major drainage basins (e.g. North and South Thompson) may need to be considered as separate Conservation Units. We discuss reference points for various coho populations and present several values calculated using data from North Thompson coho. The mean of two minimum reference points was 5.2 female spawners per kilometer of accessible habitat. We presume that a limit reference point for North Thompson coho would be greater than or equal to this value. Since coho escapements in the North Thompson watershed have been near but generally below this provisional reference point the past four years, we conclude that the viability of these fish remains at risk. This finding, combined with the short-term forecast for Thompson coho of continued poor survivals, leads to our recommendation that a cautious approach to fisheries management needs to remain in place in order to allow these populations the opportunity to rebuild.

The major recommendations from this research document are:

1. More extensive baseline coverage of interior Fraser coho, especially in non-Thompson tributaries upstream of the Fraser-Thompson confluence are required to aid in the delineation of populations and Conservation Units, and provide more precise estimates of the distribution and numbers of interior Fraser coho in catches.
2. Rates of genetic exchange between generations and among populations need to be determined.
3. To enable more effective fisheries management, coho encounter and DNA based stock composition information should be used to develop a model of coho marine distribution and migratory timing.
4. Although benefits can be seen from the extreme fishery management measures taken in recent years, these measures should remain in place to permit populations the opportunity to rebuild.

## Résumé

Les mesures radicales de gestion des pêches prises en Colombie-Britannique depuis 1998 en vue de protéger le saumon coho semblent avoir stoppé la tendance à la baisse des populations du cours supérieur du Fraser. Sont évaluées dans le présent document les répercussions des limites des prises de saumon sur l'état du stock de coho du cours supérieur du Fraser, y compris le bassin versant de la rivière Thompson, en 2000. Les prises en 2000 étaient les plus faibles enregistrées, soit environ 3,4 % du total des effectifs, dont la moitié ont été récoltées en Colombie-Britannique. Les prises au cours des deux dernières années étaient tellement faibles que le nombre de géniteurs était généralement supérieur à l'échappée. La productivité, mesurée en nombre de recrues par géniteur, a augmenté et les populations se situent maintenant au-dessus des niveaux de remplacement.

Un programme de marquage et de recapture utilisant des filets rotatifs installés dans le canyon du Fraser comme plates-formes de marquage a donné une estimation indépendante du nombre de géniteurs dans le cours supérieur du Fraser, ainsi que des renseignements utiles sur la composition du stock. Les résultats révèlent que les relevés de géniteurs ignorent peut-être un grand nombre de coho, en particulier dans les cours d'eau autres que la Thompson. D'autres travaux sont requis pour vérifier la distribution du coho dans le cours supérieur du Fraser, établir son abondance et prélever des échantillons de matériel génétique de base.

Les renseignements sur la structure de la population du coho du cours supérieur du Fraser ont été mis à jour et des éléments probants sont présentés qui indiquent que les principaux bassins versants (p. ex., la Thompson Nord et la Thompson Sud) devraient peut-être être considérés comme des unités de conservation distinctes. Les points de référence de diverses populations de coho sont examinés et plusieurs valeurs, calculées à partir de données sur le coho de la Thompson Nord, présentées. La moyenne de deux points de référence minimums se chiffre à 5,2 géniteurs femelles par km d'habitat facile d'accès. On suppose qu'un point de référence limite pour le coho de la Thompson Nord serait égal ou supérieur à cette valeur. Étant donné que les échappées de coho dans le bassin versant de la Thompson Nord se rapprochaient de ce point de référence moyen, mais sans y être égal, au cours des quatre dernières années, on conclut que la viabilité de ces géniteurs reste menacée. Cette conclusion, jointe au fait que l'on prévoit à court terme que le coho de la Thompson continuera à souffrir d'un faible taux de survie, a mené à la recommandation à l'effet qu'il faut continuer de faire preuve de prudence dans la gestion des pêches afin de permettre à ces populations de se rétablir.

Suivent les principales recommandations formulées :

1. Une couverture de base plus exhaustive du coho du cours supérieur du Fraser, en particulier des tributaires autres que la Thompson en amont de la confluence de ces deux cours d'eau, est nécessaire pour délimiter les populations et les unités de conservation et obtenir des estimations plus précises de la distribution et du nombre de coho du cours supérieur du Fraser dans les prises.
2. Les taux d'échange génétique inter-populations et intra-populations doivent être déterminés.
3. Pour que la gestion des pêches soit plus efficace, l'information sur la présence du coho et la composition des stocks établies par analyse de l'ADN devrait être utilisée pour élaborer un modèle de la distribution et de la chronologie de la migration du coho en mer.
4. Les mesures radicales de gestion des pêches mises en œuvre dans les dernières années, très efficaces, devraient continuer à s'appliquer afin de permettre aux populations de se rétablir.

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## 1.0 Introduction

This is the fourth annual assessment of coho salmon from the interior Fraser River watershed. The study area encompasses the Fraser River watershed upstream of Hells Gate and includes the Thompson River, the largest watershed within the Fraser River system. We follow the recommendation from last year's assessment (Irvine et al. 2000b) that stated the upstream boundary of the management unit for interior Fraser coho should indicate the known distribution of coho. Coho are prevalent throughout the Thompson watershed but their distribution in non-Thompson Fraser systems is not well known. They are recorded as far upstream as the Nechako drainage (Fig. 1).

The primary objective of this report is to update our knowledge of the status of interior Fraser coho salmon. As in previous assessments, we do this by revising and evaluating our time series of spawner escapement and productivity (recruits per spawner) estimates. In addition, in response to a recommendation in last year's assessment, we assess status for North Thompson coho by comparing abundance with provisional reference points developed for coho from this watershed. We also evaluate the utility of a fishwheel program in the Fraser Canyon, and incorporate and discuss new information on the population genetic structure of interior Fraser coho.

## 2.0 Data Sources and Treatments

### 2.1 Genetic Information

In last year's assessment (Irvine et al. 2000b), we provided a detailed discussion on the genetic substructuring of interior Fraser coho. In the current report, we assemble the time series of stock composition information used to assess fishery impacts, and we incorporate new baseline information in a discussion of population structure.

As in other recent years, tissue samples were taken from coho caught in most fisheries. For mixed stock samples analyzed during 2000, five microsatellite (Oki1, Oki10, Oki100, Oki101 and Ots101) and two MHC (alpha 1 and alpha 2) loci were used.

The coho salmon coast-wide baseline currently consists of approximately 22,000 fish from 141 stocks ranging from southeastern Alaska to the Columbia River. An additional three stocks have been added to the baseline since our previous assessment. These additional populations are the Nahatlatch River, Fraser Canyon (~ 220 fish), Chapman Creek, Southern Mainland (~130 fish), and Chase River, East coast of Vancouver Island (~130 fish).

As in earlier assessments, we used three baseline sets of populations (including the three additional stocks) for estimation of stock compositions in marine fisheries in British Columbia (see Appendix 1 in Irvine et al. 2000b). These three baselines were developed to account for the likely origin of coho salmon in specific fisheries. To minimize bias, we did not include populations in the baseline if they were highly unlikely to be encountered in a fishery. Stock compositions for fishery samples from Statistical Areas 14-23 and 28-29 and Washington State were estimated with a "southern baseline". The southern baseline included 85 populations, with populations from Oregon, Washington, the Fraser River, Vancouver Island, and the southern BC mainland for analysis. Stock compositions for samples from Areas 6-13 and 24-27 were estimated with the "central baseline" that included all populations except Alaska. Stock compositions for samples from northern Areas 1-6 were estimated with the "northern baseline" that included all 142 populations in the analysis. Drainage-specific baseline populations were used to estimate stock compositions in freshwater fisheries in the Fraser River.

Maximum likelihood estimates (MLE) of stock grouping contributions were produced using the Statistics Program for Analyzing Mixtures (Debevec et al. 2000). Mixtures and baselines were bootstrapped 100 times to generate standard deviations about each point estimate.

Stock composition estimates for fisheries sampled during 1997-1999 are provided in Appendix 1, and results of analysis of 2000 samples are in Appendix 2. Although preliminary results from 1997-1999 were provided in earlier assessments, Appendix 1 contains results from the analysis of additional samples from this period and therefore replaces those results in earlier reports.

## 2.2 Spawner Escapement Surveys

Analysis of spawner escapement data provides the basis for many of our inferences about the status of interior Fraser coho. Some escapement estimates are obtained using a counting fence (with or without mark-recapture), others while drifting a stream in a vessel or by snorkeling, on foot, and from a helicopter. Previous assessments (Irvine et al. 1999a, b, 2000b) describe these field studies in detail.

We were concerned with the accuracy and precision of our escapement time series. We expected that many estimates were biased low for a variety of reasons including difficulties in seeing all fish and surveyors only sampling portions of many streams. We modified our sampling procedures commencing 1998 to evaluate bias (i.e. accuracy). Before the 1998 field season began, we assembled detailed stream escapement histories going back to 1990 for as many systems as we could (Irvine et al. 1999b, Appendix 3). For each stream/year combination, we documented the field technique and location where fish were counted, and the analytical or other methods used to generate the escapement estimate from the field data. For most systems since 1998, two separate escapement estimates were generated. The first was our best estimate of the true number of coho in the system that resulted from our increased survey effort. The second was what we refer to as a trend estimate which is the probable number of fish that would have been estimated if survey effort had been similar to other recent years. We refer to these as estimates of the *true* escapement and the *trend* escapement.

As in last year's assessment, two approaches were used to examine trends in spawner numbers. The first, an escapement indicator approach, relied on escapement estimates to unenhanced North and South Thompson streams with reasonably consistent monitoring. Results provided in this report are the total numbers estimated to return to spawn in 10 unenhanced streams in the North Thompson, and 16 unenhanced streams in the South Thompson and have not been corrected for bias. Details on the approach are provided in earlier assessments (Irvine et al. 1999a, 1999b, 2000b).

The second time series approach used an escapement time series that included estimates for all streams. Using procedures documented in the most recent forecast document for southern B.C. coho (Simpson et al. 2001), total numbers of coho salmon spawners returning to the major basins within the Thompson watershed were estimated (Appendix 3). The complete escapement data set post-1975 was used, rather than only indicator stream data as described in the previous paragraph. Escapement estimates since 1975 were adjusted upwards based on individual stream estimates of the ratio between the estimate of the true escapement and the trend estimate. Missing escapement values were estimated. The escapement time series since 1998 consisted of our best estimates of the true numbers of coho spawning in each system. Streams draining into the North and South Thompson rivers have the longest and most complete time series of consistently generated estimates, streams of the lower Thompson/Nicola watersheds have a shorter time series, and non-Thompson interior Fraser streams have a short and relatively poor history of coho spawner records (Appendix 3).

### **2.3 Fraser Canyon Fishwheel Program**

The primary stock assessment objectives of the fishwheel program were to generate spawner escapement estimates that were independent of those from escapement surveys, to document run timing, and to investigate temporal patterns of stock composition. In 2000, the program was expanded from the single fishwheel operated in 1998 and 1999 at Yale, to two fishwheels near Yale and one near Siska (Fig. 1). Yale is at the downstream end of the Fraser Canyon, whereas Siska is upstream of the Fraser Canyon, about 15 km downstream of the Fraser and Thompson river confluence. Coho escapements were estimated by mark-recapture by applying tags at the fishwheels and later inspecting coho at the fishwheel tag recovery sites.

The fishwheels were similar in design to those used for stock assessment on the Nass River (Link et al. 1996). Each fishwheel, about 12.2 m long and 6.1 m wide, had three baskets on a rotating axle that could capture salmon as deep as about 4.2 m below the river surface. In 2000, fishwheels were operated during most of the coho migration period although time-periods varied among sites. Fishwheels operated 24 h/day and results are provided as numbers caught per hour of fishwheel operation (CPUE). Near Yale, the Gordon Creek fishwheel operated longer (September 7 to October 24) than the Wall fishwheel (October 14 to 28), and also longer than the Siska fishwheel (September 22 to November 3). Coho were marked with a uniquely numbered white (Yale) or yellow (Siska) jaw tag, applied to the lower jaw (Conrad et al. 2000). A circular (Yale) or square (Siska) hole punched in the operculum functioned as a secondary mark and as a source of tissue for genetic analyses. The sex, fork length, release condition, and fishwheel location and other data were recorded for all tagged coho.

Data from the two fishwheel locations were used to estimate somewhat different populations. For example, Nahatlatch River coho migrated by Yale, but they were unlikely to migrate past Siska, about 20 km upstream of the Nahatlatch/Fraser River confluence. The recovery sample for Yale was constructed from live fish examined at counting fences, fishways, the Siska fishwheel and tangle netting (Nahatlatch River), whereas the recovery sample for Siska was limited to live fish at counting fences and fishways.

Coho escapements past Yale and Siska were estimated with Chapman's modification of the unbiased Petersen estimator. Spatial, temporal, sex, size and fish stress biases were examined in the application and recovery samples following the methods described by Schubert (2000). Tagged coho probably experienced mortality rates in the range of 0 to 15% due to the capture, handling and tagging procedures at the fishwheels. At the Nass River fishwheels, coho mortality was about 8% after capture, handling and radio tagging (Link and Gurak 1997), and we are unaware of other studies examining coho mortality under similar conditions. We assumed a 10% mortality rate for coho captured and tagged at the fishwheels based on the Nass River study and the condition of tagged coho observed at the fishwheel tag recovery sites.

### **2.4 Fisheries**

In 2000, salmon fisheries in southern BC continued to be managed to minimize mortalities of coho from the Thompson River watershed. Earlier assessments (Irvine et al. 1999a, 1999b, 2000b) describe approaches used to assess fishery impacts on interior Fraser coho in detail and only a brief description of the approach is provided here. The approach used the last several years has been to allocate what was considered to be an acceptable exploitation for Thompson coho in southern BC fisheries (~2%) amongst various fisheries. Fortunately, Thompson coho are sufficiently distinct genetically that we are reasonably confident in our ability to estimate numbers of Thompson-origin fish from mixed stock fishery samples. As most BC fisheries since 1997 have been non-retention for coho, few coho have been sampled for coded-wire tags (CWTs). CWT recovery data alone would underestimate mortality in these fisheries in any case because they do not incorporate catch and release mortality. We applied stock composition

estimates developed using a DNA-based approach to estimates of coho killed in these fisheries (Appendices 1 and 2).

An in-season monitoring programme has been used the last several years to estimate coho encounters in southern BC. Attempts were made to ensure that representative samples were taken from coho caught in most fisheries. Samples were analyzed and estimated stock compositions (Appendix 2) were applied to encounter estimates from the 2000-monitoring programme to partition these amongst major population aggregates. If we did not have an adequate sample size from the same or a nearby 2000 fishery during the same or similar time period, we used stock composition estimates from sampling in earlier years (Appendix 1).

Coho mortalities in BC fisheries were determined by applying standard gear mortality estimates (sport 10%, gill net 60%, troll 26%, and seine 25%) to the encounter data. Similar values, provided by American colleagues, were used to estimate the numbers of coho mortalities in mark-selective fisheries in Areas 5 and 6 in WA. A description of the rationale for standard gear mortality estimates was provided in Irvine et al. (1999a). Additional work has taken place since these estimates were derived and new information on gear and Canadian fishery specific mortality has recently become available. However, we did not update our gear mortality rates since there was insufficient time to review this new work.

Preliminary estimates of coho encounters and mortalities for fisheries in Washington State were provided to us by American colleagues. In 2000, selective mark-only sport fisheries operated in Washington Areas 5 (Sekiu and Pillar Point) and 6 (East Juan de Fuca) but not in Area 7 San Juan Islands where coho encounters were modest (J. Haymes, Wash. Dept. Fish. Wild. pers. comm.). DNA based estimates of the proportion made up by Thompson-origin fish were applied to estimates of the numbers of unmarked coho killed in these fisheries. In addition, Boldt Treaty and non-treaty fisheries captured coho, and some of these coho would be of BC origin. Some commercial catch data were provided to us combined for Areas 3+4, however, we assumed that there were no Thompson coho amongst catches from these areas. In 2000, purse seines and reef nets were required to release coho from most areas (S. Boessow, Wash. Dept. Fish. Wild., pers. comm.), including those judged by us where they might capture migrating Thompson coho. Although gill-netters were allowed to keep coho, their coho catches were very small. Again, we used DNA evidence to estimate numbers of Thompson-origin mortalities amongst catches from Areas 4-7.

We did not have reliable estimates of mortalities or fishery exploitations for Thompson coho in Alaska or North/Central BC. We therefore assumed exploitation rates were the same as computed for 1999.

## 2.5 Stock-Recruitment

The time series of exploitation rates for Thompson coho from MRP recoveries are summarized in Appendix 3 (see Appendix 3 in Irvine et al. 2000b for details). Estimates prior to 1986 were the arithmetic average of measured values from 1986 to 1996 (68%). Estimated exploitation in 1998 and 1999 was approximately 7% and 9%, as previously reported (Irvine et al. 2000b). The estimated exploitation rate in 2000 is 3.4% (Section 5.0).

Recruitment (catch plus spawning escapement) was estimated using the time series of fishery exploitation rates:

$$(1) \quad R_t = S_{t-3}/(1-expl_t)$$

where  $R_t$ ,  $S_t$ , and  $expl_t$  are the corresponding recruits, spawners, and fishery exploitations at year  $t$ ,  $t = 1$  to  $n$ . Spawner numbers were the adjusted historical estimates from escapement surveys (Appendix 3).

Spawners were assumed to be all three years old and stock and recruitment data were analyzed using the Ricker (1975) model:

$$(2) \quad R_t = S_{t-3} e^{\alpha - \beta S_{t-3}}$$

where  $\alpha$  and  $\beta$  are parameters to describe productivity of the population at low density, and capacity limited by density dependence, respectively.

The optimal spawning stock size for maximum sustained yield (MSY) was computed (Hilborn and Walters 1992) as:

$$(3) \quad S_{msy} = \alpha(0.5 - 0.07\alpha)/\beta$$

### 3.0 Population Structure of Interior Fraser Coho

Coancestry coefficients ( $F_{st}$  values)<sup>1</sup> were used to produce an updated dendrogram illustrating the relatedness of coho from samples taken in the Fraser River watershed (Fig. 2). Samples from interior Fraser coho were distinctive from lower Fraser River fish, confirming our previous understanding of a common origin for coho upstream of the Fraser canyon.

Stock Assessment Division, Pacific Region is tasked with identifying Conservation Units for Pacific salmon. A Conservation Unit is one or more closely related local populations with similar productivity and vulnerability to fisheries that can be managed separately (DFO 2000). Local populations are collections of individuals normally distributed contiguously that can find each other and reproduce (Burgman et al. 1993). Extirpation of local populations and establishment of new ones by migration can occur. A metapopulation is defined as an assemblage of discrete local populations, with migration among them (Hanski and Gilpin 1997).

Within the interior Fraser Management Unit (Fig. 1), fish from samples taken in the North Thompson, South Thompson, and lower Thompson/Nicola basins grouped together (Fig. 2). However, fish from upper Fraser sites (Bridge and McKinley) did not pair with our recent sample from the Fraser Canyon (Nahatlatch River). This is perhaps not surprising considering the extent of the distribution of coho in the non-Thompson portion of the Fraser (Fig. 1), and the fact that we have baseline samples from only three sites outside of the Thompson. Coho are confirmed in the Seton, Bridge, Chilcotin, Westroad, and Nechako rivers, and are suspected of being in the several other non-Thompson systems. Baseline samples are required from these rivers before we can properly reconstruct the phylogeny of interior Fraser coho.

Wood and Holtby (1998) used results from genetic surveys of Skeena coho (and sockeye) in defining Conservation Units. They point out that choosing the appropriate population unit to satisfy conservation objectives is a matter of determining the spatial scale at which local adaptations exist. They found that genetic variation in coho was distributed as a cline, reflecting the almost continuous distribution of coho within the Skeena watershed. Populations were defined by rates of gene flow, which were correlated with distance. We have not computed rates of genetic exchange for interior Fraser coho as Wood and Holtby did for Skeena coho. However, results provided in last year's assessment (Irvine et al. 2000b) demonstrated that genetic diversity among major drainage basins within the Thompson watershed (Lower Thompson/Nicola, North Thompson, South Thompson, Shuswap) was three to ten times greater than variations among tributaries within basins. It appears that the major basins within the interior Fraser constitute local populations.

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<sup>1</sup>  $F_{st}$  is the correlation of genes of different individuals in the same population.

In the proposed population structure for interior Fraser coho (Fig. 3), we assume that interior Fraser coho represent a metapopulation. Migration of interior coho salmon among different Thompson River basins and between the Thompson and upper Fraser drainages is sufficiently restricted to allow local adaptation to occur, and allele frequencies provide evidence of these migrations (Irvine et al. 2000b). Proposed groupings of streams are primarily those that resulted from the Fst-value based dendrogram (Fig. 2). The major coho bearing basins within the interior Fraser (Fraser Canyon, upper Fraser, lower Thompson, North Thompson, and South Thompson) separate in the dendrogram. Major uncertainties at this level include: whether the Shuswap and Adams lake tributaries should be a separate unit from Shuswap River tributaries; whether the lower Thompson/Nicola should be separate units; and where fish from the upper Fraser should be grouped<sup>2</sup>.

The threshold for the degree of genetic distinctiveness to assign populations into Conservation Units is somewhat arbitrary. However, Conservation Units are based on productivity and manageability, plus genetic similarity. Earlier analyses did not detect appreciable differences in the marine recovery patterns among South Thompson, North Thompson, and lower Thompson/upper Fraser populations (Irvine et al. 1999a). However, since spawning and rearing distributions are distinct, populations from each basin are subjected to different pressures within the freshwater environment. Our understanding of the distribution and status of non-Thompson coho is weak. In contrast, we have good information on the distribution and status of coho in the North and South Thompson and to a lesser extent, lower Thompson. In Section 6.0 we provide evidence for differences in productivity among populations in different basins. It would appear that Conservation Units should not be larger than the major sub-basins. However, we are not able to finalize the selection of Conservation Units at this time.

In conclusion, additional baseline sampling is required, as well as additional analysis of existing genetic information, before we will be in a position to recommend the number of Conservation Units within the Interior Fraser Coho Management Unit.

### **3.1 Stock Composition of Interior Fraser Coho**

An assessment of the stock composition of interior coho was undertaken by examining DNA results from samples at the fishwheels in the Fraser Canyon. We expected that only interior Fraser coho would be caught in these fishwheels but all baseline populations from the Fraser watershed were used in the mixture model. Interestingly, some fish were detected in the fishwheel samples that were more similar to populations in the lower Fraser River than to baseline populations from the Fraser Canyon, upper Fraser River or Thompson River (Table 2). The analysis consistently detected lower Fraser River coho in all years, however the standard deviations were large with respect to the stock composition estimates, similar to results for the Fraser Canyon and upper Fraser River. The relatively large standard deviations indicated some populations may be absent from the baseline, and results should be interpreted cautiously.

Coho catches at the Yale and Siska fishwheels were mainly of Thompson River populations throughout all weekly sampling periods in 2000 (Table 2). Upper Fraser River populations represented a higher percentage of catches than lower Fraser and Fraser Canyon populations, and appeared to represent a fairly consistent percentage throughout September and October. Lower Fraser River populations represented a minor percentage at Yale throughout September and increased to about 14% of the sampled catch by mid to late October, while at Siska, they represented a minor percentage throughout September and October. Fraser Canyon populations represented a higher percentage than lower Fraser River populations. At Yale

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<sup>2</sup> The Bridge and McKinley systems join the Fraser River upstream of the Thompson/Fraser confluence while the Nahatlatch River joins the Fraser downstream. The Nahatlach River supports what appears to be the largest number of coho in the interior Fraser outside of the Thompson.

they represented higher percentages in October than September, whereas at Siska they appeared to be low and variable through September and October. In 1998, the temporal stock composition patterns at Yale were generally similar to 2000, and lower Fraser River populations represented higher percentages of the weekly catches.

At Yale, comparisons of interannual stock composition estimates were limited by temporal representation in 1998 and 1999. However, Thompson River populations consistently represented the highest component, followed by upper Fraser River, Fraser Canyon and lower Fraser River populations. Also, the percentage stock compositions appeared to vary among years, which may be attributed to variability in the annual sampling periods, and/or variation in the relative return strength of particular populations.

## 4.0 Spawner Escapements

### 4.1 Results from Spawner Surveys

There were often large differences between our *trend* and *true* estimates (Table 3). As expected, most *trend* estimates were biased low. On average, escapement estimates to North Thompson streams were biased low by 50% (i.e. individual stream escapement estimates were usually less than half the true number). Estimates to South Thompson streams were more accurate (mean negative biases between 18 and 35%), while estimates to lower Thompson streams were the most accurate (mean annual biases between 0 and -34%). A large discrepancy between *true* and *trend* estimates for the Coldwater River in 2000 was the main reason for the negative bias in lower Thompson escapements that year. Recent *trend* estimates to upper Fraser systems were generally less than 50% of *true* estimates (Table 3). It is difficult to know if the biases computed for estimates generated for the years since 1998 are appropriate for estimates for earlier years. In general, there is less documentation for older estimates.

Precision is usually more important than accuracy in time series analysis and high precision requires that field and estimation methods should be consistent through time. Total escapements to the 10 North Thompson escapement indicator streams appeared to follow similar temporal patterns as escapements to the 16 South Thompson escapement indicators (Figs. 4 and 5). To see if escapements to the two areas tracked each other through time, estimates for these aggregates were compared by regressing annual estimates for each unit (Fig. 6). Estimates for the two areas were positively correlated with each other ( $R^2 = 0.55$ ; the covariance of the two data sets divided by the product of their standard deviations ( $\rho = 0.74$ ).

The second time series approach used the adjusted historical data set for all streams (Appendix 3). Temporal patterns for the North and South Thompson drainages (Fig. 7) were similar to those of the indicator streams (Figs. 4 and 5). Escapements peaked in the mid-1980's, declined until about 1995, and have been stable or increasing since then. Of the three Thompson data sets, we have the least confidence in the data for the lower Thompson. Escapements to the lower Thompson have been less variable than other parts of the Thompson, although they also appear to have increased somewhat in recent years (Fig. 7).

We compared our two trend analysis approaches by regressing annual adjusted estimates against the total trend estimate for the South (supplemented by escapement estimates to two large enhanced systems, the Eagle and Salmon) and North Thompson (Figs. 8 and 9). The correlation for the South Thompson was very high ( $R^2=0.99$ , Fig. 8). The relationship between the two North Thompson estimation approaches was not as good ( $R^2=0.77$ , Fig. 9). The North Thompson relationship was not as good in part because the 10 stream aggregate made up a smaller portion of the total North Thompson escapement than the 16 stream aggregate plus the Eagle and Salmon rivers did of the South Thompson total.

We have been unable to reliably reconstruct the time series of lower Thompson escapement estimates prior to 1984 (Appendix 3). Consequently we have much less confidence in historical data from the lower Thompson than we do for either the North or South Thompson. We are unable to assess the status of coho from non-Thompson streams.

Spawner escapement data are compared to proposed reference points later in the report.

#### **4.2 Population Size Estimates from Fishwheel Program**

The escapement estimates developed by the fishwheel program were biased, since sampling biases were detected (Table 4), and the tag application had fair, yet unequal representation during the migration period. Tag application at the Siska fishwheel appeared biased toward males and fish migrating to different spawning areas. Furthermore, the low tag incidence resulted in low statistical power for the sampling selectivity tests; accordingly, the escapement estimates must be interpreted cautiously. These are the first mark recapture estimates of the total coho escapement past Yale and Siska, thus no previous estimates exist for comparisons (Table 5). Escapement estimates were higher at Yale than Siska because the Yale estimate included fish migrating past Siska, fish returning to the Fraser Canyon rivers and in-river mortalities between Yale and Siska.

The fishwheel program could be improved through several modifications. Tag application would be more temporally representative by operating fishwheels and tagging coho throughout September and October. Also, we encountered problems with jaw tag readability (~29% unreadable) from both sites and tag loss at Yale (~25%), accordingly different tags are required. A second fishwheel at Siska would increase the mark-rate and improve the precision of escapement estimates past Yale and Siska. Fish stress and mortality could be reduced at fishwheel sites by providing additional training for fish handling and tagging and employing recovery tanks.

#### **4.3 Comparison Between Spawner Survey and Fishwheel Population Estimates**

The 2000 escapement estimates from the Yale and Siska fishwheel mark-recapture method exceeded those from the interior Fraser coho-monitoring program. Spawner surveys generated estimates of spawning escapements past Yale and Siska of about 20,000 and 17,300 coho, respectively, whereas the corresponding mark-recapture estimates (95% confidence interval) were 51,000 (43,300-63,400) and 31,600 (27,300-38,300) coho. The mark-recapture estimates were biased (Table 4) and the estimates appeared to have positive bias, after the application and recovery samples were stratified by sex. However the influence of spatial bias, poor temporal representation for tag application and undetected biases remain unknown. As well, spawner survey estimates, particularly for non-Thompson streams, are biased low. There may be substantial numbers of coho spawning in streams inadequately surveyed by the current coho monitoring program, especially those in the upper Fraser River area where we are uncertain of coho distribution (Fig. 1). Also, environmental conditions in 2000 caused difficulty in developing precise and accurate escapement estimates. For example, visual escapement estimation methods were limited by the development of river-ice in some Thompson and upper Fraser tributaries from late November to early December 2000. After Louis Creek was covered by ice, coho were counted through the fence into January 2001 and spawning would have occurred under the ice. Jaw tagged coho examined at Louis Creek in January had been captured at the Yale and Siska fishwheels in the last week of September, indicating interior Fraser coho may spend 3 months in larger rivers before arriving at their spawning grounds.

#### 4.4 Run Timing Through Fraser Canyon

Until 2000, limited quantitative information existed to describe the migration timing of interior Fraser coho in the Fraser River. Previous descriptions were limited to CWT information collected from Thompson River coho caught in the Fraser River gillnet fishery (Irvine et al. 1999a) and temporally limited fishwheel operations at Yale (Irvine et al. 2000b). In 2000, most of the coho migration was observed at Yale in the last two weeks of September and first week of October, and was earlier than at Siska where it was observed in the last week of September and first three weeks of October. Run timing in 2000 appeared similar to that recorded at fishwheels during 1998 and 1999 (Fig. 10).

The Gordon Creek fishwheel near Yale operated throughout much of the interior Fraser coho migration and we assume the daily CPUE was proportional and representative of in-river coho abundance. Using least squares estimation and iterative solving, normal and Poisson distribution curves were fit to the daily coho CPUE to develop migration timing reference points (Fig. 11; Table 6). Both curves had similar sums of squared deviations (normal 4.73, Poisson 5.03) and the normal curve had normally distributed error (Kolmogorov-Smirnov 1-sample test,  $P = 0.188$ ). Migration timing reference points were also developed from the cumulative distribution of the observed CPUE. The fishwheel probably did not sample the earliest and latest components of coho migration, since they were observed at Yale as early as August 16, 1999, and as late as November 20, 1998. We estimated about 8% of the total CPUE occurred prior to September 8 and 1% after October 24 from the CPUE on those days and by assuming the first and last coho would have been sampled on August 16 and November 20, respectively. All three methods estimated similar median migration dates. Variability among migration timing reference points was related to the width, or spread, in the curves and the cumulative frequency distributions indicated the observed CPUE had the widest distribution, and the normal curve had the narrowest.

Migration timing is often described by normal distribution models (Gazey and Palermo 2000), however choosing the appropriate statistical distribution, or combination of distributions, can be confounded by fishery effects or variable gear efficiencies. In 2000, in-river fisheries continued until about September 13 and fishery-related mortalities would influence the shape of the migration timing curve and cause its position to appear later than for conditions of no fishery-related mortalities. For fishwheels, the gear efficiency (catchability coefficient) may change temporally due to environmental factors such as variable river discharge. Low river discharge in mid October resulted in slow fishwheel revolution rates, decreasing the gear's ability to adequately capture migrating salmon. Slow revolution rates in October would influence the shape of the migration timing curve and cause its position to appear earlier than for conditions of optimal revolution rates. Together, the interaction of these factors would lead the migration-timing curve to appear more peaked and have a smaller standard deviation than the true distribution.

#### 5.0 Catch and Exploitation

In Table 7 we summarise catch and exploitation estimates of Thompson origin coho during 2000. The 2000 exploitation rate on Thompson coho was estimated to be ~3.4% which was divided equally between mortalities in Canadian and American waters. This is the lowest exploitation estimated to date (Appendix 3).

There are several reasons why exploitation in 2000 was less than in other recent years. Firstly, fisheries were managed to continue avoiding stocks of concern. For instance, recreational fishing boundaries in 2000 along the West Coast of Vancouver Island were limited to areas inshore of the surf line and to areas offshore starting from one mile off the surf line (outside the chinook corridor closure boundary). Closing a 1-mile corridor along the West Coast discouraged many recreational fishers from fishing outside because their boats were too small to handle the rough seas. This resulted in fewer Thompson fish being encountered. Secondly, in part because of increased education and awareness, commercial fishers are

practising more selective fishery techniques and are taking actions to avoid encountering coho salmon. In Washington, there were increased requirements to release coho from commercial fisheries and to release unclipped coho from recreational fisheries. Selective mark fisheries were also initiated for sport fishers in parts of BC. During the 2000 season, DFO separated encounter data into fish with and without a fin clip. Stock compositions were determined from samples of unclipped (i.e. wild) coho only. In 1999, the stock composition included hatchery fish, which we could not separate from wild coho at the time.

## 6.0 Productivity

For this analysis, we used the escapement time series consisting of data from the 10 North Thompson and 16 South Thompson indicator streams, each series of which has relatively few missing data and is unaffected by hatchery activities. Also included are the Eagle and Salmon rivers because historically they have been the largest coho producing streams in the Thompson drainage, and data are reasonably reliable coming from weir programs on these streams. We used the *trend* estimates for 1998 - 2000 because they allow direct comparison with pre-1998 data.

We derived annual estimates of the productivity of Thompson coho as:

$$(4) \quad r_{an} = \ln [R_t/S_{t-3}]$$

where  $R_t$  is recruitment (i.e. catch plus escapement) and  $S_{t-3}$  is the abundance of parent spawners (i.e. escapement). Thus  $r$  is a measure of survival from spawners to returning (i.e. prefishery) adults. We calculated  $r_{an}$  for each of the four escapement series, and averaged these to obtain an overall trend for the North and South Thompson areas (Fig. 12). We also present the time series of  $r_{an}$  for the mean of the 10 North and 16 South Thompson indicator streams only (Fig. 13).

Regardless of whether data from the Eagle and Salmon rivers were included, there was an overall decline in  $r_{an}$  from the mid-1980's until the mid-1990's (Fig. 12 and 13). However, in each case, the average  $r_{an}$  for the 1999 and 2000 returns was positive. Because returns in 2000 were better for the South Thompson than the North Thompson, and Figure 12 includes the South Thompson wild indicator aggregate plus the Eagle and Salmon rivers in the South Thompson, this figure shows a more optimistic pattern. Since fishing mortalities were low in 1999 and 2000, escapements generally increased over the brood year, as noted earlier.

The time series was divided into four periods: (1) an initial period of apparently stable but low returns (return years 1975-1984); (2) a second period during which populations seemed to be healthy (return years 1984-1989); (3) a period of declining numbers (return years 1989-1996); and (4) the most recent 5-year period. To analyze trends in abundance, it was assumed that all fish had a 3-year life cycle and population growth rates were calculated for each brood line. Estimates of  $r$  for each period and brood line were averaged. Finite generational rates of change were:

$$(5) \quad 1 - e^r$$

The analysis identified apparent differences in productivity between the two stock aggregates (Table 8). The trend for the complete time series was downward for each group, with a mean rate of decline of 15 and 3% per generation for South and North Thompson populations respectively. South Thompson coho increased in population size by 14% per generation during the first portion of the time series (i.e. return years 1975-1984) while changes for North Thompson were not significant. South Thompson coho continued to experience positive growth during the 1984-1989 (11%) while North Thompson numbers declined at 15% per generation. Both population aggregates experienced large negative rates of return

during 1989-1996 (64% and 48% respectively). The lowest returns on record occurred for many systems during 1996 (Figs. 4 and 5). Since then, data are only available for two brood lines and one generation so it is difficult to comment with certainty on population changes. However, these data indicate substantial increases in returns to both the South Thompson (38%) and North Thompson (30%) for the one generation (two brood lines) measured (Table 8).

Mean annual estimates of  $r$  for the North and South Thompson were used to calculate the harvest rate that would have maintained wild spawner abundances at levels similar to those of the parental escapement:

$$(6) \quad h^* = 1 - e^{-r_{an}}$$

where  $h^* = 0$  if  $r \leq 0$  (Bradford and Irvine 2000a). For years when  $r > 0$ ,  $h^*$  would have maintained populations at stable levels (i.e.  $S_t = S_{t-3}$ ) assuming all other mortality factors remained constant. We then compared  $h^*$  to the actual exploitation rates. We considered fishing to have contributed to the decline in abundance when the observed values of  $h$  exceeded  $h^*$ .

When we compared the actual exploitation rates to our estimates of  $h^*$ , we found that fishing mortality was well matched to the productivity of the aggregate between 1987 to 1989, but subsequently, until 1997, harvest rates were often excessive and  $h^*$  exceeded  $h$  in all but one year, 1994, when it equaled  $h$  (Fig. 14 and 15). In 1999 and 2000, regardless of whether population data for the Salmon and Eagle rivers are included (Fig. 14) or excluded (Fig. 15), exploitations have been low enough that populations have been above replacement levels. Exploitations were deliberately low the last several years in response to a recognized conservation concern for these fish.

## 7.0 Reference Points

Last year's assessment document (Irvine et al. 2000b) recommended that target and limit reference points (TRPs and LRPs) be developed for interior Fraser River coho salmon. DFO's draft Wild Salmon Policy (DFO 2000) also states that minimum and target levels of abundance need to be determined for each Conservation Unit. According to the draft policy, a TRP represents the lower bound of the target zone, abundances between the LRP and TRP are in the rebuilding zone, while abundances below the LRP indicate that the long-term viability of the Conservation Unit is at risk.

Although provisional reference points (RPs) have been established for various salmon populations, there is no consensus within DFO on what approaches to use, or even on specific definitions for LRPs or TRPs. A recent workshop on the development of RPs for salmon<sup>3</sup> reviewed three approaches to determine LRPs: 1) risk domain or viability analysis (frequently used in the US and reviewed by McElhany et al. 2000); 2) habitat capacity/stock productivity (frequently used by BC provincial fisheries, see Johnston et al. 2000); and 3) the historic minimum, an approach based on the lowest returns observed from which the population has recovered.

The first RPs proposed for coho salmon in the Pacific Region were for Black Creek. Kadowaki et al. (1994) analyzed stock-recruit data for Black Creek coho and calculated optimal escapements and exploitations for MSY ( $S_{MSY}$  and  $expl_{MSY}$ ) and provided these as targets. Subsequent work primarily by L. B. Holtby on coho from Carnation Creek resulted in a conservation "floor" density of 3 females/km being proposed for coastal coho salmon populations (Stocker and Peacock 1998). Holtby et al. (1999) proposed an LRP for Skeena coho salmon of 10.9 females/km, which is an unweighted average of various RPs.

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<sup>3</sup> Memo from M. Stocker to L. Richards and R. Kadowaki, 16 February 2000 entitled "Workshop on development of provisional lrps for key salmon stocks"

Bradford et al. (2000) computed RPs for coho salmon based on productivity information from freshwater. Since relationships between smolts and adult coho often appear to be density independent, RPs calculated using freshwater information have the advantage of avoiding confounding effects of varying marine survivals. Bradford et al. (2000) estimated a TRP of 19 females/km based on data from 14 coho systems. Sufficient data to properly examine the relationship between spawners and smolts for interior Fraser systems do not exist.

Bradford and Irvine (2000b) provided a preliminary assessment of the possibility of using stream occupancy to assess the status of Thompson coho. It had been shown (Irvine et al. 2000b) that coho are found in fewer streams within the Thompson watershed than they were several generations previously. Bradford and Irvine (2000b) found a non-linear reduction in stream occupancy with declining coho abundance. Reductions in stream occupancy began to occur when the overall abundance was reduced by about 75% from peak abundance. They suggested that 25% of peak abundance might therefore be a reasonable conservation based RP.

Most recently, Chen et al.<sup>4</sup> extended the approach of Frank and Brickman (2000) who appear to be the first to publish a S-R model that incorporates possible compensatory mortality. In theory, compensatory mortality might occur when the population is below some critical level. In such situations, inbreeding could occur and result in reduced survivals, densities might be so low that fish cannot easily find mates, or predation might result in high proportions of fish being killed when densities are low. This is known as the Allee effect (Allee et al. 1949) when population growth declines as population density declines.

Based on the Allee effect, the S-R model in equation (2) becomes:

$$(7) \quad R_t = (S_t - S_{\text{offset}}) e^{\alpha - \beta (S_t - S_{\text{offset}})}$$

where  $S_{\text{offset}}$  is the parameter associated with the Allee effects and is the offset from the origin representing zero recruitment (Frank and Brickman 2000). Based on this extended model, Chen et al. demonstrate how to produce extinction probability curves that can be used to calculate the probability of extinction for a given spawning density. Because this approach has not yet been published, we provide the draft manuscript in Appendix 4.

### 7.1 North Thompson reference points

As discussed earlier (3.0 Population Structure of Interior Fraser Coho), identification of specific Conservation Units within the interior Fraser has not been finalized. In this section we develop several RPs using data from coho from the North Thompson drainage. The North Thompson was selected rather than other populations within the Interior Fraser for four reasons: 1) reasonable estimates of spawner numbers (since 1975) and sex ratios are available; 2) lakes are rare and we are confident in estimates of stream lengths accessible to coho salmon, necessary to express fish densities in terms of fish/km; 3) the North Thompson appears to be less impacted by enhancement and water abstraction than the South Thompson; and 4) coho from the North Thompson are genetically distinct from others (Fig. 2).

Three provisional RPs are provided in Table 9. The first two are potential LRPs while the last one could be a TRP. The lowest escapement on record to the North Thompson watershed that the population has

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<sup>4</sup> Chen, D. G., J. R. Irvine, and A. Cass. Incorporating Allee effects in salmon stock-recruitment models and applications for determining reference points. Draft manuscript (in review) is attached as Appendix 4.

recovered from (10535 coho) occurred in 1980. The next value in Table 9 is from the analyses described in Appendix 4. We did not feel that  $S_{offset}$  at the 50% probability was sufficiently precautionary so we used the value equivalent to a 10% probability of yielding 0 recruitment (Appendix 4, Table 2).  $S_{MSY}$  is the optimal number of spawners for MSY (equation 3).

To convert estimates of spawners to females per kilometer, it was necessary to know the lengths of streams accessible to coho within the North Thompson watershed, and the sex ratio of spawners. Stream lengths were provided in Irvine et al. 1999b; the total stream length accessible to anadromous coho within the North Thompson is 780 km. In Table 10 we provide a summary of data on coho sex ratios for North Thompson tributaries. The average proportion of the escapement made up by females was 0.45.

Since calculation of  $S_{offset}$  and  $S_{MSY}$  required the analysis of stock recruitment data for the North Thompson, a brief discussion of some of the potential limitations of this approach is provided. Spawner estimates appear to be reasonably accurate and precise but we are less confident in our estimates of exploitation. Since exploitation rates prior to 1985 are the mean of measured estimates from 1985-1996, the initial portion of our abundance time series is subject to more uncertainty than the recent portion. Patterns in the residuals were examined after the Ricker model (equation 2) was fit to the data. No apparent relationship was seen between the size of the population and the residuals but there was evidence of non-stationarity. A sequence of strong positive residuals in the early 1980's preceded a declining trend with negative residuals occurring in recent years. This is not surprising; a similar pattern was found when we examined patterns in productivity ( $r$ ) (Figs. 12 and 13).

While trends in the residuals cast some doubt on the validity of calculations of  $S_{MSY}$ , they do not negate the value of calculating  $S_{offset}$  and may provide an explanation why an Allee-Ricker model fit the data better than the traditional Ricker S-R model (Appendix 4 Table 1). The first-order autocorrelation was significant when the Ricker S-R model was applied (Lag 1, autocorrelation coefficient  $\rho = 0.42$ ), but was not when the Allee-Ricker model was fit to the data (Appendix 4, Fig. 5). Close examination of Figure 1 in Appendix 4 reveals that the line is very close to a cluster near the origin of four data points which correspond to four recent returns (91, 94, 96, and 97 brood years). Recent low productivities ( $\alpha$ ) result in a positive bias in estimates of  $S_{offset}$ . We consider that a small positive bias when computing an LRP is acceptable since it is risk averse.

It would seem reasonable that an LRP for North Thompson coho salmon would be equal to or exceed the mean of the two minimum RPs values which is 8986 spawners or 5.2 females/km (Table 9). We are not confident proposing a specific TRP. A consensus needs to be reached on the policy objectives of TRPs.  $S_{msy}$  relies on S-R data, which we have shown are non-stationary.

In Figure 16, we compare estimated numbers of female coho salmon per kilometre with the mean of the two provisional LRPs. It can be seen that spawner numbers have been near, but generally below this level since 1997. The forecast abundance of Thompson watershed coho in 2001 is for a similar abundance as was reported in the brood year (Simpson et al. 2001). In 1998, ~5.3 females per kilometre were estimated to return to spawn in the North Thompson watershed, and we expect similar numbers in 2001, assuming similar survivals and fishing pressures exist. In conclusion, it appears that the viability of these fish remains at risk.

## 8.0 Summary and Conclusions

A variety of approaches were used to assess the status of coho from the interior Fraser River Management Unit. While our time series were too short to adequately assess the status of coho populations from outside the Thompson watershed, we have reliable data for most of the Thompson watershed.

Coho spawner numbers in the Thompson watershed generally exceeded brood year escapements (Fig. 7) although this pattern was not seen for the North Thompson wild indicator dataset (Fig. 4). Fishery exploitations in 2000 were the lowest on record, only ~3.4% in total, of which approximately half were in British Columbia.

A large amount of effort has been undertaken in recent years to estimate mortalities of Thompson coho in southern BC fisheries. In addition, an intensive monitoring program has been undertaken which was originally designed to provide in-season estimates of coho encounter rates. We feel it is time to change this approach. There is enough information available now to develop a model of coho distribution and timing. Stock composition data in Appendices 1 and 2 should be examined with a view to determining if there is significant interannual variability in fishery specific encounter rates for particular population aggregates. Rather than sampling most fisheries every year for stock compositions, sampling effort should be directed to those areas and times where either coho are abundant, or stock compositions are highly uncertain. As well, recent information on fishery specific mortality rates needs to be reviewed and used to assess fishery impacts as appropriate.

Productivity measured in recruits per spawner improved the last two years and populations are now above replacement levels (Figs. 12 and 13). Recent fishery exploitations were low enough that populations have been able to begin to rebuild (Fig. 14 and 15). However, we must bear in mind that the short-term forecast for Thompson coho is for continued poor survivals (Simpson et al. 2001), in large part because we do not have strong evidence that marine survival rates will increase.

A mark-recapture program provided an independent estimate of spawner numbers in the interior Fraser watershed as well as useful information on stock composition. Results indicated that our spawner surveys might be missing significant numbers of coho, particularly in non-Thompson streams. Additional survey work is required to verify the distribution of coho in the upper Fraser watershed, determine abundances, and collect baseline genetic samples.

Information provided on the population structure of interior Fraser coho in this report augmented results in last year's assessment (Irvine et al. 2000b). Interior Fraser coho were distinct genetically from lower Fraser River fish, confirming our previous understanding of a common origin for coho upstream of the Fraser canyon. Last year we found that genetic variation among basins was three to ten times greater than variations among tributaries within basins. Although there is evidence to support the conclusion that major drainage basins within the interior Fraser (e.g. North Thompson, South Thompson) should be considered as separate Conservation Units, a lack of baseline samples from non-Thompson sites, combined with insufficient analysis of existing information, prevent us from recommending specific Conservation Units at this time. Rates of genetic exchange need to be computed to verify that there is adequate gene flow among local populations before finalising the selection of Conservation Units.

Several provisional reference points were discussed for coho from the North Thompson watershed. The mean of two population specific reference points was 5.2 female coho per kilometer of accessible habitat. We presume that an LRP for North Thompson coho would equal or exceed this value. Since the mean spawner density has generally been below 5.2 females per kilometer each of the last four years, we conclude that fishery management actions should remain conservative to allow spawner numbers to increase.

In conclusion, the extreme management measures undertaken in BC since 1998 to conserve coho appear to have arrested the declining trend for interior Fraser coho populations. We are less worried about population extinction than we were several years ago. However, the short-term forecast for Thompson coho is for continued poor survivals (Simpson et al. 2001), and population densities in the North Thompson watershed remain below the mean of two provisional reference points determined for these

fish. Continued low fishery exploitations, combined with balanced programs of habitat protection and watershed restoration, are required to ensure the long-term viability of these important fish.

## 9.0 Acknowledgements

Gayle Brown and Alan Sinclair provided useful comments on the manuscript. Steve Boessow, Angelika Hagen-Breaux, and Jeff Haymes provided coho encounter and catch data from Washington State. We thank the Yale First Nation and Siska Indian Band for operating the fishwheels and the Adams Lake, Bootheroyd, Bonaparte, North Thompson and Skeetchestn Indian bands, Nicola Watershed and Stewardship Authority, Okanagan First Nation, Shuswap Nation Fisheries Commission, Tisdale Environmental Consulting, Doug Lofthouse, Doug Turvey and Szczepan Wolski for operating the fishwheel tag recovery sites. We are grateful to Kendra Holt for her assistance with the fishwheel program and the collection of baseline genetic samples from the Nahatlatch River. Roberta Cook, Dean Allan, and Cindy Yockey assembled information on biological characteristics for interior coho salmon.

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**Table 1.** Definitions of the fishwheel tag application site, fishwheel tag recovery site and major watershed codes corresponding to Figure 1.

Fishwheel Tag Application Sites	Fishwheel Tag Recovery Sites	Major Watersheds
1. Gordon Creek	1. Nahatlatch River	1. Thompson River
2. The Wall	2. Coldwater River	2. Nicola River
3. Siska	3. Bonaparte River	3. North Thompson River
	4. Deadman River	4. South Thompson River
	5. McKinley Creek	5. Seton River
	6. Louis Creek	6. Bridge River
	7. Dunn Creek	7. Chilcotin River
	8. Lemieux Creek	8. Quesnel River
	9. Sinmax Creek	9. Westroad (Blackwater) River
	10. Eagle River	10. Nechako River
	11. Shuswap River	11. Stuart River
		12. Bowron River
		13. Fraser River

**Table 2.** Estimated percentage stock composition, with standard deviations in parentheses, for coho sampled at the Yale and Siska fishwheels.

Fishwheel & Year	Sample Size & Stock Group	September			October				Total
		10-16	17-23	24-30	1-7	8-14	15-21	22-28	
Siska 2000	n	NA	23 <sup>1</sup>	100	94	42	25 <sup>2</sup>	ND	284
	Lower Fraser	NA	4.4 (3.1)	5.8 (2.9)	3.0 (2.0)	2.5 (4.0)	0.0 (0.0)	ND	3.2 (1.6)
	Thompson	NA	95.6 (5.2)	71.7 (5.1)	90.2 (4.0)	93.3 (5.4)	90.8 (7.7)	ND	84.1 (3.0)
	Upper Fraser	NA	0.0 (0.7)	15.2 (4.0)	2.9 (2.6)	4.2 (3.1)	5.0 (6.4)	ND	7.6 (2.3)
	Fraser Canyon	NA	0.0 (4.8)	7.4 (2.9)	4.0 (2.6)	0.0 (1.3)	4.2 (4.4)	ND	5.1 (1.6)
Yale 2000	n	70 <sup>3</sup>	83	100	71	47	62 <sup>4</sup>		438
	Lower Fraser	1.7 (2.3)	1.2 (2.1)	0.0 (1.4)	4.5 (3.0)	13.9 (6.6)	12.8 (5.1)		4.1 (1.3)
	Thompson	76.3 (6.7)	77.0 (6.4)	83.9 (4.6)	74.3 (7.0)	60.1 (9.4)	53.1 (7.1)		73.7 (2.5)
	Upper Fraser	16.2 (5.0)	19.7 (6.1)	11.3 (4.2)	7.4 (5.3)	13.1 (6.6)	17.6 (6.2)		14.2 (2.4)
	Fraser Canyon	5.9 (3.6)	2.1 (1.9)	4.9 (2.8)	13.8 (4.9)	12.8 (6.1)	16.6 (5.2)		8.0 (1.7)
Yale 1999	n		97 <sup>5</sup>			NA	NA	NA	97
	Lower Fraser		2.4 (1.9)			NA	NA	NA	2.4 (1.9)
	Thompson		83.1 (5.5)			NA	NA	NA	83.1 (5.5)
	Upper Fraser		11.2 (4.7)			NA	NA	NA	11.2 (4.7)
	Fraser Canyon		3.3 (2.6)			NA	NA	NA	3.3 (2.6)
Yale 1998	n	NA	53 <sup>6</sup>	81	12 <sup>7</sup>	103	22 <sup>8</sup>		271
	Lower Fraser	NA	7.4 (4.1)	4.2 (3.0)	5.4 (9.8)	5.3 (3.0)	14.9 (9.7)		6.3 (1.9)
	Thompson	NA	67.0 (7.6)	65.7 (6.6)	47.7 (16.6)	72.7 (6.4)	60.0 (13.6)		67.7 (4.1)
	Upper Fraser	NA	25.6 (7.2)	14.1 (5.1)	15.9 (11.4)	18.4 (5.3)	19.4 (11.8)		18.2 (3.4)
	Fraser Canyon	NA	0.0 (0.2)	16.0 (5.8)	30.9 (17.1)	3.6 (4.0)	5.6 (8.4)		7.7 (3.0)

NA indicates no samples were collected.

ND indicates samples were collected from October 22 to November 3, but could not be analyzed because of problems with the samples.

1. Samples available for September 23 only.
2. Samples available for October 18 only.
3. Samples available for September 8 to 16.
4. Samples available for October 15 to 24.
5. Samples available for September 9 to October 3
6. Samples available for September 21 to 23.
7. Samples available for October 2 to 5.
8. Samples available for October 15 to November 19.

**Table 3.** Mean bias between trend and true escapement (esc.) estimates for major basins within the Interior Fraser Management Unit.

	North Thompson				South Thompson				Lower Thompson				Fraser			
	1998	1999	2000	98-00	1998	1999	2000	98-00	1998	1999	2000	98-00	1998	1999	2000	98-00
n <sup>1</sup>	25	29	18		21	24	28		5	6	5		5	5	10	
True total esc. <sup>2</sup>	8997	8753	6867		4770	2845	3649		2234	4363	4003		8093	5374	4723	
Mean bias <sup>3</sup>	-0.51	-0.48	-0.48	<b>-0.49</b>	-0.35	-0.18	-0.30	<b>-0.28</b>	0.00	-0.04	-0.34	<b>-0.13</b>	-0.57	-0.44	-0.71	<b>-0.57</b>

<sup>1</sup>n=number of streams assessed; streams with zero fish counted ignored in mean bias calculation.

<sup>2</sup>Fish taken for brood stock not included in estimates.

<sup>3</sup>Mean bias in escapements between true and trend escapement estimates.

**Table 4.** Summary of statistical test results for sampling selectivity bias investigations in the application (fishwheels) and recovery (tag recovery sites) samples. Data were stratified by tagging at Yale and Siska.

Bias Type	Test of	Among	Yale	Siska
<b>Application Sample</b>				
Spatial	Tag incidence	Fishwheel tag recovery sites	No bias detected	Bias high in Lemieux C. and Shuswap R. and low in McKinley C. and Bonaparte R.
Temporal	Tag incidence	Equal recovery periods	No bias detected	No bias detected
Fish Size	Size frequency distribution	Marked/unmarked recoveries	No bias detected	No bias detected
Fish Sex	Sex ratio	Marked/unmarked recoveries	No bias detected	Bias toward males
<b>Recovery Sample</b>				
Temporal	Recovery rate	Equal application periods	No bias detected	No bias detected
Fish Size	Size frequency distribution	Recovery/not recovered tags	No bias detected	No bias detected
Fish Sex	Sex ratio	Recovery/not recovered tags	No bias detected	No bias detected
Fish Stress	Recovery rate	Active/apparently stressed <sup>1</sup>	No bias detected	No bias detected

1. Apparently stressed fish were lethargic, bleeding, bruised, dropped, or difficult to tag.

**Table 5.** Summary of mark-recapture parameters and pooled Petersen escapement estimates stratified by tagging at Yale and Siska.

		<b>Yale</b>	<b>Siska</b>
Number Tagged	(M)	667	517
Number Examined <sup>1</sup>	(C)	8,139	7,393
Number Recaptured	(R)	95	108
Tag Incidence	(R/C)	1.2%	1.5%
Adjusted Tag Rate	$[(C+1)/(R+1)]$	84.8	67.8
Petersen Estimate	$(\hat{N}_{10\%taggingmortality})$	51,000	31,600
95% Confidence Interval		43,300 – 63,400	27,300 – 38,300

1. The number examined was higher for Yale than Siska because the Yale recovery sample included the Siska fishwheel and Nahatlatch River locations.

**Table 6.** Migration timing reference points from cumulative frequency distributions of the normal curve, Poisson curve, and observed CPUE at the Gordon Creek fishwheel, 2000.

<b>Percentage of the migration past Yale</b>	<b>Normal Curve</b>	<b>Poisson Curve</b>	<b>Observed CPUE</b>
5%	September 15	September 13	September 4
10%	September 17	September 15	September 10
50%	September 24	September 24	September 23
90%	September 30	October 3	October 5
95%	October 2	October 5	October 9

**Table 7.** Summary estimates of 2000 escapements, fishery mortalities, and exploitations for Thompson watershed coho in fisheries in Alaska, North/Central BC, southern BC and Washington.

	Number	Exploitation
Spawning escapement	15300	NA
Alaska <sup>1</sup>	47	0.003
North/Central BC <sup>1</sup>	77	0.005
Southern BC		
Aboriginal	23	0.002
Commercial	8	0.001
Recreational	60	0.004
Test	49	0.003
Experimental	55	0.004
Washington		
Recreational	60	0.004
Aboriginal (treaty)	165	0.011
Commercial	0	0.000
Total Canadian	272	0.017
Total US	272	0.017
TOTAL	544	0.034

<sup>1</sup>Assumed that exploitation rates were the same as computed for 1999.

**Table 8.** Generational rates of change for escapements of unenhanced coho salmon returning to indicator stream aggregates in the South and North Thompson drainages.

Return Years	1975-2000	1975-1984	1984-1989	1989-1996	1996-2000
n <sup>1</sup>	23	7	3	5	2
South Thompson - 16 streams	-0.152	0.135	0.114	-0.636	0.378
North Thompson - 10 streams	-0.030	-0.007	-0.147	-0.483	0.299

<sup>1</sup>n = sum of the generations for each brood line.

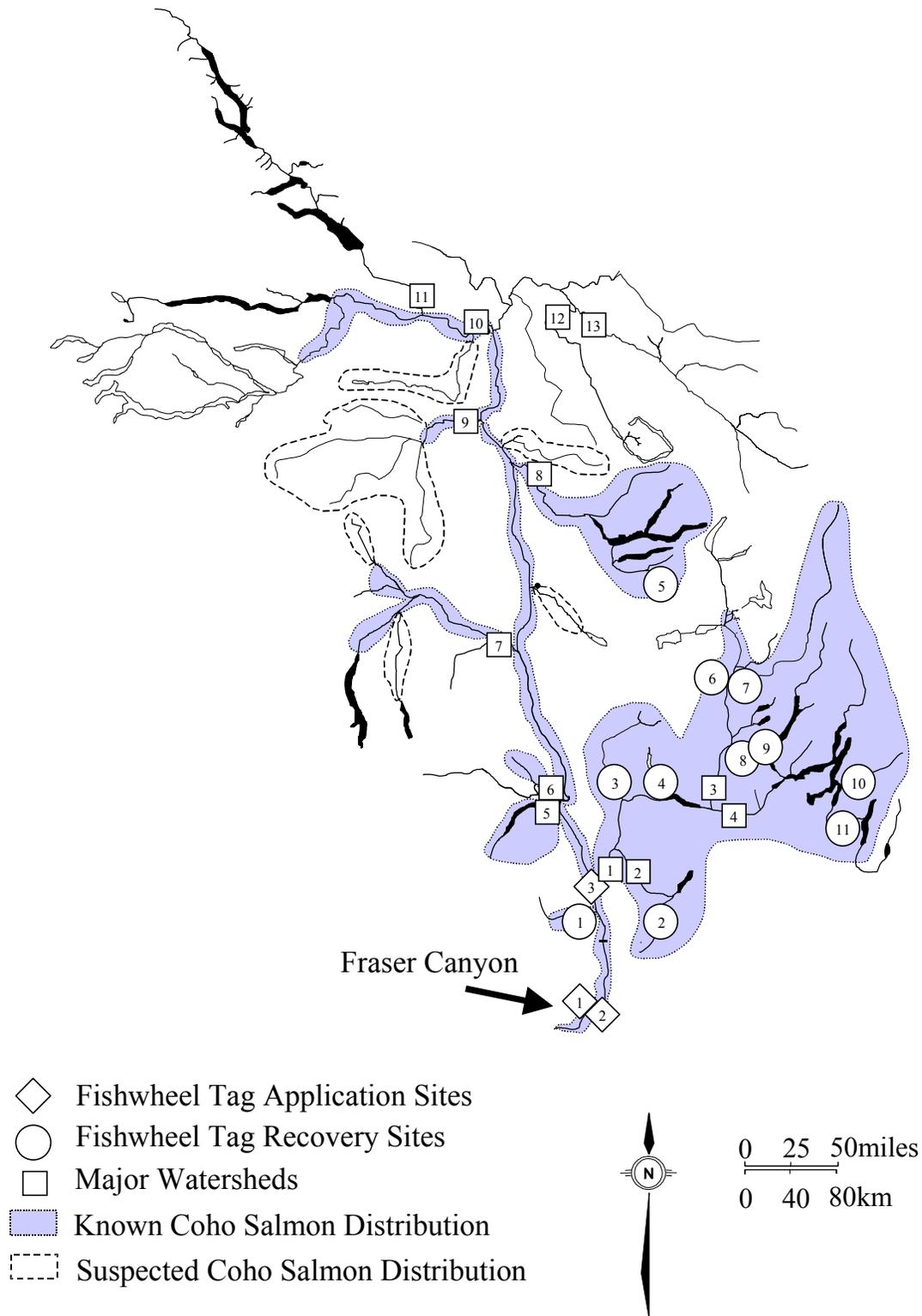
**Table 9.** Summary of provisional reference points for North Thompson coho salmon. See text for explanation ( $S$  = spawners).

Model	$S$	Females/km
Minimum escapement popn. recovered from	10535	6.1
$S_{offset}$ (10% extinction possibility)	7438	4.3
mean	8986	5.2
$S_{MSY}$	43085	24.9

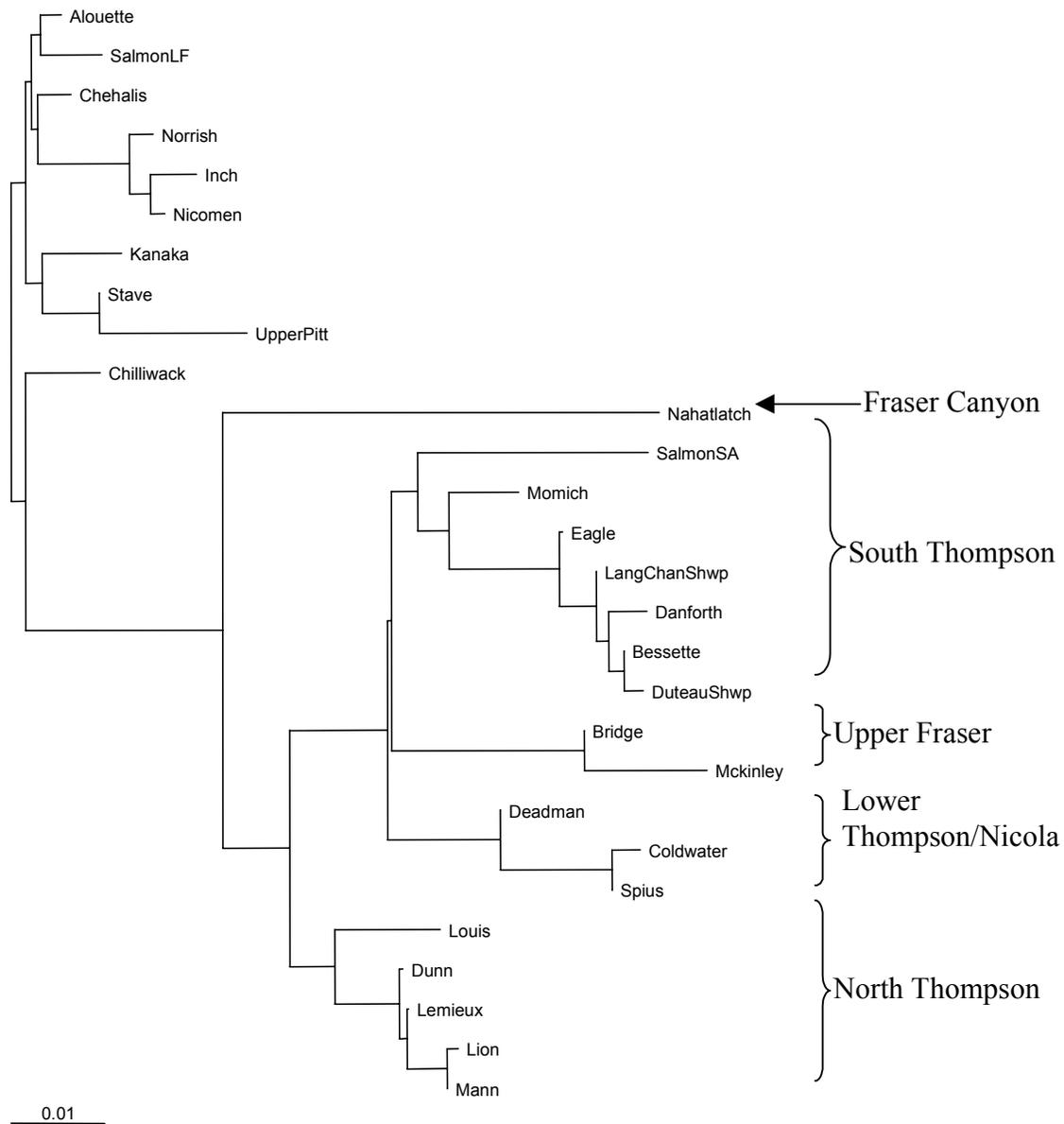
**Table 10.** Sex ratios for coho returning to streams in the North Thompson watershed<sup>1</sup>.

Ret. Year	Dunn		Lemieux		Louis		Mann		Sinmax	
	n	% Female	n	% Female	n	% Female	n	% Female	n	% Female
2000	1360	47.4	461	57.5	61	42.6	85	40	96	54.2
1999	712	48.6	506	47.2	144	43.7	259	48.6		
1998	935	46.6	625	43.7	208	41.2	65	27.7		
1997	331	39.6	367	33.4	123	21.1				
1996	211	48.8	156	40.5	236	21.5				
1995	392	40.3	388	50	446	38.9				
1994	1062	47.6	830	44.1	373	26.3				
1993	587	39.7	564	39.5	290	43.1				
1992	1984	48.2	667	49.3	364	40.4				
1991	1289	46.2	1399	47.5	416	50.7				
1990	772	45.2	592	60.5	109	35.8				
1989	338	57.1	389	51.9	868	45.3				
1988	1497	47.6	430	59.8	467	44.5				
1987	500	45.4	116	49.1						
1986	590	50.5	1041	42.4						
1985	1564	63.7								
mean		47.7		47.8		38.1		38.8		54.2

<sup>1</sup> 1995-98 Louis and Lemieux data were from Irvine et al. 2000a, other 1985-97 sex ratio data from Irvine et al. 1999a. 1998-99 sex ratio data from Galesloot 1999, 2000 sex ratio data from R. E. Bailey, unpub.

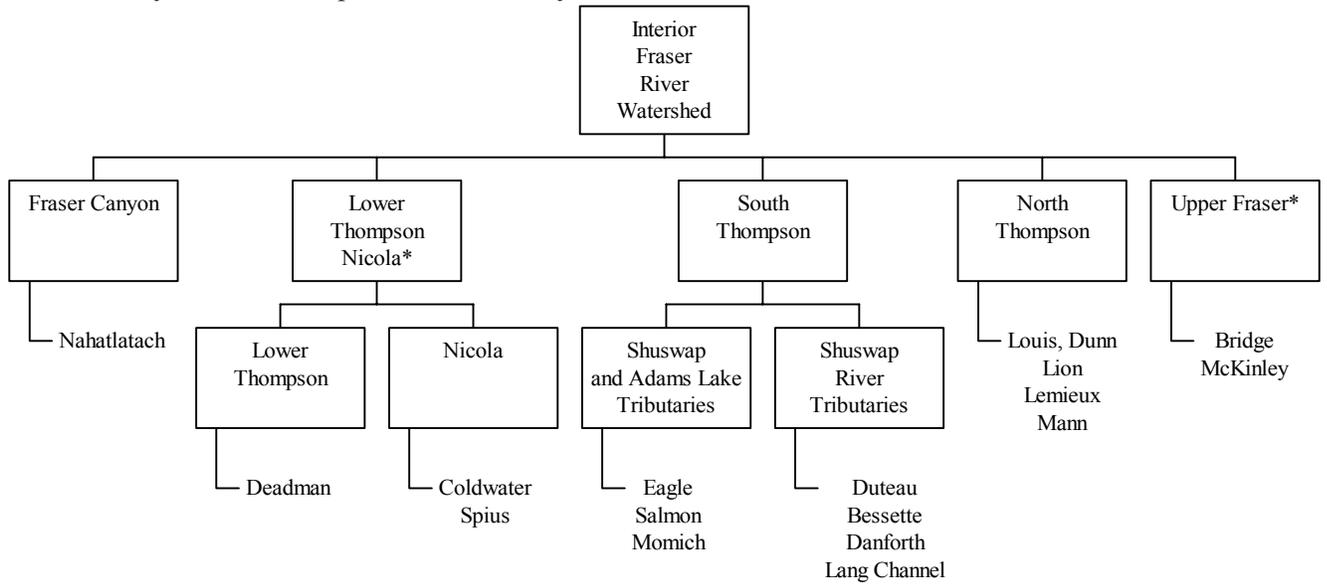


**Figure 1.** Known and suspected coho salmon distribution in the interior Fraser River watershed. Numbers for the fishwheel tag application sites, fishwheel tag recovery sites and major watersheds are defined in Table 1.



**Figure 2.** Neighbor joining dendrogram of Fraser River coho salmon populations based on  $F_{st}$  values calculated from six microsatellite loci and two MHC class I and class II loci.  $F_{st}$  scale is shown on bottom left.

**Figure 3.** Proposed population structure for interior Fraser River coho salmon. \* indicates a high degree of uncertainty. Streams sampled for DNA analysis are listed but not enclosed in boxes.



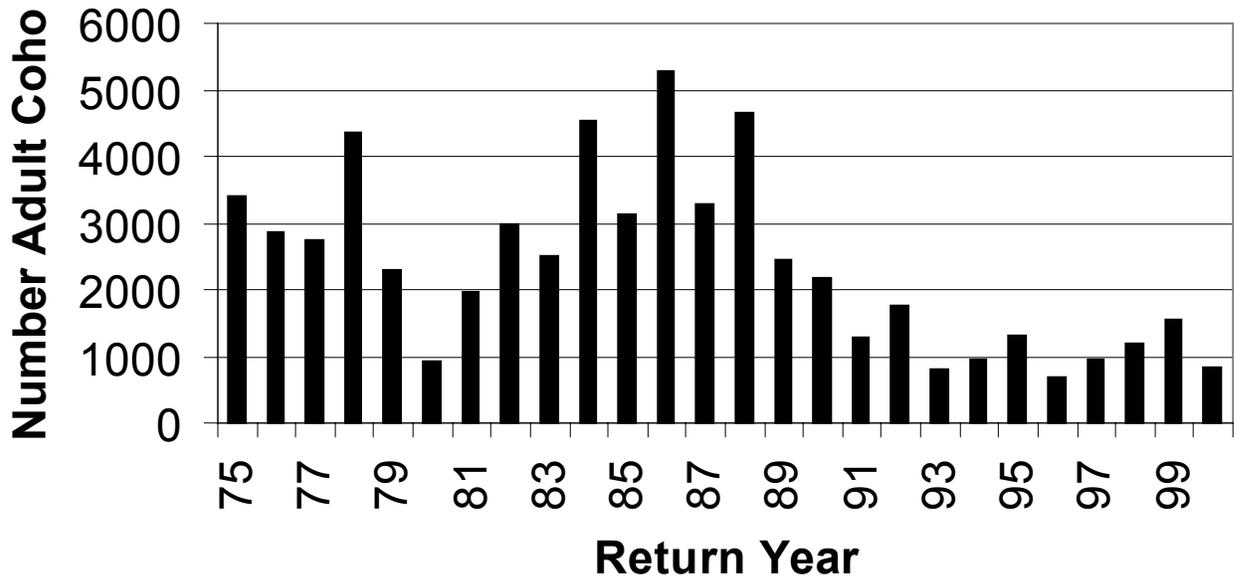


Figure 4. Aggregate coho escapement to 10 escapement indicator streams in the North Thompson watershed.

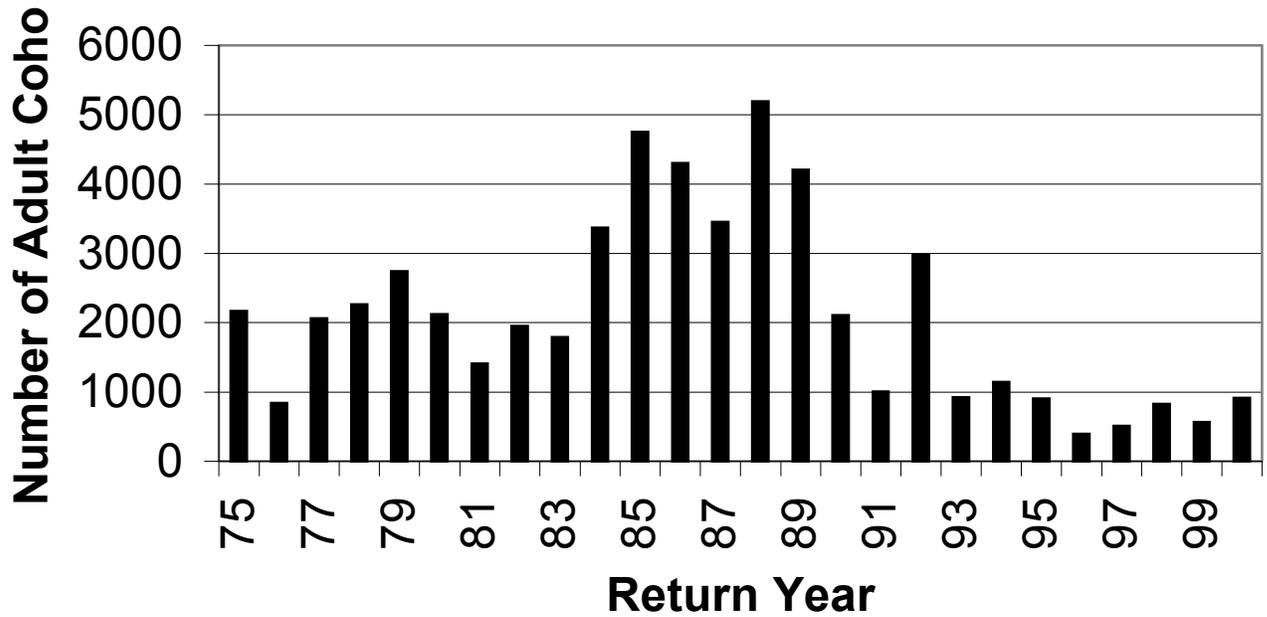
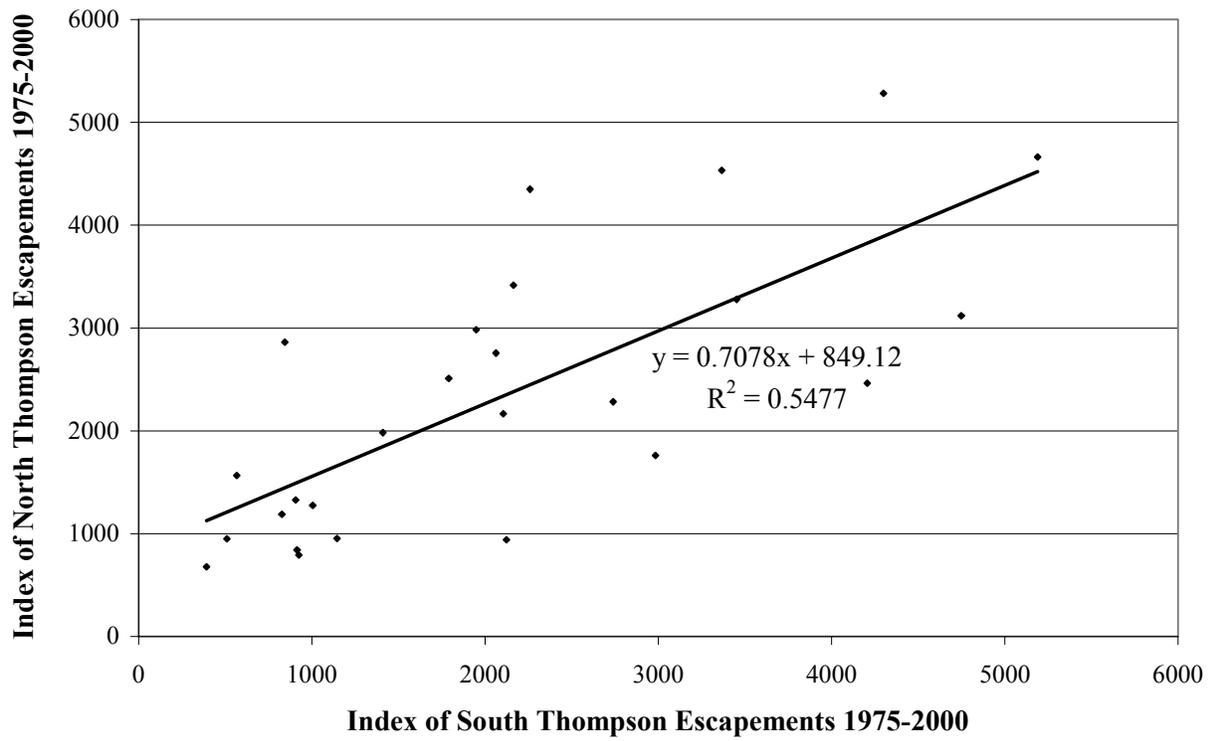
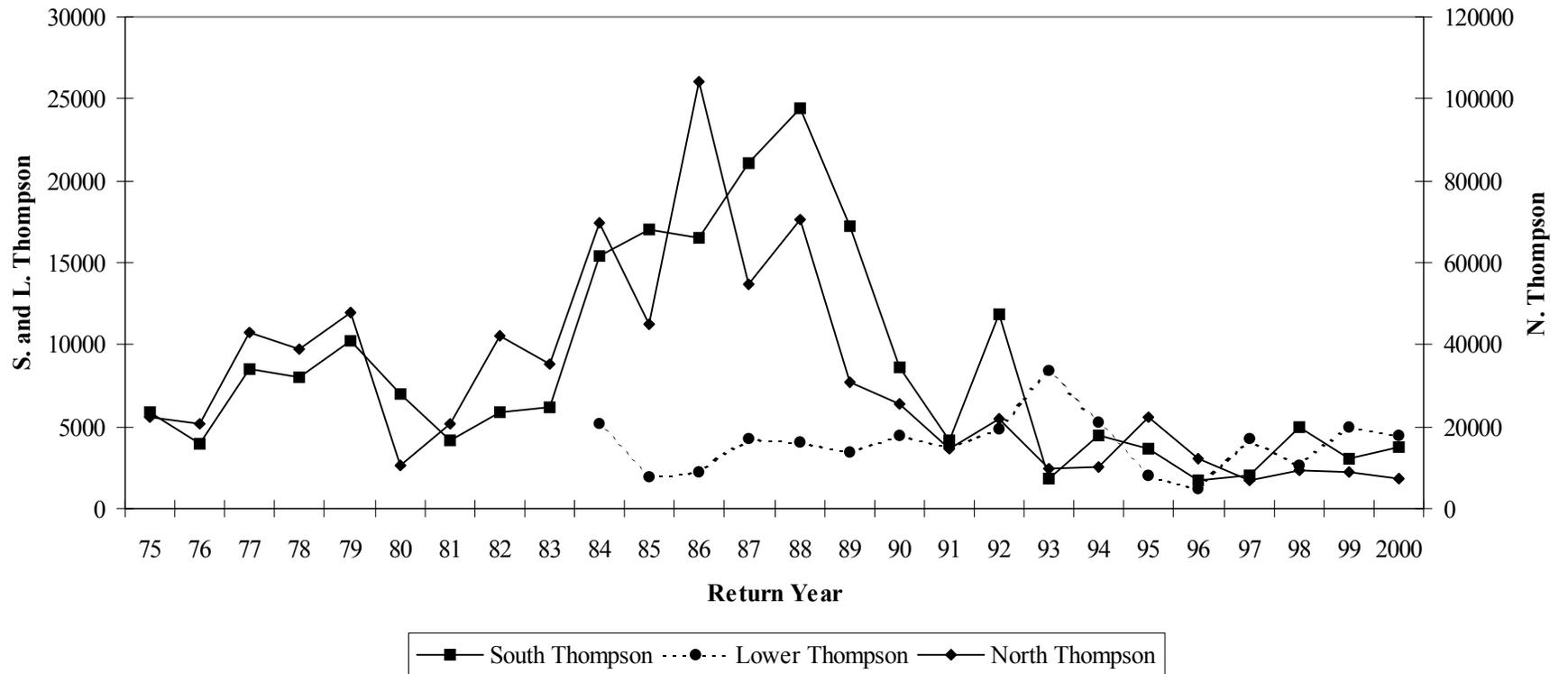


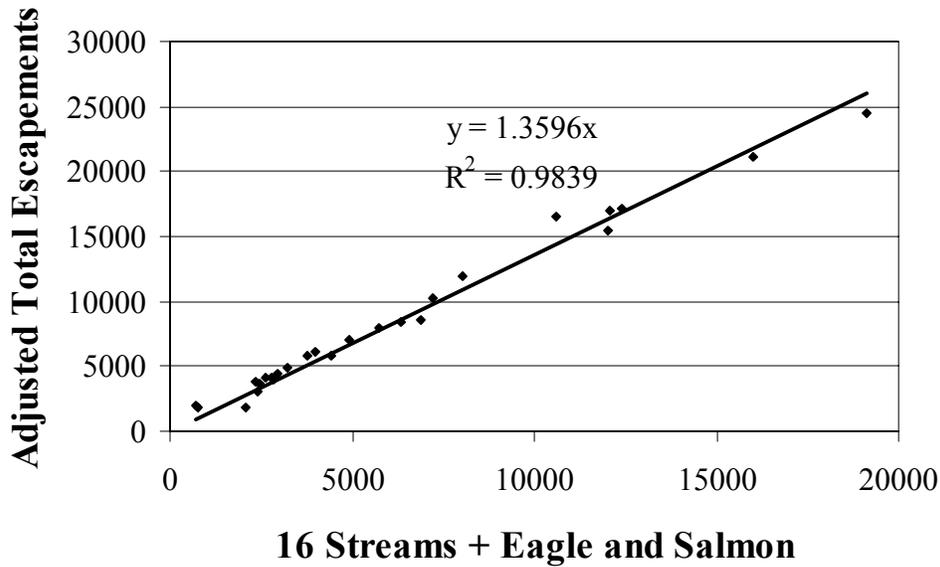
Figure 5. Aggregate coho escapement to 16 escapement indicator streams in the South Thompson watershed.



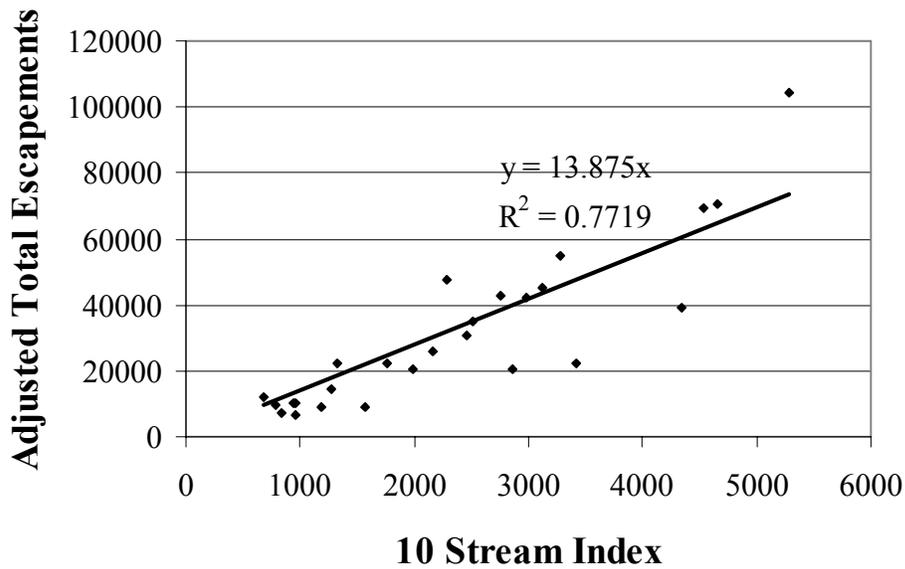
**Figure 6.** Relationship between aggregate escapements to South and North Thompson indicator streams.



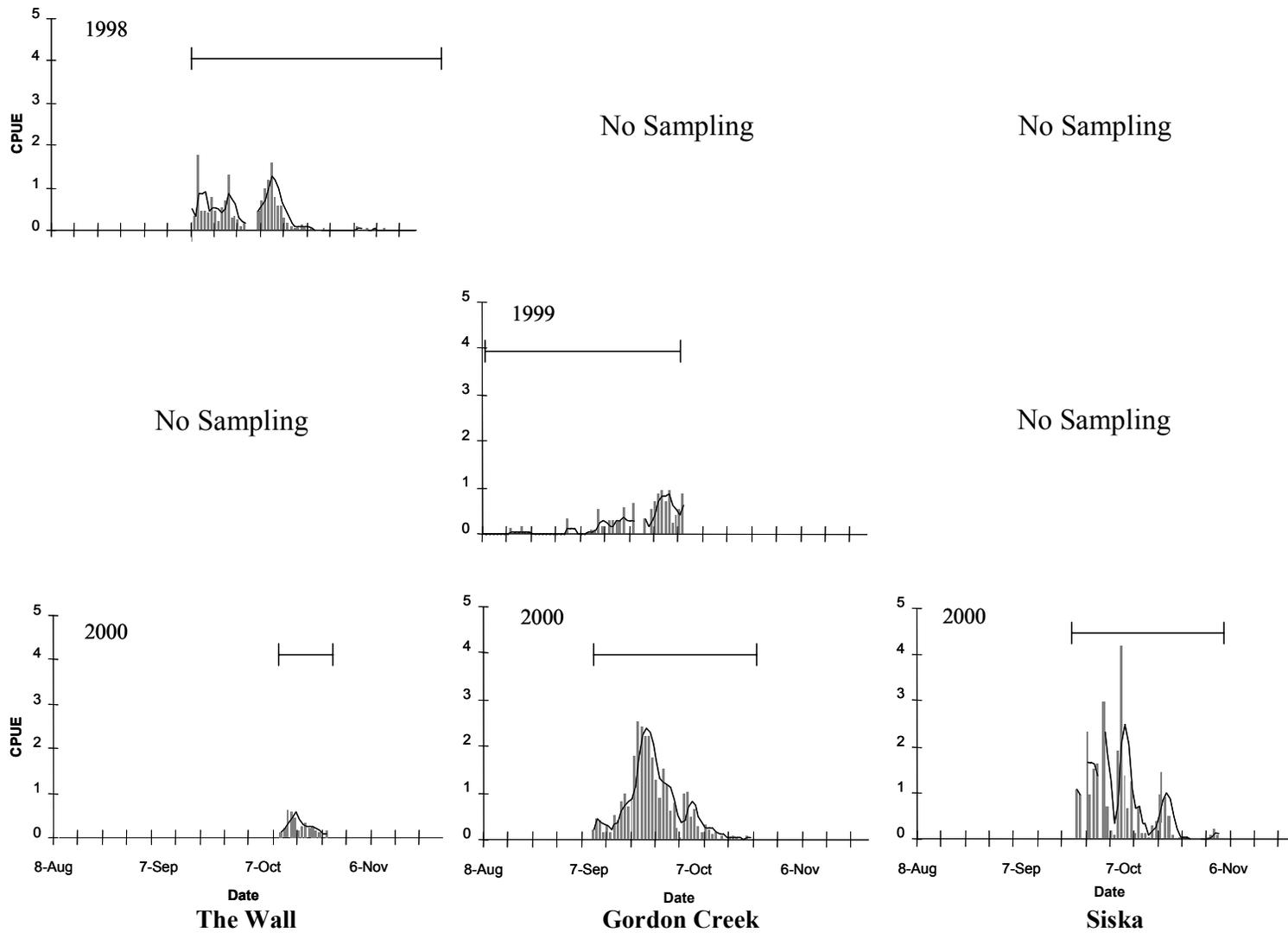
**Figure 7.** Adjusted historical escapement for coho salmon returning to the North, South, and lower Thompson watersheds (data are in Appendix 3).



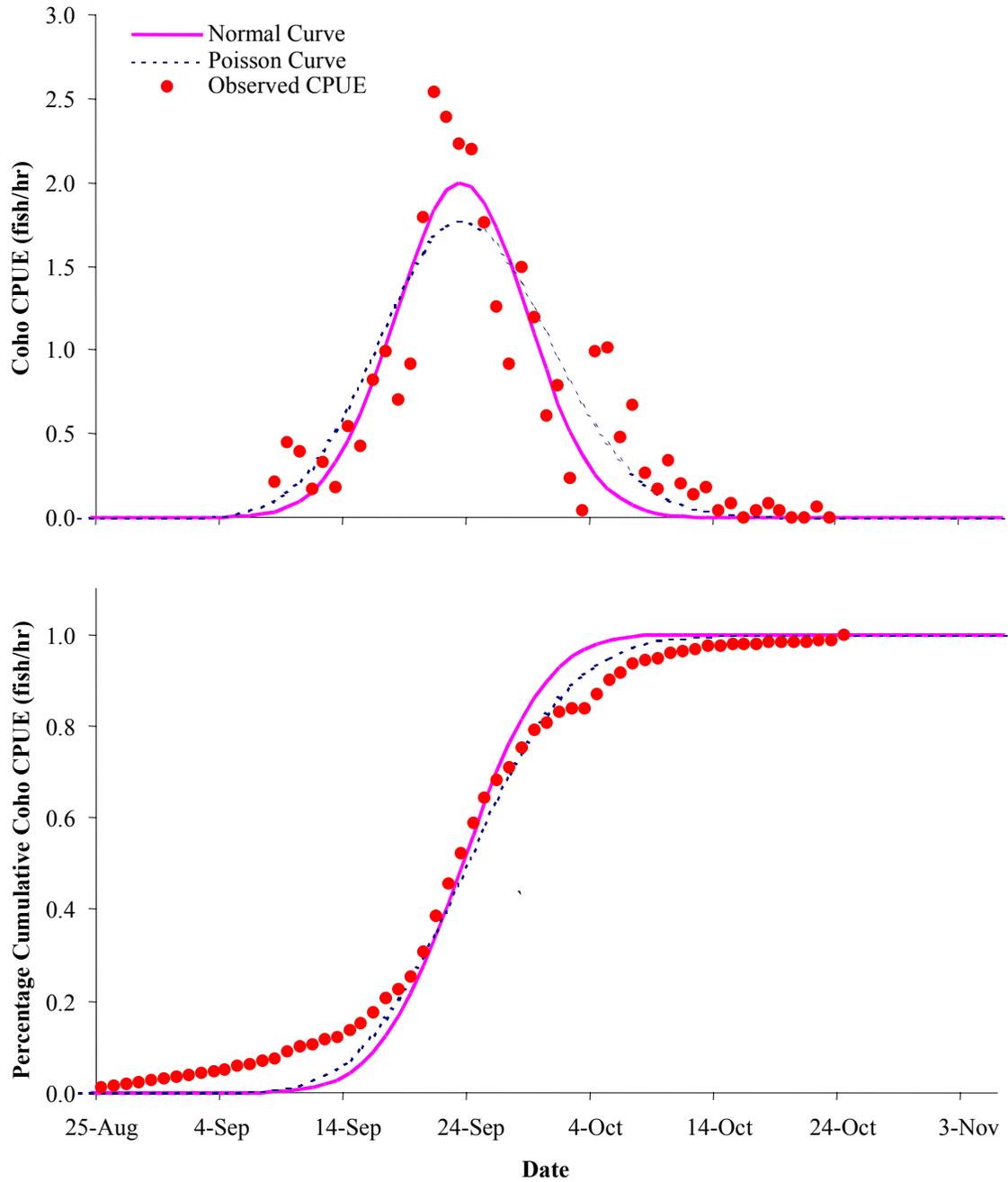
**Figure 8.** Relationship between escapements to 16 indicator streams in the South Thompson plus escapements to the Eagle and Salmon rivers and adjusted historical escapements to the South Thompson watershed.



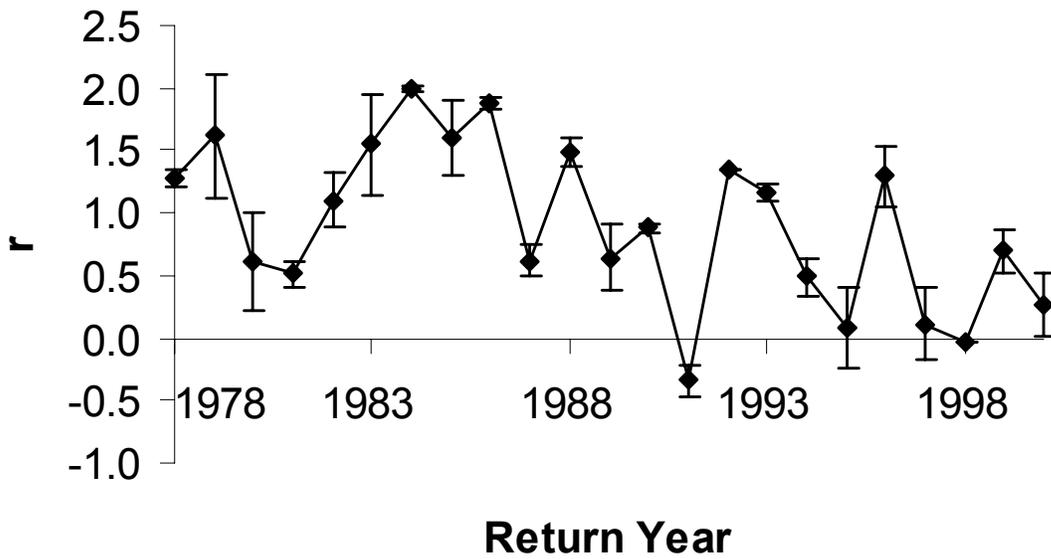
**Figure 9.** Relationship between escapements to 10 indicator streams in the North Thompson and adjusted historical escapements to the North Thompson watershed.



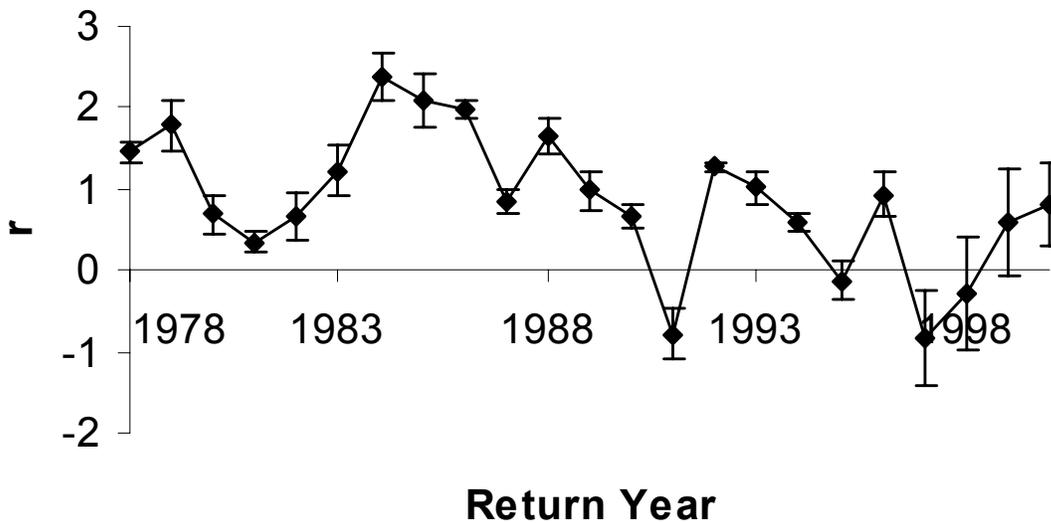
**Figure 10.** Migration timing of coho at Yale (the Wall and Gordon Creek) and Siska based on CPUE (fish/hr) at the fishwheels from 1998 to 2000. Brackets indicate the seasonal periods of fishwheel operation and the solid line indicates the three-day moving average.



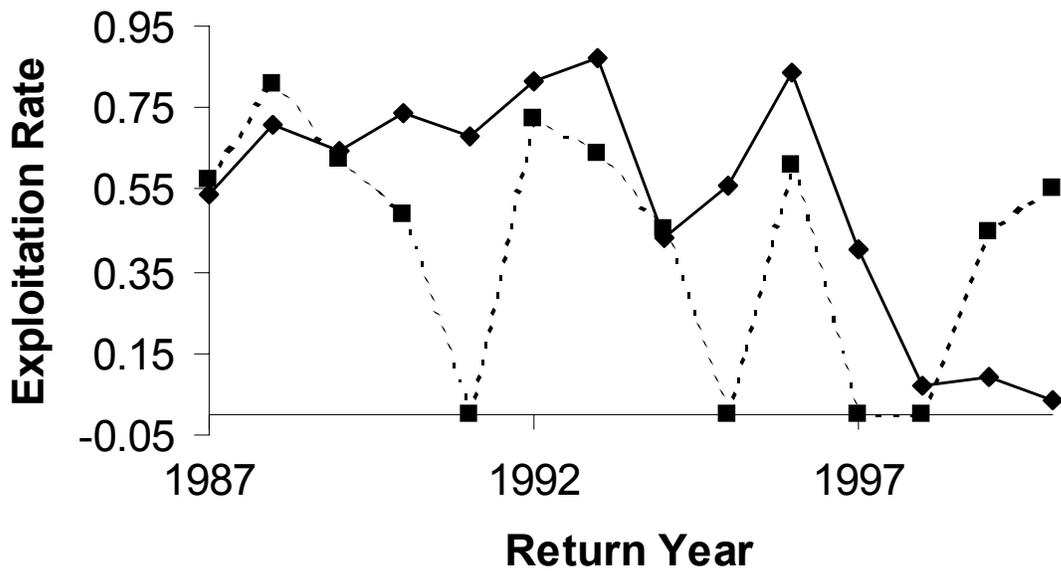
**Figure 11.** Normal and Poisson migration timing curves fit by least squares to coho CPUE observed at the Gordon Creek fishwheel, Yale, 2000.



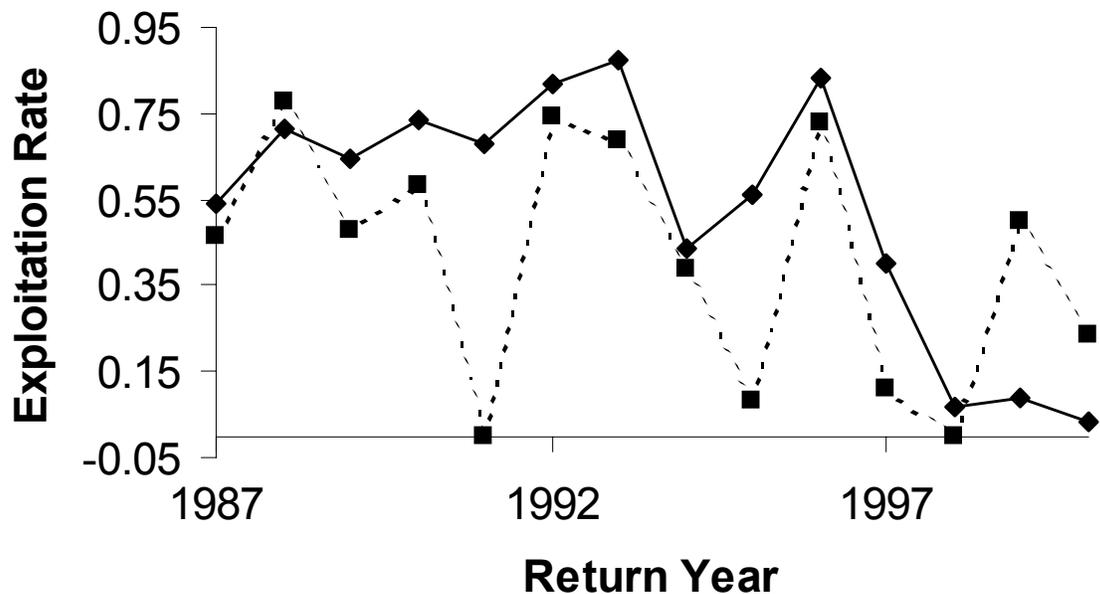
**Figure 12.** Time series of  $r_{an}$ , the annual rate of population growth for Thompson coho salmon. Each point is the average (+SE) of four time series (North and South indicator stream aggregates, Eagle and Salmon rivers). When  $r < 0$ , populations are unable to replace themselves, even in the absence of fishing.



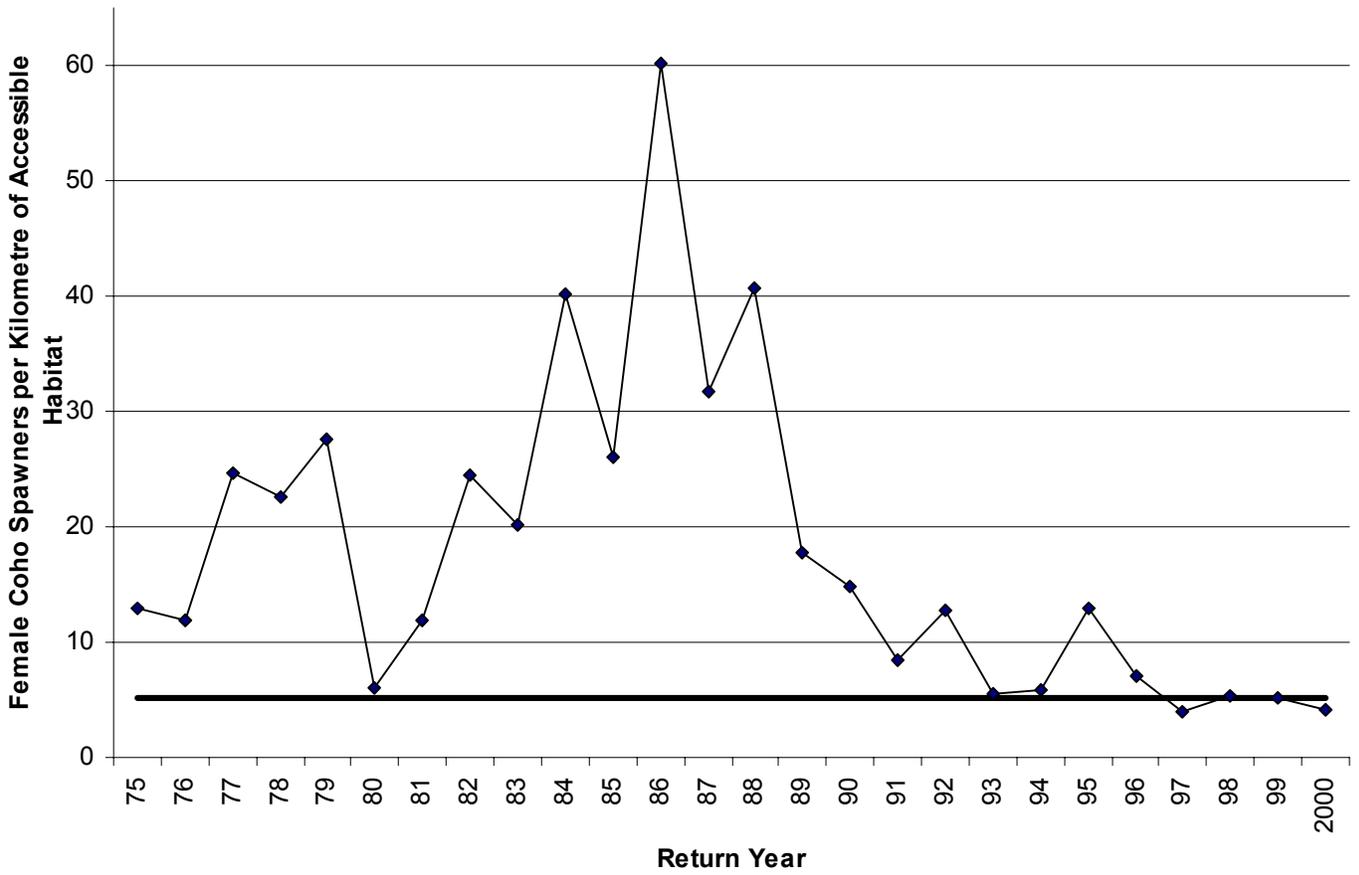
**Figure 13.** Time series of  $r_{an}$ , the annual rate of population growth of Thompson coho salmon. Each point is the average (+SE) of two time series (North and South indicator stream aggregates). When  $r < 0$ , populations are unable to replace themselves, even in the absence of fishing.



**Figure 14.** Exploitation rate estimates for Thompson watershed (North and South indicator stream aggregates, Eagle and Salmon rivers) coho (solid line) and exploitation rates that would have maintained coho production at the brood year escapement level (i.e.  $S_t = S_{t-3}$ ) (dashed line).



**Figure 15.** Exploitation rate estimates for Thompson watershed (North and South indicator stream aggregates) coho (solid line) and exploitation rates that would have maintained coho production at the brood year escapement level (i.e.  $S_t = S_{t-3}$ ) (dashed line).



**Figure 16.** Annual estimates of numbers of female coho per kilometre within the North Thompson watershed. Horizontal line indicates the mean of two possible limit reference points (5.2 females/km).

Appendix 1. Coho DNA mixed stock estimates for 1997-1999 sampling, N= number of fish in sample. Standard deviations are in brackets. Samples with \* indicates 1998 and 1999 samples analyzed in year 2000. Thompson and Upper Fraser combined for 1997 and 1998 samples analyzed in 1998.

Southern Baseline

<b>Area20 Seine Test Fishery</b>														
	1998		1999		1998		1999		1998		1999		1998	
	July 24-25	July 21-24	July 26-Aug 1	July 25-31	Aug 2 - 8	Aug 1-3	Aug 9 -15	Aug 8-14	Aug 16- 22	Aug 15-21	Aug 23-25	Aug 22-28		
N	184	172	310	252	153	50	168	99	155	207	59	63		
WCVI	14.2 (3.4)	7.2 (2.9)	3.9 (2.5)	1.7 (1.2)	5.4 (3.4)	1.7 (1.2)	9.3 (3.8)	4.5 (3.8)	6.7 (3.5)	3.9 (1.9)	8.9 (5.4)	7.4 (5.3)		
ECVI	9.3 (3.7)	4.5 (3.0)	8.4 (2.8)	12.6 (3.2)	4.6 (3.0)	12.6 (3.2)	17.6 (5.8)	22.3 (5.8)	6.7 (3.9)	19.6 (3.9)	12.5 (7.8)	20.2 (9.3)		
NCVI	1.3 (2.2)	2.3 (2.3)	6.8 (2.0)	6.0 (2.1)	0.9 (2.2)	6.0 (2.1)	1.3 (1.7)	0.0 (2.2)	3.3 (2.1)	1.4 (1.7)	4.6 (4.2)	4.7 (4.3)		
S. Mainland	10.2 (3.2)	10.3 (3.1)	7.0 (2.3)	14.9 (2.7)	12.4 (4.7)	14.9 (2.7)	7.5 (3.7)	7.4 (4.9)	4.2 (3.1)	9.5 (2.9)	5.0 (5.4)	25.9 (7.6)		
Lower Fraser	15.7 (4.2)	23.9 (4.5)	13.2 (3.0)	14.7 (3.3)	9.7 (4.4)	14.7 (3.3)	3.3 (3.4)	13.9 (5.2)	4.9 (3.3)	14.3 (3.5)	1.1 (3.3)	10.1 (6.5)		
Thompson/UPFR	1.3 (1.3)		0.8 (0.7)		2.8 (1.4)		1.4 (1.1)		1.1 (0.9)		2.3 (2.2)			
Thompson		1.3 (0.9)		0.0 (0.5)		0.0 (0.5)		1.9 (1.8)		1.9 (1.1)		0.0 (0.8)		
UPFR		0.0 (0.2)		0.0 (0.2)		0.0 (0.2)		0.0 (0.4)		0.7 (1.1)		0.0 (0.5)		
Puget S.	36.5 (4.7)	39.8 (5.2)	36.2 (4.5)	37.9 (4.5)	39.6 (6.7)	37.9 (4.5)	41.2 (5.1)	29.3 (6.6)	32.3 (6.4)	41.4 (4.6)	47.8 (8.7)	25.9 (8.7)		
Juan de Fuca	4.0 (3.3)	5.6 (2.9)	12.6 (3.5)	2.9 (2.0)	17.3 (5.2)	2.9 (2.0)	5.4 (3.6)	10.7 (5.0)	18.4 (5.7)	1.9 (1.9)	7.2 (4.8)	0.0 (2.3)		
Coastal Wash	4.1 (2.2)	2.1 (1.8)	9.5 (2.8)	4.3 (1.9)	1.1 (2.8)	4.3 (1.9)	8.8 (2.8)	8.7 (4.8)	18.3 (4.4)	1.9 (1.4)	8.4 (5.2)	0.0 (2.9)		
Columbia	3.4 (1.5)	2.9 (1.6)	1.7 (1.2)	5.0 (1.9)	6.3 (2.3)	5.0 (1.9)	4.2 (1.9)	1.4 (2.0)	4.2 (2.1)	3.5 (1.5)	2.4 (2.2)	5.9 (3.2)		
{Canada	52.1 (5.0)	49.5 (5.6)	40.1 (4.2)	49.9 (4.8)	35.7 (6.7)	49.9 (4.8)	40.4 (5.7)	49.9 (7.4)	26.8 (5.5)	51.3 (4.4)	34.3 (9.3)	68.2 (9.0)		
{US	47.9 (5.0)	50.5 (5.6)	59.9 (4.2)	50.1 (4.8)	64.3 (6.7)	50.1 (4.8)	59.6 (5.7)	50.1 (7.4)	73.2 (5.5)	48.7 (4.4)	65.7 (9.3)	31.8 (9.0)		

<b>Area 20 Gillnet Test Fishery</b>														
	1998		1999		1998		1999		1988		1999		1998	
	July 3-18	July 14-17	July 19-25	July 18-24	July 26-Aug 1	July 25-31	Aug 2-16							
N	123	111	22	116	85	58	66							
WCVI	21.2 (5.2)	8.0 (3.9)	17.4 (9.0)	0.0 (1.5)	18.5 (6.4)	6.5 (5.5)	15.4 (6.7)							
ECVI	6.9 (3.8)	14.2 (5.8)	4.7 (8.0)	12.3 (6.1)	12.1 (6.1)	15.6 (8.7)	4.3 (4.2)							
NCVI	3.6 (3.1)	6.4 (3.7)	1.7 (4.6)	2.0 (2.2)	7.4 (4.5)	9.5 (6.5)	8.2 (5.9)							
S. Mainland	9.5 (4.4)	7.7 (4.9)	13.8 (8.8)	15.9 (5.2)	9.8 (4.7)	4.8 (5.3)	16.0 (6.7)							
Lower Fraser	7.5 (3.6)	22.0 (5.4)	0.0 (7.3)	15.3 (5.7)	4.2 (5.7)	17.1 (9.3)	5.5 (7.4)							
Thompson/UPFR	1.0 (0.8)		0.0 (0.0)		1.3 (1.6)		0.0 (0.6)							
Thompson		2.1 (1.4)		0.4 (1.5)		1.1 (1.8)								
UPFR		0.0 (0.4)		1.6 (1.5)		0.0 (0.0)								
Puget S.	24.4 (5.8)	31.4 (6.9)	8.1 (11.2)	41.3 (6.6)	15.4 (6.6)	40.8 (10.4)	14.2 (7.2)							
Juan de Fuca	4.6 (3.3)	2.8 (3.2)	31.9 (13.4)	4.9 (3.7)	14.4 (6.2)	1.7 (3.2)	14.5 (7.7)							
Coastal Wash	13.1 (4.4)	5.6 (3.1)	22.4 (14.1)	5.2 (3.7)	9.2 (3.9)	0.0 (2.8)	20.6 (6.4)							
Columbia	8.3 (3.1)	0.0 (0.8)	0.0 (0.6)	1.3 (1.5)	7.7 (4.1)	2.9 (2.7)	1.4 (2.6)							
{Canada	49.6 (5.5)	60.3 (7.0)	37.7 (13.5)	47.4 (6.5)	53.3 (8.2)	54.6 (11.0)	49.3 (9.3)							
{US	50.4 (5.5)	39.7 (7.0)	62.3 (13.5)	52.6 (6.5)	46.7 (8.2)	45.4 (11.0)	50.7 (9.3)							

Appendix 1 - cont.

	<i>Gillnet</i>			<i>Seine</i>			<i>Washington Troll Fishery</i>				
	1999 Wash A5 Aug 4-5 44	1998* Area14 Nov2-10 6	1998 Area21 Oct 17-24 153	1998 Area23 Sept 9-11 100	1999 Area20 Aug 6 122	1998* Area 21 Oct 11-12 35(35)	1999 Area 3 Aug15-18 56	1999 Area 4 < Aug 15 101	1999 Area 4 Aug 16-31 180	1999 Area 4 Sept 2 199	1999 Area 4/4b Aug 22 207
N											
WCVI	12.1 (6.0)	16.2 (9.6)	38.2 (6.5)	89.2 (5.4)	2.3 (2.6)	60.9 (11.9)	9.1 (5.4)	0.1 (2.6)	6.8 (3.5)	4.4 (2.6)	2.5 (2.7)
ECVI	6.8 (7.2)	13.0 (18.6)	18.8 (4.6)	6.5 (3.7)	12.5 (6.1)	3.0 (4.6)	3.6 (5.0)	9.1 (4.0)	7.0 (3.7)	11.1 (4.6)	0.0 (2.2)
NCVI	0.0 (3.9)	0.0 (14.9)	3.6 (3.0)	2.9 (2.9)	1.2 (2.3)	0.0 (7.6)	5.4 (4.6)	2.4 (2.3)	0.7 (1.6)	0.7 (2.3)	4.2 (2.2)
S. Mainland	16.6 (8.3)	17.8 (15.6)	16.9 (5.1)	0.0 (1.2)	10.4 (5.3)	9.3 (6.5)	3.9 (4.1)	1.5 (2.4)	2.9 (2.6)	1.2 (2.9)	11.1 (3.2)
Lower Fraser	19.9 (7.8)	15.6 (25.8)	5.8 (3.2)	1.5 (1.6)	26.1 (6.7)	15.8 (7.8)	4.4 (4.0)	15.1 (5.1)	10.5 (4.3)	21.6 (4.3)	12.8 (3.5)
Thompson/UPFR			1.2 (1.1)	0.0 (0.4)							
Thompson	4.9 (3.5)	0.0 (0.0)			1.3 (1.7)	0.0 (0.0)	3.2 (2.6)	5.5 (2.9)	4.4 (2.1)	3.0 (1.6)	1.2 (1.2)
UPFR	0.0 (0.0)	0.0 (0.0)			0.0 (0.0)	0.0 (0.0)	1.4 (1.1)	1.1 (0.9)	0.0 (0.2)	0.0 (0.5)	0.0 (0.3)
Puget S.	37.1 (10.3)	17.1 (15.6)	6.9 (4.1)	0.0 (2.1)	34.1 (7.9)	1.5 (5.7)	19.6 (9.3)	44.9 (7.0)	25.5 (6.1)	29.5 (4.8)	30.6 (4.8)
Juan de Fuca	2.6 (3.6)	0.0 (9.1)	0.1 (2.6)	0.0 (1.7)	8.8 (4.3)	7.7 (4.4)	0.0 (2.1)	3.0 (3.8)	11.9 (4.1)	1.7 (1.9)	1.6 (2.4)
Coastal Wash	0.0 (1.8)	20.4 (20.9)	8.5 (4.2)	0.0 (1.2)	1.9 (3.8)	1.7 (4.3)	29.4 (9.1)	12.8 (4.9)	17.2 (5.6)	20.8 (4.7)	22.7 (4.2)
Columbia	0.0 (2.2)	0.0 (8.4)	0.0 (1.0)	0.0 (0.5)	1.4 (2.3)	0.0 (1.6)	20.0 (6.6)	4.5 (2.6)	13.0 (3.1)	6.0 (2.9)	13.3 (2.9)
{Canada	60.3 (10.9)	62.6 (23.4)	84.5 (5.7)	100.0 (3.0)	53.9 (7.7)	89.1 (7.2)	30.9 (9.2)	34.8 (7.0)	32.4 (5.2)	42.0 (6.2)	31.7 (4.9)
{US	39.7 (10.9)	37.4 (23.4)	15.5 (5.7)	0.0 (3.0)	46.1 (7.7)	10.9 (7.2)	69.1 (9.2)	65.2 (7.0)	67.6 (5.2)	58.0 (6.2)	68.3 (4.9)

	<i>Canadian Troll Fishery</i>			<i>Recreational Fishery</i>						
	1999 Area 123	1999 Area 123	1999 Area 123	1998 Area 14	1998 Area 17	1998 Area 19	1997 Area 20	1997 Area 20	1998 Area 20	1999 Area20
N										
WCVI	4.4 (2.3)	1.7 (2.3)	7.5 (2.6)	0.2 (1.9)	7.5 (10.4)	12.6 (7.2)	7.9 (4.9)	6.4 (6.1)	18.1 (8.1)	1.5 (2.4)
ECVI	9.6 (3.6)	7.6 (2.8)	12.3 (3.9)	84.7 (6.6)	16.5 (10.7)	9.5 (6.2)	4.1 (5.3)	22.2 (7.4)	9.5 (6.0)	14.2 (7.8)
NCVI	1.5 (1.5)	3.1 (2.3)	3.4 (2.5)	2.7 (2.4)	0.0 (0.6)	5.8 (4.7)	0.9 (3.2)	8.8 (5.1)	11.2 (6.5)	7.3 (4.0)
S. Mainland	7.9 (2.9)	5.9 (2.3)	7.0 (2.9)	6.3 (5.8)	0.0 (9.1)	24.0 (8.5)	1.6 (3.6)	7.3 (6.3)	15.6 (6.9)	12.8 (4.8)
Lower Fraser	24.3 (4.2)	23.6 (3.7)	32.2 (4.1)	0.0 (1.4)	45.0 (16.9)	10.1 (5.4)	37.3 (8.5)	18.0 (7.1)	11.0 (4.5)	14.2 (6.0)
Thompson/UPFR				0.0 (0.0)	8.3 (7.5)	3.8 (3.0)	3.7 (2.5)	5.8 (2.8)	6.3 (4.6)	
Thompson	3.3 (1.5)	2.2 (1.2)	0.5 (0.6)							1.2 (1.1)
UPFR	0.0 (0.6)	0.6 (0.6)	0.0 (0.4)							0.0 (0.0)
Puget S.	27.4 (4.6)	36.9 (4.2)	22.0 (3.4)	0.0 (1.6)	22.7 (11.9)	26.3 (7.5)	31.1 (9.8)	12.3 (7.0)	9.4 (6.7)	33.7 (7.9)
Juan de Fuca	13.2 (3.8)	8.0 (2.4)	4.2 (2.9)	0.8 (1.7)	0.0 (2.5)	4.4 (3.9)	10.4 (6.5)	6.0 (4.1)	7.3 (5.2)	5.9 (4.6)
Coastal Wash	8.0 (2.5)	6.6 (3.0)	7.1 (2.5)	5.2 (3.3)	0.0 (3.1)	3.6 (4.4)	3.0 (3.8)	9.2 (4.3)	6.4 (4.6)	4.8 (3.8)
Columbia	0.3 (0.8)	3.6 (1.7)	3.8 (1.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.4)	0.0 (1.3)	4.0 (3.1)	5.2 (3.4)	4.5 (2.7)
{Canada	51.2 (5.0)	44.8 (4.4)	62.9 (4.3)	94.0 (4.0)	77.3 (12.4)	65.7 (8.1)	55.5 (8.8)	68.5 (8.4)	71.7 (8.9)	51.1 (8.2)
{US	48.8 (5.0)	55.2 (4.4)	37.1 (4.3)	6.1 (4.0)	22.7 (12.4)	34.3 (8.1)	44.5 (8.8)	31.5 (8.4)	28.3 (8.9)	48.9 (8.2)

Appendix 1 – cont.

**Recreational Fisheries**

	1999		1999		1997		1998		1999		1997		1999		1998		1998		1998		1998						
	Area 20 Guides Aug10-Oct1		Area 20 BCWF Aug 15-Sept15		Area 23 Ucluelet July 12-19		Area 23 Ucluelet Aug1-Sept19		Area 23 Ucluelet July7-Sept11		Area 23 Bamfield July 20-30		Area 23 Bamfield July31-Aug16		Area28 July1-16		Area 29 July15-Oct19		Area 123/124 Aug16-Sept1		US Area 5 Aug-16		US Area 5 Aug23		US Area 5 Sept 05		
N	18		59		86		14		115		63		247		42		17		31		147		149		146		
WCVI	14.9	(11.4)	2.7	(3.0)	16.3	(6.1)	52.5	(17.5)	29.5	(5.7)	15.0	(6.0)	87.3	(3.5)	4.2	(6.9)	13.3	(12.2)	14.6	(6.7)	8.7	(4.1)	2.9	(2.5)	3.4	(2.8)	
ECVI	3.5	(9.3)	16.8	(6.3)	4.9	(5.0)	0.0	(8.9)	16.0	(5.4)	5.7	(4.5)	2.8	(1.8)	0.0	(3.3)	5.3	(10.8)	14.6	(6.6)	6.2	(3.9)	10.1	(3.8)	2.6	(3.4)	
NCVI	0.0	(5.8)	5.5	(4.2)	2.1	(3.0)	14.6	(9.8)	10.4	(4.2)	3.0	(3.3)	1.6	(2.3)	0.0	(1.1)	0.0	(3.8)	2.5	(4.2)	5.5	(2.8)	7.4	(3.1)	0.7	(1.4)	
S. Mainland	16.5	(11.9)	11.4	(6.2)	5.0	(4.1)	17.5	(14.4)	6.9	(3.6)	3.6	(4.2)	4.2	(2.1)	65.2	(15.5)	35.8	(17.3)	5.6	(5.3)	6.2	(3.8)	4.0	(2.9)	8.5	(4.3)	
Lower Fraser	30.9	(14.8)	13.6	(6.2)	30.4	(7.2)	7.6	(7.8)	15.9	(5.2)	12.3	(6.7)	2.4	(1.6)	0.0	(7.0)	14.9	(12.6)	26.1	(10.9)	7.9	(4.5)	9.3	(3.0)	5.8	(2.4)	
Thompson/UPFR					1.1	(1.5)	0.0	(0.0)			2.4	(2.2)			2.23	2.01	6.0	(6.9)			1.1	(0.9)	1.1	(1.2)	4.6	(1.7)	
Thompson	0.0	(0.0)	6.7	2.94					4.8	(2.2)			0.0	(0.4)					0.0	(3.3)							
UPFR	0.0	(0.0)	1.8	(2.0)					0.0	(0.1)			0.0	(0.3)					0.0	(0.0)							
Puget S.	20.7	(10.4)	37.5	(8.2)	22.0	(7.0)	7.8	(8.1)	5.4	(2.9)	39.1	(8.1)	1.2	(1.1)	4.08	6.23	0.0	(5.4)	13.6	(7.3)	43.1	(6.8)	45.4	(5.8)	59.4	(6.3)	
Juan de Fuca	5.5	(7.6)	0.0	(2.4)	6.4	(5.2)	0.0	(1.8)	2.9	(2.1)	6.4	(4.2)	0.0	(0.6)	0.0	(0.3)	0.0	(0.0)	0.0	(1.7)	3.5	(3.3)	5.8	(3.5)	7.2	(3.8)	
Coastal Wash	5.2	(6.5)	4.0	(3.5)	6.2	(4.6)	0.0	(3.3)	8.3	(3.7)	10.4	(5.9)	0.2	(0.8)	22.7	(12.9)	12.0	(14.7)	19.9	(7.4)	15.1	(3.8)	6.7	(4.3)	4.4	(2.5)	
Columbia	2.8	(4.2)	0.0	(1.8)	5.5	(3.2)	0.0	(0.0)	0.0	(0.7)	2.0	(1.9)	0.3	(0.4)	1.6	(6.4)	12.7	(12.2)	3.2	(3.0)	2.7	(1.6)	7.1	(2.8)	3.3	(2.0)	
{Canada	65.8	(11.3)	58.5	(7.7)	59.9	(9.0)	92.2	(8.4)	83.4	(4.7)	42.2	(8.6)	98.2	(1.5)	71.7	(13.5)	75.3	(15.4)	63.3	(10.4)	35.6	(6.2)	34.9	(5.2)	25.6	(5.1)	
{US	34.2	(11.3)	41.5	(7.7)	40.1	(9.0)	7.8	(8.4)	16.6	(4.7)	57.8	(8.6)	1.8	(1.5)	28.3	(13.5)	24.7	(15.4)	36.7	(10.4)	64.4	(6.2)	65.1	(5.2)	74.4	(5.1)	

**Central Baseline**

	<b>Seine Fisheries</b>								<b>Round Isl Test</b>			<b>Seine</b>		<b>Seized</b>													
	1998		1998*		1998*		1998*		1998		1998*		1998		1999												
	Area 12 Aug3-26		Area 12 Oct10-13		Area 12 Oct17-22		Area 12 Oct 23-24		Area 13 Aug3-8		Area 13 Oct14-17		Area 13 Oct 19-23		Area 13 Nov1-13		Area 12 July 16-31		Area 12 Aug 1-13		Area7 Aug30-Sept12		Area8 Jul18-Aug29		Area8/9 Aug 13 - Oct 24		
N	108		49		87		36(36)		18		161		112		118		59		27		22		131		40		
QCI	2.9	(2.0)	0.0	(1.1)	1.3	(1.5)	5.0	(4.2)	0.0	(5.2)	1.1	(1.8)	1.6	(1.4)	0.0	(0.7)	6.9	(4.0)	2.7	(4.8)	0.0	(1.3)	2.3	(1.7)	5.1	(4.6)	
Nass	0.0	(1.6)	0.0	(0.8)	0.0	(1.7)	3.5	(3.2)	0.0	(2.7)	0.0	(1.4)	0.0	(0.4)	0.0	(1.0)	0.0	(1.6)	0.0	(1.8)	0.0	(1.9)	1.9	(1.7)	0.0	(1.0)	
Upper Skeena	1.7	(1.7)	0.0	(2.0)	1.0	(1.4)	0.0	(0.8)	0.0	(4.5)	1.3	(1.6)	0.0	(0.3)	2.0	(1.5)	5.1	(3.1)	0.0	(2.8)	0.0	(3.4)	0.0	(0.6)	0.0	(1.3)	
Lower Skeena	0.0	(2.2)	0.0	(2.7)	3.0	(2.9)	1.8	(4.1)	6.4	(6.2)	0.5	(1.9)	0.7	(2.5)	3.0	(2.4)	9.5	(4.5)	3.9	(5.4)	8.6	(7.9)	4.2	(2.7)	2.8	(3.7)	
North/Central Coast	17.5	(7.4)	7.1	(6.0)	14.4	(6.8)	1.2	(5.3)	20.1	(12.7)	9.1	(3.2)	1.4	(3.7)	1.2	(2.4)	16.5	(7.1)	14.7	(7.5)	37.6	(15.3)	69.6	(6.7)	28.9	(9.1)	
WCVI	7.3	(4.0)	11.2	(5.1)	4.1	(3.3)	8.1	(4.6)	0.0	(7.5)	3.5	(3.4)	5.0	(3.6)	6.0	(3.8)	11.1	(6.9)	21.9	(11.4)	13.4	(10.0)	10.7	(3.8)	7.2	(7.1)	
ECVI	15.7	(6.3)	42.1	(10.4)	30.1	(7.1)	44.1	(11.7)	30.1	(14.4)	30.6	(7.0)	32.0	(6.2)	40.7	(6.6)	10.5	(6.4)	11.0	(9.8)	0.0	(5.4)	2.2	(3.1)	10.0	(6.5)	
NCVI	8.2	(3.9)	2.2	(3.1)	8.2	(5.8)	6.3	(6.0)	0.0	(3.6)	2.0	(2.6)	4.7	(3.1)	0.9	(2.7)	15.3	(5.8)	11.0	(7.1)	35.0	(13.2)	2.0	(2.3)	9.2	(6.1)	
South Main	25.1	(7.7)	11.9	(9.1)	5.9	(5.3)	0.0	(3.0)	18.1	(12.1)	12.4	(4.6)	13.4	(5.2)	7.9	(3.9)	11.7	(5.2)	0.0	(3.7)	0.5	(9.2)	5.6	(4.0)	15.0	(7.6)	
Lower Fraser	7.1	(3.0)	9.5	(7.2)	21.0	(5.6)	13.1	(6.4)	4.0	(7.8)	28.3	(6.1)	28.2	(5.8)	26.5	(6.2)	2.1	(3.0)	7.8	(6.3)	5.0	(6.3)	0.0	(0.9)	5.8	(5.1)	
Thompson/UPFR	2.6	(1.5)					5.6	(5.0)									0.0	(0.0)	0.0	(0.0)	0.0	(2.5)	0.0	(0.5)			
Thompson			1.4	(2.4)	0.0	(1.1)	7.7	(3.9)			1.0	(1.2)	0.4	(1.1)	0.0	(0.6)										0.0	(0.0)
UPFR			3.1	(3.3)	1.2	(1.2)	3.0	(5.0)			0.0	(0.5)	2.7	(1.7)	0.0	(0.7)										0.0	(0.0)
Puget Sound	9.0	(4.2)	7.4	(6.8)	3.7	(3.5)	0.0	(2.9)	15.8	(10.0)	8.6	(4.5)	5.4	(4.1)	6.6	(4.6)	9.1	(4.8)	14.0	(9.0)	0.0	(0.0)	0.0	(1.1)	10.2	(5.9)	
Juan de Fuca	3.2	(2.8)	0.0	(2.4)	0.5	(2.6)	6.1	(5.9)	0.0	(0.0)	0.0	(1.7)	1.6	(1.5)	0.7	(2.0)	0.0	(1.2)	0.0	(1.1)	0.0	(5.0)	1.5	(1.5)	0.0	(1.6)	
Coastal Wash	0.0	(2.5)	4.1	(5.5)	3.5	(2.5)	0.0	(2.2)	0.0	(0.0)	1.8	(2.5)	0.7	(1.4)	2.1	(1.9)	0.0	(3.0)	5.8	(6.9)	0.0	(0.0)	0.0	(0.9)	3.6	(2.7)	
Columbia	0.0	(0.2)	0.0	(2.3)	2.1	(1.8)	0.0	(1.6)	0.0	(3.8)	0.0	(0.8)	2.1	(1.9)	2.5	(1.9)	2.3	(1.9)	7.3	(4.9)	0.0	(0.0)	0.0	(0.4)	2.2	(1.6)	
{Canada	87.8	(4.6)	88.5	(7.9)	90.2	(5.0)	93.9	(6.8)	84.2	(10.0)	89.6	(5.2)	90.1	(4.7)	88.2	(5.1)	88.7	(6.1)	72.9	(8.8)	100.0	(5.1)	98.5	(2.0)	84.0	(6.7)	
{U.S.	12.2	(4.6)	11.5	(7.9)	9.8	(5.0)	6.1	(6.8)	15.8	(10.0)	10.4	(5.2)	9.9	(4.7)	11.8	(5.1)	11.3	(6.1)	27.1	(8.8)	0.0	(5.1)	1.5	(2.0)	16.1	(6.7)	

Appendix 1 – cont.

	<b>Gillnet</b>					<b>Troll Fishery</b>				
	1998	1999*	1998	1999	1998	1999*	1999*	1999*	1999*	
	Area 12 Aug26-30	Area12 Jul24-Aug5	Area 11 July 26-Aug8	Area 11 Aug 3	Area 12 July 24-31	Area12 Jul01	Area12 Jul11	Area12 Jul18-19	Area12 Jul24-Oct17	Area13 Aug6-Sep29
N	27	65(65)	47	23	196	52(52)	43(43)	268(268)	13(13)	65(65)
QCI	0.0 (8.2)	0.0 (2.0)	7.8 (4.2)	2.7 (4.3)	0.3 (1.1)	1.5 (2.5)	0.0 (1.9)	2.2 (1.6)	0.0 (6.1)	0.0 (1.0)
Nass	2.9 (4.8)	1.8 (1.8)	0.0 (3.6)	4.4 (4.8)	1.4 (1.9)	0.0 (0.4)	1.5 (2.3)	0.8 (1.4)	0.2 (6.2)	0.0 (4.5)
Upper Skeena	0.0 (2.9)	0.0 (1.2)	3.9 (3.4)	0.0 (1.2)	1.0 (0.9)	0.0 (0.5)	0.0 (1.7)	0.5 (0.9)	8.9 (10.4)	3.1 (2.3)
Lower Skeena	3.3 (7.4)	0.0 (2.0)	9.8 (5.4)	4.4 (5.8)	1.6 (1.4)	5.1 (4.5)	2.7 (2.4)	1.6 (1.9)	0.0 (5.0)	7.9 (6.1)
North/Central Coast	33.9 (13.2)	17.7 (8.4)	19.9 (7.6)	33.6 (12.5)	7.0 (3.9)	11.7 (5.4)	8.9 (8.1)	26.4 (4.5)	47.9 (21.7)	14.4 (6.7)
WCVI	18.0 (12.2)	2.3 (5.9)	7.5 (6.3)	11.3 (9.0)	16.3 (4.8)	15.7 (5.9)	13.4 (7.6)	5.8 (2.7)	0.9 (8.4)	8.0 (4.8)
ECVI	19.6 (13.2)	12.1 (9.1)	12.8 (6.8)	2.2 (3.9)	24.6 (5.3)	33.1 (7.8)	37.2 (10.9)	21.9 (4.0)	28.3 (14.0)	9.7 (6.0)
NCVI	7.9 (9.0)	16.2 (6.2)	9.6 (6.2)	15.5 (10.9)	8.5 (3.2)	2.2 (3.4)	12.5 (6.9)	15.1 (3.4)	0.1 (6.9)	1.8 (2.9)
South Main	6.5 (7.9)	28.8 (8.3)	0.4 (4.1)	4.9 (7.1)	18.0 (5.9)	16.1 (6.7)	6.4 (5.9)	8.0 (3.2)	0.0 (11.3)	39.8 (10.6)
Lower Fraser	0.0 (5.8)	12.2 (7.0)	14.8 (6.2)	3.8 (5.7)	5.4 (2.9)	8.4 (5.8)	6.4 (6.0)	7.2 (2.9)	0.0 (4.1)	8.5 (5.3)
Thompson/UPFR	0.4 (3.8)		2.3 (2.2)		3.0 (1.3)					
Thompson		0.0 (0.6)		8.1 (5.8)		1.8 (1.8)	0.0 (0.4)	0.7 (0.5)	0.0 (0.0)	2.1 (2.4)
UPFR		0.3 (2.3)		0.0 (1.0)		0.0 (0.8)	0.0 (0.1)	0.2 (0.6)	4.8 (6.6)	0.9 (1.1)
Puget Sound	7.7 (7.7)	6.5 (4.7)	3.4 (3.7)	0.0 (1.7)	8.8 (4.0)	2.0 (3.3)	5.3 (3.1)	7.7 (2.4)	0.9 (9.0)	0.0 (3.6)
Juan de Fuca	0.0 (4.1)	2.3 (4.3)	3.1 (3.0)	3.4 (3.4)	1.9 (1.7)	0.0 (0.2)	0.0 (2.5)	1.4 (1.6)	8.0 (8.8)	0.0 (2.2)
Coastal Wash	0.0 (3.0)	0.0 (1.8)	4.8 (4.4)	0.0 (0.0)	0.7 (1.2)	2.4 (3.5)	0.0 (1.7)	0.4 (1.0)	0.0 (1.4)	1.9 (2.6)
Columbia	0.0 (1.2)	0.0 (1.8)	0.0 (0.7)	5.7 (5.5)	1.6 (1.3)	0.0 (1.8)	5.8 (4.0)	0.1 (1.2)	0.0 (3.2)	2.1 (2.2)
{Canada	92.3 (8.7)	91.2 (6.1)	88.8 (5.8)	90.9 (6.6)	87.0 (4.4)	95.6 (4.7)	88.9 (5.5)	90.4 (2.9)	91.2 (12.4)	96.0 (5.2)
{U.S.	7.7 (8.7)	8.8 (6.1)	11.3 (5.8)	9.1 (6.6)	13.0 (4.4)	4.4 (4.7)	11.1 (5.5)	9.6 (2.9)	8.8 (12.4)	4.0 (5.2)

	<b>Troll Fisheries</b>										
	1998	1998	1998	1999	1999	1998	1999	1999	1999	1999	1998
	Area 12 Aug 1-7	Area 12 Aug 8-16	Area 12 Aug 17-25	Area 12 July 23-Aug6	Area124 Jul23-31	Area124 Aug1-7	Area124 Aug1-7	Area124 Aug8-14	Area124 Sept12-15	Area125 Jul25-31	Area125 Aug1-7
N	68	292	44	158	260	55	110	199	191	264	260
QCI	2.6 (2.4)	1.6 (0.8)	1.4 (2.8)	0.9 (1.4)	0.8 (1.0)	1.5 (1.8)	0.0 (1.0)	0.3 (1.4)	1.5 (1.5)	0.8 (0.8)	1.3 (1.3)
Nass	1.7 (3.0)	0.0 (1.4)	0.0 (1.0)	0.0 (1.0)	0.0 (0.8)	0.0 (1.0)	1.2 (1.1)	0.0 (0.5)	0.3 (1.0)	0.3 (0.7)	1.2 (1.2)
Upper Skeena	1.6 (2.5)	0.3 (0.5)	0.0 (0.7)	0.0 (0.7)	0.9 (0.7)	0.0 (0.2)	0.5 (1.3)	0.0 (0.7)	0.0 (0.3)	0.7 (0.8)	0.0 (0.6)
Lower Skeena	5.2 (3.6)	5.1 (2.5)	1.7 (3.6)	1.4 (1.8)	3.0 (1.8)	2.7 (3.2)	0.2 (1.5)	4.3 (2.2)	0.2 (0.9)	2.6 (1.9)	1.0 (1.0)
North/Central Coast	6.5 (5.0)	19.8 (3.8)	0.0 (6.6)	23.7 (4.9)	9.7 (2.7)	3.3 (2.8)	6.0 (3.1)	7.5 (2.9)	2.8 (1.9)	2.1 (1.9)	3.3 (2.1)
WCVI	10.4 (6.5)	14.4 (4.8)	4.8 (6.9)	19.3 (5.1)	19.2 (3.4)	26.8 (6.9)	25.5 (4.9)	20.4 (4.4)	33.2 (5.0)	18.6 (3.3)	23.7 (4.0)
ECVI	21.8 (8.5)	4.1 (2.9)	22.7 (7.7)	11.1 (3.9)	11.9 (3.6)	0.0 (3.2)	1.9 (3.8)	11.8 (3.2)	17.5 (4.8)	13.3 (3.3)	12.2 (3.9)
NCVI	18.7 (7.4)	18.8 (3.3)	24.7 (8.2)	10.9 (4.4)	8.5 (2.7)	8.6 (5.7)	4.1 (3.4)	6.0 (2.7)	9.3 (3.6)	5.5 (2.2)	7.1 (3.1)
South Main	12.4 (6.3)	14.9 (3.8)	9.3 (6.0)	20.0 (5.6)	3.6 (2.2)	5.8 (4.0)	2.8 (2.2)	0.0 (1.3)	5.6 (2.9)	5.7 (2.4)	2.6 (2.0)
Lower Fraser	12.5 (6.1)	3.2 (1.9)	17.2 (6.8)	5.3 (2.8)	19.9 (3.4)	16.0 (7.2)	17.1 (5.0)	20.1 (3.8)	13.8 (3.5)	24.8 (3.3)	12.3 (3.2)
Thompson/UPFR	2.1 (1.6)	2.3 (1.0)	2.3 (2.9)			1.0 (1.3)					2.3 (1.2)
Thompson				0.0 (0.5)	1.2 (1.0)		0.9 (1.7)	0.6 (0.6)	0.6 (0.7)	0.9 (0.9)	
UPFR				0.0 (0.1)	1.5 (0.9)		1.5 (1.1)	0.5 (0.5)	0.0 (0.2)	1.5 (1.0)	
Puget Sound	3.8 (3.8)	7.5 (2.5)	7.3 (4.9)	1.6 (1.8)	12.0 (3.5)	13.9 (7.8)	19.2 (4.9)	16.6 (3.7)	5.3 (2.7)	13.1 (2.9)	13.9 (3.6)
Juan de Fuca	0.0 (2.9)	4.6 (2.2)	0.0 (3.1)	4.1 (2.1)	1.9 (1.6)	3.0 (4.5)	1.8 (2.1)	4.9 (2.7)	2.4 (1.8)	2.8 (1.9)	6.3 (3.0)
Coastal Wash	0.9 (3.5)	3.4 (1.5)	8.7 (6.3)	0.2 (2.0)	4.4 (1.9)	17.3 (6.7)	15.2 (4.6)	7.2 (3.0)	6.5 (2.8)	5.3 (1.8)	8.9 (3.1)
Columbia	0.0 (0.6)	0.0 (0.2)	0.0 (0.7)	1.6 (1.4)	1.5 (0.8)	0.0 (1.4)	2.3 (1.6)	0.0 (0.2)	1.4 (1.0)	2.1 (0.9)	3.8 (1.5)
{Canada	95.3 (6.0)	84.6 (3.2)	84.0 (8.4)	92.5 (3.3)	80.2 (4.4)	65.7 (8.5)	61.5 (6.1)	71.4 (4.4)	84.5 (3.9)	76.8 (3.7)	67.1 (4.9)
{U.S.	4.7 (6.0)	15.5 (3.2)	16.0 (8.4)	7.5 (3.3)	19.8 (4.4)	34.3 (8.5)	38.5 (6.1)	28.6 (4.4)	15.6 (3.9)	23.2 (3.7)	33.0 (4.9)

Appendix 1 – cont.

	<b>Troll Fisheries</b>						<b>Recreational Fishery</b>	
	1999	1999	1998	1999	1998	1999	1998	1998
	Area125	Area126	Area127	Area127	Area 124-127	Area 124-127	Area 24	Area25
	Aug1-13	Jul 26- Aug13	Jul31- Aug7	Jul26- Aug4	Aug 1-16	Jul 23-Aug2	July26-Aug1	July24-Sept25
N	142	219	155	177	106	195	91	18
QCI	0.8 (1.4)	0.0 (0.7)	0.1 (1.6)	3.6 (1.7)	0.3 (2.1)	1.3 (0.9)	3.1 (2.3)	10.7 (8.9)
Nass	0.3 (1.2)	2.0 (1.2)	0.0 (0.8)	0.0 (1.1)	6.9 (3.9)	0.1 (0.9)	0.0 (0.2)	9.9 (8.0)
Upper Skeena	2.0 (1.4)	0.0 (0.8)	1.2 (1.2)	0.0 (0.5)	1.4 (2.3)	1.1 (1.2)	2.3 (1.4)	0.0 (2.9)
Lower Skeena	2.3 (2.1)	1.8 (2.2)	0.0 (1.1)	3.9 (2.6)	2.6 (3.4)	2.3 (1.9)	1.3 (1.8)	4.3 (8.0)
North/Central Coast	5.2 (2.9)	4.3 (2.3)	4.8 (3.2)	12.3 (3.9)	8.4 (3.9)	4.1 (2.0)	4.8 (2.8)	19.9 (11.2)
WCVI	16.5 (4.2)	18.9 (3.9)	15.0 (5.3)	19.2 (3.9)	28.3 (6.9)	19.9 (3.5)	74.0 (7.4)	9.3 (10.9)
ECVI	16.4 (4.6)	11.7 (2.7)	11.9 (4.4)	12.0 (4.3)	8.6 (4.9)	10.1 (3.4)	0.0 (2.6)	18.6 (13.2)
NCVI	2.4 (2.2)	7.7 (2.6)	8.0 (3.6)	14.7 (4.1)	7.1 (4.2)	7.8 (2.8)	5.9 (5.3)	13.1 (9.6)
South Main	3.8 (2.8)	6.8 (3.1)	5.7 (3.7)	7.8 (4.2)	7.9 (5.5)	3.9 (2.5)	3.4 (3.6)	0.0 (4.1)
Lower Fraser	29.7 (5.0)	28.9 (4.2)	16.0 (4.9)	12.9 (3.6)	15.4 (6.5)	26.8 (4.1)	0.0 (1.0)	0.0 (1.4)
Thompson/UPFR			3.1 (1.6)		3.8 (2.1)		0.0 (1.0)	5.8 (5.3)
Thompson	3.1 (1.9)	3.0 (1.5)		0.0 (0.4)		0.8 (0.9)		
UPFR	4.5 (2.1)	0.0 (0.6)		0.0 (0.6)		0.4 (0.5)		
Puget Sound	5.7 (3.0)	7.7 (2.6)	20.9 (5.6)	5.5 (2.9)	3.0 (3.7)	15.2 (3.6)	3.0 (2.5)	2.5 (6.2)
Juan de Fuca	2.1 (1.7)	2.3 (1.6)	6.7 (3.5)	3.7 (2.3)	1.8 (2.6)	0.5 (1.3)	0.0 (0.0)	0.0 (2.8)
Coastal Wash	3.6 (2.5)	4.6 (2.9)	6.1 (3.2)	2.2 (1.9)	4.5 (3.0)	3.1 (2.1)	2.1 (2.2)	0.0 (6.1)
Columbia	1.6 (1.7)	0.3 (0.8)	0.5 (1.2)	2.3 (1.5)	0.0 (0.0)	2.6 (1.5)	0.0 (0.0)	5.9 (5.3)
{Canada	87.0 (4.1)	85.1 (3.8)	65.8 (5.8)	86.4 (4.2)	90.7 (5.5)	78.6 (4.3)	94.8 (3.2)	91.6 (9.4)
{U.S.	13.0 (4.1)	14.9 (3.8)	34.2 (5.8)	13.6 (4.2)	9.4 (5.5)	21.4 (4.3)	5.2 (3.2)	8.4 (9.4)

Northern Baseline

	<b>Recreational Fisheries</b>					<b>Commercial Fisheries -1998</b>							
	1998	1999	1998	1999	1999	Seine	Seine	Troll	Troll	Gillnet	Seine	Seine	Seine
	Area3	Area3	Area4	Area4	Langara Isl.	Area 1	Area 2W	Area2W	Area2W	Area2E	Area2E	Area 3	Area3
July 25-Aug23	Jul 26	July 25-Aug 15	Jul 25-Aug 15	Aug 23	Aug 8-22	Aug 22-29	Jul 25-Aug1	Aug 8-29	Sep 19-Oct 10	Sep 19-Oct 10	Jul 18-Aug 1	Aug 2- 8	
N	71	135	67	30	71	21	12	99	152	123	260	153	498
S.E. Alaska	5.6 (4.3)	6.0 (3.5)	2.0 (2.6)	0.0 (3.9)	0.0 (2.7)	17.5 (10.5)	0.0 (3.0)	4.7 (3.0)	5.1 (2.7)	3.5 (2.6)	1.9 (1.4)	9.9 (4.0)	18.3 (2.8)
QCI	7.2 (4.2)	3.0 (2.0)	9.0 (4.5)	5.2 (3.9)	29.8 (7.1)	12.8 (9.7)	20.9 (12.1)	7.3 (4.2)	12.6 (3.8)	68.9 (5.6)	69.1 (4.4)	0.7 (1.2)	2.0 (0.9)
Nass	6.6 (4.5)	5.2 (3.7)	0.0 (2.7)	6.5 (4.2)	10.2 (5.7)	0.0 (1.8)	0.0 (4.1)	1.3 (1.4)	0.0 (1.4)	0.0 (0.6)	2.3 (1.6)	5.4 (3.0)	11.7 (2.3)
Upper Skeena	10.2 (4.1)	12.9 (3.9)	7.5 (3.7)	6.6 (4.7)	0.0 (2.0)	0.0 (0.5)	0.0 (0.0)	3.0 (2.4)	0.0 (1.0)	0.0 (0.7)	0.4 (0.5)	15.0 (3.8)	3.8 (1.5)
Lower Skeena	7.0 (5.3)	14.7 (4.9)	16.6 (5.7)	17.3 (10.3)	8.2 (5.2)	8.8 (7.6)	8.9 (10.3)	6.9 (3.3)	1.1 (1.8)	2.1 (1.4)	0.0 (0.9)	9.6 (4.4)	12.3 (2.8)
North/Central Coast	35.7 (7.8)	29.2 (5.4)	43.4 (8.8)	28.2 (10.8)	19.4 (6.6)	9.5 (10.4)	38.9 (16.5)	10.1 (4.4)	23.5 (5.6)	3.3 (2.7)	7.5 (2.6)	20.8 (4.8)	29.0 (3.3)
WCVI	3.0 (3.2)	4.9 (2.6)	8.1 (4.4)	0.0 (0.9)	1.7 (3.0)	24.3 (11.2)	21.0 (14.6)	13.4 (6.3)	13.3 (4.8)	6.2 (3.9)	5.6 (2.5)	5.2 (3.0)	3.0 (1.8)
ECVI	1.5 (4.0)	9.3 (3.5)	0.1 (3.7)	12.7 (7.2)	0.0 (2.0)	0.0 (2.4)	0.0 (10.1)	24.2 (6.3)	11.9 (4.5)	2.3 (3.0)	2.8 (2.3)	11.1 (4.7)	2.3 (1.9)
NCVI	6.1 (4.3)	5.6 (2.8)	3.7 (4.4)	11.7 (7.9)	7.5 (4.5)	10.2 (9.2)	0.0 (4.1)	5.5 (4.1)	7.5 (3.9)	7.8 (3.6)	3.4 (2.6)	6.2 (3.2)	9.0 (2.3)
South Main	7.7 (4.1)	7.2 (3.0)	3.6 (4.6)	0.0 (5.5)	6.9 (4.4)	16.3 (9.2)	0.0 (6.3)	6.2 (3.7)	10.9 (3.5)	0.6 (1.1)	3.9 (2.0)	3.0 (2.5)	3.5 (2.3)
Lower Fraser	1.8 (3.2)	1.7 (2.2)	0.1 (2.8)	0.0 (3.4)	5.4 (4.1)	0.0 (1.3)	0.0 (0.0)	0.1 (2.9)	2.9 (2.7)	4.8 (2.8)	1.7 (1.4)	6.2 (3.3)	0.0 (0.9)
Thompson/UPFR	0.0 (0.1)		1.4 (1.3)										
Thompson		0.0 (0.1)		3.8 (4.3)	0.0 (0.0)								
UPFR		0.0 (0.0)	0.0 (2.2)	0.0 (0.0)	0.0 (0.2)	0.0 (0.0)	0.0 (0.0)	2.0 (1.6)	0.0 (0.4)	0.6 (0.7)	0.0 (0.2)	0.7 (0.6)	0.3 (0.4)
Puget Sound	7.7 (4.2)	0.0 (1.6)	0.0 (0.6)	3.4 (4.0)	0.0 (1.3)	0.0 (5.8)	10.3 (9.1)	3.0 (3.2)	2.2 (2.0)	0.1 (2.3)	1.5 (1.1)	3.7 (3.3)	1.8 (1.2)
Juan de Fuca	0.0 (1.4)	0.0 (0.7)	2.6 (2.6)	0.0 (1.5)	0.0 (2.6)	0.0 (2.5)	0.0 (3.5)	8.1 (4.0)	2.4 (2.8)	0.0 (0.3)	0.0 (0.1)	1.2 (1.7)	0.7 (0.9)
Coastal Wash	0.0 (0.5)	0.4 (0.9)	2.1 (2.3)	4.1 (3.6)	10.9 (4.6)	0.7 (4.1)	0.0 (2.0)	4.2 (3.0)	6.7 (2.7)	0.0 (0.2)	0.0 (0.5)	1.3 (1.6)	2.1 (1.0)
Columbia	0.0 (0.5)	0.0 (0.3)	0.0 (0.0)	0.6 (3.0)	0.0 (0.9)	0.0 (0.0)	0.0 (0.0)	0.0 (1.0)	0.0 (0.4)	0.0 (0.9)	0.0 (0.1)	0.0 (0.7)	0.2 (0.5)
{Canada	86.7 (5.6)	93.6 (3.9)	93.4 (5.0)	91.9 (6.4)	89.1 (5.3)	81.8 (11.4)	89.7 (10.1)	80.0 (5.3)	83.7 (4.0)	96.5 (3.3)	96.6 (1.9)	83.9 (5.1)	77.0 (3.3)
{U.S.	13.3 (5.6)	6.4 (3.9)	6.7 (5.0)	8.1 (6.4)	10.9 (5.3)	18.2 (11.4)	10.3 (10.1)	20.0 (5.3)	16.3 (4.0)	3.6 (3.3)	3.4 (1.9)	16.1 (5.1)	23.0 (3.3)

Appendix 1 – cont.

**Commercial Fisheries 1998**

N	Seine Area3		Gillnet Area3		Gillnet Area4		Seine Area6		Seine Area6		Seine Area6		Seine Area6		Gillnet Area6	
	Aug 15-31 90	Jul 11- Aug 22 25	Jul 11- Aug 22 25	Jul 18-25 8	July12-18 116	Jul19-25 232	Jul26-Aug1 111	Aug2-8 109	Aug16-22 36	Jul25-Aug29 76						
S.E. Alaska	6.8 (7.7)	21.8 (10.7)	8.4 (10.5)	11.0 (5.3)	3.9 (2.8)	0.9 (1.9)	5.9 (4.0)	3.4 (2.8)	2.1 (4.3)							
QCI	5.3 (3.4)	0.0 (2.2)	26.4 (17.0)	1.4 (3.3)	0.8 (1.6)	2.3 (2.5)	2.5 (2.1)	3.9 (3.4)	0.0 (0.9)							
Nass	0.0 (4.0)	0.0 (6.9)	0.0 (0.0)	0.0 (2.3)	0.0 (0.4)	0.0 (1.4)	4.6 (2.9)	0.0 (3.5)	5.4 (4.7)							
Upper Skeena	1.3 (2.7)	8.6 (5.9)	23.7 (14.6)	0.9 (2.6)	0.0 (0.7)	0.3 (1.0)	1.5 (1.5)	0.0 (0.5)	2.5 (1.5)							
Lower Skeena	3.2 (5.2)	22.7 (12.3)	0.0 (5.7)	19.7 (6.7)	9.5 (3.7)	1.4 (3.2)	4.7 (3.9)	17.3 (8.4)	0.0 (3.7)							
North/Central Coast	35.7 (9.7)	22.0 (10.4)	0.5 (11.2)	35.7 (8.7)	55.5 (6.0)	40.6 (8.8)	61.6 (6.4)	51.7 (12.5)	69.7 (10.4)							
WCVI	5.0 (4.2)	21.7 (8.9)	19.7 (16.8)	7.6 (5.2)	0.1 (1.5)	3.9 (4.8)	2.8 (3.2)	4.2 (5.2)	2.0 (2.4)							
ECVI	6.3 (4.6)	0.0 (2.1)	16.2 (17.0)	0.4 (4.2)	7.2 (3.4)	0.9 (4.7)	13.5 (4.5)	8.0 (6.8)	0.0 (2.6)							
NCVI	12.8 (7.7)	0.0 (0.7)	5.0 (10.1)	4.8 (3.7)	3.5 (2.6)	9.9 (5.3)	0.0 (1.4)	6.6 (7.5)	6.1 (4.0)							
South Main	5.4 (4.8)	0.0 (3.9)	0.0 (0.5)	11.5 (5.8)	9.1 (3.9)	19.1 (8.4)	0.1 (3.3)	0.0 (2.8)	7.1 (4.5)							
Lower Fraser	5.5 (4.5)	0.0 (3.8)	0.0 (3.5)	0.0 (2.7)	6.5 (3.1)	5.6 (4.4)	1.7 (2.6)	0.1 (3.5)	0.0 (0.8)							
Thompson/UPFR	0.0 (1.4)	3.3 (3.4)	0.0 (4.3)	0.0 (0.6)	0.4 (0.6)	0.9 (1.2)	0.0 (0.1)	2.6 (2.6)	0.0 (0.0)							
Puget Sound	1.2 (3.6)	0.0 (5.5)	0.0 (4.7)	3.6 (4.9)	2.5 (2.5)	4.7 (3.2)	0.0 (1.0)	0.0 (1.6)	1.5 (3.0)							
Juan de Fuca	0.0 (1.2)	0.0 (1.2)	0.0 (0.0)	2.1 (1.8)	0.0 (0.6)	1.1 (3.1)	1.2 (1.3)	2.3 (2.3)	2.7 (2.2)							
Coastal Wash	11.6 (6.0)	0.0 (3.8)	0.0 (9.0)	1.3 (2.8)	0.0 (1.5)	3.0 (4.1)	0.0 (1.5)	0.0 (2.1)	0.0 (3.4)							
Columbia	0.0 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.8)	1.1 (0.8)	5.4 (3.4)	0.0 (0.2)	0.0 (0.7)	1.0 (3.0)							
{Canada	80.5 (8.7)	78.2 (11.1)	91.6 (13.7)	82.0 (6.7)	92.5 (3.8)	84.9 (6.7)	93.0 (4.4)	94.4 (4.8)	92.7 (6.7)							
{U.S.	19.5 (8.7)	21.8 (11.1)	8.4 (13.7)	18.0 (6.7)	7.5 (3.8)	15.1 (6.7)	7.0 (4.4)	5.6 (4.8)	7.3 (6.7)							

**Fraser Baseline**

**LWFR River Fisheries (Area29)**

**Selective Fisheries**

N	1997		1998		1999		1998		1999		1999		1999	
	Seine	Gillnet	Gillnet	Gillnet	Gillnet	Gillnet	Sel#371	SelKadi	Sooktrap	DarcieHook				
	pink tag Aug29-Oct1	Oct15-Nov4	Aug 1-25	Oct10-Nov6	Cottonwood Aug26-Sept17	Whonnock Sept4-Sept21	Oct16-31	Oct16-30	Sep27-Oct22	Sep29-Oct24				
	209	18	22	82	49	22	34	23	28	160				
LWFR	33.9 (3.3)	93.6 (6.4)	85.6 (9.1)	94.7 (2.6)	25.5 (8.5)	19.0 (10.8)	97.0 (3.6)	95.8 (4.0)	95.0 (3.9)	97.2 (1.8)				
Thompson/UPFR	66.1 (3.3)	6.4 (6.4)	14.4 (9.1)		74.6 (8.5)	81.0 (10.8)								
Thompson				4.6 (2.4)			2.7 (2.8)	4.2 (3.7)	0.0 (2.3)	2.8 (1.6)				
UPFR				0.7 (1.5)			0.3 (2.8)	0.0 (2.5)	5.0 (3.7)	0.0 (0.9)				

Appendix 2. Coho DNA mixed stock estimates for year 2000 sampling, N = number of fish in sample. Standard deviations are in brackets.

Southern Baseline					PSC Gillnet Test		Seine Fisheries		Recreational Fisheries			U.S Net Fisheries					
PSC Seine Test					PSC Gillnet Test		Area20	Area123	Area 20-1	Area 23	Area 23	Area7a&7 (nontreat)	Area 7(reef)	Area 7(reef)	Area 7(reef)	Area 7a (Treaty)	
Jul19-22	Jul23-29	Jul30-Aug5	Aug6-12	Aug13-19	Jun20-Jul7	July13-Aug6	Aug20 (JOT)	Sep25-Oct5	Aug12-19	Aug1-5	Aug2-Sep3	Aug 15-16	Sep10-23	24-Sep	Oct 1-8	1-Sep	
199	176	190	190	199	164	105	66	194	4	156	57	123	154	130	83	11	
N	199	176	190	190	199	164	105	194	4	156	57	123	154	130	83	11	
WCVI	5.5 (2.6)	3.0 (2.2)	5.8 (2.5)	2.7 (2.0)	2.7 (2.1)	8.1 (3.3)	6.9 (4.0)	0.0 (2.5)	8.9 (3.1)	25.1 (22.7)	63.3 (4.6)	63.3 (7.2)	4.7 (3.1)	2.3 (2.2)	5.9 (3.2)	5.5 (3.2)	0.0 (4.6)
ECVI	8.7 (3.3)	20.8 (4.5)	18.2 (4.0)	16.4 (3.7)	26.8 (4.9)	14.2 (4.8)	20.9 (7.0)	23.1 (7.2)	15.6 (4.0)	27.1 (26.8)	6.7 (2.7)	9.4 (5.0)	7.4 (3.2)	14.4 (4.9)	33.8 (5.7)	18.1 (6.7)	15.8 (12.4)
NCVI	4.8 (2.5)	3.8 (2.5)	1.8 (1.8)	5.3 (2.4)	0.3 (2.0)	6.3 (3.5)	3.0 (2.4)	10.8 (5.8)	1.8 (1.7)	0.0 (0.0)	9.2 (3.7)	8.6 (5.5)	3.8 (2.7)	3.1 (2.3)	2.4 (1.9)	0.7 (2.1)	15.5 (11.8)
S. Main	10.5 (3.7)	5.5 (2.9)	9.6 (3.4)	10.6 (3.9)	14.8 (3.3)	26.4 (5.4)	35.2 (6.2)	6.8 (6.2)	12.9 (4.3)	23.5 (20.5)	6.6 (4.0)	7.4 (4.9)	69.9 (5.3)	8.9 (3.4)	6.6 (3.8)	14.5 (5.2)	0.4 (7.9)
L. Fraser	17.1 (4.0)	29.5 (4.4)	21.2 (4.1)	18.4 (4.4)	15.2 (3.3)	5.1 (3.6)	7.6 (4.4)	15.5 (6.3)	31.8 (4.9)	0.0 (10.0)	2.5 (1.7)	4.4 (3.4)	4.2 (2.4)	42.9 (5.4)	41.9 (5.7)	47.1 (6.6)	56.5 (18.9)
Thompson	1.1 (0.8)	1.1 (0.7)	0.9 (0.8)	0.8 (0.9)	0.1 (0.4)	0.0 (0.3)	1.3 (1.2)	1.5 (1.7)	0.0 (0.9)	0.0 (0.0)	0.0 (0.0)	1.0 (1.2)	10.5 (3.3)	2.2 (1.5)	0.0 (0.0)	0.0 (4.7)	
UPFR	0.0 (0.0)	0.0 (0.0)	0.0 (0.2)	0.0 (0.5)	0.4 (0.5)	0.0 (0.3)	0.0 (0.7)	0.0 (0.0)	1.5 (1.1)	0.0 (0.0)	1.0 (0.8)	0.0 (1.0)	2.0 (1.4)	7.9 (2.9)	0.0 (0.6)	0.0 (0.5)	
Puget S.	30.3 (4.7)	23.7 (4.8)	24.7 (4.5)	27.2 (4.6)	32.3 (4.6)	21.3 (4.6)	13.4 (5.0)	31.7 (8.8)	15.7 (4.1)	24.2 (22.6)	6.2 (2.2)	4.6 (3.6)	6.3 (2.8)	6.8 (3.2)	7.2 (3.5)	12.8 (4.7)	0.0 (9.9)
J. de Fuca	9.4 (3.1)	7.9 (2.9)	8.8 (3.0)	3.5 (1.8)	1.0 (1.4)	4.2 (2.4)	1.8 (2.0)	7.4 (4.0)	6.0 (2.1)	0.0 (0.0)	0.9 (1.3)	0.0 (1.4)	0.6 (1.1)	2.3 (2.6)	0.0 (0.8)	0.6 (2.3)	0.0 (0.5)
C. Wash	7.7 (3.0)	2.9 (2.0)	2.9 (2.2)	5.8 (2.6)	3.2 (1.7)	6.4 (2.6)	4.2 (3.4)	1.5 (4.5)	4.2 (2.9)	0.0 (3.9)	0.6 (1.0)	0.0 (1.2)	0.2 (0.8)	1.1 (1.4)	0.0 (1.5)	0.7 (2.2)	11.8 (10.1)
Columbia	4.9 (1.6)	1.9 (1.3)	6.1 (2.3)	9.2 (2.7)	3.2 (1.6)	8.1 (2.7)	5.7 (2.5)	1.8 (2.0)	1.7 (1.4)	0.0 (0.0)	3.1 (1.6)	2.4 (2.1)	0.0 (0.5)	0.0 (0.4)	0.0 (0.8)	0.0 (2.7)	
{Canada	47.7 (5.6)	63.5 (4.7)	57.4 (5.1)	54.3 (4.8)	60.3 (4.4)	60.1 (5.9)	74.9 (6.5)	57.7 (8.7)	72.5 (4.9)	75.8 (22.4)	89.3 (2.8)	93.0 (4.5)	92.9 (3.4)	89.8 (3.9)	92.8 (3.8)	85.9 (5.3)	88.2 (13.6)
{US	52.3 (5.6)	36.5 (4.7)	42.6 (5.1)	45.7 (4.8)	39.7 (4.4)	40.0 (5.9)	25.1 (6.5)	42.3 (8.7)	27.5 (4.9)	24.2 (22.4)	10.7 (2.8)	7.0 (4.5)	7.2 (3.4)	10.2 (3.9)	7.2 (3.8)	14.1 (5.3)	11.8 (13.6)

Central Baseline

	Troll Fisheries				Seine/Troll		FSC		Seine							
	Area 11 Aug2-3	Area12 Aug 2-5	Area12 Aug6-12	Area125 Jul29-Aug1	Area126 Jul30-Oct11	Area 13 Aug8-21	Area12 Aug 25	Area 12 Aug6-10	Area 12 Aug14-17	Area 12 Aug23-Oct4	Area 13 Aug9-23	Area 13 Oct2-8	Area 12/13 Oct4-5	Area 12/13 Oct12	Area 12/13 Oct19-Nov6	Area 25 Oct11-12
N	5	109	89	40	93	35	7	83	175	64	49	88	55	91	51	5
QCI	0.0 (1.8)	0.8 (1.3)	0.5 (1.8)	0.0 (0.3)	3.0 (2.2)	0.0 (0.0)	0.0 (0.0)	0.4 (1.1)	0.4 (1.1)	11.1 (4.7)	1.0 (2.0)	0.8 (1.9)	0.0 (1.0)	0.3 (2.4)	0.0 (2.0)	0.0 (0.1)
Nass	0.0 (0.0)	0.0 (0.8)	4.1 (2.6)	0.0 (1.3)	0.0 (1.2)	2.0 (3.1)	0.0 (0.0)	1.7 (3.1)	0.5 (1.3)	5.3 (4.3)	0.0 (0.6)	0.0 (1.5)	1.3 (2.1)	2.6 (3.5)	0.0 (1.3)	20.2 (18.7)
Upper Skeena	0.0 (0.0)	0.8 (1.0)	0.0 (0.4)	0.0 (1.5)	1.0 (1.0)	5.3 (3.4)	0.0 (0.0)	0.0 (1.6)	0.0 (0.6)	1.4 (2.6)	2.2 (1.9)	2.6 (2.2)	1.7 (2.2)	0.4 (1.8)	2.9 (2.6)	0.0 (0.0)
Lower Skeena	0.0 (6.0)	0.7 (2.5)	1.5 (3.1)	0.5 (4.7)	0.0 (2.6)	0.0 (4.8)	0.0 (0.0)	7.0 (4.5)	2.1 (2.3)	0.0 (1.8)	8.1 (4.7)	0.0 (1.8)	1.4 (4.2)	2.9 (3.5)	2.4 (2.9)	0.0 (9.0)
North/Central Coast	60.6 (27.3)	26.0 (5.7)	20.5 (6.9)	7.8 (6.0)	8.9 (3.3)	10.8 (9.8)	36.2 (20.7)	14.5 (8.3)	40.2 (5.6)	11.6 (6.3)	8.9 (6.7)	2.6 (5.5)	9.6 (7.1)	14.7 (5.6)	2.7 (5.0)	16.7 (22.2)
WCVI	0.0 (16.2)	3.2 (3.2)	16.8 (5.5)	14.0 (6.9)	6.9 (3.8)	2.5 (4.0)	0.0 (5.9)	8.5 (3.9)	9.8 (4.2)	2.1 (4.0)	1.1 (4.0)	7.7 (3.3)	7.1 (4.3)	0.0 (2.1)	3.1 (4.1)	24.8 (16.3)
ECVI	1.3 (14.1)	27.7 (5.4)	20.5 (6.7)	1.8 (5.9)	16.2 (5.3)	24.6 (8.4)	17.1 (15.5)	24.3 (6.4)	1.3 (2.5)	45.7 (8.3)	15.2 (6.6)	29.8 (6.0)	29.2 (9.0)	21.4 (7.7)	21.8 (9.4)	0.1 (11.8)
NCVI	18.6 (15.6)	18.0 (5.8)	13.7 (4.9)	10.4 (6.4)	12.0 (5.1)	1.5 (2.8)	0.0 (3.0)	1.5 (2.9)	7.3 (3.4)	3.3 (3.5)	4.2 (3.5)	0.3 (3.6)	2.8 (3.5)	6.3 (3.9)	8.8 (6.3)	38.1 (25.4)
South Main	0.0 (2.1)	10.3 (4.5)	13.7 (5.5)	12.7 (6.1)	4.9 (2.8)	43.1 (12.0)	31.7 (21.4)	28.3 (6.9)	20.9 (4.9)	3.0 (3.8)	25.5 (9.5)	16.8 (5.7)	15.5 (7.9)	8.2 (5.7)	10.4 (6.7)	0.0 (8.3)
Lower Fraser	0.0 (0.0)	4.0 (3.5)	6.1 (3.8)	1.4 (3.5)	19.1 (5.5)	4.1 (7.5)	0.0 (12.7)	5.4 (3.2)	12.1 (3.8)	9.1 (4.3)	30.1 (9.7)	21.1 (5.5)	14.1 (5.9)	27.5 (6.8)	23.1 (8.0)	0.0 (0.0)
Thompson	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.9 (3.2)	1.8 (1.5)	0.0 (1.1)	0.0 (0.0)	0.5 (2.0)	0.6 (0.6)	0.0 (0.5)	0.0 (0.4)	0.4 (1.3)	2.3 (2.2)	0.0 (1.7)	0.0 (2.2)	0.0 (7.3)
UPFR	0.0 (0.1)	1.6 (1.6)	0.0 (0.0)	3.1 (3.2)	1.3 (1.3)	0.0 (0.0)	0.0 (0.0)	0.7 (1.8)	0.3 (0.8)	1.5 (2.1)	0.0 (0.0)	0.0 (0.5)	0.0 (0.6)	0.0 (0.0)	1.2 (1.9)	0.0 (0.0)
Puget Sound	0.0 (0.0)	1.8 (1.6)	0.0 (2.0)	35.0 (8.2)	10.9 (5.1)	6.1 (5.9)	2.0 (13.0)	0.6 (2.2)	2.9 (2.1)	5.9 (4.3)	0.0 (1.1)	10.5 (4.3)	7.6 (4.3)	5.4 (4.5)	9.4 (5.5)	0.0 (2.9)
Juan de Fuca	0.0 (0.0)	1.8 (1.7)	0.0 (1.2)	6.9 (5.3)	3.2 (2.6)	0.0 (0.0)	13.0 (10.8)	0.0 (0.6)	1.2 (1.5)	0.0 (0.4)	3.0 (2.6)	0.0 (2.0)	5.6 (3.4)	7.9 (5.0)	5.5 (6.7)	0.0 (7.5)
Coastal Wash	19.4 (20.4)	3.2 (1.8)	2.7 (1.9)	4.6 (4.5)	10.7 (4.3)	0.0 (1.0)	0.0 (7.3)	1.4 (1.9)	0.0 (1.1)	0.0 (0.4)	0.74 (1.7)	6.4 (3.7)	1.9 (3.1)	0.7 (1.8)	2.1 (4.1)	0.0 (0.0)
Columbia	0.0 (0.0)	0.0 (1.2)	0.0 (0.0)	0.0 (0.2)	0.0 (1.5)	0.0 (0.0)	0.0 (0.0)	5.4 (2.7)	0.5 (0.8)	0.0 (0.0)	0 (1.0)	1.0 (1.4)	0.0 (1.0)	1.7 (2.2)	6.5 (5.0)	0.0 (0.0)
{Canada	80.6 (20.5)	93.2 (3.0)	97.3 (2.8)	53.6 (9.4)	75.2 (6.0)	94.0 (6.0)	85.0 (15.1)	92.7 (4.4)	95.4 (2.8)	94.1 (4.3)	96.29 (3.4)	82.1 (5.9)	84.8 (6.3)	84.3 (7.2)	76.4 (9.1)	100.0 (7.9)
{U.S.	19.4 (20.5)	6.8 (3.0)	2.7 (2.8)	46.5 (9.4)	24.8 (6.0)	6.1 (6.0)	15.0 (15.1)	7.3 (4.4)	4.6 (2.8)	5.9 (4.3)	3.71 (3.4)	17.9 (5.9)	15.2 (6.3)	15.7 (7.2)	23.6 (9.1)	0.0 (7.9)

Appendix 2 –cont.

	<b>Gillnet Fishery</b>			<b>Recreational Fisheries</b>	
	<b>Area12 Aug2-27</b>	<b>Area13 Aug2-Oct9</b>	<b>Area12,13 Aug11</b>	<b>Area 24 Aug13-26</b>	
	30	9	3	14	
N					
QCI	1.9 (3.1)	11.8 (11.7)	16.8 (26.4)	0.0 (2.1)	
Nass	0.0 (3.6)	0.0 (7.6)	0.0 (0.0)	0.0 (0.0)	
Upper Skeena	0.0 (2.8)	0.0 (3.5)	0.0 (0.0)	0.0 (0.7)	
Lower Skeena	7.6 (6.4)	0.0 (4.6)	0.0 (0.0)	3.9 (7.0)	
North/Central Coast	28.2 (10.7)	11.6 (14.0)	0.0 (6.5)	18.7 (12.5)	
WCVI	14.2 (6.6)	0.0 (9.3)	80.9 (33.9)	36.3 (16.6)	
ECVI	12.3 (7.7)	33.3 (20.2)	0.0 (0.0)	7.5 (9.9)	
NCVI	3.7 (4.5)	0.0 (3.6)	0.0 (1.0)	22.0 (15.9)	
South Main	29.4 (9.9)	20.3 (12.1)	0.1 (6.6)	11.6 (10.9)	
Lower Fraser	0.0 (3.4)	11.6 (14.4)	0.0 (1.4)	0.0 (2.0)	
Thompson	0.0 (0.0)	0.0 (0.0)	2.1 (16.2)	0.0 (0.0)	
UPFR	0.0 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	
Puget Sound	2.7 (4.6)	0.0 (2.7)	0.0 (0.0)	0.0 (0.0)	
Juan de Fuca	0.0 (1.0)	0.0 (5.9)	0.0 (0.0)	0.0 (1.4)	
Coastal Wash	0.0 (1.9)	11.4 (13.7)	0.0 (0.0)	0.0 (0.0)	
Columbia	0.0 (2.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	
{Canada	97.4 (5.2)	88.6 (15.0)	99.98	0.02	100.0 (1.4)
{U.S.	2.7 (5.2)	11.4 (15.0)	0.02	0.02	0.0 (1.4)

Appendix 3. Estimated fishery exploitation rates (expl), adjusted historical escapements (esc), marine fishery catches and total abundances (abund) for interior Fraser River watershed coho salmon.

Return		South Thompson			North Thompson			Lower Thompson			Non-Thompson Fraser		
Year	expl	esc	catch	abund	esc	catch	abund	esc	catch	abund	esc	catch	abund
1975	0.68	5864	12490	18354	22286	47468	69754						
1976	0.68	3920	8349	12268	20675	44037	64713						
1977	0.68	8490	18082	26572	42804	91171	133975						
1978	0.68	7996	17032	25028	39095	83269	122364						
1979	0.68	10198	21720	31918	47819	101851	149670						
1980	0.68	7025	14964	21989	10542	22454	32996						
1981	0.68	4120	8775	12895	20615	43909	64524						
1982	0.68	5849	12459	18308	42295	90087	132382						
1983	0.68	6196	13196	19392	35086	74731	109816						
1984	0.68	15394	32789	48183	69552	148141	217692	5155	12050	17205			
1985	0.68	16998	36205	53204	45160	96188	141349	1913	4060	5973			
1986	0.66	16521	31665	48186	104267	199846	304113	2211	4300	6511			
1987	0.54	21087	24478	45564	54884	63710	118594	4208	4945	9153			
1988	0.71	24426	60376	84802	70612	174539	245150	4013	9830	13843			
1989	0.65	17208	31288	48496	30677	55779	86455	3423	6340	9763			
1990	0.74	8609	24069	32677	25697	71844	97542	4421	12600	17021			
1991	0.68	4160	8737	12896	14585	30633	45217	3794	8825	12619			
1992	0.81	11886	52239	64125	22042	96875	118917	4905	21000	25905			
1993	0.88	1873	13172	15045	9669	67999	77667	8416	61500	69916			
1994	0.43	4485	3430	7915	10031	7671	17702	5252	3965	9217			
1995	0.56	3622	4639	8261	22477	28794	51272	1984	2525	4509			
1996	0.83	1760	8906	10667	12319	62325	74645	1209	5900	7109			
1997	0.40	2034	1384	3418	6722	4573	11295	4217	2820	7037			
1998	0.07	4946	375	5321	9125	685	9810	2628	200	2828	8147	610	8757
1999	0.09	3074	305	3379	8916	885	9801	5007	495	5502	5389	535	5924
2000	0.034	3785	134	3919	7032	250	7282	4459	157	4616	4723	144	4867

### Abstract

A new type of stock-recruitment model is examined that incorporates Allee effects that may occur when fish populations are small. The model is a natural extension of traditional stock-recruitment models, which only consider density dependent effects when population densities are high. Since the new model is intrinsically nonlinear to the parameters, the theory of maximum likelihood estimation is used to estimate model parameters and the associated statistical inferences. Having found the local optima for the likelihood function, a global genetic search algorithm is entertained to obtain the parameter estimates. Based on this extended model, an extinction probability curve is developed based on the parameter defining the Allee effects in the new model. This curve can readily be used to calculate the theoretical probability of extinction for any particular spawner number or biomass. Alternatively, since managers may wish to assign reference points corresponding to particular extinction probabilities, corresponding spawner numbers can be determined for these reference points. Data from North Thompson coho and Chilko sockeye salmon are used to demonstrate the approach.

### Introduction

The analysis of fish stock-recruitment (S-R) is often the first step to evaluate and implement fishery policies designed to optimize spawner numbers and exploitation rates. The analysis typically begins with the assumption of a functional relationship, denoted by  $F(\bullet)$ , between spawners and recruits:

$$(1) \quad R_t = S_t F(S_t, \theta)$$

where  $S_t$  is the spawners at year  $t$ ,  $t = 1$  to  $n$  and  $R_t$  is the corresponding recruits for the spawners at that brood year  $t$  calculated as total escapements and catches.  $\theta$  is a vector of parameters associated with this relationship and may be associated with a fishery management policy.

The two most commonly used functional forms based on biologically sound grounds are the Beverton-Holt model (Beverton-Holt 1957) and the Ricker model (Ricker 1975):

$$(2) \quad R_t = \frac{\alpha S_t}{1 + \beta S_t} \quad \text{Beverton-Holt Model}$$

$$(3) \quad R_t = S_t e^{\alpha - \beta S_t} \quad \text{Ricker Model}$$

where  $\alpha$  and  $\beta$  are the parameters to describe productivity of the population at low density, and capacity limited by density dependence, respectively. As a unified S-R model, Deriso (1980) introduced an additional shape parameter  $\gamma$  and proposed the following model:

$$(4) \quad R_t = \alpha S_t (1 - \gamma \beta S_t)^{1/\gamma} \quad \text{Deriso Model}$$

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<sup>5</sup> Manuscript submitted to Can. J. Fish. Aquat. Sci.

where  $\gamma$  is a shape parameter to modify the S-R relationship. It can be seen that the Beverton-Holt model (2) and Ricker model (3) are in fact special cases of the Deriso Model (4) when  $\gamma = -1$  and  $\gamma \rightarrow 0$ , respectively.

These models allow for compensatory mortality. At high population densities, resources will become limiting and recruits per spawner will decrease. However, the models ignore depensatory mortality, which may occur when the population is below some critical level. This is known as the Allee effect (Allee et al. 1949) when population growth declines as population density declines. A variety of processes can result in depensation occurring at low population sizes. For example, inbreeding may occur and result in reduced survivals, spawning fish may not easily find mates, depensatory predation may result in higher proportions of fish being killed, poor conditioning of the spawning environment and low efficiency of food location may all contribute to depensatory mortality at low spawner densities (Hilborn and Walters 1992; Emlen 1984; Asmussen 1979). When abundances are low, depensation (if it exists) will accelerate population declines and increase their probability of extinction (McElhany et al 2000).

Whether depensation is a significant factor for fish populations is not clear. Myers et al. (1995) found that 3 of 26 fish stocks had lower than expected recruits per spawner at low densities than would be expected using a Beverton-Holt model. Liermann and Hilborn (1997) examined the same data and found that the most likely values for the stock recruit relationship were usually close to or within the range of no depensation. However, since there was a significant amount of uncertainty about whether depensation existed, Liermann and Hilborn concluded that analyses of stock recruitment data should incorporate spawner recruit curves that allow for the possibility of depensation.

Several approaches have been used to incorporate possible depensatory effects in the analysis of stock recruit data. Hilborn and Walters (1992) recommended replacing  $\alpha S$  with  $\alpha S^m$  where the power parameter  $m$  is greater than 1.0. Liermann and Hilborn (1997) used a Bayesian hierarchical model to estimate the distribution describing the variability of depensation within various taxa. Routledge and Irvine (1999) introduced a cutoff value  $c$  to allow for the effects of possible depensation at low abundance and modified their formulas when  $S \leq c$ . In the discussion of compensatory population dynamics within a stock complex, Frank and Brickman (2000) were the first to introduce a S-R model that incorporated Allee effects by permitting a non-zero intercept representing recruitment failure. Incorporating depensation, the S-R model in equation (1) becomes:

$$(5) \quad R_t = (S_t - S_{offset}) F(S_t - S_{offset}, \theta)$$

where  $S_{offset}$  is the parameter associated with the Allee effects and is the offset from the origin representing zero recruitment (Frank and Brickman 2000). Hereafter model (5) will be called Allee S-R model. For the S-R models (2)–(4), the corresponding Allee S-R models would be:

$$(6) \quad R_t = \frac{\alpha (S_t - S_{offset})}{1 + \beta (S_t - S_{offset})}$$

$$(7) \quad R_t = (S_t - S_{offset}) e^{\alpha - \beta (S_t - S_{offset})}$$

$$(8) \quad R_t = \alpha (S_t - S_{offset}) [1 - \gamma \beta (S_t - S_{offset})]^{1/\gamma}$$

In this paper, we apply the maximum likelihood estimation (MLE) approach combined with a global search algorithm to estimate S-R parameters. We discuss the properties of the parameter  $S_{offset}$

associated with Allee effects in the new model, apply it and develop an operational extinction probability curve, and use this approach to quantify reference points in the domain of risk analysis. The methodology is applied using S-R data from North Thompson coho salmon and Chilko River sockeye salmon.

### Parameter estimation and global genetic search algorithm

For the purpose of illustration, we shall use model (7), hereafter referred to as the Allee-Ricker model, to illustrate the development of the new model, the estimation of parameters, and also the evolution of an extinction probability curve and reference points. The same procedures can be readily applied for models (6) and (8) or any extensions.

### Parameter estimation

To be compatible with the traditional assumptions for the S-R analyses, we assume that recruitment is log-normally distributed. Therefore, model (7) is:

$$(9) \quad \ln(R_t) = \ln(S_t - S_{\text{offset}}) + \alpha - \beta(S_t - S_{\text{offset}}) + \varepsilon_t$$

where  $\varepsilon_t \sim N(0, \sigma^2)$ . The commonly used linear regression estimation approach cannot be used since the new model (9) is nonlinear for the parameters  $(S_{\text{offset}}, \alpha, \beta)$ . We therefore utilize theories of nonlinear regression (e.g. Draper and Smith 1981) and MLE (e.g. Kalbfleisch 1985) to estimate model parameters and associated statistical inferences for the parameters and model.

The log-likelihood function for model (9) is defined as:

$$(10) \quad \ln L(S_{\text{offset}}, \alpha, \beta | \text{data}) \propto -\frac{n}{2} \ln(\sigma^2) - \frac{\sum_{i=1}^n [\ln(R_i) - \ln(S_i - S_{\text{offset}}) - \alpha + \beta(S_i - S_{\text{offset}})]^2}{2\sigma^2}.$$

Conventionally, twice the negative log likelihood is used as the ‘‘inference function’’ in the MLE, which is  $l(S_{\text{offset}}, \alpha, \beta) = -2 \times \ln[L(S_{\text{offset}}, \alpha, \beta | \text{data})]$ . According to the theory of MLE,  $l(S_{\text{offset}}, \alpha, \beta)$  is chi-square distributed by the degrees of freedom  $n-3$ , i.e.  $l(S_{\text{offset}}, \alpha, \beta) \sim \chi_{n-3}^2$ . Estimates of the parameters  $\hat{\Theta} = (\hat{S}_{\text{offset}}, \hat{\alpha}, \hat{\beta})$  are obtained by minimizing  $l(S_{\text{offset}}, \alpha, \beta)$ . The uncertainty in  $\hat{\Theta} = (\hat{S}_{\text{offset}}, \hat{\alpha}, \hat{\beta})$  is assessed from the estimated covariance matrix, which is obtained from the inverse of the Fisher information matrix defined as:

$$(11) \quad \text{Cov}(\hat{S}_{\text{offset}}, \hat{\alpha}, \hat{\beta}) \cong -\frac{1}{2} E \begin{pmatrix} \frac{\partial^2 l}{\partial S_{\text{offset}}^2}, & \frac{\partial^2 l}{\partial S_{\text{offset}} \partial \alpha}, & \frac{\partial^2 l}{\partial S_{\text{offset}} \partial \beta} \\ \frac{\partial^2 l}{\partial \alpha \partial S_{\text{offset}}}, & \frac{\partial^2 l}{\partial \alpha^2}, & \frac{\partial^2 l}{\partial \alpha \partial \beta} \\ \frac{\partial^2 l}{\partial \beta \partial S_{\text{offset}}}, & \frac{\partial^2 l}{\partial \beta \partial \alpha}, & \frac{\partial^2 l}{\partial \beta^2} \end{pmatrix}_{(\hat{S}_{\text{offset}}, \hat{\alpha}, \hat{\beta})}$$

The estimated standard error for each parameter can be obtained from the corresponding elements from (11). According to theory of MLE, the parameter estimates  $\hat{a}$ ,  $\hat{b}$  and  $\hat{S}_{offset}$  in (9) and (10) are normally distributed as:

$$(12) \quad \hat{a} \sim N(a, \sigma_a^2); \quad \hat{b} \sim N(b, \sigma_b^2) \quad \text{and} \quad \hat{S}_{offset} \sim N(S_{offset}, \sigma_{S_{offset}}^2).$$

Special attention is paid to the parameter  $\hat{S}_{offset}$  since this parameter represents the number of spawners that will theoretically produce zero recruitment (i.e. a high probability that this year class would go extinct). We wish to evaluate whether including the Allee parameter  $\hat{S}_{offset}$  improves the model fit from model (7) relative to the traditional Ricker model (3). Since models (3) and (7) are nested, the likelihood ratio test can be used to test whether the inclusion of  $\hat{S}_{offset}$  significantly improves the model fit:

$$(13) \quad l(\alpha, \beta) - l(S_{offset}, \alpha, \beta) \sim \chi_1^2$$

where  $l(\alpha, \beta)$  and  $l(S_{offset}, \alpha, \beta)$  are twice the negative log likelihood function from models (3) and (7), respectively.

### Global genetic search algorithm

The parameter estimates can be obtained from equation (10) by any search algorithms, including gradient and hill-climbing search methods. These algorithms are known as local search algorithms where the initial starting points are essential. We found that there are local optima for the minimization of equation (10) with only three parameters which led us to employ the global genetic search algorithm (GA). GA is a search algorithm from the mechanics of natural selection and genetics with natural populations evolve according to the principles of “survival of the fittest”. (Holland 1975). The highly fit individuals are given high opportunities to “reproduce”, by “cross breeding” with others in the population. GA differs from conventional search techniques, because it considers many points in the search space simultaneously, and therefore has a reduced chance of converging to some local optima. Since Holland (1975) introduced and investigated this algorithm, the approach has been used in many areas, such as in curve fitting, mathematical optimization, and training neural network models. Recent descriptions of the approach with applications to fisheries are found in Saila (1996) and Chen et al. (2000).

To use the GA in this paper, we specify a large but reasonable range for each parameter in  $\Theta = (S_{offset}, \alpha, \beta)$  and randomly generate an initial population with 100 starting points. Based on the fundamental “genetic” operators as reproduction, crossover and mutation, 10% of the best solutions among the 100 are reproduced. By analogy with a biological genetic system where mutations are rare, a higher probability (80%) is given to the crossover process than to the mutation process (5%). This provides a “crossover” mechanism for the search to mix and match desirable qualities through a random process with the occasional “mutation” of a value at a particular search position.

### Definition of an extinction probability curve

Spawner numbers or biomass is the most readily available and also the most commonly used quantity in fisheries research and management. Clearly we would like to manage fisheries above the parameter,  $S_{offset}$ , with known probability. Then the stock extinction probability function of the stock is defined as  $\Pr(\text{Stock Extinction}) = \Pr(S \leq S_{offset})$ . Since  $S_{offset}$  can be estimated from the MLE (10) with the distribution in (11), the operational definition of the extinction probability (denoted by  $OPr(EP)$ ) is:

$$(14) \quad OPr(EP) = \Pr(S \leq \hat{S}_{offset}) = \Pr(\hat{S}_{offset} > S) = 1 - \Phi\left(\frac{\hat{S}_{offset} - S}{\sigma_{S_{offset}}}\right)$$

for any level of spawning biomass,  $S$ . In equation (14),  $\Phi(\bullet)$  is the cumulative density function for the normal distribution. Since  $\sigma_{S_{offset}}$  in equation (14) is generally unknown, then the MLE estimate from equation (11) can be used to give an estimate of  $OPr(EP)$ :

$$(15) \quad \widehat{OPr(EP)} = \Pr(\hat{S}_{offset} > S) = 1 - T\left(\frac{\hat{S}_{offset} - S}{\hat{\sigma}_{S_{offset}}}\right)$$

where  $T(\bullet)$  is the cumulative density function for the t-distribution with degrees of freedom  $n-3$ .

Equation (15) can be used for two purposes. One is to calculate the probability of extinction for any given spawner number or biomass  $S$ . Another is to obtain reference points for a given extinction probability that is based on an acceptable level of extinction risk.

### Data Applications

#### North Thompson Coho

Identification of reference points and extinction probabilities at low spawner numbers are needed for coho salmon from the Thompson River watershed in central British Columbia. Numbers of coho salmon returning to the Thompson River have declined significantly in recent years and these fish have been the focus of much attention (Bradford and Irvine 2000). Precise estimates of spawner numbers are available for North Thompson coho commencing in 1975, and annual recruitment (catch plus spawning escapement) was estimated using a time series of fishery exploitation rates (Irvine et al. 2000):

$$(16) \quad R_t = S_t / (1 - expl_t)$$

where spawners were assumed to be all three years old and  $expl_t$  are the fishery exploitations at year  $t$ . We first fit the Ricker model (3) to S-R data for North Thompson coho by a simple regression approach, and then fit the same S-R data with the Allee Ricker S-R model (9) by the MLE with the GA approach (Fig. 1). Figure 2 illustrates the GA search algorithm with 100 points in the search space. It can be seen from Figure 2 that convergence is achieved after ~60 generations (a term used in GA, which is equivalent to “iterations” in any other search algorithms). Parameter estimates and the resulting value for the twice-negative likelihood function are summarized in Table 1. The Allee-Ricker model (9) gave the lowest value for the negative log-likelihood function indicating that the Allee-Ricker model fit the data best. This

conclusion can also be found from the likelihood ratio test in (13) since  $l(\alpha, \beta) - l(S_{offset}, \alpha, \beta) = 1.7$ . Although not significant at the 95% level, this is significant at the 80% confidence level ( $\chi^2_{0.80,1} = 1.642$ ), which indicates that the inclusion of the parameter  $S_{offset}$  significantly improved the model fit. We conclude that the Allee-Ricker model (9) should be used to analyze the S-R relationship. For the new model, the estimate of  $S_{offset}$  is 5,211 (Fig. 1) with a standard error of 1,680. Following the distribution in (12) for  $\hat{S}_{offset}$ , a distribution plot is given in Figure 3 with the 80% confidence interval. The 80% confidence interval is (2994, 7428);  $S_{offset}$  is statistically different from zero. Therefore the inclusion of  $S_{offset}$  significantly improves the model fit, which is consistent with the result from the likelihood ratio test.

With the new Allee-Ricker model (9), the operational extinction probability function from (15) can be constructed. Figure 4 illustrates the extinction probability as the function of spawner numbers. With this function, the extinction probability can be readily calculated for any given spawner number (Figure 4 and Table 2). Also, with any extinction probability suggested by managers, the corresponding spawner numbers can be calculated from this function as a management reference point (Figure 4). Table 2 lists several reference points for particular probabilities.

Patterns in the residuals were examined after the Ricker model (3) was fit to the data. No apparent relationship was seen between the size of the population and the residuals but there was evidence of non-stationarity. A sequence of strong positive residuals in the early 1980's preceded a declining trend with negative residuals occurring in most recent years. In this instance, trends in the residuals do not negate the value of calculating  $S_{offset}$  since recent low productivities ( $\alpha$ ) result in a positive bias in estimates of  $S_{offset}$ . We consider that a small positive bias when computing a reference point is acceptable since it is risk averse. The patterns in the residuals may provide an explanation why the Allee-Ricker model fit the data better than the traditional Ricker S-R model (Table 1). The first-order autocorrelation was significant when the Ricker S-R model was applied (Lag 1, autocorrelation coefficient  $\rho = 0.42$ ), but was not when the Allee-Ricker model was fit to the data (Fig. 5).

### Chilko Sockeye

Spawner and recruit data for Chilko Lake sockeye are available for brood years 1948 to 1995 (Fig. 6). Chilko Lake is one of the largest producers of sockeye within the Fraser River watershed with an average of 340,000 spawners and 1.4 million recruits per year. This stock has rebuilt since the 1980s and the numbers of spawners increased to nearly 700,000 per year since 1989. The S-R relationship suggests the stock is now near the maximum capacity of Chilko Lake. Chilko Lake was fertilized intermittently in four years beginning in 1987 and ending in 1992. Bradford et al. (2000) present evidence for increased sockeye freshwater productivity as a result of fertilization. The S-R data used in our analysis excludes the four years of fertilization to avoid potential problems of parameter bias.

We first fit the Ricker model (3) by a simple regression approach and then fit the Allee Ricker S-R model (9) by the MLE with the GA for the same data. The parameter estimates and the resulted value for the twice-negative likelihood function are summarized in Table 1. It can be seen that all the estimates for  $\alpha$  and  $\beta$  are statistically significant along with the significant model fit. The estimate of  $S_{offset}$  is 1,585 with standard error of 11,065. Figure 6 gives the S-R data series and the model fits. Because of the data range and the small value of the estimated  $S_{offset}$  (=1,585), it is not obvious from Figure 6 to see the behavior of  $S_{offset}$ . In order to see the end behavior of  $S_{offset}$ , a small range of data is plotted in Figure 7.

Following the distribution in (12) for  $\hat{S}_{offset}$ , a distribution plot is given in Figure 8. It can be seen from this plot that 95% confidence interval covers 0, which means that  $S_{offset}$  is not statistically significantly different from zero. Therefore the inclusion of  $S_{offset}$  does not significantly improve the

model fit. This conclusion can also be found from the likelihood ratio test in (13) since  $l(\alpha, \beta) - l(S_{offset}, \alpha, \beta) = 0.025 < 3.84 = \chi_{0.95,1}^2$ .

Following the distribution in (12) for  $\hat{S}_{offset}$ , a distribution plot is given in Figure 9 with the 95% confidence interval. The 95% confidence interval covers zero, which means that  $S_{offset}$  is not statistically significantly different from zero. Therefore the inclusion of  $S_{offset}$  is not significantly improve the model fit, which is consistent with the result from the likelihood ratio test.

In Figure 9 we illustrate the extinction probability for Chilko sockeye as the function of spawner numbers. The extinction probability can be calculated for a given spawner abundance (Figure 9) and depending on the level of risk tolerance, a management reference in terms of spawner abundance can be calculated from this function. Table 2 lists several reference points for the given probabilities.

## Discussion

In this paper we make several contributions to the field of conservation biology and in particular the evaluation of extinction risk. Firstly, we demonstrate how traditional S-R models can be extended by incorporating potential Allee effects that may occur at low spawner densities. Methods to estimate parameters and associated statistical inferences are developed including the use of GA. Secondly, with the extended Allee-SR model, we develop an operational formula for the extinction probability function. This formula can be used to calculate the extinction probability for any given spawner abundance, and also allows managers the opportunity to define reference points according to particular extinction probabilities.

The precautionary approach is increasingly being applied in fisheries management to comply with international agreements for sustainable resource use (e.g. Richards and Maguire 1999). This approach is intended to ensure that conservation takes precedence over other objectives (NMFS 1999). Reference points provide the primary mechanism by which the precautionary approach can be applied (Richards and Maguire 1999). In our paper we define the probability distribution associated with  $S_{offset}$  and propose this as a suitable reference point that can be used by managers to minimize the possibility of population extinction.

Managers applying the precautionary approach would like a low probability of populations going extinct. One way to do this is to “buffer” reference points by incorporating uncertainty. Sources of uncertainty and statistical pitfalls that can bias stock-recruitment model parameters are discussed in Hilborn and Walters (1992). These include lack of contrast in the spawning escapement variable, measurement errors in escapement and recruitment, temporal auto-correlation in the S-R series and non-stationarity of S-R relationships. Apart from the lack of contrast in the escapement time series, various statistical remedies can deal with S-R biases. To minimize the likelihood of a population falling below the  $S_{offset}$ , the limit should be set higher than the point estimate. For instance, one might wish to select a reference point corresponding to the 10% extinction probability rather than the 50% value. Uncertainty in  $S_{offset}$  as a result of S-R bias should be carefully examined on a case specific basis as with any of the classical S-R models. If there is a temporal pattern in productivity, one could model productivity as a function of time. Reference points may need to be raised during periods of low productivity.  $S_{offset}$  could be used in a Bayesian decision analysis to evaluate the consequence of alternative management objectives on extinction risk.

The two salmonid examples considered here demonstrate the potential effect of data variability uncertainty at low spawner densities on estimates of  $S_{offset}$ . For North Thompson coho,  $S_{offset}$  is statistically significant from zero despite the variability in the data at low spawner densities. Because  $S_{offset}$  for Chilko sockeye is not significant, it is unclear if compensatory mortality at low spawner density is negligible or if compensatory mortality is masked by high survival variability and/or data measurement error. Liermann and Hilborn (1997) similarly concluded from their analysis of Chilko sockeye data that compensatory mortality at low spawner density is insignificant.

The extended model (5) can also be used to incorporate environmental information and fishery interventions, such as,  $R_t = (S_t - S_{offset})F(S_t - S_{offset}, X_t, \theta)$ , where  $X_t$  is a vector of environmental and fishery intervention variables. This model can be combined with the semiparametric approach discussed in Chen and Irvine (2001) to analyse the compensatory and depensatory effects embedded in the S-R relationship with environmental and fishery interventions.

We feel that the new Allee S-R model is a useful extension for the traditional S-R model to be used for fishery S-R analysis, and we believe that the operational definition of the extinction probability function developed in this paper is a useful tool for fishery management.

### Acknowledgements

We thank Bill Clark, Steven Hare, Gayle Brown and Alan Sinclair for helpful comments on the manuscript and approach.

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**Appendix 4; Table 1:** Summary of parameter estimates for North Thompson coho (“N. Thompson Coho”) and Chilko sockeye (“Chilko Sockeye”) salmon and under Ricker S-R models (“Ricker”) and the new Allee S-R models (“Allee-Ricker”). The column “ $l$ ” is the value for the twice the negative log-likelihood function. Values in parentheses represent one standard error.

Stock	Model	$\alpha$	$\beta$	$S_{offset}$	$l$
<b>N. Thompson Coho</b>	Ricker	1.281(0.346)	1.22E-5(8.39E-6)	NA	-4.818
	Allee-Ricker	1.808(0.458)	2.13E-5(9.75E-6)	5,211(1,680)	-6.518
<b>Chilko Sockeye</b>	Ricker	2.155(0.253)	1.61E-6(4.95E-7)	NA	-36.715
	Allee-Ricker	2.179(0.232)	1.65E-6(5.03E-7)	1,585(11,065)	-36.740

**Appendix 4; Table 2:** Relationship between calculated extinction probabilities for given spawners (the middle column) and the calculated spawner biomass for given extinction probability (the last column) based on equation (15).  $S_{offset}$  is the estimated values from the new Allee-Ricker model and the “Hist. Min” the historical minimum of the observed spawner numbers.

	Spawner Biomass	Extinction Probability	Extinction Probability	Spawner Biomass
<b>Chilko Sockeye</b>	$S_{offset}$	0.898	0.1	19,200
	Hist. Min.	0.139	0.3	12,270
	10,000	0.401	0.5	8,084
	20,000	0.086	0.7	4,680
	30,000	0.009	0.9	1,550
<b>N.Thompson Coho</b>	$S_{offset}$	0.501	0.1	7,438
	Hist. Min.	0.191	0.3	6,106
	2,000	0.968	0.5	5,222
	5,000	0.551	0.7	4,316
	10,000	0.005	0.9	2,984

#### Appendix 4 Figure Captions:

**Figure 1:** Stock recruitment relationships for North Thompson coho salmon. Solid curve is the Ricker model (3) fit and the dashed line is the Allee Ricker model (9) fit. The straight line is the replacement line. Value “5,211” is the estimated  $S_{offset}$ .

**Figure 2:** The performance of the GA search algorithm using the North Thompson coho data. The lines from the top to the bottom are the worst, median, and the best values from the 100 points in every generation.

**Figure 3.** The distribution of  $\hat{S}_{offset}$  for North Thompson coho. The vertical line is  $\hat{S}_{offset} = 5,211$  and the horizontal line with arrows at both ends is the 80% confidence interval.

**Figure 4:** Extinction probability as a function of the North Thompson coho spawner numbers. The two vertical lines are the extinction probabilities corresponding to the estimated  $S_{offset}$  and the historical minimum spawner number. The horizontal line is the calculated spawner numbers corresponding to the 80% extinction probability.

**Figure 5:** Autocorrelation patterns for the residuals applying the standard Ricker model (plot a) and the Allee-Ricker model (plot b) to North Thompson coho data. The first order (i.e. Lag 1) autocorrelation with the standard Ricker model was just significant since it was barely outside the 95% confidence band (dotted lines).

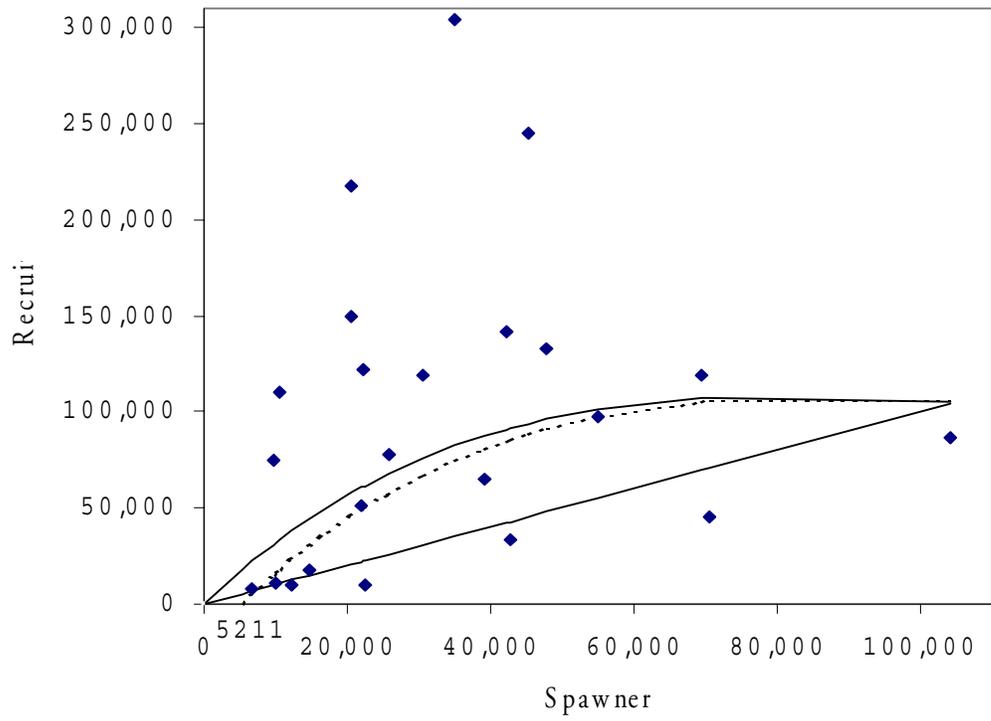
**Figure 6:** Stock recruitment relationships for Chilko River sockeye salmon. Solid curve is the Ricker model (3) fit and the dashed line is the Allee Ricker model (9) fit. Because of the data range and scale, both lines are so close that it is difficult to distinguish them. The straight line is the replacement line. Value 1,585 close to the origin is the estimated  $S_{offset}$ .

**Figure 7:** Re-plot of Figure 6 for the part close to the origin. The solid line is the Ricker model (3) fit and the dashed line the fit from the Allee Ricker model (9). Value “1,585” is the estimated  $S_{offset}$ . The only dot in the figure is the last observed S-R data point with 17,308 spawners and 204,386 recruits.

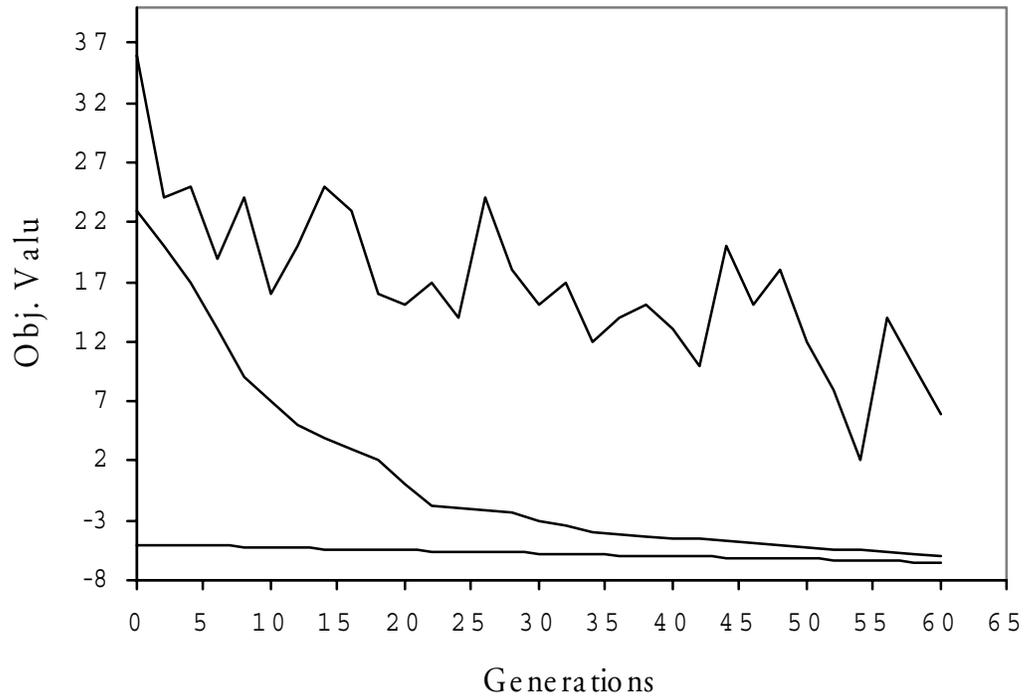
**Figure 8:** The distribution of  $\hat{S}_{offset}$  for Chilko sockeye salmon. The vertical line is  $\hat{S}_{offset}=1,585$  and the horizontal line with arrows at both ends is the 95% confidence interval.

**Figure 9:** Extinction probability as function of the Chilko sockeye spawner numbers re-scaled so that the extinction probability is zero for the spawner biomass to be zero. The two vertical lines are the extinction probabilities corresponding to the estimated  $S_{offset}$  and the historical minimum observed spawner numbers. The horizontal line is the calculated spawner numbers corresponding to the 50% extinction probability.

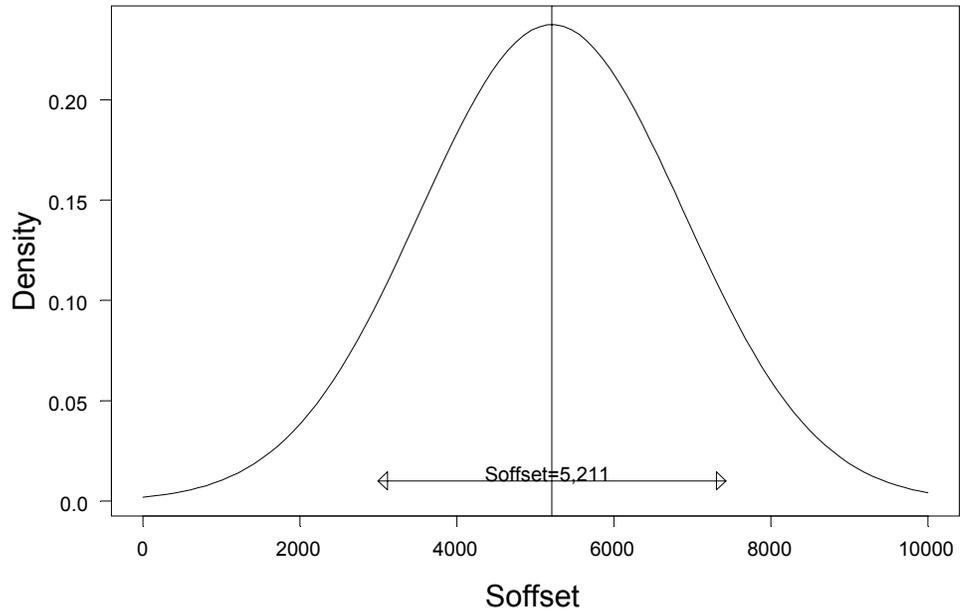
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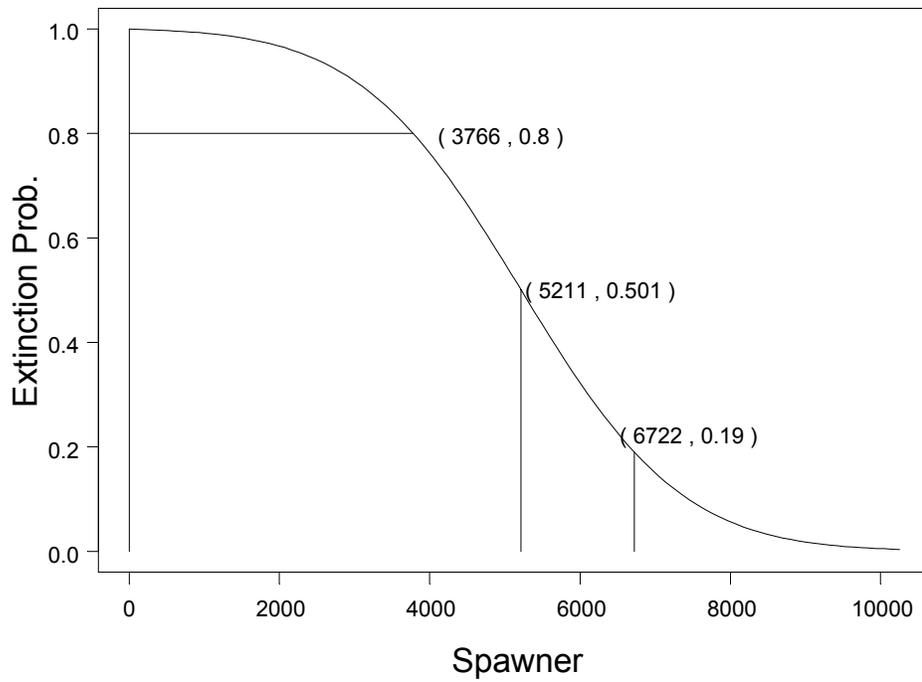
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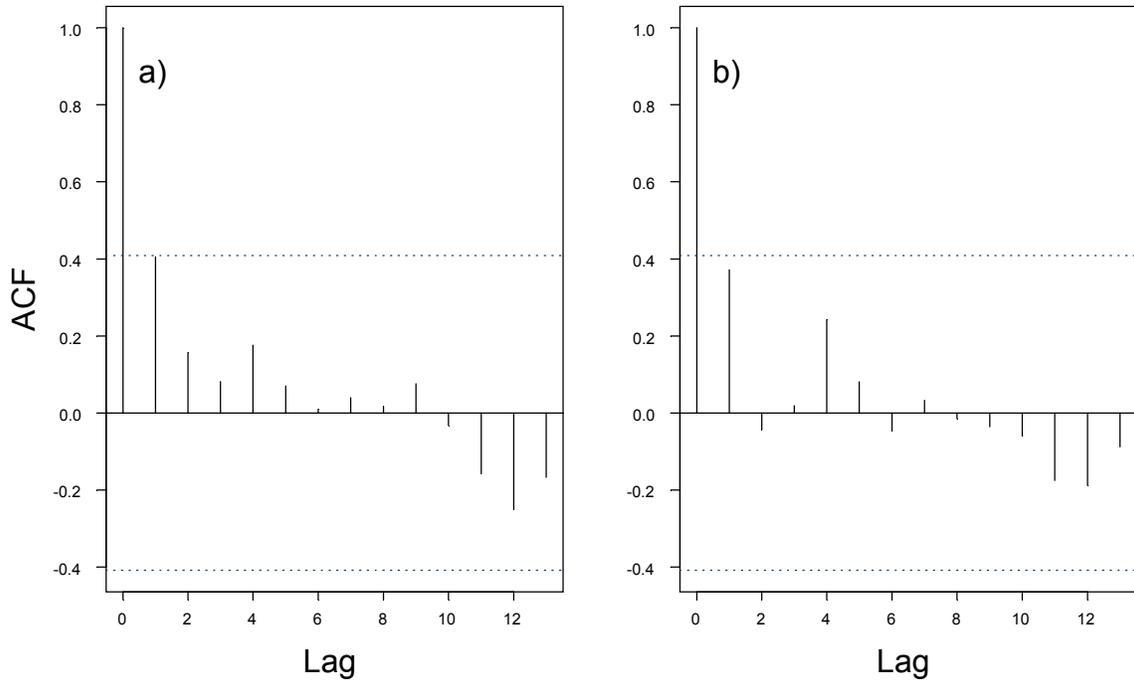
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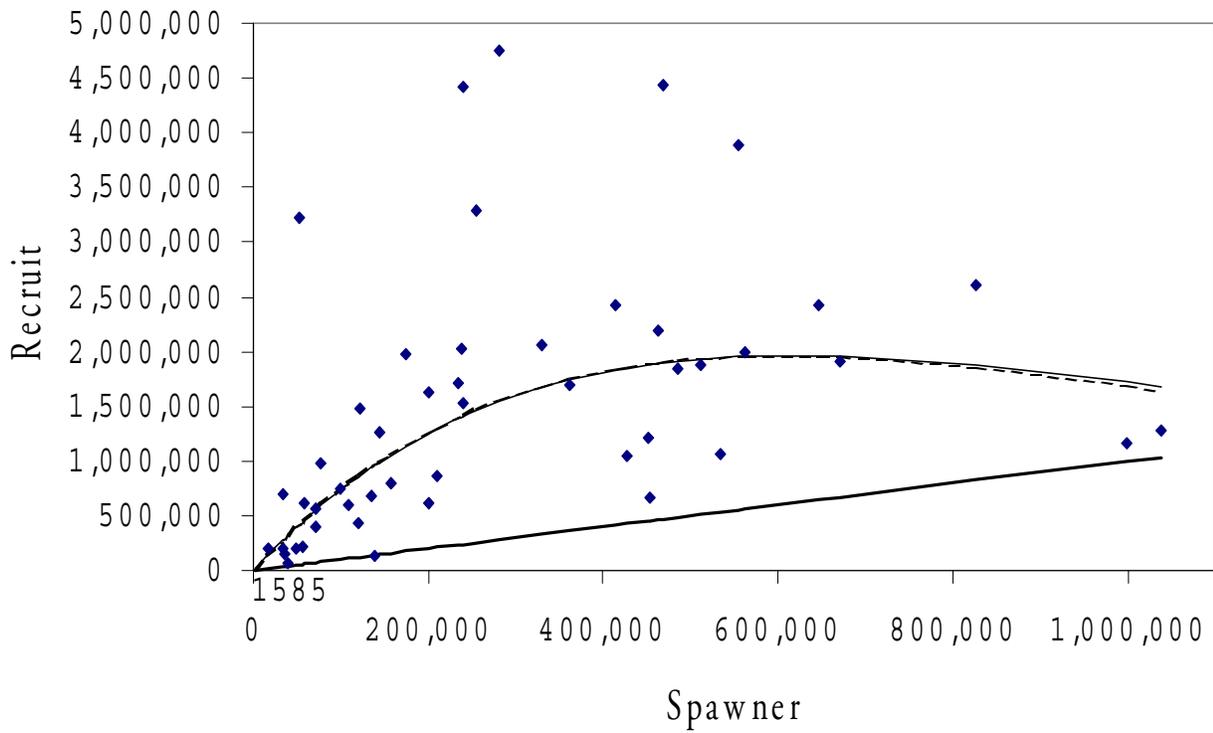
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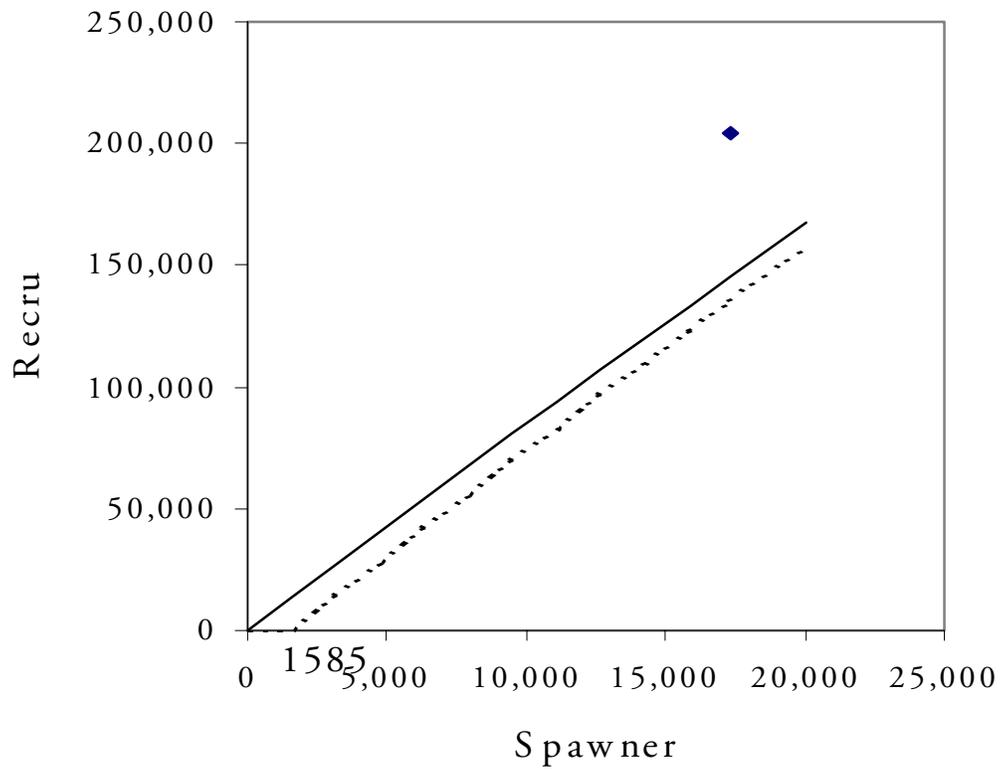
Appendix 4; Figure 5.



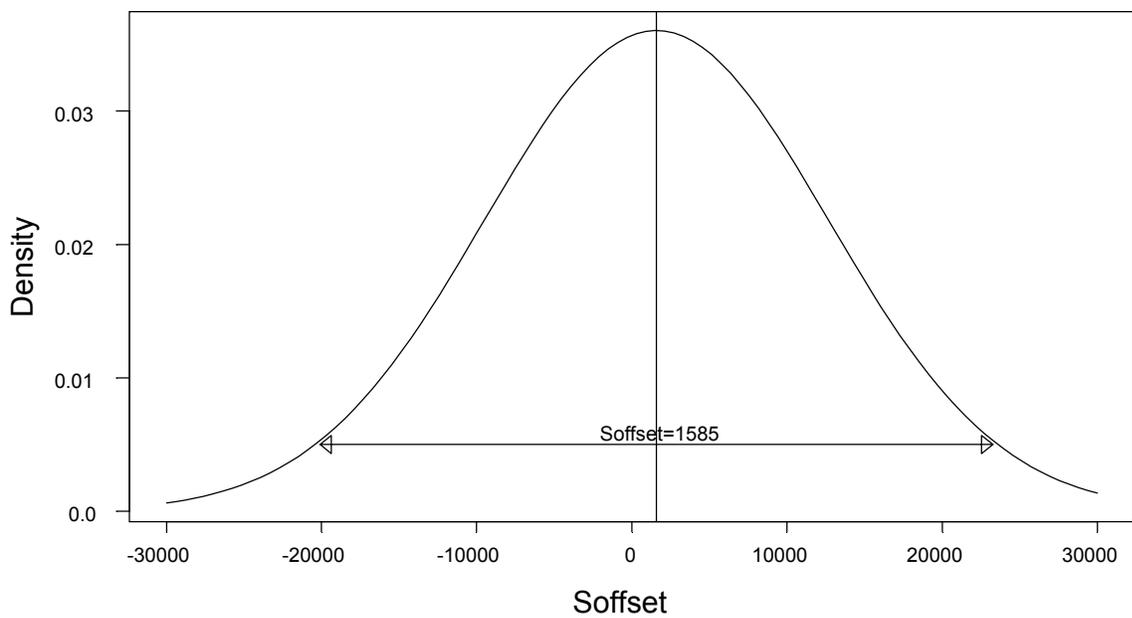
Appendix 4; Figure 6:



Appendix 4; Figure 7:



Appendix 4; Figure 8.



Appendix 4; Figure 9:

