

Estimation of the Escapement of the South Thompson 0.3 Chinook Aggregate in 2010 and 2011 using a Bayesian Model that Combines Data on Coded Wire Tag Recoveries, Genetic Stock Identification, and Scale Age Identification in Distant Fisheries

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Abstract

We used a Bayesian model to estimate the escapement of an aggregate salmon stock based on Genetic Stock Identification (GSI) data and recoveries of Coded Wire Tags (CWTs) from a hatchery indicator stock in distant fisheries and on the spawning grounds. In this report, we estimate escapement in 2010 and 2011 for the South Thompson Age 0.3 Chinook aggregate, a significant component of the Fraser early model stock used by the Pacific Salmon Commission's (PSC) Chinook Technical Committee (CTC). Escapement in 2010 and 2011 based on data from the NBC troll fishery was 213,200 (CV=0.14) and 147,700 (CV=0.18), respectively. The 2011 estimate was less precise owing to fewer recoveries of CWTs in the fishery than in 2010, especially for age 3 Chinook. In 2010, escapement estimates based on data from the Albion test fishery (77,340) were much lower than those based on data from the NBC troll fishery. Data from the Albion test fishery underestimated the escapement due to reduced catchability of Chinook during the period when an unusually large sockeye run returned. The Albion-based escapement estimate in 2011 was 127,500 (CV=0.00). As in 2010, the 2011 Albion-based estimate was lower than the one based on the NBC troll fishery, but there was some overlap in confidence intervals indicating that there was a reasonably high probability that differences could be due to sampling error alone as very few CWTs were found in the Albion test fishery catch. Due to problems with catchability of Chinook in the Albion test fishery in 2010, and few CWT recoveries in both years from this fishery, the NBC troll-based escapement estimate will likely provide a more reliable estimate for the South Thompson aggregate in most years. Increased CWT releases as part of the Sentinel Stock Program began to return in 2011 which will yield more CWT data and higher quality escapement estimates over the upcoming years. As the results of the increased tagging accrue to fisheries and spawning grounds, we will be better informed about an optimal future study design.

Introduction

Accurate estimates of the spawner abundances are fundamental to manage Pacific salmon populations and the fisheries that depend on them. In the majority of cases for Chinook salmon (*Oncorhynchus tshawytscha*), catch in ocean fisheries consists of a mixture of stocks. For three fisheries managed under the Pacific Salmon Treaty, the allowable catches depend on abundance indices generated by the Pacific Salmon Commission's coastwide model which uses cohort analysis and exploitation patterns (PSC 2009a). Escapement estimates are a fundamental component of cohort analysis and are also needed to evaluate whether conservation goals and management objectives are being met. The Fraser River Chinook Summer-Run Age 0.3 aggregate stock is a major contributor to ocean fisheries in Southeast Alaska (SEAK) and Northern British Columbia (NBC). Since 2002, this stock represented upwards of 30-40% of the NBC troll fishery catches (Winther and Beacham 2006). Good quality spawning ground estimates for this stock group are needed to develop accurate forecasts of the NBC and SEAK abundance indices to define allowable catch. However, the current visual survey methods are thought to underestimate spawner numbers because of poor counting conditions experienced during helicopter surveys in the South and lower Thompson rivers (R. Bailey, DFO Kamloops, pers. Comm.). Results from the Lower and Middle Shuswap escapement survey calibration programs indicate escapements can be underestimated by 20-65% in the Fraser Summer-run Age 0.3 aggregate (Chamberlain and Parken 2007).

Obtaining unbiased and relatively precise estimates of spawning escapement for larger stock aggregates has been one of the holy grails in salmon management. Intensive methods, such as mark-recapture, can provide accurate estimates of escapements for individual stocks. These programs usually require considerable effort and resources, which limits the area and number of stocks where they can be applied. There can be considerable error introduced by setting catches based on escapements for a subset of stocks that are assumed to represent the abundance of the aggregate of stocks that are fished. This can be especially true for northern ocean fisheries which harvest stocks ranging from coastal Oregon to southeast Alaska. Less intensive methods, such as visual surveys, can be applied over a wider area and therefore potentially provide a more representative abundance index for an aggregate stock. However such indices may be

quite biased and imprecise because detection probability is generally not estimated and surveys are typically only conducted for a short period relative to the duration of spawning. These characteristics limit the use of abundance indices obtained from uncalibrated visual surveys in salmon management.

In 1985, Canada and the U.S. agreed to maintain a coded wire tag (CWT) mark and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations (PSC 2009b). This program provides CWT recovery data for Chinook salmon in pre-terminal and terminal fisheries and at spawning grounds and hatcheries (PSC 2005). These data are used to estimate fishery- and age-specific exploitation rates for the indicator stocks, which are assumed to be similar to those for the larger wild stock aggregates they are meant to represent (the so-called ‘gorilla’ assumption, PSC 2005). Genetic Stock Identification (GSI) data is an emerging source of information that can be used to compliment the CWT program. For the most part, GSI has been used by fisheries management to modify fisheries reducing harvest rates on stocks of concern. Coupling the “gorilla” assumption with GSI-based estimates of stock-composition can provide a means of estimating escapements for larger aggregate stocks based on the so-called “ratio method (PSC 2005, see Appendix C). With this approach, the catch for a large aggregate stock in a fishery is first calculated from the product of the total catch and the proportion of the catch comprised of the aggregate stock as determined by GSI data. Assuming the ratio of fish in the escapement to the number in the fishery is the same for indicator and wild aggregate stocks (i.e., the gorilla assumption), the escapement for the latter is determined by multiplying the catch of the aggregate in the fishery by the ratio of CWTs in the escapement to the CWTs in the fishery.

In this analysis, we develop a Bayesian model using a variation on the ratio-method. A Bayesian approach offers a number of advantages compared to the existing analytic model. For example, estimates of uncertainty from the Bayesian model will be more realistic when sample size is small. The Bayesian model can easily incorporate uncertainty associated with age assignments from scale reading or stock assignments from GSI data. Prior information on expected CWT recoveries based on sibling models or cohort reconstruction can also be incorporated. Information can be combined across multiple fisheries to produce estimates with uncertainty based on the amount and quality

of the sample data from each fishery. In this paper, we apply the Bayesian model to data for the South Thompson 0.3 Chinook aggregate to estimate escapement in 2010 and 2011.

Methods

Data

The South Thompson summer-run age 0.3 aggregate has represented approximately 58% of the total run size of the Fraser early CTC model stock, and visual surveys indicate that escapements have increased substantially since the mid 1990's (Fig.'s 1 and 2). The South Thompson aggregate spawns in the Lower Thompson River below Kamloops Lake, the South Thompson River mainstem, Lower and Middle Shuswap rivers, Little River, and Lower Adams River. The exploitation rate indicator stock for the South Thompson aggregate is located at the Lower Shuswap River. The Lower Shuswap fish are reared at the Shuswap Falls hatchery, which also enhances the Middle Shuswap stock (a component of the South Thompson age 0.3 aggregate). The sentinel stock program began funding a CWT marking program for this stock with brood year 2008 (released in 2009). 2011 was the first year when Middle Shuswap River Chinook that received a CWT returned. Data used to estimate the escapement of the South Thompson 0.3 aggregate includes information on abundance of the Lower Shuswap (2010 and 2011) and Middle Shuswap River (2011 only) indicator stocks on the spawning grounds, the recovery of CWTs from these stocks on the spawning grounds and in fisheries, and genetic stock identification and age data to determine the catch-by-age of the aggregate stock in fisheries. We applied the model to data collected from a troll fishery in Northern British Columbia (NBC) and a test fishery on the Fraser River at Albion.

Total spawning escapement of Chinook in the Lower and Middle Shuswap rivers and consequently the number of CWT'd Chinook within that escapement are estimated annually from two-event sex-stratified mark-recapture experiments (Chamberlain and Parken 2007). During the first event, a representative sample of Chinook salmon is captured by beach seining throughout the entire river and run, and subsequently tagged and released. The second event consists of a carcass recovery conducted throughout the entire system for the duration of the spawning and die-off period, where carcasses are

recovered and sampled for marks and adipose fin clip (AFC) status. During the recovery portion of the project, biological information (length, sex, scales, spawning success) is collected from all fish identified with marks, as well as from a sub-sample of unmarked fish. All carcasses encountered with an AFC are sampled for the same biological information and also have their heads collected for CWT analysis. Hatchery brood stock collected from the Middle and Lower Shuswap rivers were sampled for CWTs also.

As part of a large, coordinated program for the sampling of CWTs (Nandor et al. 2010), recoveries of CWTs are estimated by sampling fisheries and the subsequent extraction and decoding of the tags. CWT data are maintained by Canada and the U.S. and used to measure several statistics, such as fishing impacts by stock, age, and fishery, and survival and maturation rates by stock and brood year (PSC 2008). The estimated CWT recoveries for the northern BC troll fishery were extracted from the Regional Mark Processing Center (www.rmpec.org).

Genetic samples were analyzed using methods outlined by Beacham et al. (2006). For the northern B.C. troll fishery, genetic and scale age samples were collected from commercial fishery landings (Winther and Beacham 2006; Beacham et al. 2006; 2008). Genetic variation at 12 microsatellite markers (*Ogo2*, *Ogo4*, *Oke4*, *Oki100*, *Ots100*, *Ots101*, *Ots104*, *Ots107*, *Ots2*, *Ots9*, *Omy325* and *Ssa197*) was compared to a baseline of approximately 12,000 fish consisting of 55 Fraser River populations to assign individual fish to populations and regional reporting groups (Beacham et al. 2003a; 2003b) and 19 populations for the WCVI (Beacham et al. 2006; 2008).

We used the 12-microsatellite locus baseline outlined by Beacham et al. (2006) that incorporated Chinook salmon populations ranging from the Alsek River in southeast Alaska to the Sacramento River in California to estimate stock composition of the NBC fishery samples. Individual genetic assignments were performed using the program cBayes (Neaves et al. 2005) which uses the algorithms from Pella and Masuda's (2001) program bayes. Eight chains were run for each estimate, each with a Markov Chain Monte Carlo sample size of 20,000. Estimates of individual assignments were based on the last 1000 steps of each chain combined.

To characterize the accuracy of scale age identifications for ocean-type Chinook salmon originating from the South Thompson aggregate, we assembled paired CWT and

scale age data that had been collected from 1987 to 2009 by commercial fishery sampling programs in northern B.C. The CWT ages were considered the true age (McNicol and MacLellan 2010). We used the DFO CWT mark recovery program sample data base to identify the scale book and scale numbers that were associated with CWTs originating from the Middle and Lower Shuswap River hatchery stocks, and extracted scale age identifications from DFO's Pacific Age Data System. For some years, all the scales were re-read because the aging procedures and criteria used previously were not the same as those applied currently. Also, scales were read for fish that were not aged previously when the samples had been sent directly to archives before aging. Overall, 303 paired CWT and scale samples were available for fish with Middle or Lower Shuswap CWTs, and after exclusion of scales that were unreadable or had partial ages, there were 218 fish that were age 0.2, 0.3, and 0.4. There are a relatively few Chinook salmon in the south Thompson watershed with stream-type life history compared to ocean-type life history. The stream-type populations have had fewer CWT fish released from hatcheries, relative to the ocean-type fish, which produced too few paired scale and CWT samples to characterize the accuracy for fish with stream-type life history in the South Thompson genetic regional reporting group.

Model Structure

We developed a Bayesian model to estimate the annual spawning escapement of the South Thompson age 0.3 aggregate stock based on catch in a distant fishery and the recovery of CWTs from its associated exploitation rate indicator stock(s) in the fishery and in the spawning escapement. The stock contribution method that we implement relies on the key assumption that the ratio of indicator stock CWTs to the wild aggregate in the distant fishery is the same for wild aggregate and indicator stocks in the escapement. Under this “gorilla” assumption, which holds if maturation schedules and harvest regimes among stocks are similar, the catch of the aggregate in a fishery, determined by GSI data, can be converted into an escapement estimate by multiplying it by the ratio of CWTs in the escapement to CWTs in the fishery. A detailed description of the model is provided below and a graphical representation of the model is provided in Figure 3.

The total spawning escapement for the aggregate stock (W_E , see Table 1 for parameter definitions) is the sum of age-specific estimates ($W_{E,a}$, eqn. 1.1 from Table 2). The expected value for the age-specific escapement estimates of the aggregate stock are determined by the product of the expanded catch of fish from the aggregate in the fishery ($W_{F,a}$) and the CWT expansion ratio (eqn. 1.2). The CWT expansion ratio is simply the sum of estimated number of CWTs in the in-river ($C_{E,a}$) and hatchery escapement ($C_{B,a}$) or terminal fishery ($C_{E,a}$) to the estimated number caught in the distant fishery ($C_{F,a}$). The total expanded number of fish from the aggregated stock in the fishery by age ($W_{F,a}$) is the sum across strata (eqn. 1.3). The expanded number of fish from the aggregate stock caught in the fishery by age and time-area strata ($W_{F,a,s}$) is the product of the strata-specific total catch ($N_{F,s}$), the estimated proportion of the aggregate in the catch determined by the GSI data ($P_{F,s}$), and the estimated proportion of fish in the aggregate for each age (sum of product of $P_{F,a,s}$ and $P_{S,a,aa}$, eqn. 1.4). This latter term is based on age determinations in the GSI sample (which determine $P_{F,a,s}$) and error in age assignments (as determined by $P_{S,a,aa}$). The expected proportion of fish from the aggregate stock in the GSI sample by strata ($P_{F,s}$) is the number assigned to the aggregate ($N_{W,s}$, eqn. 1.6) divided by the total size of the GSI sample ($N_{GSI,s}$ eqn. 1.5). The expected proportion of fish by age ($P_{F,a,s}$) is simply the ratio of the number of fish at each age that are assigned to the aggregate stock ($N_{W,a,s}$, eqn. 1.8) to the total number assigned that have been aged (eqn. 1.7). The expected proportion of fish assigned to age ‘a’ that are actually age ‘aa’ ($P_{S,a,aa}$) is simply the ratio of the former number to the total number of fish assigned to age ‘a’ in the ageing error matrix (eqn. 1.9).

The expected value for the expanded catch of CWTs from the indicator stock in the fishery by age ($C_{F,a}$) is the sum across estimation strata (eqn. 1.10), determined as the number of CWTs that are caught ($m_{F,a}$) expanded by the effective sampling rate for CWTs in the catch (λ_F , eqn. 1.11). λ_F is fixed by strata and is the product of the sampling rate on the catch, the proportion of heads removed from fish with adipose fin clips, the proportion of those heads that make it to the decoding lab, and the proportion of heads with CWTs that are successfully decoded. The expected value for the expanded number of CWTs in the escapement of the indicator stock by age ($C_{E,a}$) is simply the sum across escapement estimation strata (male and female, $C_{E,a,s}$, eqn. 1.12). The expected value for

each strata $C_{E,a,s}$ is the number of CWTs recovered in the escapement ($m_{E,a,s}$) divided by the product of the proportion of the indicator stock escapement that is handled ($P_{E,s}$) during the recovery effort (dead-pitch), the proportion of those fish where the presence of an adipose fin can be unambiguously determined ($P_{AFS,s}$), and the decoding rate of CWTs for fish with adipose fin clips ($\lambda_{E,s}$, eqn. 1.13). In the case where the escapement of the indicator stock is estimated, $P_{E,s}$ is determined based on the ratio of Petersen tags recaptured to Petersen tags released during the mark-recapture experiments to estimate the escapement for the indicator stock (eqn. 1.14). $P_{AFS,s}$ is determined by the ratio of the number of fish where the status of adipose fin clip can be determined (N_{AFS}) to the total recovered ($N_{E,s}$, eqn. 1.15). $\lambda_{E,s}$ is fixed and is the product of the proportion of heads removed from fish with adipose fin clips, the proportion of those heads that make it to the decoding lab, and the proportion of heads with CWTs that are successfully decoded. The expanded number of CWTs in the escapement in the hatchery ($C_{B,a}$) is simply the sum across estimation strata (eqn. 1.16), determined as the ratio of CWT recoveries ($m_{B,a,s}$) by the effective sampling rate in the hatchery ($\lambda_{B,s}$ in eqn. 1.17).

The aggregated stock escapement estimation approach is implemented in a Bayesian framework and therefore requires specification of probability distributions to represent uncertainty in parameter estimates. The number of fish from the GSI sample that are assigned to the aggregate stock within a stratum depends on the individual probabilities of assignment for each fish. Individual fish are assigned to the aggregate stock ($x_{i,s} = 0$ (no) or 1 (yes)) in proportion to their estimated assignment probabilities ($p_{w,i,s}$) by drawing from a Bernoulli distribution (eqn. 2.1). The proportion of the aggregate stock ($P_{F,s}$) in the total catch by strata is assumed to be a binomially-distributed random variable (eqn. 2.2) which depends on the number of fish assigned to the aggregate stock ($N_{W,s}$) and the total sample size of the GSI sample ($N_{GSI,s}$). Note that there is very little uncertainty in $N_{W,s}$ in cases when the GSI sample size is large and the assignment probabilities to the stock of interest are highly informative (i.e., either very low or high values). In this situation, $N_{W,s}$ can be treated as data (i.e., fixed) rather than a random variable. The proportion-at-age for fish from the GSI sample that are assigned to the aggregate stock by strata ($P_{F,a,s}$) is assumed to be a multinomially-distributed random variable (eqn. 2.3) that depends on the number of assigned fish of each age ($N_{W,a,s}$) and

the total number of fish that were assigned and aged. Age assignments based on scales can be incorrect (McNicol and MacLellan 2010), so the effects of ageing error are incorporated in the model. The proportion of fish of estimated age ‘a’ that are actually age ‘aa’ in the ageing error matrix ($P_{S,a,aa}$) is assumed to be a multinomially-distributed random variable (eqn. 2.4) that depends on the number of assigned fish in strata ‘a’, ‘aa’ ($n_{a,aa}$) and the total number of fish assigned to age ‘a’. Finally, the expanded catch of fish from the aggregate stock by age and strata ($W_{F,a,s}$) is assumed to be a Poisson-distributed random variable (eqn. 2.5) that depends on total catch ($T_{F,s}$), the proportion of the GSI sample assigned to the aggregate stock ($P_{F,s}$), and the age structure for those assigned fish that accounts for ageing error ($\sum P_{F,a,s} P_{S,a,aa}$). We used a Poisson rather than binomial distribution for this component because the former distribution is computationally more efficient than the latter and yields equivalent results because the total catches within strata are large numbers.

The estimated catch of CWTs from the indicator stock in the fishery for each strata ($C_{F,a,s}$) is assumed to be a binomially-distributed random variable (eqn. 2.6) that depends on the number of CWTs recovered from the catch ($m_{F,a,s}$) and the effective sampling rate on the catch for CWTs ($\lambda_{F,s}$). The estimated number of CWTs in the escapement of the indicator stock by strata ($C_{E,a,s}$) is also assumed to be a binomially-distributed random variable that depends on the number of CWTs recovered in the escapement ($m_{E,a,s}$) and the effective sampling rate on the escapement ($P_{E,s} P_{AFS,s} \lambda_{E,s}$ in eqn. 2.7). For the South Thompson aggregate, $P_{E,s}$ is assumed to be a binomially-distributed random variable (eqn. 2.8) that depends on the number of tags recaptured and the total number released. $P_{AFS,s}$ is also assumed to be a binomially-distributed random variable (eqn. 2.9) that depends on the number of fish recovered where the presence of an adipose fin clip is known ($N_{AFS,s}$) and the total number recovered ($N_{E,s}$).

The model estimates escapement for each age independently, but can also be run in an age-aggregated mode, where the data is pooled across ages prior to estimation. Precision based on this latter approach will be better because of the reduced number of parameters and increased sample size due to pooling. However, age-aggregated estimates based on pre-terminal data will be biased if there are substantive differences in maturity schedules and differential exploitation between CWT fish and the rest of the stock

aggregate (see discussion). The Bayesian model can also be simplified to avoid computations that address uncertainty in individual stock assignments (eqn. 2.1). In cases where the GSI total sample size is large, and where individual assignment probabilities to the aggregate ($P_{W,i}$) are either very small or very large, because the stock aggregate is genetically distinctive relative to others, the total number of individuals from the GSI sample assigned to the aggregate stock (N_W in eqn. 1.5) will be very well defined. In this situation, run-times for the Bayesian model can be substantially reduced by aggregating the GSI information prior to running the model. To do this, fish are assigned to the South Thompson aggregate if the probability of belonging to that stock group is greater than the probabilities for other stock groups included in the GSI analysis. The number of South Thompson assignments are then summed to compute N_W and $N_{W,a}$.

Bayesian implementation requires specification of prior probability distribution for all parameters that are estimated. For estimates of proportions, beta or Dirichlet distributions were used (eqn.'s 3.1-3.5). Prior parameters were set so the prior distributions were uninformative, except in the case of the prior for ageing error, where information was available for DFO scale readers from another study for 13 ocean-type hatchery stocks: Big Qualicum, Chilliwack, Harrison, Lower Shuswap, Nitinat, Priest Rapids, Queets, Quinsam, Robertson, Salmon, Samish, Sooes, and Stillaguamish (McNicol and MacLellan 2010). The estimates of expanded catch or escapement of fish with CWTs from the indicator stock in the fishery or escapement were based on uninformative uniform (eqn.'s 3.6-3.8). Note that the expanded CWTs returned from this prior distribution represent the number of CWTs not recovered, so these values are added to the actual recoveries to determine the prior for the total expanded number of CWTs. Upper limits for the uniform distributions of expected CWT recoveries in the fishery (p_F in eqn. 3.6), escapement (p_E in eqn. 3.7), and broodstock (p_B in eqn. 3.8) were set at 5 times the expected values determined from equations 1.11, 1.12, and 1.17, respectively.

The Bayesian escapement model is implemented in WinBUGS version 1.4 called from the 'R' statistical package via the R2WinBUGS library. Posterior probability distributions for model parameters were estimated using the Markov chain Monte Carlo (MCMC) sampling method as implemented in WinBUGS. A total of 2,500 iterations were conducted with the first 500 discarded to remove potential effects of the random

parameter values used to initiate the simulation. Posterior distributions were based on saving every second sample from the remaining 2000 iterations. This sampling approach was sufficient to achieve model convergence in all cases. The mean and standard deviation from the posterior distribution was used to compute the coefficient of variation (CV) of parameter estimates. Uncertainty in parameter estimates was also quantified by determining the 95% credible interval from the posterior distribution based on the 2.5% and 97.5% quantiles.

We compared results from the Bayesian escapement model with those from the deterministic version where escapement and uncertainty are computed from analytic equations (Bayesian integration not required). Estimates from the latter model were determined from the expected value equations of the Bayesian model (eqn.'s 1.1-1.17). Variance in estimates from the deterministic model can be computed based on methods described in Bernard and Clark (1996) and PSC (2007) for analysis of CWT data, and in later work focusing specifically on GSI and CWT data (PSC 2005, Appendix C) using variance approximations described by Goodman (1960).

Estimation Strata

Escapement of the South Thompson aggregate in 2010 and 2011 were estimated using alternate combinations of data. In 2010 there were no returns of CWT'd fish from the Middle Shuswap River hatchery, so escapement CWT data from only the Lower Shuswap River was used. In 2011 we computed estimates using escapement data from only the Lower Shuswap River only, as well as the combined data from Lower and Middle Shuswap rivers. The escapement data from the latter source was simply added to the model as additional strata (male and female).

Escapement estimates in both years are estimated using GSI and age information from the NBC troll (5 fishery strata) and Albion test fisheries (1 fishery strata), and based on the combined information across these fisheries. For this latter combined estimation, the CWT recoveries and GSI data are used to compute the abundance of the wild stock for each fishery strata, which is then summed across strata (eqn. 1.3). A total of 6 fishery strata are estimated in this case (5 strata for NBC troll + 1 stratum for Albion). A key

assumption in this combined estimation is that the $(C_E+C_B)/C_F$ ratio (eqn. 1.2) is the same for NBC and Albion fisheries.

There was an unusually large return of sockeye to the Fraser River in 2010 which overlapped with the latter half of the South Thompson run at Albion (Fig.4). This resulted in a significant reduction in catch of South Thompson Chinook at the Albion fishery, evident in the multipanel net. However, the Chinook catch in the 8 inch net at Albion was less affected because the larger mesh catches fewer sockeye. We therefore computed an additional estimate of escapement in 2010 based on CWT recoveries and GSI data collected from the Albion test fishery using data from only the 8 inch net.

Results and Discussion

The South Thompson aggregate is genetically distinctive from other stocks in the NBC troll fishery (Fig. 5). As a result, the probability of fish sampled in 2010 and 2011 in the NBC troll fisheries and at the Albion test fishery belonging to the South Thompson aggregate was either very low or very high. In cases like these, there is very little uncertainty associated with assignment error to the South Thompson aggregate, so the Bayesian implementation is simplified because it does not have to account for this uncertainty. That is, $x_{i,s}$ in eqn. 2.1 can be treated as fixed (a fish is always a member of the aggregate or not) rather than as a random Boolean variable. There was very little ageing error for the South Thompson aggregate, which was consistent with results for South Thompson stocks from an independent study for a larger number of stocks (Table 3). Thus ageing error will contribute very little uncertainty to escapement estimates for this aggregate.

GSI assignments to the aggregate stocks and CWT recoveries in the NBC troll and Albion test fisheries and in escapement are presented in Table 4. This summary, which sums stock assignments and recoveries across escapement estimation (males, females, large males) and fishery strata, shows high numbers of CWT recoveries for most strata, with the exception of age 5 fish in the escapement, for all ages in the Albion fishery, for age 5 fish in the NBC troll fishery in both years, and for age 3 fish in the NBC troll fishery in 2011 (Table 4). The sample size for GSI assignments was generally large except for age 3 fish. Across ages, the South Thompson aggregate represented

about 45% of the total Chinook catch in both Albion and NBC troll fisheries, with the exception of the NBC troll fishery in 2011 (~25%). Considering the large sample size of the wild aggregated in these fisheries, it is clear that the precision in escapement estimates will generally be limited by the low number of CWT recoveries in the fishery.

Total escapement in 2010 (based on the sum of age-specific estimates) based on the NBC troll CWT and GSI data was 213,200 fish with a coefficient of variation (CV) of 0.14 (Table 5a). This estimate was close to the estimates based on aggregating the age-specific data prior to estimation (Aggregated, 215,500) and to the estimates based on the analytic model (212,965). Estimates for age 4 escapements were more precise than for age 3 and 5 due to the lower sample sizes for the latter ages. Escapement estimates based on CWT recovery and GSI data from the Albion fishery were much lower than from NBC troll data, ranging from about 59,000 (sum across ages, all nets) to 77,000 (8" net only). These lower estimates relative to NBC troll data are very likely caused by reduced catchability of Chinook in the Albion nets due to high sockeye abundance (Fig. 4). The combined NBC + Albion 8" net estimate was very similar to the estimate from NBC troll data only because the wild stock proportions across fisheries were similar (Table 4) and the number of CWT recoveries from the Albion fishery were so low (so the estimate is dominated by NBC troll CWT recoveries).

Total escapement in 2011 (based on the sum of age-specific estimates) based on the NBC troll CWT and GSI data was 146,200 fish with a coefficient of variation (CV) of 0.18 (Table 5b). Escapement estimates based on Albion data in 2011 were lower than the NBC troll-based estimates, but the difference was less than in 2010 and there was considerable overlap in confidence limits based on the two data sources. There was very little difference between 2011 estimates based on data from only the Lower Shuswap River and those that included data from the Middle Shuswap River (Table 5c), not a surprising result considering the minor contribution from the latter stock on age 3 CWT recoveries in the fishery and on the spawning grounds. Much greater numbers of Middle Shuswap CWT recoveries will occur when all returning broods are marked.

Analytic and Bayesian estimates differed in strata where CWT sample size in the fishery was low (Tables 4 and 5). In these cases, the prior for C_F contributes relatively more information to the estimate of C_F than the data. This resulted in a higher estimate of

C_F from the Bayesian model, leading to lower value of the second term in eqn. 1.2 and therefore a smaller expansion of the catch of the Wild stock (W_F), and ultimately a lower escapement estimate for the wild aggregate. Few CWT recoveries produce a situation where the Bayes model inflates C_F from the prior, and hence underestimates escapement compared to the analytical calculations; for example, using the direct analytic model for the Albion 8 inch net yielded an escapement estimate (183,000) that was similar to the NBC troll estimate. Using data from the 8" net resulted in slightly higher escapement estimates, but still well below the estimate from the NBC troll data.

All else being equal, the Albion-based escapement estimates should be more robust than estimates based on NBC troll data because the gorilla assumption ($(C_E+C_B)/C_F = W_E/W_F$) is more likely to hold for the former data source for two reasons: 1) the extent of harvest upstream of the Albion test fishery is much less than between the NBC troll fishery and the spawning grounds, so differences in the exposure of wild aggregate and indicator stocks to harvest will have a greater effect on estimates based on the NBC troll data; and 2) differences in maturation rates between the wild aggregate and the indicator stock could have a potentially large effect on escapement estimates based on NBC troll data, and likely little to no effect based on Albion data (as all fish moving past that fishery mature). That said, escapement estimates based on the Albion data have been based on very few CWT recoveries. This uncertainty is not reflected in the model because the sampling rate of the Albion fishery is 100%. Thus, there is no uncertainty in the expanded number of CWT recoveries because no expansion is required. However, capture of just a few more CWTs in that fishery would have a big effect on the estimate. In 2009, there was generally good agreement between estimates from NBC troll and Albion fisheries (Korman et al. 2010). In 2010, the NBC estimate was much higher, and we attribute this difference to reduced catchability of Chinook in the Albion test fishery due to very high sockeye abundance. Escapement estimates from NBC data in 2011 were also higher than from Albion, but the difference was much less than in 2010. Some of the difference in escapement estimates in 2011 was therefore due to sampling error (note overlap in confidence limits in Table 5b). Overall, we consider the NBC troll-based escapement estimates to be more robust than those from Albion because the sample size of CWT recoveries is so much larger in the former data set. Increased sampling of a

higher percentage of the South Thompson aggregate return would be needed to increase CWT recoveries of the indicator stocks. Currently, CWT data from three other Fraser River test fisheries could be included in future analysis. The benefits of including this additional sample information will be examined as part of the 2012 data analysis.

We attempted to develop a new version of the Bayesian model that integrated data from multiple fisheries (i.e., NBC troll and Albion test fisheries) to derive a single escapement estimate for the wild aggregate (Appendix A). Such a model avoids the need to decide which escapement estimates (based on NBC troll or Albion) to use for management, and avoids having to throw away data from the fishery that is excluded. The estimates presented here based on data from both fisheries (Albion + NBC) assume that the expansion ratio $((C_E+C_B)/C_F)$ used to estimate the escapement of the wild aggregate is the same for both fisheries. The more advanced model we considered would allow for different indicator stock contribution ratios for each fishery, but would assume that wild aggregate escapement estimates came from a common distribution whose variance would be specified by the user. When this variance is set to a large value we would expect the fishery-specific escapements to be very close to the ones presented here (i.e., independent estimates). However, when the variance of the common distribution is reduced, the escapement estimates from each fishery would converge, and the mean of the distribution would represent an information-weighted average escapement. Given the differences in sample sizes among fisheries, we suspect that this model would result in very similar escapement estimates to those derived from the NBC troll data alone. To date, we have not been able to implement this model due to constraints in the WinBugs software, but hope to solve this problem in the near future.

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Table 1. Definition of variables used in the Bayesian model to estimate escapement for an aggregate stock.

Variable	Description
Parameter Estimates	
W_E	Escapement of wild stock
W_F	Expanded catch of wild stock in fishery
C_F	Expanded number of CWTs from indicator stock in fishery
C_E	Expanded number of CWTs in the escapement of indicator stock
C_B	Expanded number of CWTs for fish that entered the hatchery (broodstock)
P_F	Proportion of the wild stock in fishery
$P_{F,a}$	Proportion-at-age for wild stock in fishery based on scale ages
$P_{S,a,aa}$	Proportion of fish aged as ‘a’ that are actually age ‘aa’ from age-error matrix
N_W	Number of fish in GSI fishery sample assigned to the wild stock
$N_{W,a}$	Number fish in GSI fishery sample assigned to the wild stock of age ‘a’
x_i	Binary value specifying whether a fish from GSI sample from fishery is assigned to wild stock or not (0=no, 1=yes)
P_E	Proportion of total escapement of indicator stock available to be sampled
P_{AFS}	Proportion of escapement where status of adipose fin (clipped or not) is known
Data	
m_E	Decoded CWTs from escapement for indicator stock
m_B	Decoded CWTs from indicator stock in the hatchery (broodstock)
r_E	Tags recaptured in escapement of indicator stock in dead-pitch recovery
R_E	Tags applied to escapement of indicator stock
N_E	Total dead-pitch recoveries in escapement of indicator stock
N_{AFS}	Recoveries in escapement of indicator stock where status of adipose fin is known (clipped or not)
N_F	Total catch in fishery (all stocks)
m_F	Decoded CWTs from indicator stock in the fishery
$P_{W,i}$	Probability of assignment of individual fish in GSI fishery sample to wild stock
N_{GSI}	Number of GSI samples from fishery
$n_{a,aa}$	Number of fish of estimated age ‘a’ that are actually age ‘aa’

Table 1. Con't.

Constants

λ_F	Proportion of the total catch from fishery that is sampled and successfully decoded
λ_E	Proportion of sampled fish with an adipose fin clip from the escapement of the indicator stock that are successfully decoded
λ_B	Proportion of fish in the hatchery with an adipose fin clip that are successfully decoded
p_a	Prior for proportion at age in fishery (prior sample size for age 'a')
$p_{a,aa}$	Prior for proportion of fish of age 'a' that are actually age 'aa' (prior sample size)
p_F	Upper limit for uniform prior for expected recovery of CWTs in fishery
p_E	Upper limit for uniform prior for expected recovery of CWTs in escapement
p_B	Upper limit for uniform prior for expected recovery of CWTs in broodstock

Indices

a, aa	Index for total age (a or aa = 3 to 5)
s	Index for fishery (time-area) strata or escapement (male, female, small) strata
i	Index for individual fish in GSI sample from fishery (i=1 to N_{gsi})

Table 2. Equations used to determine expected values and uncertainty (sampling and prior distributions) in parameters and derived variables of the Bayesian escapement estimation model. See Table 1 for definitions of model parameters, constants, and indices.

Expected Values

$$(1.1) \quad W_E = \sum_a W_{E,a}$$

$$(1.2) \quad W_{E,a} = W_{F,a} \frac{C_{E,a} + C_{B,a}}{C_{F,a}}$$

$$(1.3) \quad W_{F,a} = \sum_s W_{F,a,s}$$

$$(1.4) \quad W_{F,a,s} = N_{F,s} P_{F,s} \sum_a P_{F,a,s} P_{S,a,aa}$$

$$(1.5) \quad P_{F,s} = \frac{N_{W,s}}{N_{GSI,s}}$$

$$(1.6) \quad N_{W,s} = \sum_{i=1}^{N_{GSI,s}} x_{i,s}$$

$$(1.7) \quad P_{F,a,s} = \frac{N_{W,a,s}}{\sum_a N_{W,a,s}}$$

$$(1.8) \quad N_{W,a,s} = \sum_{i=1}^{N_{GSI,s}} x_{i,a,s}$$

$$(1.9) \quad P_{S,a,aa} = \frac{n_{a,aa}}{\sum_{aa} n_{a,aa}}$$

Table 2. Con't.

$$(1.10) \quad C_{F,a} = \sum_s C_{F,a,s}$$

$$(1.11) \quad C_{F,a,s} = \frac{m_{F,a,s}}{\lambda_{F,s}}$$

$$(1.12) \quad C_{E,a} = \sum_s C_{E,a,s}$$

$$(1.13) \quad C_{E,a,s} = \frac{m_{E,a,s}}{P_{E,s} P_{AFS,s} \lambda_{E,s}}$$

$$(1.14) \quad P_{E,s} = \frac{r_{E,s}}{R_{E,s}}$$

$$(1.15) \quad P_{AFS,s} = \frac{N_{AFS,s}}{N_{E,s}}$$

$$(1.16) \quad C_{B,a} = \sum_s C_{B,a,s}$$

$$(1.17) \quad C_{B,a,s} = \frac{m_{B,a,s}}{\lambda_{B,s}}$$

Table 2. Con't.

Sampling Distributions

$$(2.1) \quad x_{i,s} \sim dbern(p_{W,i,s})$$

$$(2.2) \quad N_{W,s} \sim dbin(P_{F,s}, N_{GSI,s})$$

$$(2.3) \quad N_{W,a,s} \sim dmulti(P_{F,a,s}, \sum_a N_{W,a,s})$$

$$(2.4) \quad n_{a,aa} \sim dmulti(P_{S,a,aa}, \sum_{aa} n_{a,aa})$$

$$(2.5) \quad W_{F,a,s} \sim dpois(N_{F,s} P_{F,s} \sum_a P_{F,a,s} P_{S,a,aa})$$

$$(2.6) \quad m_{F,a,s} \sim dbin(\lambda_{F,s}, C_{F,a,s})$$

$$(2.7) \quad m_{E,a,s} \sim dbin(P_{E,s} P_{AFS,s} \lambda_{E,s}, C_{E,a,s})$$

$$(2.8) \quad r_{E,s} \sim dbin(P_{E,s}, R_{E,s})$$

$$(2.9) \quad N_{AFS,s} \sim dbin(P_{AFS,s}, N_{E,s})$$

$$(2.10) \quad m_{B,a,s} \sim dbin(\lambda_{B,s}, C_{B,a,s})$$

Table 2. Con't.

Prior Distributions

$$(3.1) \quad P_{F,s} \sim dbeta(1,1)$$

$$(3.2) \quad P_{F,a,s} \sim ddirch(p_{a,\dots,Nages} = .01)$$

$$(3.3) \quad P_{S,aa} \sim ddirch(p_{a,aa} = prior_data)$$

$$(3.4) \quad P_{E,s} \sim dbeta(1,1)$$

$$(3.5) \quad P_{AFS,s} \sim dbeta(1,1)$$

$$(3.6) \quad C_{F,a} \sim dunif(1, p_F^1) + m_{F,a}$$

$$(3.7) \quad C_{E,a,s} \sim dunif(1, p_E) + m_{E,a,s}$$

$$(3.8) \quad C_{B,a,s} \sim dunif(1, p_B) + m_{B,a,s}$$

¹ $p_F = 5 * m_F / \lambda_F$ for NBC fishery where $\lambda_F < 1$ (thus there is uncertainty in C_F), $p_F = 1$ for Albion test fishery where $\lambda_F = 1$ (thus no uncertainty in C_F).

Table 3. Data used to estimate uncertainty in age assignments for the South Thompson age 0.3 Chinook aggregate in the Bayesian escapement model. The ageing error matrices represent the number of fish assigned age ‘a’ (based on scale reading) whose actual age was ‘aa’ (as determined from CWTs). The top matrix is based on fish from the South Thompson aggregate ($n_{a,aa}$ from Table 1), while the lower matrix is based on data from a ocean-type stocks as summarized in McNicol and MacLellan (2010). Prior information on age assignment error used in the model is based on the lower matrix (prior sample size in eqn. 3.3 of Table 2).

Stock	Estimated Age ('a')	Known Age ('aa')		
		3	4	5
South Thompson (data)				
	3	29	1	0
	4	0	175	1
	5	0	1	11
Ocean-type Stocks from McNicol and MacLellan (prior)				
	3	93	2	0
	4	1	126	2
	5	0	2	25

Table 4. Summary of Coded Wire Tag recovery (a) and Genetic Stock Identification (b) data used to estimate Chinook escapement for the Southern Thompson ocean-type aggregates (SoTh) in 2010 and 2011. Data are summarized by fishery (Albion 8'' net only, Albion all nets, Northern BC Troll, and South East Alaska) and age (3₁,4₁,5₁).

a) Coded Wire Tag Recoveries

2010

Age	Escapement		Fisheries		
	Lower Shuswap	Middle Shuswap	Albion 8''	Albion	NBC Troll
3	164	0	0	1	28
4	244	0	3	8	36
5	2	0	0	0	1
Total	410	0	3	9	65

2011

Age	Escapement		Fisheries		NBC Troll
	Lower Shuswap	Middle Shuswap	Albion (Lower Shuswap Only)	Albion (Lower + Middle Shuswap)	
3	74	9	0	1	4
4	377	1	3	3	23
5	0	0	0	0	0.25
Total	451	10	3	4	27.25

Table 4. Con't.

b) Genetic Stock Identification Data

2010

South Thompson Aged

Age	Albion 8"	Albion	NBC
3	2	15	13
4	451	727	547
5	36	50	69
Total	489	792	629
Total Catch	1,244	2,160	90,213
Sampling Rate	1.00	1.00	0.36
GSI Samples	1,233	2,136	1,463
SoTh GSI Samples	561	913	629
SoTh Proportion	0.45	0.43	0.43

2011

South Thompson Aged

Age	Albion	NBC
3	11	3
4	696	278
5	141	44
Total	848	325
Total Catch	2,340	74,660
Sampling Rate	1.00	0.25
GSI Samples	2,291	1,236
SoTh GSI Samples	987	281
SoTh Proportion	0.43	0.23

Table 5. Escapement estimates for the South Thompson ocean-type Chinook aggregate in 2010 and 2011 based on different information sources. The mean, coefficient of variation (CV) and the lower (LCL) and upper (UCL) 95% credible intervals from the Bayesian model are shown, along with the maximum likelihood estimates (MLE) from the analytic model (Table 2, 1.1-1.17). Age-specific estimates, the sum of age-specific estimates (Total), and an alternate estimate of the total based on aggregating data across ages prior to estimation (aggregated) are shown.

a) 2010 based on Lower Shuswap Escapement Data Only

Albion 8" Net Only

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	1,549	0.75	0	4,306	
4	77,340	0.08	64,290	87,820	100,466
5	426	0.38	202	827	
Total	77,340	0.08	65,810	87,820	
Aggregated	137,500	0.07	120,500	157,400	183,470

Albion All Nets

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	3,968	0.36	1,689	7,129	6,824
4	54,570	0.07	47,250	62,840	61,120
5	607	0.38	293	1,236	
Total	59,150	0.07	51,360	67,770	
Aggregated	90,790	0.06	80,220	101,600	99,686

NBC

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	4,534	0.33	2,195	7,975	3,933
4	199,100	0.15	149,700	264,900	199,251
5	9,590	0.57	2,499	23,620	6,943
Total	213,200	0.14	164,000	278,000	210,128
Aggregated	215,500	0.11	174,500	262,100	212,965

Table 5. Con't.

Albion 8" Net Only + NBC

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	4,503	0.33	2,188	4,282	3,945
4	193,700	0.15	142,200	191,600	196,374
5	8,535	0.49	2,866	7,777	7,011
Total	214,400	0.12	172,500	266,700	212,483

b) 2011 based on Lower Shuswap Escapement Data Only

Albion All Nets

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	1,911	0.42	703	3,740	
4	123,100	0.06	109,000	137,400	161,515
5	1,155	0.25	694	1,820	
Total	126,100	0.06	111,600	140,500	
Aggregated	178,700	0.06	159,800	198,900	236,026

NBC

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	2,336	0.65	485	6,173	1,858
4	135,700	0.19	94,320	193,600	134,668
5	8,243	0.65	2,271	22,210	
Total	146,300	0.18	102,800	206,800	
Aggregated	163,500	0.17	117,000	225,900	161,610

Albion + NBC

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	2,519	0.68	542	6,990	1,953
4	142,100	0.20	97,330	206,000	135,515
5	8,289	0.65	2,354	21,850	
Total	152,900	0.19	108,000	217,600	
Aggregated	170,200	0.18	118,300	239,900	168,106

Table 5. Con` t.

c) 2011 based on Lower + Middle Shuswap Escapement Data

Albion All Nets

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	1,243	0.41	435	2,466	1,856
4	124,300	0.06	110,700	139,800	161,781
5	1,973	0.22	1,230	2,883	
Total	127,500	0.06	114,100	142,800	
Aggregated	149,500	0.06	132,800	167,000	183,612

NBC

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	2,816	0.68	564	7,654	2,258
4	132,400	0.19	92,910	189,300	134,890
5	10,520	0.50	3,737	23,870	
Total	145,700	0.18	103,900	204,600	
Aggregated	163,500	0.17	116,500	229,000	161,694

Albion + NBC

Age	Mean	Bayesian Model			Analytic
		CV	LCL	UCL	MLE
3	2,939	0.62	710	7,564	2,235
4	137,400	0.18	94,410	192,600	135,739
5	11,280	0.48	3,883	23,520	
Total	151,600	0.17	109,400	207,600	
Aggregated	171,000	0.17	121,100	238,700	168,194

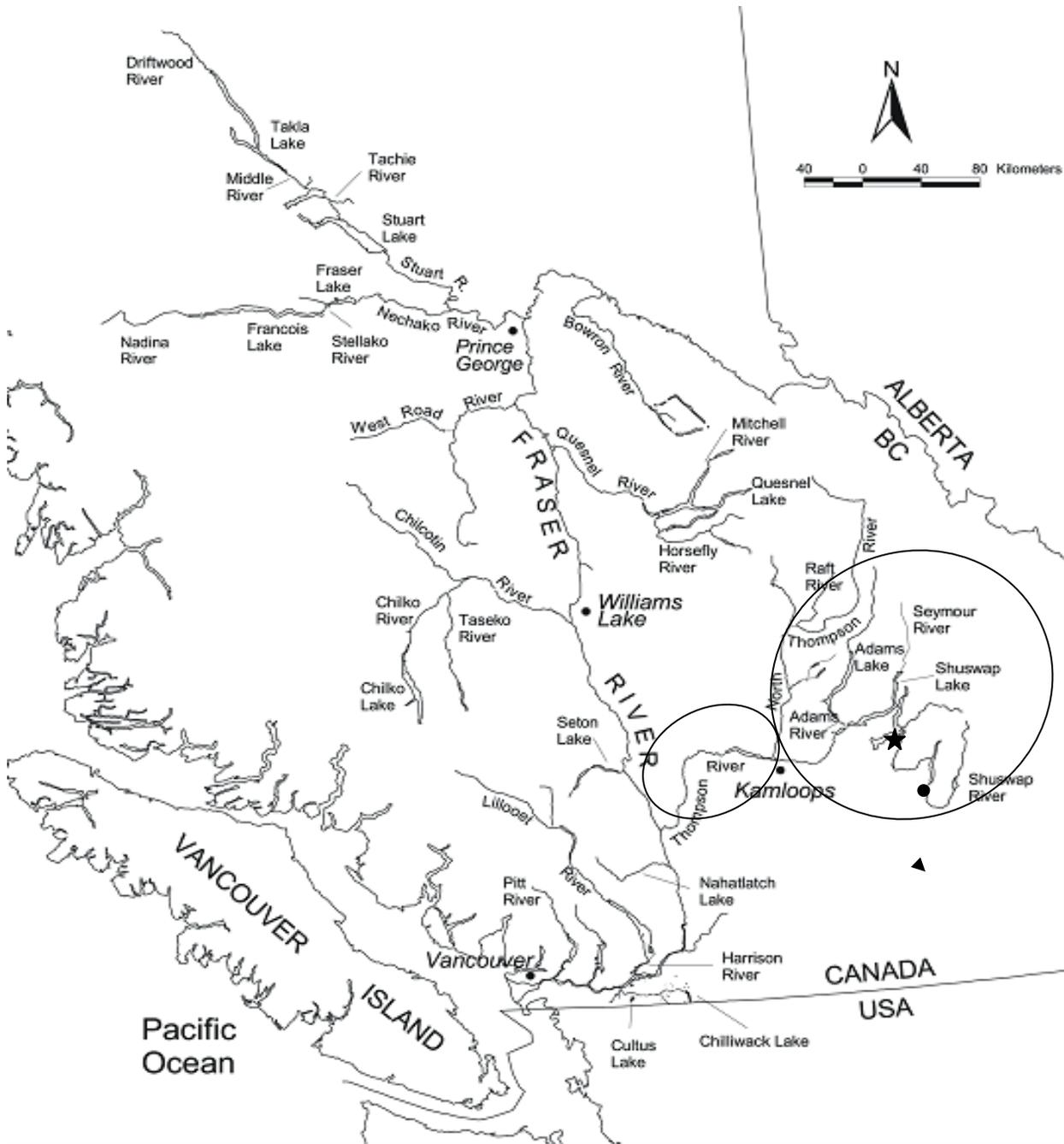


Figure 1. Map of Southern British Columbia showing the location of the major streams used by the South Thompson 0.3 Chinook aggregate stock (circled) and the location of the Lower and Middle Shuswap indicator stocks (star and filled circle, respectively). The Albion test fishery is located near Vancouver and the Northern BC troll fishery is located well north of Vancouver Island and is not shown on the map.

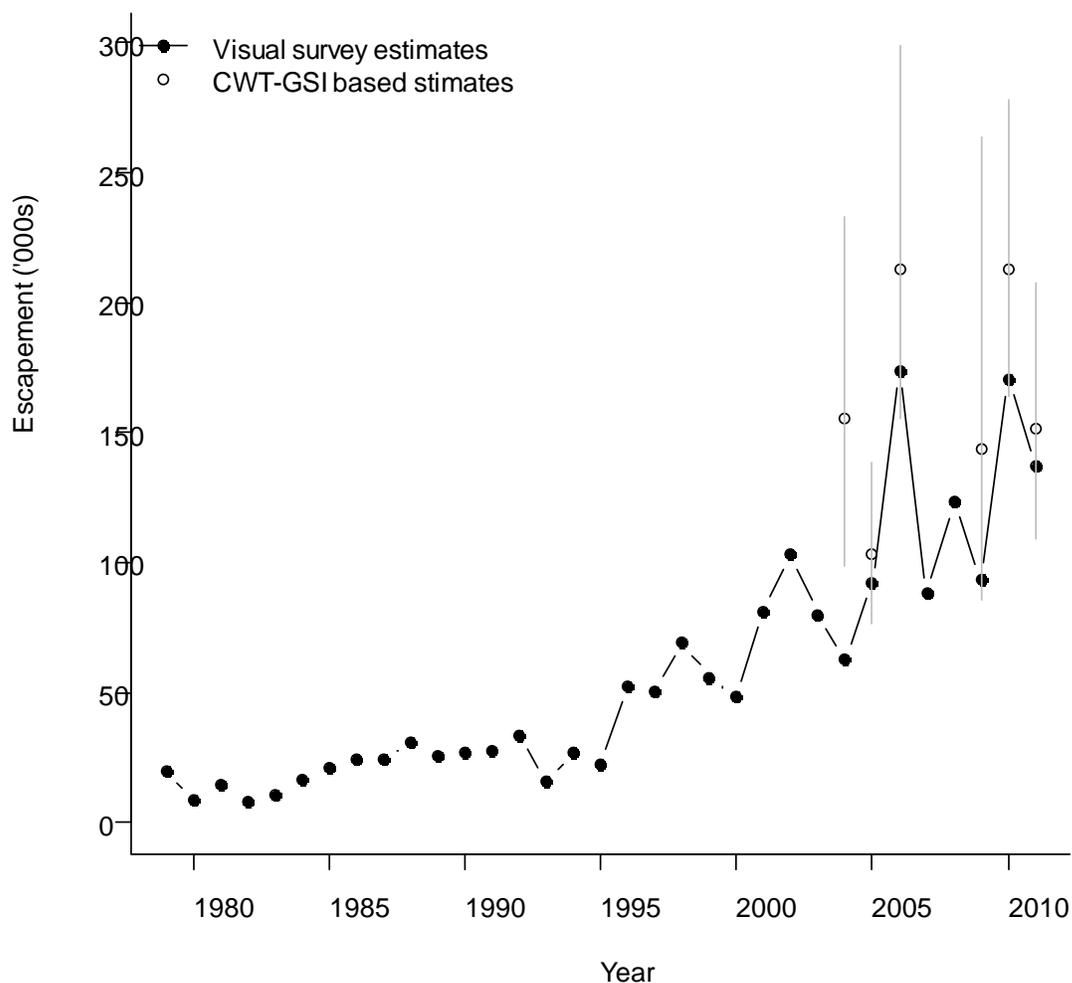


Figure 2. Historical trend in the estimated spawning escapement of the South Thompson 0.3 aggregate based on visual surveys (R. Bailey, Fisheries and Oceans Canada, unpublished data) and GSI-CWT based estimates from the Bayesian model presented here (2010 and 2011) and in previous reports (2004, 2005, 2006, 2009) using data from the NBC troll fishery (open points and vertical lines represent the posterior means and 95% credible intervals, respectively).

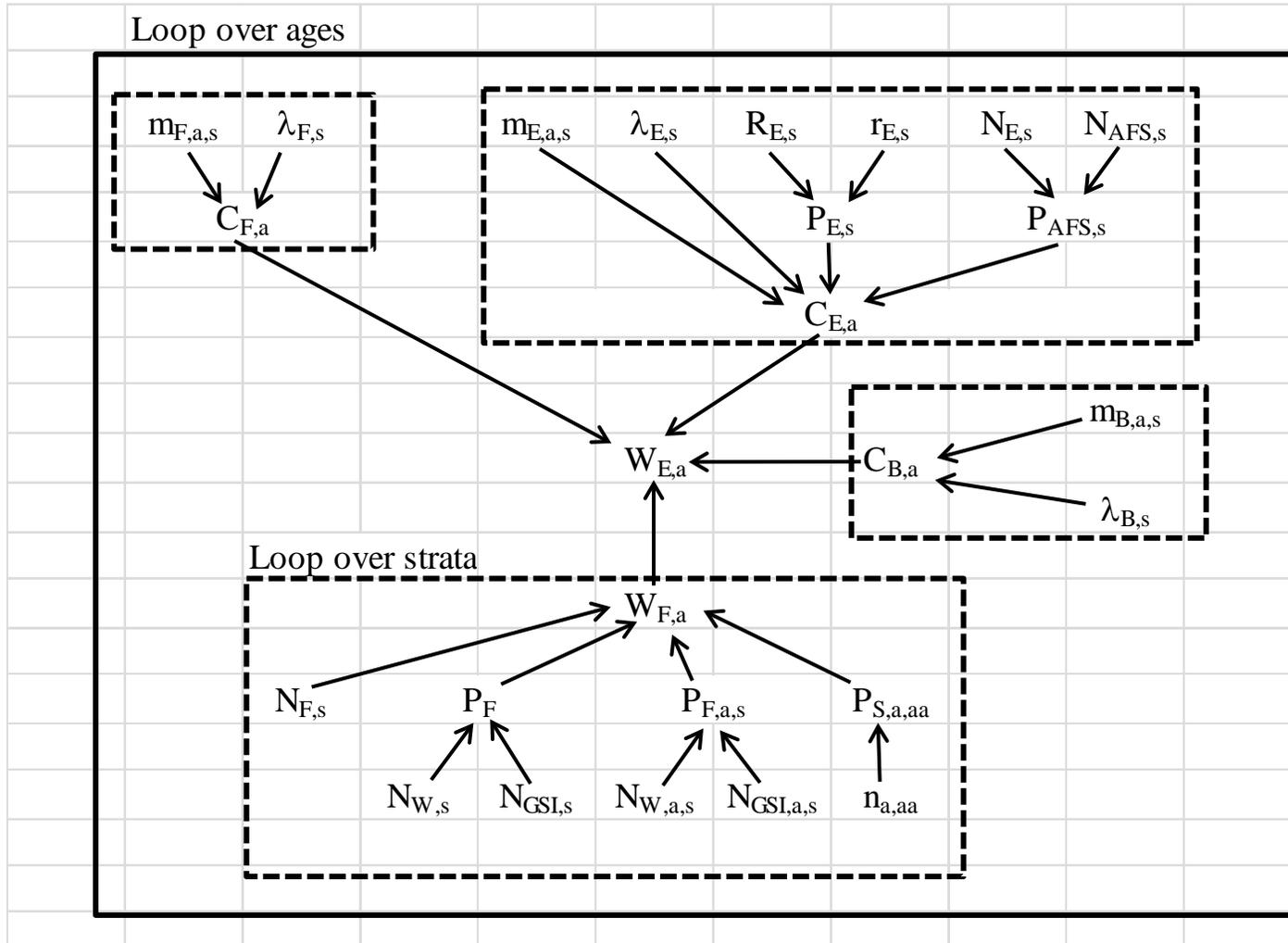


Figure 3. Visual representation of the Bayesian model used to estimate escapement of the South Thompson 0.3 Chinook aggregate. Variables are defined in Table 1. Arrows indicate conditional dependencies; the boxes represent repetition of structure over age (a) and fishery or escapement estimation (s) strata.

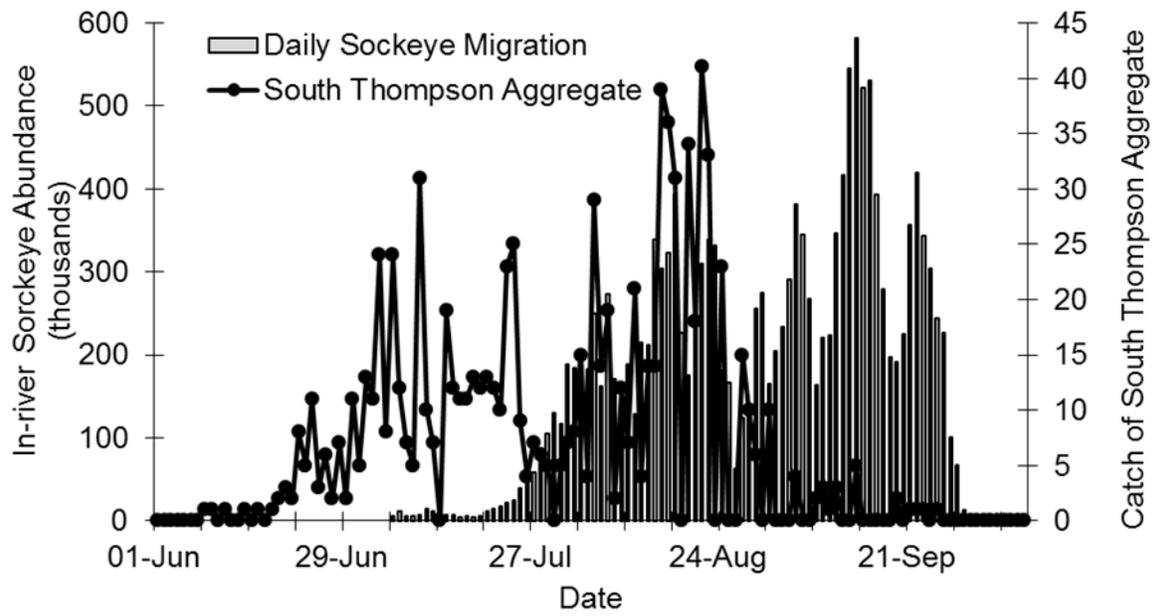


Figure 4. Comparison of the abundance of Fraser River sockeye at Mission, BC with the catch of the South Thompson Chinook aggregate in the Albion test fishery.

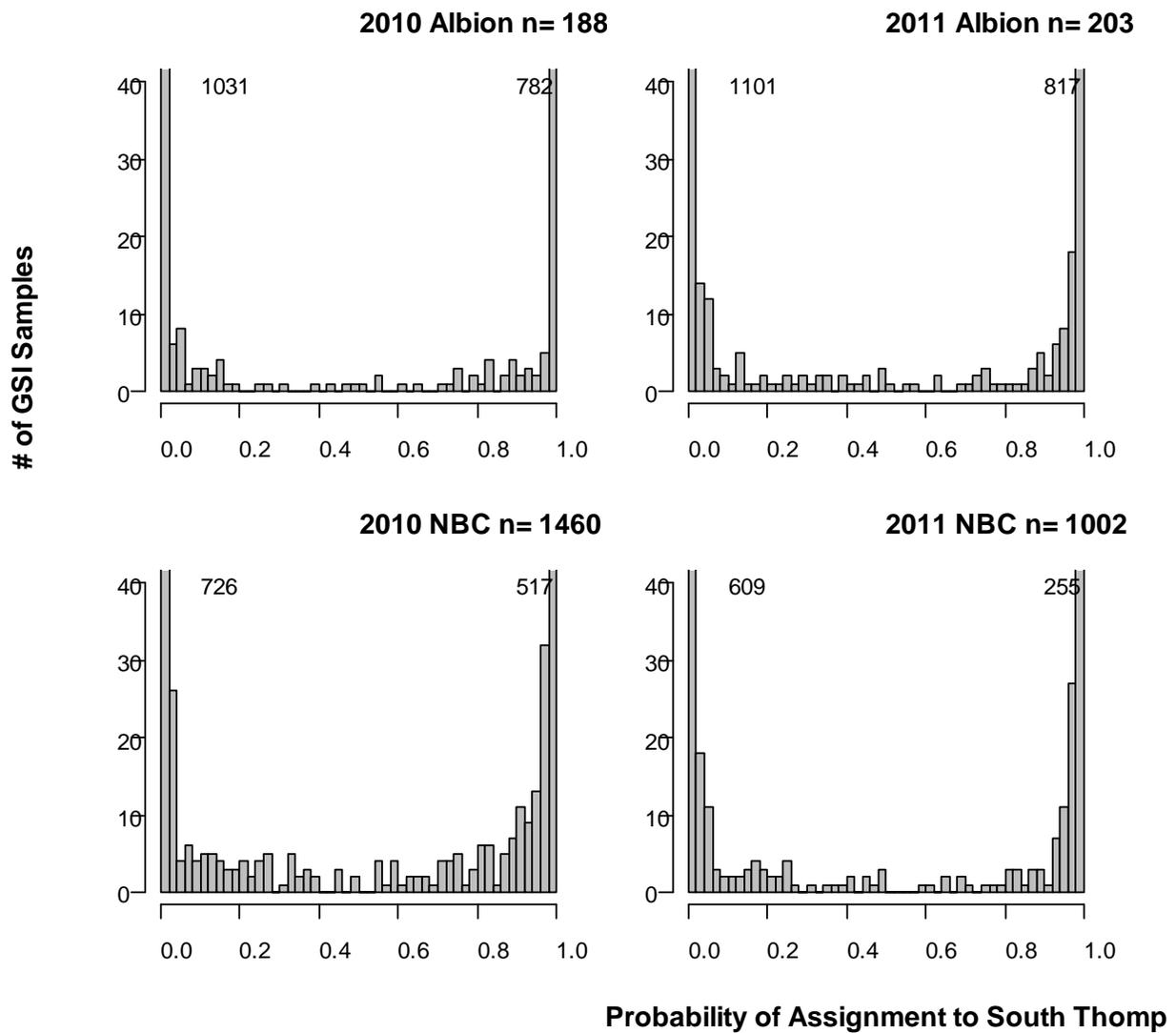


Figure 5. Frequency distributions of the number of samples with different probabilities of assignment to the South Thompson Chinook ocean-type aggregate based on genetic stock identification (GSI) data collected from the Northern BC troll fisheries and the Albion test fishery, 2010-2011. ‘n’ specifies the total GSI sample size for each year. Note that the y-axes do not extend to the full range of the data and frequencies for probabilities <0.02 (first bar) and > 0.098 (last bar) are cut-off (frequencies for these cases are shown by the text at the top of the bars).

Appendix A

Example Model that Incorporates Data from Multiple Fisheries

The code below is a simple example to highlight the key issues associated with combining data from multiple fisheries (e.g. SEAK, NBC, Albion) into our Bayesian Chinook model to estimate a fisheries-weighted average escapement estimate. The example model below estimates the abundance of unmarked fish (N) from two populations based on independent mark-recapture estimates. It assumes that each N comes from a hyper distribution with mean μ and precision τ (the distribution actually predicts $\log N$, which is then transformed into N). When τ is low (low precision), the N estimates are almost identical to a model where they are estimated completely independently (see table below). However, when τ is high then the N estimates get closer to each other. The population with less information moves a lot more from its independent estimate relative to the one with more information, and the across-population estimate is much closer to the latter.

Data and Estimates based on Independent Models						
	Data			Means		
Population	M	r	u	p	N	CV of N
1	20	10	50	0.5	104	0.29
2	2000	1000	100	0.5	200	0.10
HBM Results						
	tau = 1			tau = 100		
Population	Mean N	CV of N		Mean N	CV of N	
1	107	0.26		170	0.16	
2	199	0.10		189	0.10	
SuperN	192	0.02		179	0.13	

The Model

```
mu~dnorm(0,1.0E-6)           #hyper prior on log of super population estimate (~ a wgt'd avg.)
for (i in 1:2) {
  p[i]~dbeta(1,1)            #uninformative prior on capture probability p
  r[i]~dbin(p[i],M[i])       #binomial likelihood to estimate capture probability p given #recaps (r) and
                             # of marks released (M)
  expu[i]<-N[i]*p[i]         #expected number of unmarked fish captured on 2nd pass given N and p
  u[i]~dpois(expu[i])        #This makes N[i] a stochastic node which allows HBM to work
  logN[i]~dnorm(mu,tau)      #log N for each population comes from a common (super) distribution
  N[i]<-exp(logN[i])         #transform log N

  #This form won't work, so must solve for Cf rather than We in Chiook model
  #N[i]<-u[i]/p[i]           #doesn't work cause multiple definitions of N[i]
}
SuperN<-exp(mu)             #This is the single estimate based on information across populations
```

The problem with implementing this type of approach in the Chinook model is that W_E is a derived variable based on multiple data sources. It is not possible for W_E to be calculated as a function of C_E , C_B , and W_F , and also to a stochastic variable coming from the common distribution of W_E 's across fisheries. We have rearranged the code to solve for C_F to avoid this problem. However, to date, we have not been able to implement the model in WinBugs because the order of the binomial for C_F is based on the estimated order of the binomials for C_E , C_B , and W_F . This creates a problem for WinBugs (“unable to choose updater for node...”) which we have not been able to work around to date. We plan on consulting with more experienced WinBugs users to find a solution to this problem. Alternate modeling environments (e.g. STANS) may also not have these limitations.

Relevant URL's:

<http://users.aims.ac.za/~mackay/BUGS/Manuals/Tips%20and%20Troubleshooting.html>
<http://andrewgelman.com/2012/08/a-stan-is-born/>