In-River Backwards Run Reconstruction of Fraser River Sockeye Fisheries from 2002 - 2009 and Initial Validation of the Fraser River Salmon Management Model (FRSMM)

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Abstract

Management of Fraser River sockeye is becoming increasingly complicated due to environmental and fishery change. To assist managers I develop an in-river backwards run reconstruction to provide Conservation Unit (CU) specific harvest rates and arrival abundance at Steveston from 2002 – 2009. Annual total harvest rates vary from a low of 4.5% (2009) to a high of 34.7% (2004), while CU specific harvest rates vary from a low of 0.1% for Chilliwack (2007) to a high of 45.3% for the Early Summer Shuswap complex (2004). Harvest rates of Cultus Lake sockeye, a population of concern, never exceed 12.9% (2006). I then provide a coarse validation of the Fraser River Salmon Management Model (FRSMM), and find that FRSMM arrival timing at Mission is simulated to within +/- 2.5 days for 90% of CUs at the 50th percentile, while FRSMM harvests can differ by up to +/-30%.

Keywords: Fraser sockeye; simulation; stock assessment; model validation; Wild Salmon Policy

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1: Run Reconstruction

1.1 Abstract

We develop an in-river run reconstruction model for Fraser River sockeye to estimate harvest rates, catch and arrival abundances at Steveston, B.C. for each of the 23 Conservation Units (CUs), which is the new level of salmon management defined within Canada's Wild Salmon Policy in 2005. The reconstruction incorporates estimates of migration rate, harvest and escapement (2002 - 2009), and en-route mortality for all 23 management areas within the Fraser River watershed. Across all years, fishing areas, and user groups, catch is dominated by both Shuswap Complex CUs (Early Summer and Late), and the Summer-run CUs including Chilko, Fraser, and Quesnel. These five CUs make up 77%, 86%, and 88% of harvest for First Nations, commercial and recreational sectors respectively, and 80% of the overall average annual catch. Four Summer-run CUs (Chilko, Fraser, Quesnel and Stuart) and two Late-run CUs (Lillooet and Shuswap Complex) comprise 82% of cumulative arrival abundance at Mission over the 8 years of our study. Reconstructed CU harvest rates range from 1% (Chilliwack, 2007) to approximately 45% (Shuswap Complex Early Summer, 2004), total annual reconstructed abundance ranges from 15,165,222 (2002) to 1,355,211 (2009), and estimated catch ranges from 3 (Cultus, 2004) to 1,083,144 (Quesnel – S, 2002). This model is the first to provide CU-specific estimates for Fraser River sockeye which managers can use to inform future fisheries decisions under the Wild Salmon Policy.

1.2 Introduction

Management of Fraser River sockeye fisheries is increasingly challenged by environmental and fishery change (Cass et al. 2004) and this has led fishery managers to adopt a strategy aimed at limiting total mortality rates due to both environmental (e.g., elevated water temperatures in the Fraser River) and fishery (e.g., increased First Nation fisheries for food, social, and ceremonial purposes) related causes (Pestal et al. 2008; McRae and Pearse 2004). According to Canada's Wild Salmon Policy (DFO 2005) managers must control fishery related mortality so as to achieve target spawning escapement benchmarks for 23 individual sockeye salmon populations (henceforth referred to as conservation units or CUs). Such a task is made difficult because of the so-called "mixed-stock" problem (Collie et al. 1990) in which managers cannot target fishing mortality on 23 individual stocks because stocks that migrate together must be harvested together. Furthermore, fishery managers can only control fishery related mortality by regulating fisheries at specific times and areas along the sockeye homeward migration route. These management objectives stand in contrast to historical approaches in which DFO managed fisheries so as to achieve aggregate escapement goals for four mixed-stock groups, Early Stuart, Early Summer, Summer and Late (English et al. 2005; Pacific Salmon Commission 2005). Such an increase in management complexity demands robust quantitative approaches in support of in-season decision-making.

Adopting a finer-scale approach to management of sockeye salmon fisheries in the Fraser River requires reliable estimates of historical harvest rates that are specific to individual CUs, times within the season, and fishing areas along the river. Such information, along with knowledge of sockeye salmon migration behaviour (e.g., arrival patterns and in-river movement rates), is needed to develop and evaluate the expected effectiveness of proposed fishing plans (i.e., pre-season planning models Starr 1988). Backwards run reconstruction is an assessment method that can provide this information using only catch, escapement, and migration rate data (Templin et al. 1996).

Run reconstruction methods have been used on the West Coast for over 60 years to provide estimates of population-specific exploitation rates, fishery catch, and arrival abundance of Pacific salmon (English et al. 2007; Starr and Hilborn 1988). Run reconstructions can operate as either a backward, or a forward model, with the former used as a post-season assessment method to provide population specific abundance and exploitation rate estimates, and the latter used for pre-season planning and in-season assessment. We chose to develop a backwards reconstruction model, because the purpose of this project is to estimate historic CU specific abundances and in-river harvest rates.

Backwards reconstructions use information on CU-specific escapement counts, residence times within discrete management areas throughout their migration, and the reported catch for each management area (Starr and Hilborn 1988; Cave and Gazey 1994; English et al. 2007). Reconstructions are initialized with CU-specific daily escapement to terminal areas (i.e. spawning grounds). These fish are moved backward in both time and space (downriver) according to deterministic residence times in each management area. Catches obtained in each downstream management area are sequentially added to the time-and area specific abundances as the population move downriver (English et al. 2007; Starr and Hilborn 1988). This process is repeated until all fish have been backed down the river, through all relevant fisheries, to the first fishery area.

Forward run reconstruction calculates catch and escapement using forecasts of arrival abundance and timing to the first fishery area, along with estimated residence times and exploitation rates in each management area to sequentially move fish forward through fisheries in space and time to the last area modeled (Cave and Gazey 1994). By altering harvest rates among areas and times, fishery managers can evaluate alternative pre-season harvest plans to determine how CU-specific escapement goals, and catch allocations can best be met. Within a season, managers may refine the pre-season plan using the forward reconstruction in combination with more accurate timing and abundance estimates from test fisheries (Branch and Hilborn 2010; Cave and Gazey 1994; Springborn et al. 1998).

Modifications on the details of run reconstruction have recently been made to meet area and management specific needs. For instance, sockeye returns to Bristol Bay, Alaska are highly compressed temporally, with up to 80% of harvest occurring over only a two week period (Helton 1991). Given interannual variability of run-timing common with Bristol Bay sockeye, Flynn et al (2006) incorporated process error into a run reconstruction to estimate indices of run-timing. Branch and Hilborn (2010) modify a forward reconstruction to incorporate age and spawn area data to model “groups” of sockeye in Bristol Bay. These specific modifications are not necessary for our purposes as historical run-timing parameters of Fraser River sockeye are relatively well established through annual test fisheries, and are already modeled in “groups” (i.e. CUs), with the majority of fish being of one age class.

Fraser River sockeye sometimes experience extremely high mortality in-river (en-route mortality) when exposed to extreme summer environmental conditions (high temperature, high flow) (Macdonald et al. 2000; Macdonald 2000), or when they begin their up – river migration earlier than their historical average (Cooke et al. 2004). In 2001, estimates of en-route mortality exceeded 90% in many stocks (Cooke et al. 2004), and since the mid 1990’s, over four million Late-run sockeye have died en-route to spawning grounds (Crossin et al. 2007). Accounting for en-route loss in the reconstruction is therefore critical for accurate estimation of catch and harvest rates.

Direct sampling of catches and analysis of DNA or scale data are empirical alternatives to run reconstruction for estimating catch composition for mixed-stock fisheries (Gable and Cox-Rogers 1993; Beacham et al. 2004). These methods have been used to estimate stock composition for all major marine and lower Fraser River sockeye fisheries; however representative samples for the smaller in-river fisheries are more difficult and costly to obtain because of the broad spatial and temporal distribution of these fisheries. Direct identification methods also assume that fish sampled have been selected randomly and are representative of both catch and availability (i.e., if a stock wasn’t sampled, it wasn’t available), whereas run reconstructions rely on assumptions of stock availability (i.e. if we don’t think a stock is available in a fishery, it can’t be caught) (Gable 2002). Direct identification methods also rely on biological data such as scale or DNA (tissue) samples, making historic analyses impossible where such samples are not available. Run reconstructions do no rely on scale or DNA samples, and therefore are the only alternative where this data is lacking. There is conflicting evidence when comparing performance of run reconstructions to methods like scale-based Discriminant Function Analysis (DFA). Starr and Hilborn (1998) found comparable estimates of catch by stock between the two methods, whereas Gable (2002) found that estimates of stock composition derived from run reconstruction models differ by as much as 50% from DFA methods. Stock discrimination methods also tend to overestimate the proportions of stocks composing less than 5% of the run (Gable 2002), which is a fundamental concern when managing stocks of low abundance.

We developed a run reconstruction that models 23 unique CUs of Fraser River sockeye through 23 management areas. A unique aspect of our method is that we incorporate estimates of en-route mortality into abundance, harvest, and harvest rate estimates. The specific objectives of this study were to provide CU-specific estimates of harvest (many CUs currently have no harvest estimates), arrival abundance, and harvest rates. This study is the first to provide in-river harvest rate estimates at the CU level for Fraser River sockeye that can help managers to assess their ability to meet conservation objectives on weak stocks (e.g. Cultus Lake), assess expected performance of historic and future management decisions in the context of the WSP (e.g. how historic fishery openings affected the harvest of the Takla/Trembluer CU), and generate stock-recruitment data at the CU level (e.g. establish recruits per spawner for Widgeon), which has not been possible due to a lack of estimates of CU specific harvest. Here, we use the term harvest rate to refer to the proportion of fish harvested within a specific area (management area, or the Fraser River watershed).

1.3 Methods

1.3.1 Data

The run reconstruction model includes all Fraser River sockeye CUs for which escapement estimates are available (Table 1). Historical commercial, First Nation, and recreational harvest for each of the 23 management areas along the Fraser River was provided by the Pacific Salmon Commission (PSC) and DFO while escapement estimates were provided by DFO (Grant et al. 2011). LGL Limited (Karl English) provided residence times inferred from radio telemetry programs that track the migration rates of selected sockeye (larger than 55 cm) captured and removed at random from their fishwheel operating near-shore at Mission, B.C., or captured and released in marine areas using seine nets. There is some year to year variability in the CUs subject to tagging as well as migration rates, but tagged sockeye are generally from all four stock timing groups.

1.3.2 Fishery Definitions and Harvest

The 23 management areas along the Fraser River include 16 within the mainstem, 4 within the Thompson River Watershed, and one area for each of the Nechako, Stuart, and Chilcotin rivers (Figure 1, Table 2). All CUs are exposed to harvest at the Fraser River mouth, whereas a declining number of CUs are exposed upriver, as different CUs migrate off the mainstem to their tributary streams and spawning grounds.

First Nations fisheries occur in all management areas throughout the Fraser, and therefore represent the majority of harvest taken above Hope, B.C. Harvest is self-monitored and reported for each management area through observers stationed at major access sites and boat launches. Information collected is considered accurate because there is no information available on possible biases in reported harvest (Macdonald et al. 2010). Commercial harvest occurs exclusively by gillnet in Area 29 (Figure 1) and daily catch is monitored and recorded through a number of programs operated by DFO or the PSC. The commercial fishery effort is monitored via over flights, charter patrols, and the Canadian Coast Guard. Harvest is recorded through phone-in and logbook programs, (fish) plant surveys, fish slips, and on-water catch hails (Collicutt 2007). Harvest phone-in and logbook programs are unverified, fisher-reported catch, and are therefore considered by some resource managers to be observationally biased because of less than 100% compliance. Fish slips are required by DFO for all commercial landings, and are to be completed by the fisher and submitted within seven days of offloading. Due to problems with compliance, time lags and less than 100% coverage, the final harvest estimates for sockeye have not been derived from sale slip records since 1995 (DFO 2009). More independent data, which is the source of commercial harvest used in this study, is collected by the PSC, which surveys fish plants following the closure of a fishery to get landed catch information (Collicut 2007).

Recreational harvest estimates are provided by DFO for the area from Mission to Hope, where the majority of recreational effort is applied. Annual creel surveys provide estimates of daily effort and fish harvested per hour of effort (HPUE). HPUE and daily effort (adjusted for differences in effort on weekends and weekdays for all years after 2003) are then expanded to estimate daily recreational catch for each year (Schubert 1992; Schubert 1995).

1.3.3 Escapement estimation by CU

Recent reviews of Fraser River escapement data have identified the need to fill gaps in the annual escapement records or expand available estimates to account for escapement to unmonitored streams (English et al. 2006; 2007; 2009; Grant et al. 2010). While the number of gaps in the escapement time series for Fraser sockeye is small relative to other salmon species and watersheds, there are substantial differences in the quality and quantity of escapement estimates between the various spawning enumeration areas within a CU. One way to minimize the impact of year-to-year and stream-to-stream variability in data reliability is to use index streams to provide the baseline trends in escapement by cycle year. Gaps in the time series of estimates for the non-index streams can then be filled to account for potential escapement to all non-index streams accounted. It is important to conduct these analyses by cycle year for Fraser River sockeye because the contribution of the various spawning areas within each CU can vary substantially between the cycle lines. The traditional approach of simply summing all the available escapement estimates for each Fraser sockeye stock or CU will invariably lead to misleading trends between years and underestimation of the escapement for CUs with multiple spawning locations and/or enumeration sites. Grant et al. (2011) use a gap-filling method to adjust escapement to account for year-to-year, and stream-to-stream variability in assessment effort and quality. Gaps are filled based on the proportion each (missing) site contributes to the total CU abundance, when averaged across years for which data are available. We refer the reader to Grant et al. (2011) for documentation of methods. Across all eight years and CUs, escapements were adjusted by less than +/- 10% from observed estimates in 70% of the cases, and by +/- 100% or more in 4.5% of the cases (Table 3). The Kamloops (True Late) and Shuswap Complex (True Late) CUs are the only cases where the adjusted escapement changed by +/- 100% from observed estimates more than once. In 2002 the adjusted escapement of the Lillooet CU is ~235,000% larger than the observed estimate due to the fact that in that year, escapement to the Birkenhead River (the largest spawning area within the Lillooet CU) was not assessed at all.

1.3.4 Escapement timing

Reliable information on spawning area arrival timing is an essential component of all run reconstruction models. With the exception of spawning fences, DFO does not regularly assess arrival timing to the spawning grounds (Bailey et al. 2000); consequently, CUs do not have consistent or reliable estimates of arrival timing. To fill this information gap, we added in-river travel times to spawning grounds (estimated from radio telemetry studies) to escapement profiles at Mission as estimated by the PSC. Escapement profiles generated at Mission use both split beam and single beam hydroacoustic techniques, while two downriver gillnet test fisheries and two fishwheels, provide information on species and stock composition for up to 13 indicator stocks, from which we estimate CU specific arrival at Mission (PSC 2009).

All sockeye within the Early Stuart, Early Summer, and Summer-run timing groups arrive at Mission in a pattern similar to a normal probability density function, and were modelled as such. Late-run Fraser River sockeye, however, are unique because the timing group is composed of two distinct classes, the "Lates" and the "True Lates" (PSC, 2008). The former group include all CUs that spawn in the Lillooet River system (Lillooet, Birkenhead and Harrison (D/S)) and, like CUs from all other run timing groups, return to the river in a pattern similar to a normal probability density function (Cave and Gazey 1994). The True Late group, however, includes all other late timed CUs (Seton, Shuswap, Harrison (U/S), Cultus, Widgeon, Lower Fraser and Kamloops), which return to the river in a multimodal distribution pattern (Hague and Patterson 2007). Earlier than expected river entry of some True Late sockeye has resulted in increased en-route mortality of those early entrants, which also migrate at a faster rate than later entrants (English et al. 2005). For these reasons, True Late Run CUs were modelled as three overlapping normal distributions referred to as “Late - Early” (Late – E), “Late - Middle” (Late – M), and “Late - Late” (Late – L), each with a different migration rate and estimate of en-route mortality. CU specific timing parameters at Mission and spawning grounds for all years are provided in Tables 4 – 11.

1.4 Movement

Migration rates of some Fraser River sockeye stocks have been assessed using radiotelemetry since 2002 (English et al. 2005). Radio tags were first applied to Summer-run and Late-run Fraser sockeye in 2002 following two years of high pre-spawn mortality of Weaver Creek sockeye (PFRCC 2002) at which point significant data gaps in migration behaviour were recognized (English et al. 2005). In 2005, the focus of the tagging effort shifted to Summer-run sockeye stocks and in 2006 the program was expanded to include all four run-timing groups through a combination of marine and freshwater tagging (Robichaud and English 2007). Fraser River sockeye have been caught and tagged in the marine environment (Johnstone Strait and Juan De Fuca Strait) using seine nets (2002, 2003, 2006), in the Fraser River 10 km downstream of Mission using either a fishwheel and/or tangle nets (2005-09), and in 2002 only, near Ashcroft on the Thompson River using a beach seine. Fork length, DNA, and scale samples of all radio tagged sockeye are recorded before fish receive a unique radio tag immediately prior to release. DNA samples are used to allocate tagged fish to their respective run-timing group and CU whereas fish tracked to their spawning grounds are assigned to a CU and timing group based on the location and timing of detection (English et al. 2005). As sockeye migrate up the Fraser River, they pass receiver stations deployed at management (fishery) area boundaries and major tributaries (Figure 2) where unique tag (fish) identification numbers and times of passage are recorded. The numbers of fixed stations vary from 14 in 2008 to 24 in 2006, and the number of tagged fish ranges from 110 in 2008 to 1038 in 2006 (Robichaud and English 2007; Smith et al. 2009) (Table 12).

To estimate average fishery specific residence times for each year, we multiplied estimated length of each management area (in kilometres) by stock-specific average migration speeds (days/km) derived from radio-telemetry. Migration speeds (km/day) for each radio-tagged fish were estimated by dividing the distance between two consecutive receivers by the difference in detection times between those same receiver stations. Migration speeds were then averaged for each run-timing group in each area. Management areas are large enough that fish spend a minimum of one day in each so we rounded residence times to the nearest fully day. CU-specific sample sizes of radio tagged sockeye are not large enough in any year to establish CU-specific residence times without assuming that all CUs within a run-timing group travel at the same rate. Consequently, there is a maximum of seven different estimates of residence time for any management area (one for each of the four run-timing groups plus three for each of the True Late units). For example, we assume that every fish from Summer-run CUs in 2006 migrating through the Sawmill – Thompson management area will reside there for 2 days before moving to the next area (Table 13). Migration rates of Fraser River sockeye have been shown to vary substantially between the different run-timing groups with Early Stuart sockeye being the fastest swimmers (40-50 km/d) and Late-run stocks consistently being the slowest (20-30 km/d) (Robichaud et al. 2010).

Where residence times cannot be directly estimated due restricted study focus (i.e. tagging limited to Summer-run and Late-run stock only), an incomplete set of receivers (2002), or small sample sizes (2008), we used migration rates from other years for that run-timing group (Early Stuart values for 2002 are from 2006), or assumed migration rates were equal to the value estimated for an adjacent reach in that year. This latter assumption is particularly important for the Steveston-Port Mann and Port Mann- Mission management areas, where telemetry signals cannot be received due to the presence of brackish water. Furthermore, many CUs are known to "hold" in major tributaries (including Lakes) for up to 50 days, waiting for the appropriate conditions in which to spawn. These estimated “Tributary Times”, as well as CU-specific residence times for each management area in 2006 are provided in Table 13.

1.4.1 En-route loss

Incorporating estimates of en-route loss into the run reconstruction is critical to improving the accuracy of arrival abundance estimates, harvest rate, and harvest assuming that the timing, location, and extent of en-route mortality is reasonably well-known. Estimates of en-route mortality are typically generated using the difference between the abundance estimate from the hydroacoustic facility at Mission, and the abundance estimate of all up-river catch plus escapement to the spawning grounds (Cooke et al. 2004), however this method does not indicate in which management area mortality occurs.

Tagging data from the sockeye radio-telemetry studies was used to estimate en-route mortality by area for all years 2002 – 2009. Tagged fish that were last detected in management areas away from their spawning grounds, and not reported as catch are assumed “lost” due to en-route mortality. We extrapolated tag-loss data to represent total en-route mortality for each CU within each management area using management area specific ratios of lost tags to total tags applied to a CU.

1.4.2 Model Description

Upriver migration patterns arising from deterministic residence times within each management area can best be described as “boxcar” like movement, in which fish move in discrete units from one area to another, similar to individual boxcars of a train (Starr and Hilborn, 1988; Branch and Hilborn 2010). When fish are removed following a harvest event, the change in the abundance of the affected boxcars persists throughout the migration due to the deterministic nature of the model. In fisheries with residence times greater than one day, multiple boxcars of fish from a CU may be available for harvest, though fish are not able to move between boxcars.

The run reconstruction, based on Cave and Gazey (1994), uses the following parameters and algorithm:

f = fishery identifier ($f = 1, 2, 3, \ldots 23$)
i = day ($i = 1, 2, 3, \ldots 140$)
s = CU identifier ($s = 1, 2, 3, \ldots 23$)

$N_{f,i,s}$ = abundance in fishery *f* on day *i* for CU *s*
$E_{f+1,\, i+1,s}$ = escapement of CU *s* to area *f* +1 on day *i* +1
$C_{f,i}$ = catch from fishery *f* on day *i*
$h_{f,i}$ = harvest rate in fishery *f* on day *i*
$M_{f,s}$ = en-route mortality in fishery *f* for CU *s*
$TL_{f,s}$ = quantity of lost tags in fishery *f* of CU *s*
TT_s = the total number of tagged fish of CU *s*
$P_{f,s}$ = en-route mortality in fishery *f* of CU *s*
P'_s = en-route loss between Mission and the spawning area for CU *s* expressed as a percent of the Mission abundance (provided by the PSC)

1. Calculate fishery-specific estimates of en-route mortality using radio-telemetry tracking data and PSC estimates of en-route losses:

$$P_{f,s} = (TL_{f,s} / TT_s) \times P'_s$$

$$M_{f,s} = P_{f,s} /(1 - \sum_{f=1}^{f-1} P_{f,s})$$

2. For the simple example where the fish reside in a fishery for a single day, the total abundance of sockeye in fishery *f* on day *i* is;

$$N_{f,.} = C_{f,i} + \sum_{s=1}^{S} E_{f+1,i+1,s} /(1 - M_{f,s})$$

3. The daily harvest rate for each fishery and day is:

$$h_{f,i} = C_{f,i} / N_{f,i,.}$$

4. The daily abundance for each stock in each fishery, assuming equal vulnerability of all CUs present, was calculated using:

$$N_{f,i,s} = E_{f+1,i+1,s}(1 - h_{f,i})/(1 - M_{f,s})$$

5. Therefore, the daily catch for each CU by fishery was:

$$C_{f,i,s} = h_{f,i} \cdot N_{f,i,s}$$

Assumptions made in this model are similar to other reconstruction frameworks (Cave & Gazey 1994 and Gazey & English 2000), e.g.,

1. All fish in a fishery are equally vulnerable to harvest;
2. All fish from a CU have identical residence times within each fishery, and:
   a. All fish follow the same progression through fisheries in the river
   b. All fish are assumed to reside in a management area to the nearest whole day.
   c. Fish, on their migration, are assumed to only move upstream.

3. Fish arrive on spawning grounds according to a normal probability density function;
4. Total catch, either daily or weekly (as it is reported in areas above Sawmill) is known exactly, and, when reported weekly, is distributed equally amongst the seven days in a week.

1.5 Results

1.5.1 Harvest Rate

Total annual in-river harvest rates of Fraser River sockeye varied from a high of 31.4% in 2004 to a low of 4.4% in 2009, with an average of 18.2%. Early Stuart and Early Summer timed groups experienced the highest harvest rates in 2004, the Summer group in 2008, and the Late and True Late timed groups in 2006. Run-timing groups returning in the greatest abundance do not necessarily experience the highest harvest rate. For instance, in 2002 and 2006 when the Late and True Late-run timing groups returned in their highest abundances, they experienced the third lowest harvest rates of all run-timing groups within those years. Lower harvest of the Late and True Late-run CUs is expected as fisheries managers may adjust escapement goals to accommodate expected en-route loss of this timing group, but managers also limit harvest so as to not exceed a total (marine and in-river) exploitation of 30% on endangered Cultus lake sockeye (Cultus Sockeye Recovery Team, 2005). Consequently, all co-migrating Late-run CUs experience lower harvest rates regardless of abundance. Our analysis shows that Cultus sockeye experienced their highest in-river harvest rate of 12.3% in 2006, while harvest rates were less than 5% in all other years (Figure 3 to Figure 10).

CU-specific annual in-river harvest rates range from 0.1% (Chilliwack, 2007) to 45 % (Shuswap Complex – Early Summer, 2004) (Figure 3 to Figure 10). As expected, CUs within the same run-timing group with similar migration distances and run timing generally experience similar harvest rates (e.g. Shuswap Complex- Late and Kamloops - Late). However, in cases where tributary fisheries are large and target only one or two CUs, harvest rates can be quite different, even for CUs with similar timing and spawning areas. This is particularly evident for Summer-run CUs in 2009 where differences in harvest rates are seen between Chilko and Quesnel (Figure 10). In all other years, these two CUs are harvested at very similar rates, however in 2009, harvest from the Chilcotin River was 20,206 which represented 7.8% of total return abundance whereas, in all other years, tributary harvest from the Chilcotin River never exceeded 3% of total return abundance.

1.5.2 Arrival Abundance at Steveston

Between 2002 and 2009, six CUs composed 82% of total cumulative arrival abundance at Steveston. These six CUs include four Summer CUs (Chilko, Fraser, Quesnel and Stuart) and two Late CUs (Lillooet and Shuswap Complex), which together represent 90%, 83%, 55%, 83%, 80%, 70%, 65% and 65%, respectively of annual arrival abundance from 2002 to 2009. These results are consistent with those of the PSC, which annually estimates that these same six CUs together make up the majority of arrival abundance. CUs that consistently return in low abundances relative to other CUs include Cultus and Kamloops (Late) as well as Taseko and Nahatlatch (Early Summer) (Table 15

Total reconstructed abundance at Steveston was highest in 2002 and 2006 (15,165,222 and 8,192,744 respectively) and lowest in 2007 and 2009 (1,290,262 and 1,355,211 respectively) with an average of 4,995,399 (Table 15). The average annual contribution to arrival abundance, by timing group is 2% (Early Stuart), 11% (Early Summer), 45% (Summer), and 43% (Lates).

1.5.3 In-river Catch

Annual reconstructed in-river harvest of Fraser River sockeye over the study period averages 863,574, with 62% of catch coming from the Summer-run timing group, 21% from the True – Lates, 12% from Early Summer, 4% from the Late group, and 1% from Early Stuart group (Table 14).

Across all years, management areas, and fisheries, harvest is dominated by both Shuswap CUs (Early Summer and Late), and Chilko, Fraser, and Quesnel CUs (Summer) (Table 14) that make up 77%, 86%, and 88% of catch for First Nations, Commercial, and Sport fishermen respectively, and 80% of overall annual catch.

The lowest annual harvests occur in 2007 and 2009 (153,847 and 60,691, respectively), when all reported harvest was taken in First Nations fisheries in the river. The highest annual catches occurred in 2002 and 2006 (1,965,724 and 1,741,987, respectively) (Table 14), with the majority of harvest coming from the previously mentioned 5 CUs that account for 90% and 87% of harvest in 2002 and 2006, respectively. Harvest in 2002 and 2006 was nearly equally distributed between First Nations (890,529 and 832,626) and commercial sectors (950,154 and 775,069). Timing and quantity of daily reported harvest in 2006 against reconstructed abundances is shown for the areas between Steveston to Mission, Mission to Sawmill, Sawmill to Lytton and Lytton to Kelly creek (Figure 11 to Figure 14).

1.6 Discussion

Reconstructions of the 2002-2009 sockeye returns to the Fraser River provide the first quantitative, CU-specific estimates of abundance at the river's mouth, harvest rates in-river, and total CU-specific in-river harvest. These results should be useful to managers charged with implementing Canada's WSP.

The relative contribution to harvests, by timing group, were expected as management generally restrains harvest on Early Stuart and Early Summer fish due to low abundance. In contrast, harvest is restrained on Late-run fish due to concerns about en-route mortality, and a maximum allowable fishing mortality on the Cultus CU. Estimates of annual harvests are similar (though not identical) to estimates provided in Fraser River Panel (FRP) Annual Reports. FRP harvest and abundance estimates include all harvests from First Nations (including from the marine area), and commercial fisheries (including First Nation economic harvest), are generated through combining stock monitoring and genetic ID data, and, unlike estimates provided here, do not account for en-route loss in-river. Furthermore, FRP estimates are provided for discrete stock groups, and are not CU specific, therefore our estimates are more applicable to managers in the context of the Wild Salmon Policy, and are not directly comparable to those of the FRP. Run reconstruction outputs therefore are the most useful to management as the results are CU-specific, account for en-route loss, and do not rely on genetic ID data for allocating catch, which is known to bias harvests of CUs of low abundance (Gable, 2002; Cass and Wood, 1994).

The accuracy of the reconstruction estimates depends on the robustness of our model and data assumptions to the realities of Fraser River sockeye dynamics, fisheries, and monitoring programs. The model's four main assumptions allow it to work in the absence of perfect information, and are worth further discussion.

Our first assumption - that all sockeye within a fishery are equally vulnerable to harvest – must be robust to variation in the biophysical processes involved in fishing. At the simplest physical level, all sockeye of a given girth are equally susceptible to harvest by gill net. Gill nets are the preferred method of harvest in-river, and are especially size-selective by girth (Kendall et al. 2009). However, girth can change during salmon migration in response to energy use and maturation. Consequently it is common to use length of fish as a proxy for girth (Hamon et al. 2000), because length changes little with migration and maturity (Cox and Hinch 1997). Sockeye lengths from some Fraser stocks differ significantly from one another, and between years (Healey 1986; Cox and Hinch 1997); however, differences in size of Fraser sockeye are relatively small (standard lengths of 49-53 cm for females and 49-58 cm for males) because most of the fish are of similar age (Cox and Hinch 1997). The Bristol Bay sockeye fishery shows intricate and dynamic relationships between length of fish and vulnerability to gill nets. Kendall et al. (2009) show a temporal progression of length-based vulnerability in which prior to the 1970's, longer fish were more vulnerable than shorter fish, through the 1970's, selection was for 'intermediate' sized fish, and recently the fishery has been relatively unselective with respect to length. Additionally, due to different temperature preferences/tolerances and potential variations in water temperature within a management area, fish of different CUs may not distribute themselves equally throughout a management area, though this has not yet been explored in detail, nor has it been quantified. Given the cyclic dominance of Fraser sockeye and the relatively small differences in length distribution amongst stocks and years, the violation of our first assumption may be minor.

Our second assumption - that CUs within a run-timing group have the same residence times within each fishery - is probably not valid for all CUs. For instance, a 2005 Fraser sockeye radio-telemetry study (Robichaud and English 2007) found that estimated migration speeds for one Summer run-timing stock (Stellako) differed significantly from three co-migrating stocks within that group. However, the differences in migration speeds were relatively small (e.g., 25 versus 32 km/day) and would amount to differences of less than one day in residence times for a specific fishery, therefore not likely effecting estimated residence times. However, to test this assumption, a sensitivity analysis was run on Summer run CUs, whereby residence times below Mission were artificially inflated to two days for the Takla/Trembleur/Stuart CU, from their original value of one day per FMA. As expected, results indicate that when residence times in an FMA are longer than expected, harvest rate estimates change, in this example, increasing by nearly 30% (i.e. from 25.2% to 35.3%). However, the change in harvest rate of the stock group increased by less than 1% (i.e. from 20.6% to 20.8%), likely due to the fact that the Takla/Trembleur/Stuart CU is the least abundant CU in this group/year combination. Furthermore, harvest rates of other CUs not belonging to the Summer Run timing group were also impacted due overlapping distributions, and the change in relative abundances available for harvest. Though it is highly unlikely that residence times are underestimated by 100%, this analysis highlights the degree of error possible in harvest estimates due to imperfect information on residence times, and that, due to co-migrating stocks, error in even a single CU can impact estimates of many other CUs.

Our third assumption – that fish arrive on spawning grounds according to a normal probability density function – is not perfectly valid for all CUs. Salmon of a specific CU may be exposed to varying harvest and predation levels during migration, which can result in a non-normal arrival pattern. Specifically, CUs with high harvests (or predation) can have large “holes” in daily arrival abundance(s) due to the removal of these fish. Furthermore, this assumption is not supported by daily escapement data at Mission, where the arrival of some CUs is punctuated with abundances of zero fish (Chilliwack, Pitt, Stellako and Birkenhead, 2006; Mitchell, Pitt and Birkenhead 2008). Naturally, it would not be realistic to expect fish to arrive in a pattern exactly replicating a normal distribution, however, in the absence of daily arrival abundances at spawn, we must assume a normal arrival pattern. This assumption, however can result in harvest rates being underestimated due to catch being added back onto an escapement distribution that is smoothed out relative to the actual abundance profiles present in a FMA (Kolody, 1998).

Our fourth assumption - that harvest is known exactly and is evenly distributed over seven days of each week for fisheries above Sawmill Creek - is likely the weakest assumption of all. For instance, although catch monitoring programs have been fairly rigorous for the years included in our analysis, there is evidence from all First Nations fisheries that catches are not reported accurately. Similarly, it is unlikely that harvest is equally distributed over all days of the week, because effort likely increases on the weekends when many First Nations harvesters have time available for fishing. Although it might be possible to use effort data to more accurately distribute weekly catch, we have not attempted to do so because of budget and time restrictions.

The run reconstruction acts as a lens of modernity, through which we can filter past fishery experiences and decisions, making management of Fraser sockeye easier by providing valuable, historic information in a modern-day context. Management of Fraser sockeye is becoming increasingly complex, making historical fishery information obsolete for today's managers unless it is translated into modern terms, a service our run reconstruction provides. When planning a fishing season, managers often look to past years with similar features (abundance, timing, water temperatures, etc.) to help inform harvest decisions. However, with new fishery policies (WSP, on-going treaty negotiations), management units (CU), catch allocations, and environmental challenges, historical data is less applicable now than ever before. It is our intention that results presented are of help to current managers of Fraser River sockeye. Furthermore, the run reconstruction enables the development of CU specific stock-recruit relationships that can be used to assess and monitor productivity of populations.

Though the focus of this paper has been on providing post-season CU and FMA specific estimates of abundance and harvest, there is considerable potential in applying these methods to pre and in-season planning. The backwards run reconstruction could be modified to run forward through space and time under differing levels of harvest and en-route mortality. The application to pre and in-season planning is particularly useful. Using pre-season estimates of arrival abundance, migration rate and timing, en-route loss, and harvests, the effects of alternative fishing plans can be evaluated. Managers could then apply the option that best represents their goals and objectives under the assumed conditions. As pre-season estimates are updated in-season, the model could be re-run, with fishery plans being modified accordingly.

1.7 Figures

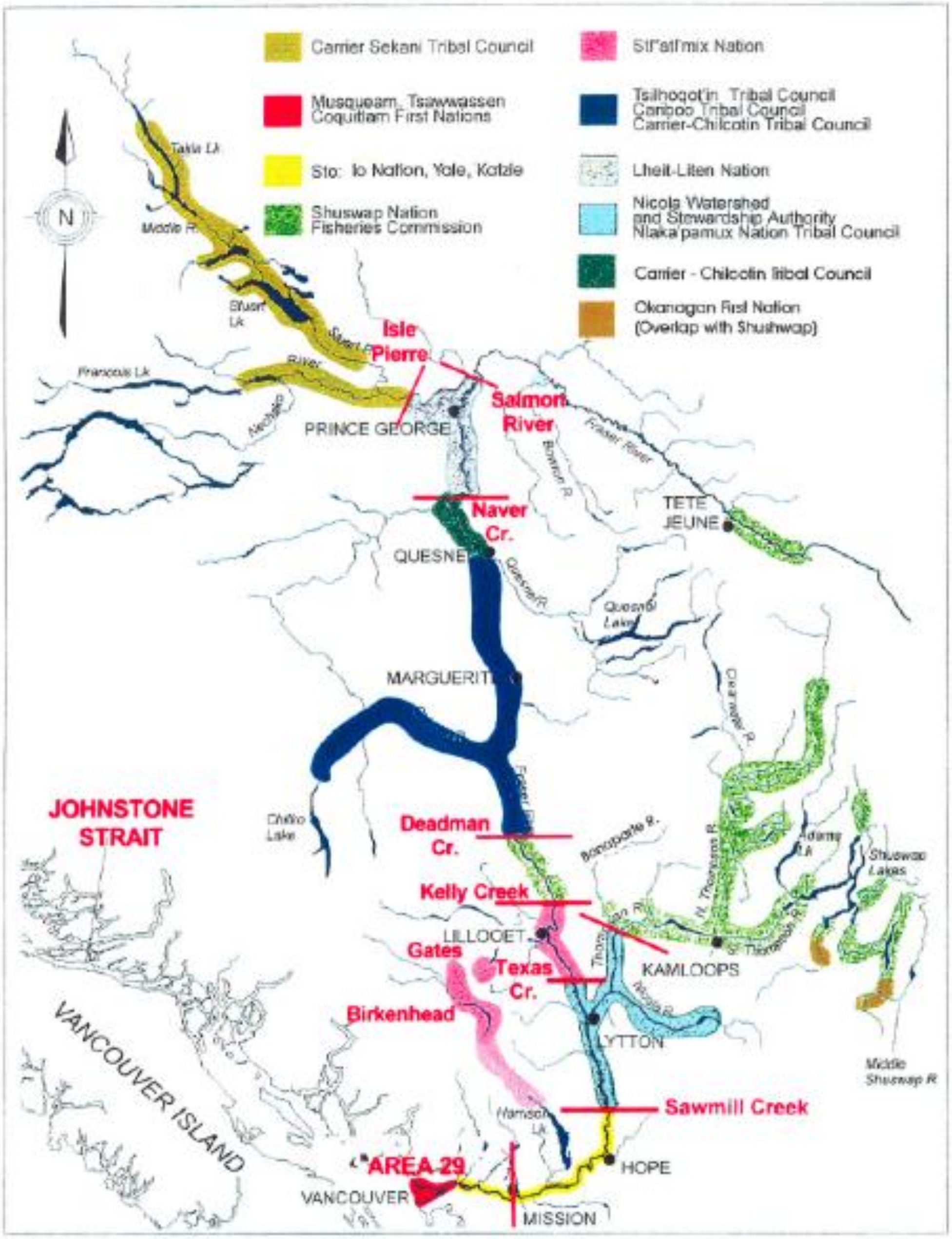

Figure 1. Geographic location and boundaries of the major management areas within the Fraser River watershed (From English et al. 2007).

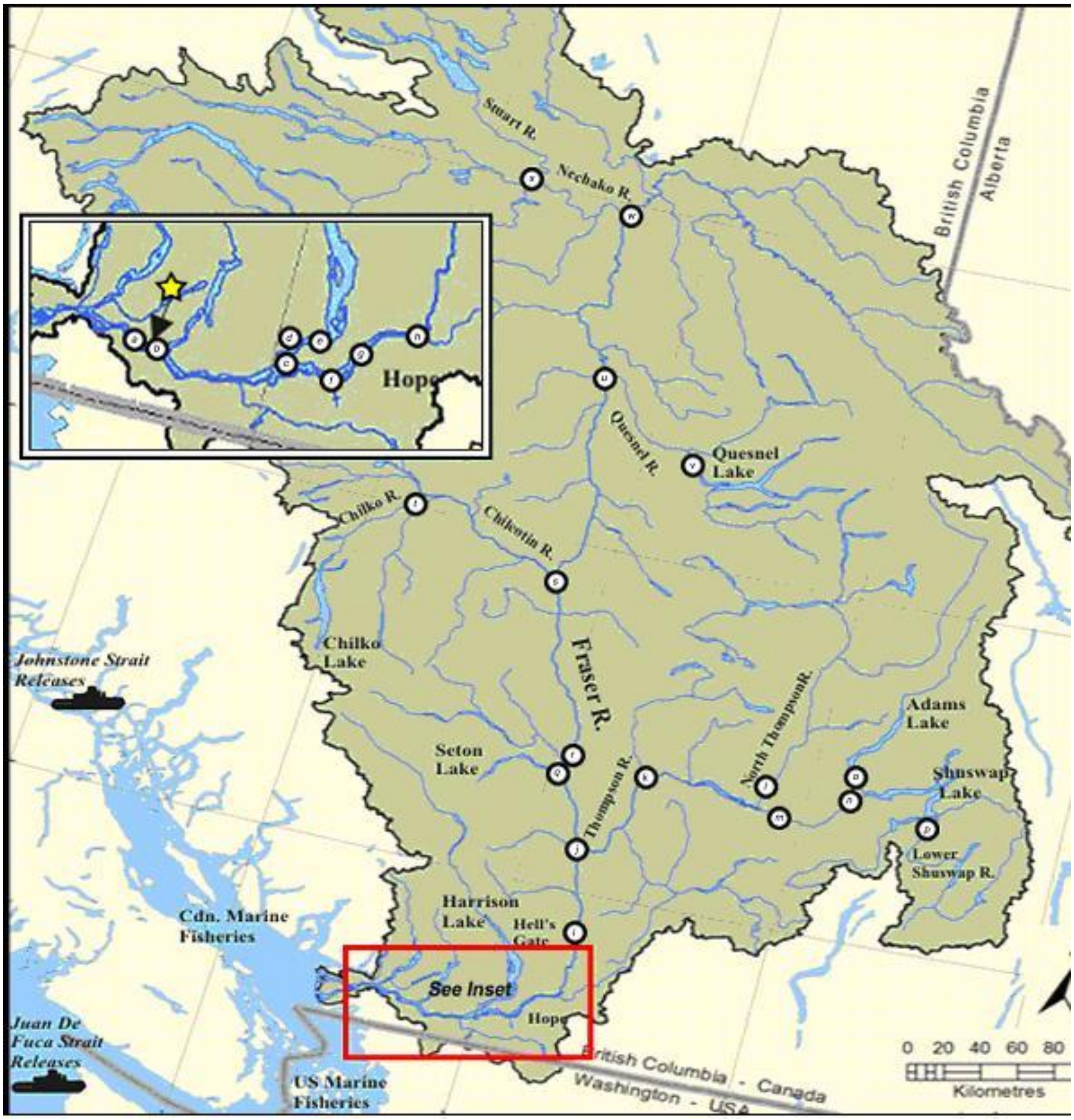

Figure 2. Location of release and fixed-station sites for the 2006 radio-telemetry study. Fixed Station sites: a: Crescent Island; b: Mission; c: Harrison confluence; d: Weaver Creek; e: Upper Harrison; f: Rosedale; g: Hope; h: Sawmill Creek; i: Hell's Gate; j: Thompson confluence; k: Spence's Bridge; l: North Thompson; m: top of Kamloops Lake; n: Little River; o: Adams Lake; p: Lower Shuswap; q: Seton confluence; r: Bridge River; s: Chilcotin confluence; t: Chilko; u: Quesnel confluence; v: Horsefly River; w: Nechako confluence; x: Stuart River.

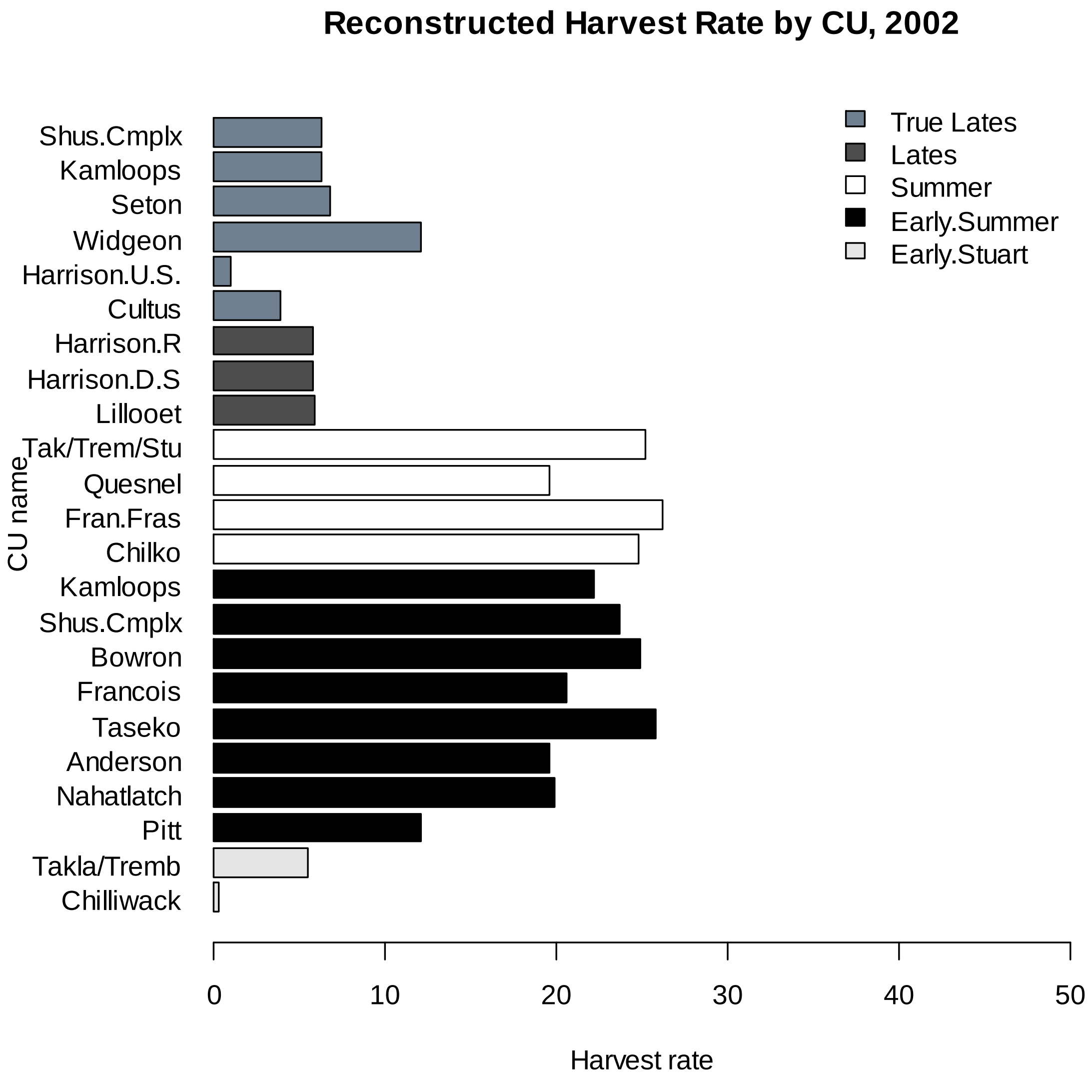

Figure 3. In- river harvest rates (%) by Conservation Unit, 2002.

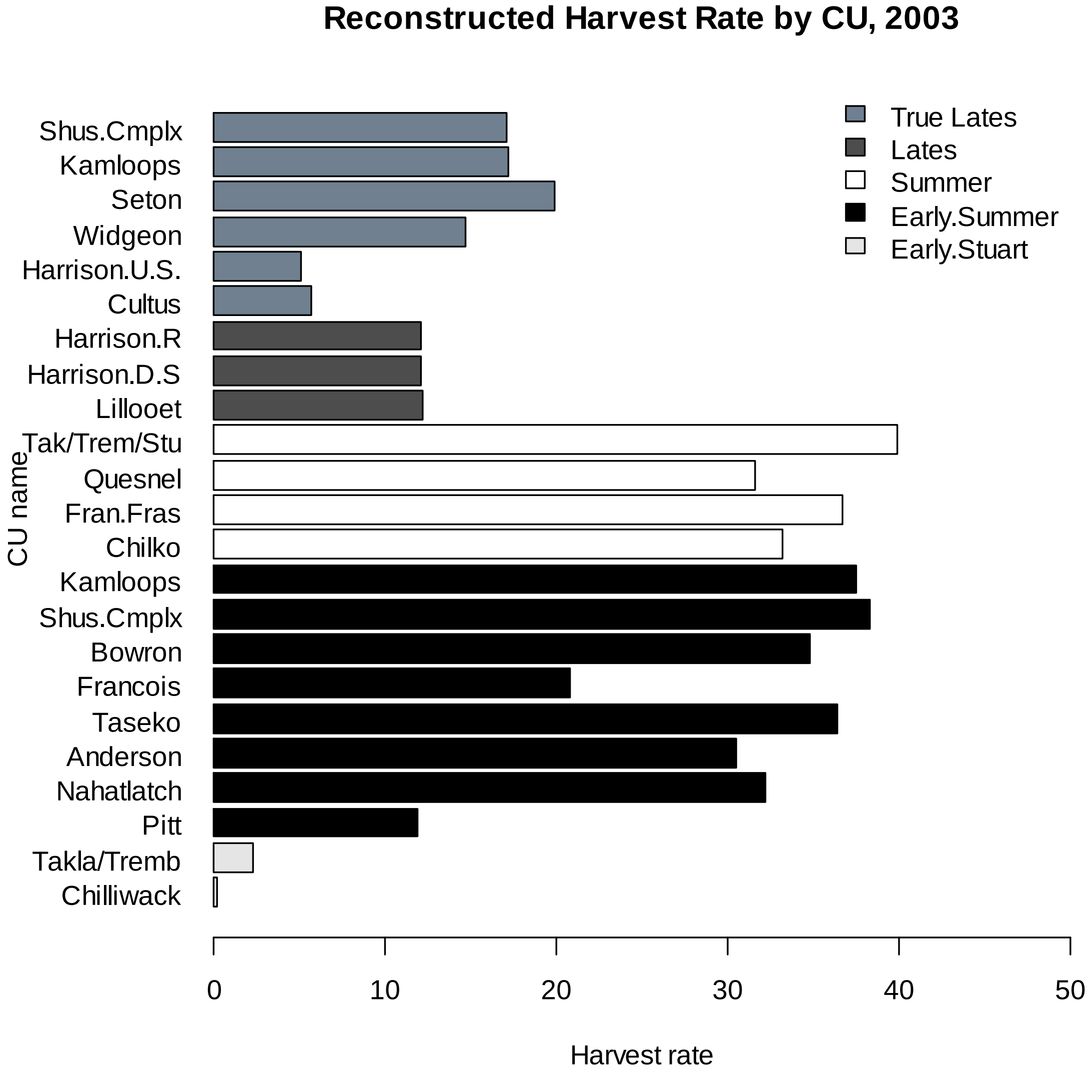

Figure 4. In- river harvest rates (%) by Conservation Unit, 2003.

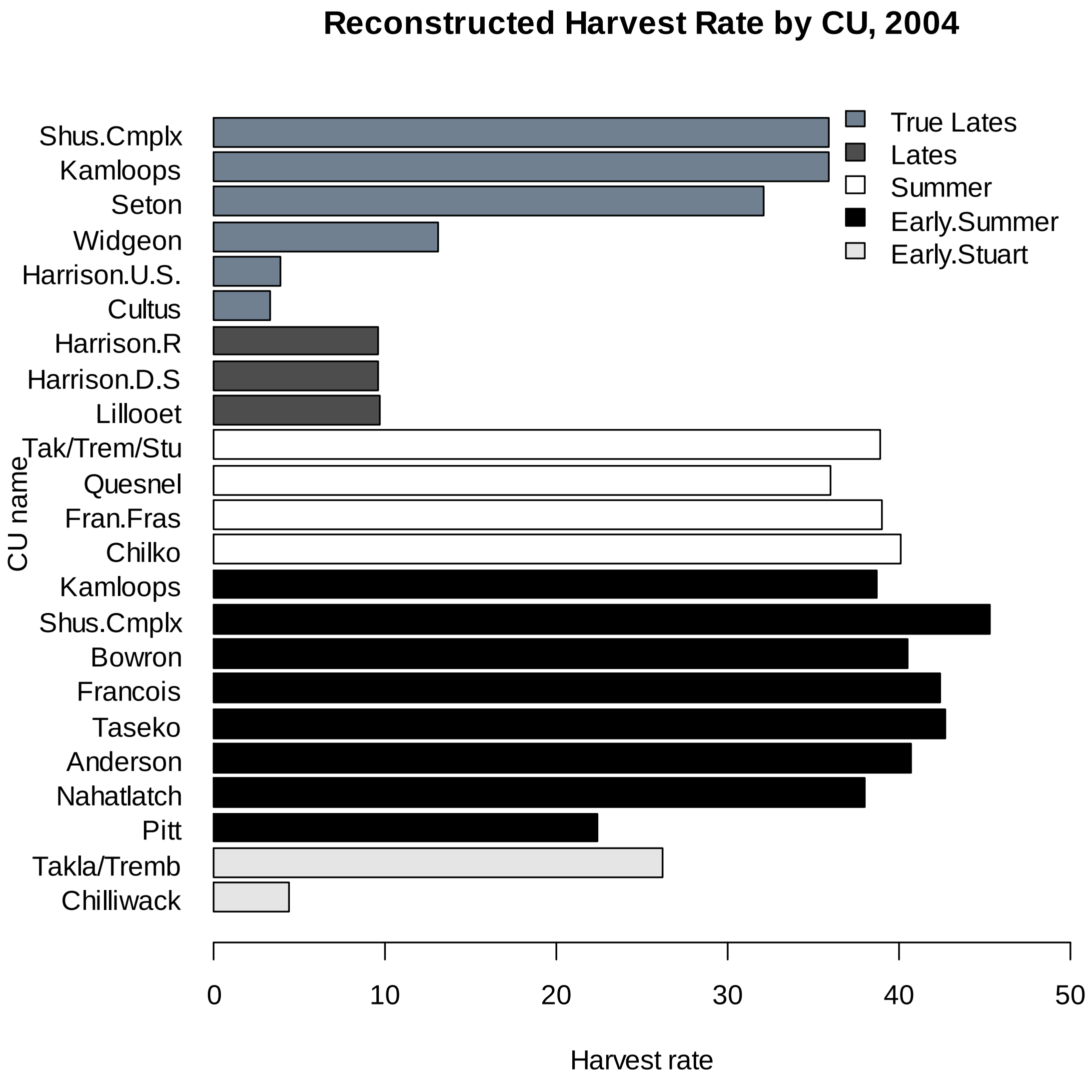

Figure 5. In- river harvest rates (%) by Conservation Unit, 2004.

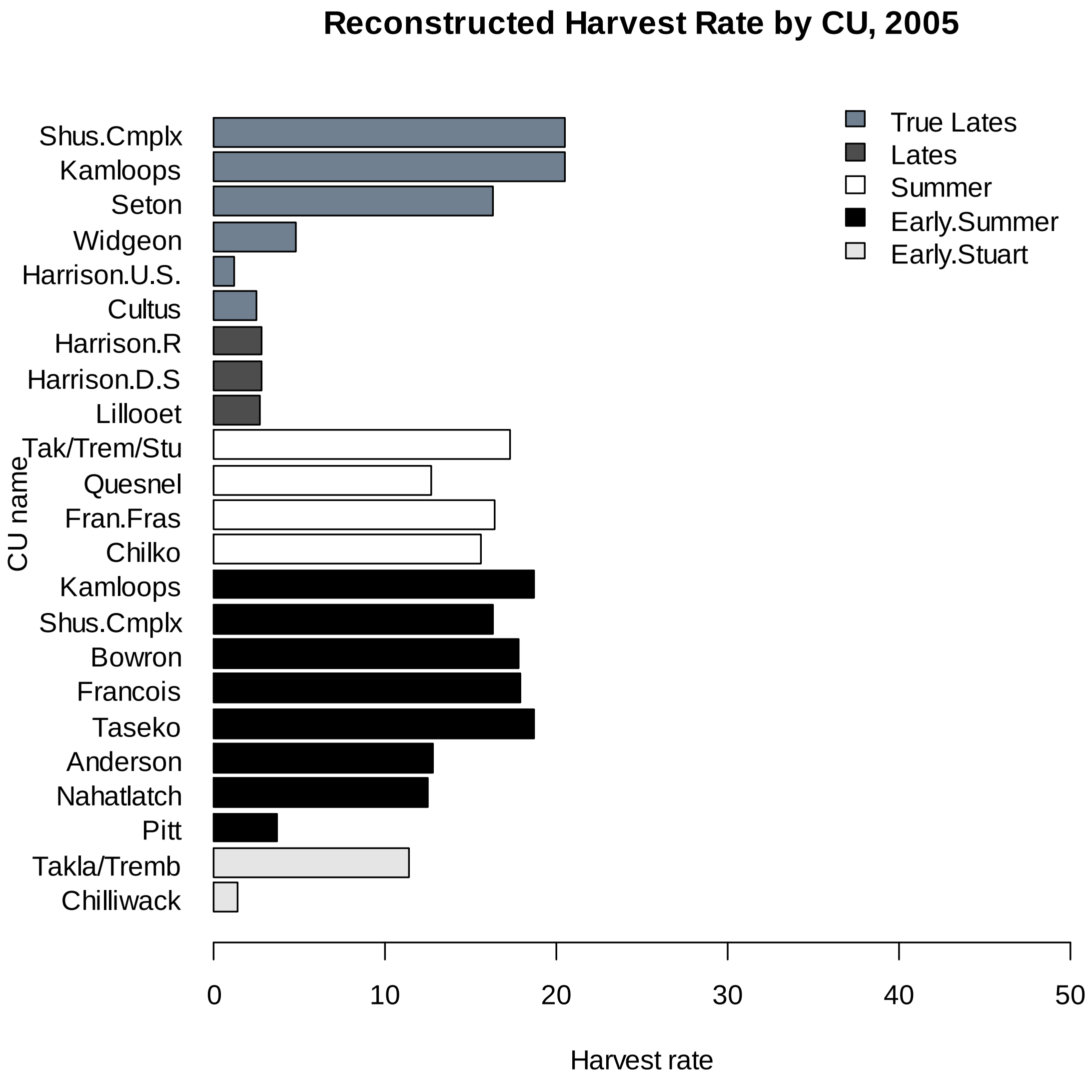

Figure 6. In- river harvest rates (%) by Conservation Unit, 2005.

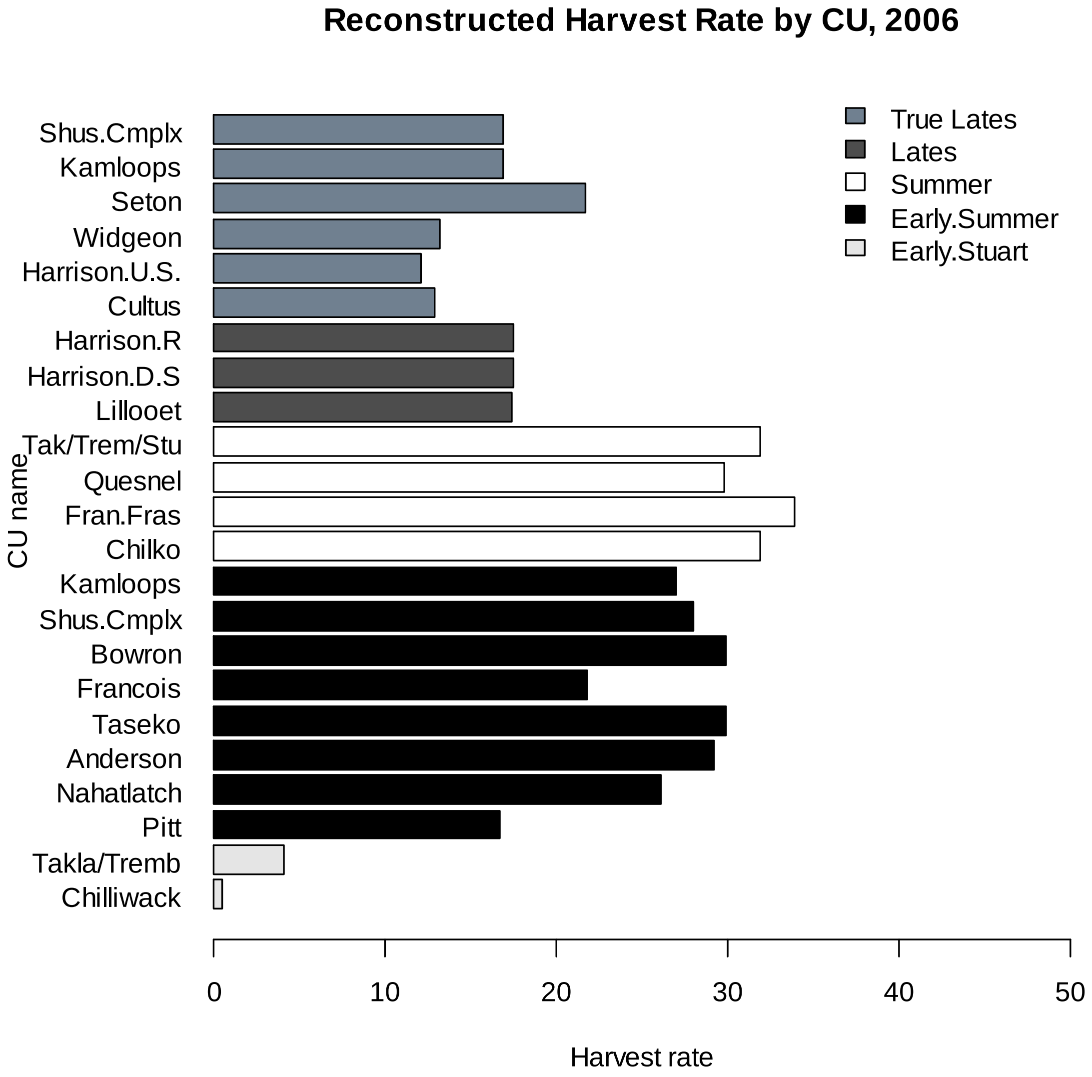

Figure 7. In- river harvest rates (%) by Conservation Unit, 2006.

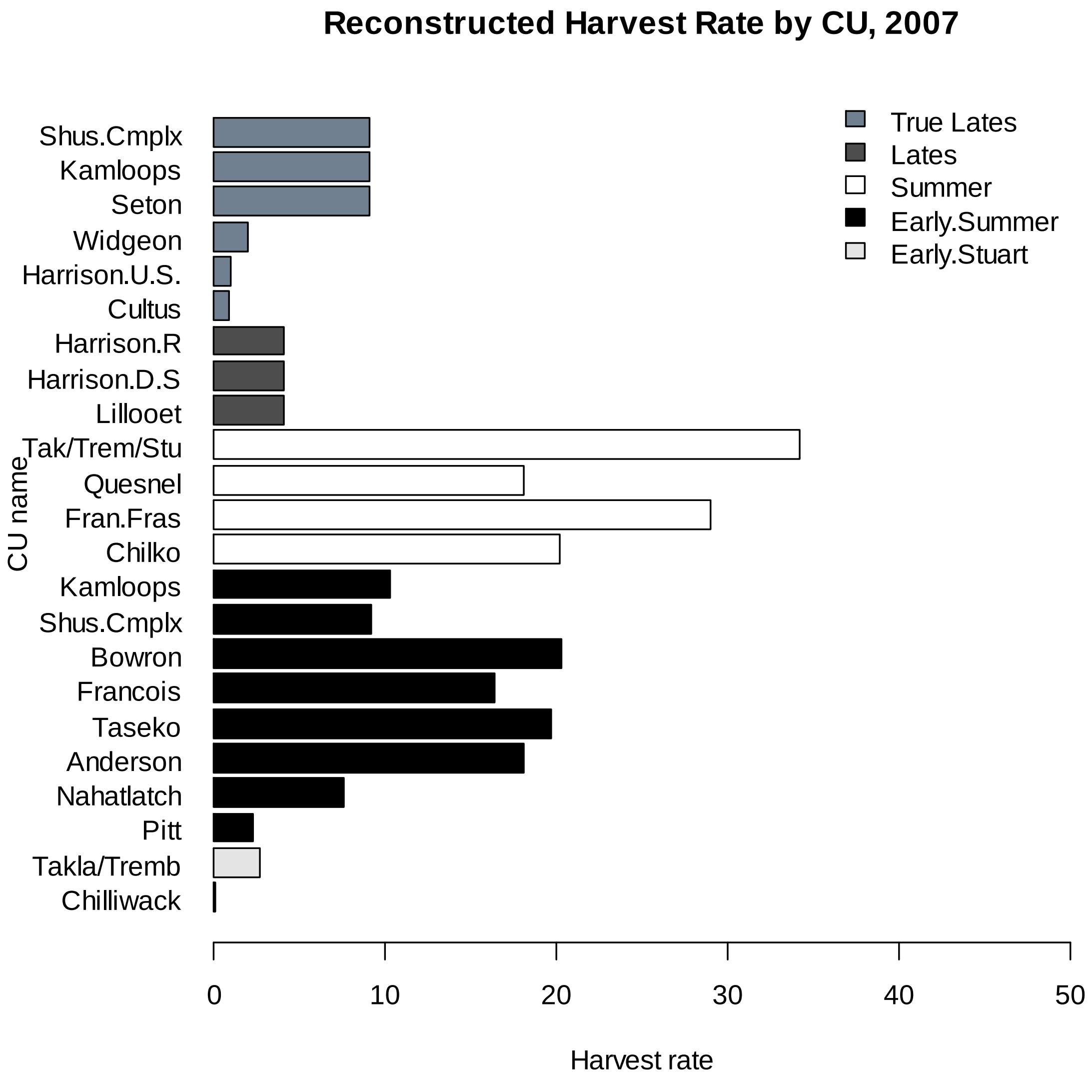

Figure 8. In- river harvest rates (%) by Conservation Unit, 2007.

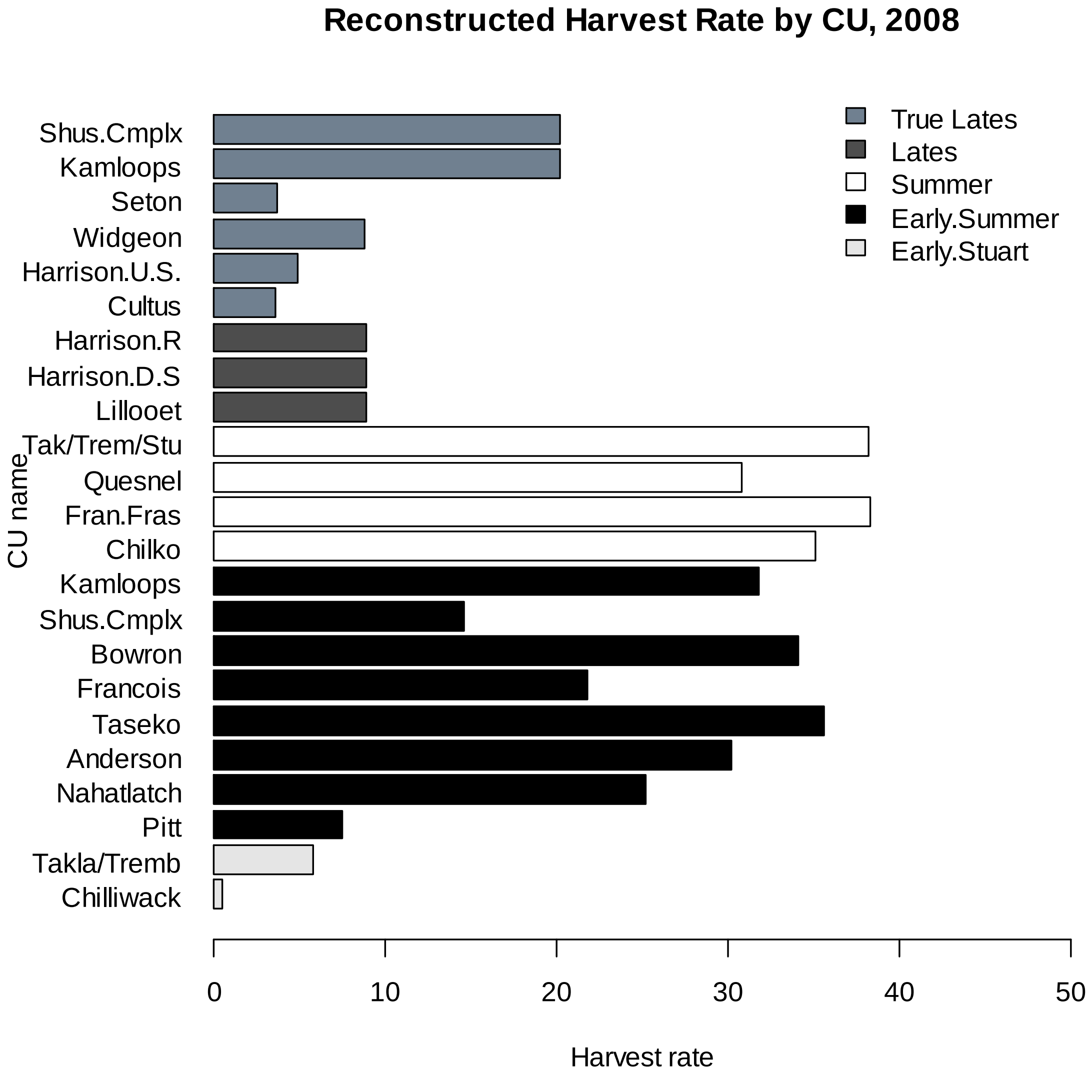

Figure 9. In- river harvest rates (%) by Conservation Unit, 2008.

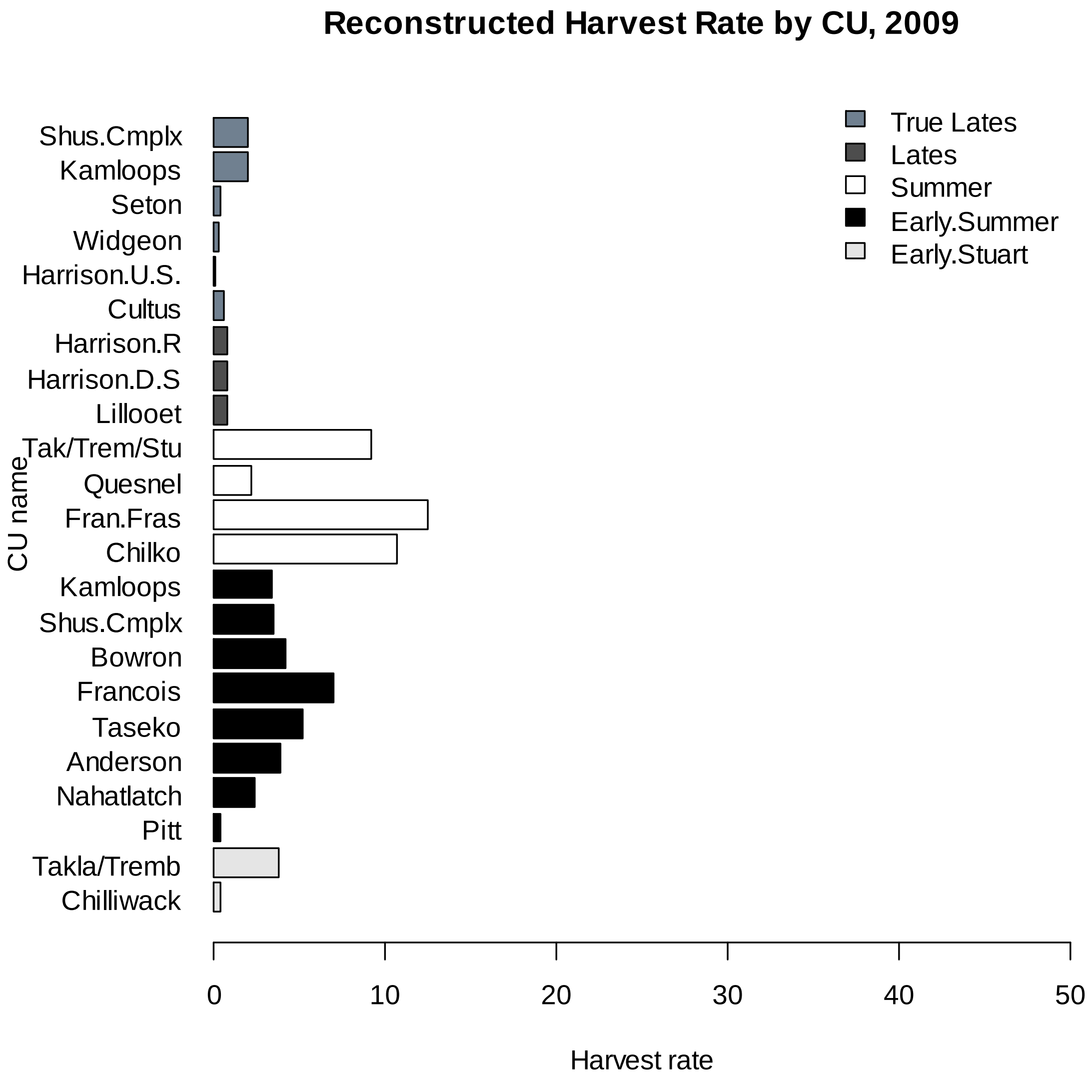

Figure 10. In- river harvest rates (%) by Conservation Unit, 2009.

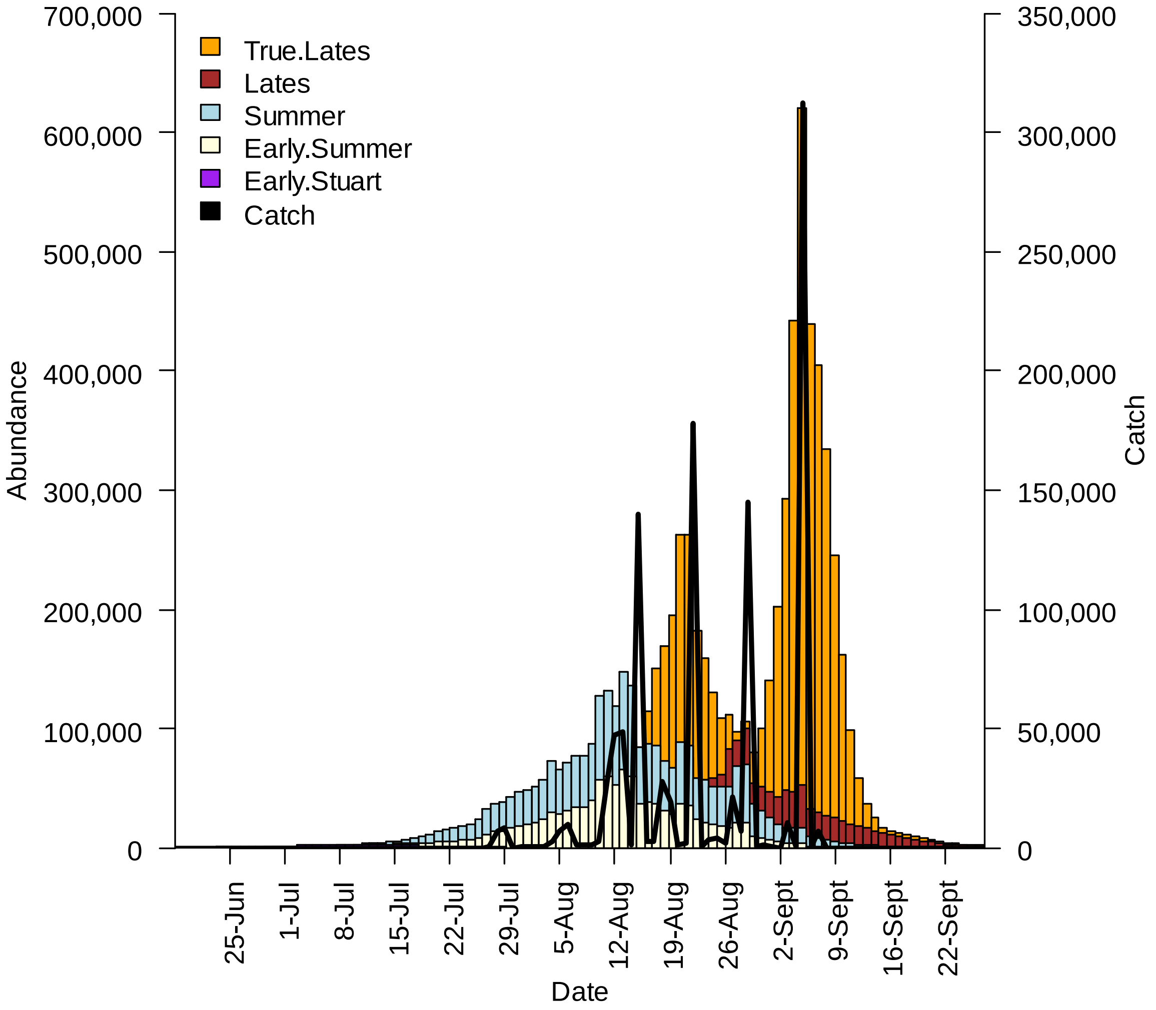

Figure 11. Reconstructed abundances (by run-timing group) entering the Steveston to Mission reach and reported catch for this reach in 2006. The solid dark line indicates reported catch from this area.

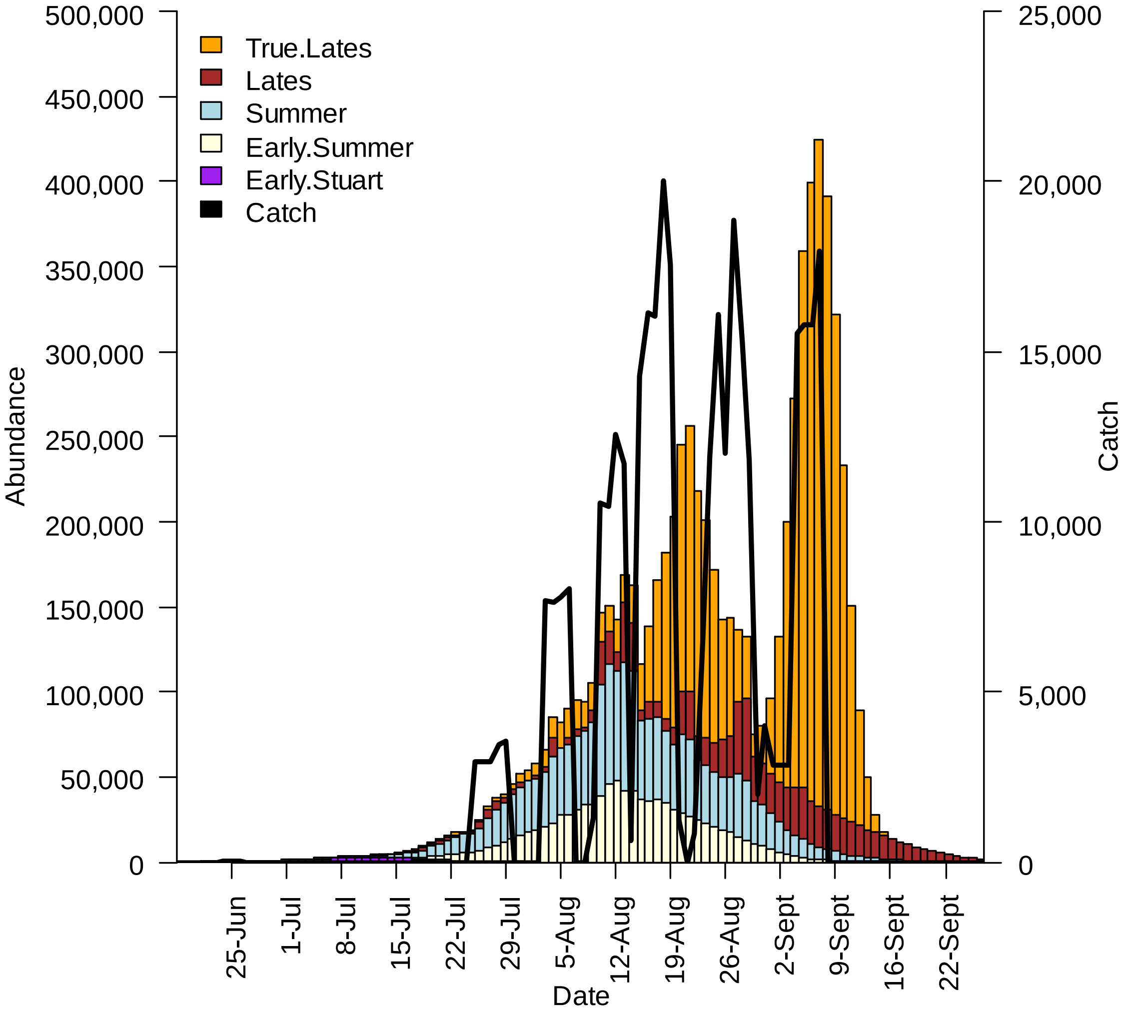

Figure 12. Reconstructed abundances (by run-timing group) entering the Mission to Sawmill reach and reported catch for this reach in 2006. The solid dark line indicates reported catch from this area.

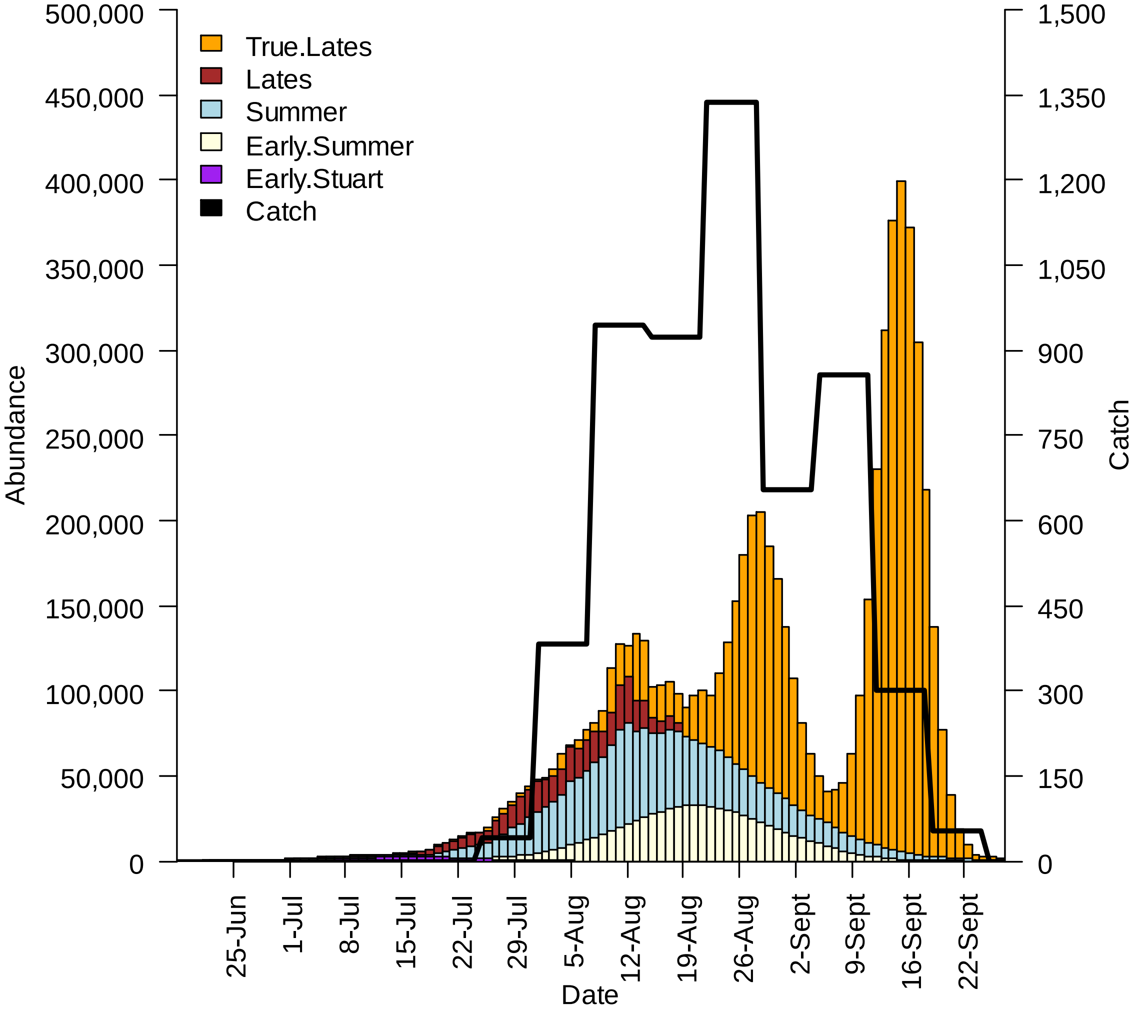

Figure 13. Reconstructed abundances (by run-timing group) entering the Sawmill to Lytton reach and reported catch for this reach in 2006. The solid dark line indicates reported catch from this area.

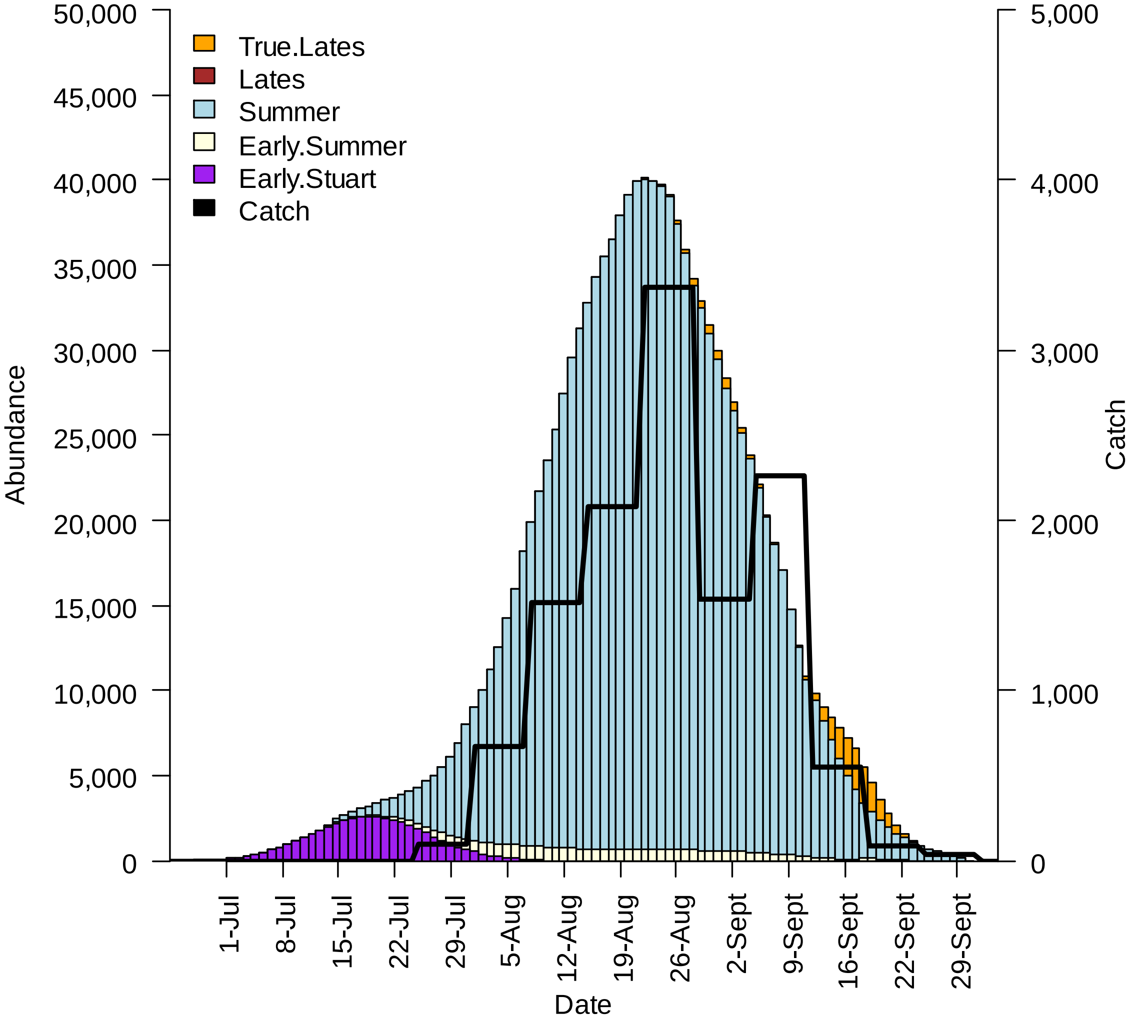

Figure 14. Reconstructed abundances (by run-timing group) entering the Lytton to Kelly Creek reach and reported catch for this reach in 2006. The solid dark line indicates reported catch from this area.

1.8 Tables

Table 1. 23 Fraser Sockeye Conservation Units (CUs) included in the run reconstruction, the run-timing group to which each belongs, and indicator stocks used to estimate timing of arrival at Mission for each CU.

CU Name	Run Timing Group	Indicator Stock
Chilliwack	Early Stuart	Early Stuart
Takla/Trembleur	Early Stuart	Early Stuart
Pitt	Early Summer	Fen/Bow/Pitt/Raft
Nahatlatch	Early Summer	Fen/Bow/Pitt/Raft
Anderson	Early Summer	Nadina/Gates
Taseko	Early Summer	Fen/Bow/Pitt/Raft
Francois	Early Summer	Late Stuart/Stellako
Bowron	Early Summer	Fen/Bow/Pitt/Raft
Shuswap Complex	Early Summer	Scotch/Seymour
Kamloops	Early Summer	Fen/Bow/Pitt/Raft
Chilko	Summer	Chilko
Fraser	Summer	Chilko
Quesnel	Summer	Quesnel
Takla/Trembleur/Stuart	Summer	Late Stuart/Stellako
Lillooet	Late	Birkenhead
Harrison (D/S)	Late	Birkenhead
Harrison-River	Late	Birkenhead
Cultus	True Late	Weaver/Cultus
Harrison (U/S)	True Late	Weaver/Cultus
Widgeon	True Late	Harrison
Seton	True Late	Adams/L. Shuswap/Portage
Kamloops	True Late	Adams/L. Shuswap/Portage
Shuswap Complex	True Late	Adams/L. Shuswap/Portage

Table 2. Definition and length (km) of 23 Fraser River sockeye fisheries included in the reconstruction model.

Fishery Number	Short Name	Description	Length (km)
1	Statistical Area 29b - estuary to Mission	Area 29b GN-E	n.a.
2	Statistical Area 29d - estuary to Mission	Area 29d GN-E	n.a.
3	Steveston to Port Mann bridge	Stev-P. Mann	33
4	Port Mann bridge to Mission	P. Mann-Mission	42
5	Mission to Harrison River confluence	Mission-Harrison	32
6	Harrison river confluence to Hope	Harrison-Hope	51
7	Hope to Sawmill creek	Hope-Sawmill	29
8	Sawmill creek to Thompson river confluence	Sawmill-Thompson	77
9	Thompson river confluence to Texas creek	Thompson-Texas	43
10	Texas creek to Kelly creek	Texas-Kelly	59
11	Kelly creek to Deadman creek	Kelly-Deadman	49
12	Deadman creek to Chilcotin river confluence	Deadman-Chilcotin	59
13	Chilcotin river confluence to Quesnel river confluence	Chilcotin-Quesnel	160
14	Quesnel river confluence to Naver creek	Quesnel-Naver	87
15	Naver creek to Nechako river	Naver-Nechako	65
16	Nechako river to Bowron river confluence	Nechako-Bowron	121
17	Nechako river	Nechako	100
18	Stuart river	Stuart	180
19	Chilcotin river	Chilcotin	180
20	Thompson confluence to Bonaparte river	Thompson-Bonaparte	79
21	Bonaparte river to Kamloops lake	Bonaparte-Kamloops	77
22	North Thompson river	North Thompson	135
23	Kamloops to Shuswap lake	Kamloops-Shuswap	81

Table 3. Annual spawning escapements for each CU (2002-2009) adjusted for spatio-temporal gaps in escapement data. Numbers in parentheses are the un-adjusted escapement estimate. Source: Grant et al. (2011).

CU Name	Timing Group	2002	2003	2004	2005
Chilliwack	Early Stuart	3,841	4,956	40,329	3,407
		(3,867)	(4,997)	(40,329)	(3,407)
Takla/Trembleur	Early Stuart	23,306	12,894	8,894	92,591
		(24,637)	(13,158)	(9,276)	(98,297)
Pitt	Early Summer	90,280	78,229	60,942	62,047
		(90,280)	(78,244)	(60,942)	(62,062)
Nahatlatch	Early Summer	7,305	3,070	1,097	2,168
		(7,320)	(3,070)	(1,097)	(2,178)
Anderson	Early Summer	2,173	9,811	9,606	15,150
		(4,681)	(10,435)	(9,921)	(16,412)
Taseko	Early Summer	1,300	380 (380)	320 (320)	520 (520)
		(1,300)			
Francois	Early Summer	1,925	3,163	22,603	21,834
		(1,945)	(3,163)	(22,603)	(99)
Bowron	Early Summer	8,770	6,752	916 (836)	1,730
		(8,770)	(6,752)		(1,649)
Shuswap Cmplx	Early Summer	214,677	36,434	2,106	7,753
		(313,032)	(41,966)	(3,888)	(12,055)
Kamloops	Early Summer	25,567	19,127	8,329	30,676
		(31,658)	(45,637)	(10,388)	(108,695)
Chilko	Summer	38,2753	608,321	91,909	535,967
		(38,5042)	(612,239)	(92,143)	(540,481)
Fran.Fras	Summer	322,711	78,093	86,738	175,299
		(32,271)	(78,093)	(86,688)	(175,346)
Quesnel	Summer	4,454,074	274,318	10,000	1,388,755
		(1,022,192)	(279,170)	(10,264)	(894,308)
Tak/Trem/Stu	Summer	30,630	32,443	76,181	273,345
		(34,489)	(38,474)	(83,447)	(293,144)
Lillooet	Late	281,064	309,878	37,617	53,546
		(157)	(310,555)	(37,573)	(54,444)
Harrison (D/S)	Late	29,419	10,962	19,831	4,466
		(31,055)	(13,211)	(21,624)	(5,536)
Harrison.River	Late	41,542	8,259	2,106	388,605
Cultus	True Late	5,140	2,184	88 (52)	198 (226)
		(4,882)	(1,939)		
Harrison (U/S)	True Late	101,033	49,488	25,379	48,516
		(101,051)	(49,877)	(25,429)	(48,837)
Widgeon	True Late	680 (680)	122 (184)	49 (49)	294 (301)
Seton	True Late	14,953	4,940	1,287	12,082
		(14,965)	(5,026)	(1,312)	(12,446)
Kamloops	True Late	18,369	10,040 (7)	5,611 (-)	26,456
		(5,720)			(99)
Shuswap Cmplx	True Late	5,488,178	380,643	2,994	21,048
		(5,523,739)	(381,271)	(3,082)	(63,248)

Table 3. Cont'd. Annual spawning escapements for each CU (2002-2009) adjusted for spatio-temporal gaps in escapement data. Numbers in parentheses are the un-adjusted escapement estimate. Source: Grant et al. (2011).

CU Name	Timing Group	2006	2007	2008	2009
Chilliwack	Early Stuart	1,097	1,965	67,822	5,587
		(1,097)	(1,987)	(67,822)	(5,587)
Takla/Trembleur	Early Stuart	35,102	5,303	29,006	44,021
		(35,809)	(5,347)	(29,884)	(45,291)
Pitt	Early Summer	38,816	41,829	16,921	31,034
		(38,816)	(41,839)	(16,921)	(31,042)
Nahatlatch	Early Summer	1,678	3,853	573 (573)	1,439
		(1,678)	(3,853)		(1,439)
Anderson	Early Summer	2,858	2,555	14,838	9,878
		(3,071)	(2,898)	(15,018)	(10,856)
Taseko	Early Summer	2,140	233 (233)	60 (60)	40 (40)
		(2,140)			
Francois	Early Summer	8,655	1,741	65,754	11,400
		(8,655)	(1,773)	(98,257)	(7,008)
Bowron	Early Summer	1,554	2,173	1,005	2,170
		(1,501)	(2,069)	(1,005)	(1,814)
Shuswap Cmplx	Early Summer	252,140	18,251	2,004	9,836
		(292,301)	(24,798)	(4,988)	(14,211)
Kamloops	Early Summer	17,190	25,565	12,676	12,634
		(43,020)	(43,908)	(16,555)	(215,711)
Chilko	Summer	468,947	305,853	249,863	213,379
		(469,504)	(306,707)	(250,583)	(217,778)
Fran.Fras	Summer	147,189	41,328	159,737	27,551
		(147,194)	(41,481)	(159,749)	(27,627)
Quesnel	Summer	160,363	71,809	7,019	135,541
		(169,768)	(75,100)	(7,091)	(147,545)
Tak/Trem/Stu	Summer	24,934	6,674	136,007	81,626
		(27,155)	(8,700)	(141,042)	(57,870)
Lillooet	Late	266,459	93,480	19,500	53,977
		(266,539)	(93,527)	(19,500)	(53,977)
Harrison (D/S)	Late	21,298	4,784	2,419	6,037
		(23,076)	(5,033)	(2,621)	(6,631)
Harrison.River	Late	168,259	128,295	6,717	307,210
Cultus	True Late	3,784	661 (538)	483 (340)	837 (705)
		(3,509)			
Harrison (U/S)	True Late	39,781	37,300	2,756	35,556
		(39,804)	(37,392)	(2,756)	(35,556)
Widgeon	True Late	171 (171)	176 (176)	85 (97)	1,556
					(1,836)
Seton	True Late	18,882	1,699	97 (97)	1,773
		(18,882)	(1,699)		(1,773)
Kamloops	True Late	6,073	14,353 (0)	10,406 (0)	11,464
		(1,278)			(168)
Shuswap Cmplx	True Late	2,875,332	60,888	164 (164)	32,364
		(2,895,537)	(61,043)		(31,277)

Table 4. CU-specific timing parameters at Mission and spawning grounds for 2002. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

		Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Timing Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	30-Jun	22-Jul	12-Aug	11	19-Jun	11-Jul	1-Aug
Takla/Trembleur	Early Stuart	44	17-Jul	8-Aug	29-Aug	28	19-Jun	11-Jul	1-Aug
Pitt	Early Summer	48	19-Jul	12-Aug	5-Sep	10	9-Jul	2-Aug	26-Aug
Nahatlatch	Early Summer	55	13-Jul	10-Aug	6-Sep	8	5-Jul	2-Aug	29-Aug
Anderson	Early Summer	55	12-Jul	9-Aug	5-Sep	13	29-Jun	27-Jul	23-Aug
Taseko	Early Summer	55	28-Jul	25-Aug	21-Sep	23	5-Jul	2-Aug	29-Aug
Francois	Early Summer	55	23-Jul	20-Aug	16-Sep	24	29-Jun	27-Jul	23-Aug
Bowron	Early Summer	55	30-Jul	27-Aug	23-Sep	25	5-Jul	2-Aug	29-Aug
Shuswap Complex	Early Summer	55	29-Jul	26-Aug	22-Sep	20	9-Jul	6-Aug	2-Sep
Kamloops	Early Summer	55	25-Jul	22-Aug	18-Sep	20	5-Jul	2-Aug	29-Aug
Chilko	Summer	74	26-Jul	2-Sep	9-Oct	23	3-Jul	10-Aug	16-Sep
Francois/Fraser	Summer	58	2-Aug	1-Sep	30-Sep	22	11-Jul	10-Aug	8-Sep
Quesnel	Summer	66	1-Aug	4-Sep	7-Oct	17	15-Jul	18-Aug	20-Sep
Takla/Trembleur/Stuart	Summer	60	2-Aug	1-Sep	30-Sep	25	8-Jul	7-Aug	5-Sep
Lillooet	Late	62	7-Aug	7-Sep	8-Oct	11	27-Jul	27-Aug	27-Sep
Harrison (D/S)	Late	61	2-Aug	2-Sep	2-Oct	6	27-Jul	27-Aug	26-Sep
Harrison-River	Late	61	2-Aug	2-Sep	2-Oct	6	27-Jul	27-Aug	26-Sep
Cultus	Late-E	25	7-Aug	20-Aug	1-Sep	6	1-Aug	14-Aug	26-Aug
Cultus	Late-M	16	30-Aug	7-Sep	15-Sep	6	24-Aug	1-Sep	9-Sep
Cultus	Late-L	80	13-Aug	22-Sep	1-Nov	6	7-Aug	16-Sep	26-Oct
Harrison (U/S)	Late-E	25	20-Sep	3-Oct	15-Oct	51	31-Jul	13-Aug	25-Aug
Harrison (U/S)	Late-M	19	17-Sep	27-Sep	6-Oct	26	22-Aug	1-Sep	10-Sep
Harrison (U/S)	Late-L	16	19-Sep	27-Sep	5-Oct	11	8-Sep	16-Sep	24-Sep
Widgeon	Late-E	25	1-Aug	14-Aug	26-Aug	1	31-Jul	13-Aug	25-Aug
Widgeon	Late-M	19	23-Aug	2-Sep	11-Sep	1	22-Aug	1-Sep	10-Sep
Widgeon	Late-L	16	9-Sep	17-Sep	25-Sep	1	8-Sep	16-Sep	24-Sep
Seton	Late-E	25	12-Aug	25-Aug	6-Sep	12	31-Jul	13-Aug	25-Aug
Seton	Late-M	19	1-Sep	11-Sep	20-Sep	10	22-Aug	1-Sep	10-Sep
Seton	Late-L	16	26-Sep	4-Oct	12-Oct	18	8-Sep	16-Sep	24-Sep
Kamloops	Late-E	25	19-Aug	1-Sep	13-Sep	19	31-Jul	13-Aug	25-Aug
Kamloops	Late-M	19	6-Sep	16-Sep	25-Sep	15	22-Aug	1-Sep	10-Sep
Kamloops	Late-L	16	26-Sep	4-Oct	12-Oct	18	8-Sep	16-Sep	24-Sep
Shuswap Complex	Late-E	25	2-Sep	15-Sep	27-Sep	33	31-Jul	13-Aug	25-Aug
Shuswap Complex	Late-M	19	18-Sep	28-Sep	7-Oct	27	22-Aug	1-Sep	10-Sep
Shuswap Complex	Late-L	16	1-Oct	9-Oct	17-Oct	23	8-Sep	16-Sep	24-Sep

Table 5. CU-specific timing parameters at Mission and spawning grounds for 2003. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

		Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Timing Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	30-Jun	22-Jul	12-Aug	11	19-Jun	11-Jul	1-Aug
Takla/Trembleur	Early Stuart	44	17-Jul	8-Aug	29-Aug	28	19-Jun	11-Jul	1-Aug
Pitt	Early Summer	48	16-Jul	9-Aug	2-Sep	10	6-Jul	30-Jul	23-Aug
Nahatlatch	Early Summer	55	15-Jul	12-Aug	8-Sep	8	7-Jul	4-Aug	31-Aug
Anderson	Early Summer	55	14-Jul	11-Aug	7-Sep	12	2-Jul	30-Jul	26-Aug
Taseko	Early Summer	55	29-Jul	26-Aug	22-Sep	22	7-Jul	4-Aug	31-Aug
Francois	Early Summer	55	18-Jul	15-Aug	11-Sep	23	25-Jun	23-Jul	19-Aug
Bowron	Early Summer	55	31-Jul	28-Aug	24-Sep	24	7-Jul	4-Aug	31-Aug
Shuswap Complex	Early Summer	55	26-Jul	23-Aug	19-Sep	19	7-Jul	4-Aug	31-Aug
Kamloops	Early Summer	55	26-Jul	23-Aug	19-Sep	19	7-Jul	4-Aug	31-Aug
Chilko	Summer	74	2-Aug	9-Sep	16-Oct	22	11-Jul	18-Aug	24-Sep
Francois/Fraser	Summer	58	29-Jul	28-Aug	26-Sep	22	7-Jul	6-Aug	4-Sep
Quesnel	Summer	66	29-Jul	1-Sep	4-Oct	17	12-Jul	15-Aug	17-Sep
Takla/Trembleur/Stuart	Summer	60	1-Aug	31-Aug	29-Sep	25	7-Jul	6-Aug	4-Sep
Lillooet	Late	62	7-Aug	7-Sep	8-Oct	11	27-Jul	27-Aug	27-Sep
Harrison (D/S)	Late	61	2-Aug	2-Sep	2-Oct	6	27-Jul	27-Aug	26-Sep
Harrison-River	Late	61	2-Aug	2-Sep	2-Oct	6	27-Jul	27-Aug	26-Sep
Cultus	Late-E	25	1-Aug	14-Aug	26-Aug	6	26-Jul	8-Aug	20-Aug
Cultus	Late-M	16	21-Aug	29-Aug	6-Sep	6	15-Aug	23-Aug	31-Aug
Cultus	Late-L	81	9-Aug	19-Sep	29-Oct	6	3-Aug	13-Sep	23-Oct
Harrison (U/S)	Late-E	25	15-Sep	28-Sep	10-Oct	51	26-Jul	8-Aug	20-Aug
Harrison (U/S)	Late-M	19	8-Sep	18-Sep	27-Sep	26	13-Aug	23-Aug	1-Sep
Harrison (U/S)	Late-L	16	16-Sep	24-Sep	2-Oct	11	5-Sep	13-Sep	21-Sep
Widgeon	Late-E	25	27-Jul	9-Aug	21-Aug	1	26-Jul	8-Aug	20-Aug
Widgeon	Late-M	19	14-Aug	24-Aug	2-Sep	1	13-Aug	23-Aug	1-Sep
Widgeon	Late-L	16	6-Sep	14-Sep	22-Sep	1	5-Sep	13-Sep	21-Sep
Seton	Late-E	25	5-Aug	18-Aug	30-Aug	10	26-Jul	8-Aug	20-Aug
Seton	Late-M	19	23-Aug	2-Sep	11-Sep	10	13-Aug	23-Aug	1-Sep
Seton	Late-L	16	19-Sep	27-Sep	5-Oct	14	5-Sep	13-Sep	21-Sep
Kamloops	Late-E	25	13-Aug	26-Aug	7-Sep	18	26-Jul	8-Aug	20-Aug
Kamloops	Late-M	19	31-Aug	10-Sep	19-Sep	18	13-Aug	23-Aug	1-Sep
Kamloops	Late-L	16	22-Sep	30-Sep	8-Oct	17	5-Sep	13-Sep	21-Sep
Shuswap Complex	Late-E	25	28-Aug	10-Sep	22-Sep	33	26-Jul	8-Aug	20-Aug
Shuswap Complex	Late-M	19	15-Sep	25-Sep	4-Oct	33	13-Aug	23-Aug	1-Sep
Shuswap Complex	Late-L	16	3-Oct	11-Oct	19-Oct	28	5-Sep	13-Sep	21-Sep

Table 6. CU-specific timing parameters at Mission and spawning grounds for 2004. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

Stock Name	Timing Group	Duration (Days)	Arrival Timing at Spawn			Travel (Days)	Arrival Timing at Mission		
			Start	Peak	End		Start	Peak	End
Chilliwack	Early Stuart	44	30-Jun	22-Jul	12-Aug	11	19-Jun	11-Jul	1-Aug
Takla/Trembleur	Early Stuart	44	17-Jul	8-Aug	29-Aug	28	19-Jun	11-Jul	1-Aug
Pitt	Early Summer	48	23-Jul	16-Aug	9-Sep	10	13-Jul	6-Aug	30-Aug
Nahatlatch	Early Summer	55	17-Jul	14-Aug	10-Sep	8	9-Jul	6-Aug	2-Sep
Anderson	Early Summer	55	11-Jul	8-Aug	4-Sep	13	28-Jun	26-Jul	22-Aug
Taseko	Early Summer	55	1-Aug	29-Aug	25-Sep	23	9-Jul	6-Aug	2-Sep
Francois	Early Summer	55	24-Jul	21-Aug	17-Sep	24	30-Jun	28-Jul	24-Aug
Bowron	Early Summer	55	3-Aug	31-Aug	27-Sep	25	9-Jul	6-Aug	2-Sep
Shuswap Complex	Early Summer	55	24-Jul	21-Aug	17-Sep	20	4-Jul	1-Aug	28-Aug
Kamloops	Early Summer	55	29-Jul	26-Aug	22-Sep	20	9-Jul	6-Aug	2-Sep
Chilko	Summer	74	26-Jul	2-Sep	9-Oct	23	3-Jul	10-Aug	16-Sep
Francois/Fraser	Summer	58	3-Aug	2-Sep	1-Oct	22	12-Jul	11-Aug	9-Sep
Quesnel	Summer	66	23-Jul	26-Aug	28-Sep	17	6-Jul	9-Aug	11-Sep
Takla/Trembleur/Stuart	Summer	60	6-Aug	5-Sep	4-Oct	25	12-Jul	11-Aug	9-Sep
Lillooet	Late	62	31-Jul	31-Aug	1-Oct	11	20-Jul	20-Aug	20-Sep
Harrison (D/S)	Late	61	26-Jul	26-Aug	25-Sep	6	20-Jul	20-Aug	19-Sep
Harrison-River	Late	61	26-Jul	26-Aug	25-Sep	6	20-Jul	20-Aug	19-Sep
Cultus	Late-E	24	2-Aug	14-Aug	25-Aug	6	27-Jul	8-Aug	19-Aug
Cultus	Late-M	17	20-Aug	29-Aug	6-Sep	6	14-Aug	23-Aug	31-Aug
Cultus	Late-L	64	18-Aug	19-Sep	20-Oct	6	12-Aug	13-Sep	14-Oct
Harrison (U/S)	Late-E	25	15-Sep	28-Sep	10-Oct	51	26-Jul	8-Aug	20-Aug
Harrison (U/S)	Late-M	19	8-Sep	18-Sep	27-Sep	26	13-Aug	23-Aug	1-Sep
Harrison (U/S)	Late-L	16	16-Sep	24-Sep	2-Oct	11	5-Sep	13-Sep	21-Sep
Widgeon	Late-E	25	27-Jul	9-Aug	21-Aug	1	26-Jul	8-Aug	20-Aug
Widgeon	Late-M	19	14-Aug	24-Aug	2-Sep	1	13-Aug	23-Aug	1-Sep
Widgeon	Late-L	16	6-Sep	14-Sep	22-Sep	1	5-Sep	13-Sep	21-Sep
Seton	Late-E	25	7-Aug	20-Aug	1-Sep	12	26-Jul	8-Aug	20-Aug
Seton	Late-M	19	23-Aug	2-Sep	11-Sep	10	13-Aug	23-Aug	1-Sep
Seton	Late-L	16	23-Sep	1-Oct	9-Oct	18	5-Sep	13-Sep	21-Sep
Kamloops	Late-E	25	14-Aug	27-Aug	8-Sep	19	26-Jul	8-Aug	20-Aug
Kamloops	Late-M	19	28-Aug	7-Sep	16-Sep	15	13-Aug	23-Aug	1-Sep
Kamloops	Late-L	16	23-Sep	1-Oct	9-Oct	18	5-Sep	13-Sep	21-Sep
Shuswap Complex	Late-E	25	28-Aug	10-Sep	22-Sep	33	26-Jul	8-Aug	20-Aug
Shuswap Complex	Late-M	19	9-Sep	19-Sep	28-Sep	27	13-Aug	23-Aug	1-Sep
Shuswap Complex	Late-L	16	28-Sep	6-Oct	14-Oct	23	5-Sep	13-Sep	21-Sep

Table 7. CU-specific timing parameters at Mission and spawning grounds for 2005. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

	Timing	Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	10-Jul	1-Aug	22-Aug	11	29-Jun	21-Jul	11-Aug
Takla/Trembleur	Early Stuart	44	29-Jul	20-Aug	10-Sep	30	29-Jun	21-Jul	11-Aug
Pitt	Early Summe	48	26-Jul	19-Aug	12-Sep	10	16-Jul	9-Aug	2-Sep
Nahatlatch	Early Summe	55	21-Jul	18-Aug	14-Sep	9	12-Jul	9-Aug	5-Sep
Anderson	Early Summe	55	14-Aug	11-Sep	8-Oct	14	31-Jul	28-Aug	24-Sep
Taseko	Early Summe	55	5-Aug	2-Sep	29-Sep	24	12-Jul	9-Aug	5-Sep
Francois	Early Summe	55	6-Aug	3-Sep	30-Sep	25	12-Jul	9-Aug	5-Sep
Bowron	Early Summe	55	7-Aug	4-Sep	1-Oct	26	12-Jul	9-Aug	5-Sep
Shuswap Complex	Early Summe	55	16-Aug	13-Sep	10-Oct	20	27-Jul	24-Aug	20-Sep
Kamloops	Early Summe	55	1-Aug	29-Aug	25-Sep	20	12-Jul	9-Aug	5-Sep
Chilko	Summer	74	15-Aug	22-Sep	29-Oct	25	21-Jul	28-Aug	4-Oct
Francois/Fraser	Summer	58	18-Aug	17-Sep	16-Oct	25	24-Jul	23-Aug	21-Sep
Quesnel	Summer	66	13-Aug	16-Sep	19-Oct	19	25-Jul	28-Aug	30-Sep
Takla/Trembleur/Stuart	Summer	60	20-Aug	19-Sep	18-Oct	27	24-Jul	23-Aug	21-Sep
Lillooet	Late	62	10-Aug	10-Sep	11-Oct	11	30-Jul	30-Aug	30-Sep
Harrison (D/S)	Late	61	5-Aug	5-Sep	5-Oct	6	30-Jul	30-Aug	29-Sep
Harrison-River	Late	61	5-Aug	5-Sep	5-Oct	6	30-Jul	30-Aug	29-Sep
Cultus	Late-E	24	30-Jul	11-Aug	22-Aug	6	24-Jul	5-Aug	16-Aug
Cultus	Late-M	17	21-Aug	30-Aug	7-Sep	6	15-Aug	24-Aug	1-Sep
Cultus	Late-L	64	14-Aug	15-Sep	16-Oct	6	8-Aug	9-Sep	10-Oct
Harrison (U/S)	Late-E	25	12-Sep	25-Sep	7-Oct	51	23-Jul	5-Aug	17-Aug
Harrison (U/S)	Late-M	19	9-Sep	19-Sep	28-Sep	26	14-Aug	24-Aug	2-Sep
Harrison (U/S)	Late-L	16	12-Sep	20-Sep	28-Sep	11	1-Sep	9-Sep	17-Sep
Widgeon	Late-E	25	24-Jul	6-Aug	18-Aug	1	23-Jul	5-Aug	17-Aug
Widgeon	Late-M	19	15-Aug	25-Aug	3-Sep	1	14-Aug	24-Aug	2-Sep
Widgeon	Late-L	16	2-Sep	10-Sep	18-Sep	1	1-Sep	9-Sep	17-Sep
Seton	Late-E	25	4-Aug	17-Aug	29-Aug	12	23-Jul	5-Aug	17-Aug
Seton	Late-M	19	24-Aug	3-Sep	12-Sep	10	14-Aug	24-Aug	2-Sep
Seton	Late-L	16	19-Sep	27-Sep	5-Oct	18	1-Sep	9-Sep	17-Sep
Kamloops	Late-E	25	11-Aug	24-Aug	5-Sep	19	23-Jul	5-Aug	17-Aug
Kamloops	Late-M	19	29-Aug	8-Sep	17-Sep	15	14-Aug	24-Aug	2-Sep
Kamloops	Late-L	16	19-Sep	27-Sep	5-Oct	18	1-Sep	9-Sep	17-Sep
Shuswap Complex	Late-E	25	25-Aug	7-Sep	19-Sep	33	23-Jul	5-Aug	17-Aug
Shuswap Complex	Late-M	19	10-Sep	20-Sep	29-Sep	27	14-Aug	24-Aug	2-Sep
Shuswap Complex	Late-L	16	24-Sep	2-Oct	10-Oct	23	1-Sep	9-Sep	17-Sep

Table 8. CU-specific timing parameters at Mission and spawning grounds for 2006. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

		Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Timing Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	2-Jul	24-Jul	14-Aug	11	21-Jun	13-Jul	3-Aug
Takla/Trembleur	Early Stuart	44	19-Jul	10-Aug	31-Aug	28	21-Jun	13-Jul	3-Aug
Pitt	Early Summer	48	5-Aug	29-Aug	22-Sep	10	26-Jul	19-Aug	12-Sep
Nahatlatch	Early Summer	55	31-Jul	28-Aug	24-Sep	9	22-Jul	19-Aug	15-Sep
Anderson	Early Summer	55	10-Aug	7-Sep	4-Oct	15	26-Jul	23-Aug	19-Sep
Taseko	Early Summer	55	18-Aug	15-Sep	12-Oct	27	22-Jul	19-Aug	15-Sep
Francois	Early Summer	55	29-Jul	26-Aug	22-Sep	28	1-Jul	29-Jul	25-Aug
Bowron	Early Summer	55	20-Aug	17-Sep	14-Oct	29	22-Jul	19-Aug	15-Sep
Shuswap Complex	Early Summer	55	7-Aug	4-Sep	1-Oct	21	17-Jul	14-Aug	10-Sep
Kamloops	Early Summer	55	13-Aug	10-Sep	7-Oct	22	22-Jul	19-Aug	15-Sep
Chilko	Summer	74	1-Aug	8-Sep	15-Oct	25	7-Jul	14-Aug	20-Sep
Francois/Fraser	Summer	58	10-Aug	8-Sep	6-Oct	27	14-Jul	12-Aug	9-Sep
Quesnel	Summer	66	7-Aug	10-Sep	13-Oct	20	18-Jul	21-Aug	23-Sep
Takla/Trembleur/Stuart	Summer	60	11-Aug	10-Sep	9-Oct	29	13-Jul	12-Aug	10-Sep
Lillooet	Late	62	14-Aug	14-Sep	15-Oct	11	3-Aug	3-Sep	4-Oct
Harrison (D/S)	Late	61	9-Aug	9-Sep	9-Oct	6	3-Aug	3-Sep	3-Oct
Harrison-River	Late	61	9-Aug	9-Sep	9-Oct	6	3-Aug	3-Sep	3-Oct
Cultus	Late-E	31	29-Jul	14-Aug	29-Aug	6	23-Jul	8-Aug	23-Aug
Cultus	Late-M	20	18-Aug	28-Aug	7-Sep	6	12-Aug	22-Aug	1-Sep
Cultus	Late-L	50	19-Aug	13-Sep	8-Oct	6	13-Aug	7-Sep	2-Oct
Harrison (U/S)	Late-E	25	15-Sep	28-Sep	10-Oct	51	26-Jul	8-Aug	20-Aug
Harrison (U/S)	Late-M	19	7-Sep	17-Sep	26-Sep	26	12-Aug	22-Aug	31-Aug
Harrison (U/S)	Late-L	16	10-Sep	18-Sep	26-Sep	11	30-Aug	7-Sep	15-Sep
Widgeon	Late-E	25	27-Jul	9-Aug	21-Aug	1	26-Jul	8-Aug	20-Aug
Widgeon	Late-M	19	13-Aug	23-Aug	1-Sep	1	12-Aug	22-Aug	31-Aug
Widgeon	Late-L	16	31-Aug	8-Sep	16-Sep	1	30-Aug	7-Sep	15-Sep
Seton	Late-E	25	6-Aug	19-Aug	31-Aug	11	26-Jul	8-Aug	20-Aug
Seton	Late-M	19	24-Aug	3-Sep	12-Sep	12	12-Aug	22-Aug	31-Aug
Seton	Late-L	16	12-Sep	20-Sep	28-Sep	13	30-Aug	7-Sep	15-Sep
Kamloops	Late-E	25	16-Aug	29-Aug	10-Sep	21	26-Jul	8-Aug	20-Aug
Kamloops	Late-M	19	31-Aug	10-Sep	19-Sep	19	12-Aug	22-Aug	31-Aug
Kamloops	Late-L	16	17-Sep	25-Sep	3-Oct	18	30-Aug	7-Sep	15-Sep
Shuswap Complex	Late-E	25	31-Aug	13-Sep	25-Sep	36	26-Jul	8-Aug	20-Aug
Shuswap Complex	Late-M	19	12-Sep	22-Sep	1-Oct	31	12-Aug	22-Aug	31-Aug
Shuswap Complex	Late-L	16	26-Sep	4-Oct	12-Oct	27	30-Aug	7-Sep	15-Sep

Table 9. CU-specific timing parameters at Mission and spawning grounds for 2007. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

	Timing	Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	25-Jun	17-Jul	7-Aug	11	14-Jun	6-Jul	27-Jul
Takla/Trembleur	Early Stuart	44	12-Jul	3-Aug	24-Aug	28	14-Jun	6-Jul	27-Jul
Pitt	Early Summer	48	24-Jul	17-Aug	10-Sep	10	14-Jul	7-Aug	31-Aug
Nahatlatch	Early Summer	55	18-Jul	15-Aug	11-Sep	8	10-Jul	7-Aug	3-Sep
Anderson	Early Summer	55	28-Jul	25-Aug	21-Sep	12	16-Jul	13-Aug	9-Sep
Taseko	Early Summer	55	1-Aug	29-Aug	25-Sep	22	10-Jul	7-Aug	3-Sep
Francois	Early Summer	55	26-Jul	23-Aug	19-Sep	23	3-Jul	31-Jul	27-Aug
Bowron	Early Summer	55	3-Aug	31-Aug	27-Sep	24	10-Jul	7-Aug	3-Sep
Shuswap Complex	Early Summer	55	2-Aug	30-Aug	26-Sep	19	14-Jul	11-Aug	7-Sep
Kamloops	Early Summer	55	29-Jul	26-Aug	22-Sep	19	10-Jul	7-Aug	3-Sep
Chilko	Summer	74	26-Jul	2-Sep	9-Oct	22	4-Jul	11-Aug	17-Sep
Francois/Fraser	Summer	58	6-Aug	5-Sep	4-Oct	22	15-Jul	14-Aug	12-Sep
Quesnel	Summer	66	25-Jul	28-Aug	30-Sep	17	8-Jul	11-Aug	13-Sep
Takla/Trembleur/Stuart	Summer	60	9-Aug	8-Sep	7-Oct	25	15-Jul	14-Aug	12-Sep
Lillooet	Late	62	3-Aug	3-Sep	4-Oct	11	23-Jul	23-Aug	23-Sep
Harrison (D/S)	Late	61	29-Jul	29-Aug	28-Sep	6	23-Jul	23-Aug	22-Sep
Harrison-River	Late	61	29-Jul	29-Aug	28-Sep	6	23-Jul	23-Aug	22-Sep
Cultus	Late-E	14	7-Aug	14-Aug	21-Aug	6	1-Aug	8-Aug	15-Aug
Cultus	Late-M	16	16-Aug	24-Aug	1-Sep	6	10-Aug	18-Aug	26-Aug
Cultus	Late-L	44	25-Aug	16-Sep	8-Oct	6	19-Aug	10-Sep	2-Oct
Harrison (U/S)	Late-E	25	15-Sep	28-Sep	10-Oct	51	26-Jul	8-Aug	20-Aug
Harrison (U/S)	Late-M	19	3-Sep	13-Sep	22-Sep	26	8-Aug	18-Aug	27-Aug
Harrison (U/S)	Late-L	16	13-Sep	21-Sep	29-Sep	11	2-Sep	10-Sep	18-Sep
Widgeon	Late-E	25	27-Jul	9-Aug	21-Aug	1	26-Jul	8-Aug	20-Aug
Widgeon	Late-M	19	9-Aug	19-Aug	28-Aug	1	8-Aug	18-Aug	27-Aug
Widgeon	Late-L	16	3-Sep	11-Sep	19-Sep	1	2-Sep	10-Sep	18-Sep
Seton	Late-E	25	5-Aug	18-Aug	30-Aug	10	26-Jul	8-Aug	20-Aug
Seton	Late-M	19	18-Aug	28-Aug	6-Sep	10	8-Aug	18-Aug	27-Aug
Seton	Late-L	16	16-Sep	24-Sep	2-Oct	14	2-Sep	10-Sep	18-Sep
Kamloops	Late-E	25	13-Aug	26-Aug	7-Sep	18	26-Jul	8-Aug	20-Aug
Kamloops	Late-M	19	26-Aug	5-Sep	14-Sep	18	8-Aug	18-Aug	27-Aug
Kamloops	Late-L	16	19-Sep	27-Sep	5-Oct	17	2-Sep	10-Sep	18-Sep
Shuswap Complex	Late-E	25	28-Aug	10-Sep	22-Sep	33	26-Jul	8-Aug	20-Aug
Shuswap Complex	Late-M	19	10-Sep	20-Sep	29-Sep	33	8-Aug	18-Aug	27-Aug
Shuswap Complex	Late-L	16	30-Sep	8-Oct	16-Oct	28	2-Sep	10-Sep	18-Sep

Table 10. CU-specific timing parameters at Mission and spawning grounds for 2008. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

		Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Timing Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	23-Jun	15-Jul	5-Aug	11	12-Jun	4-Jul	25-Jul
Takla/Trembleur	Early Stuart	44	10-Jul	1-Aug	22-Aug	28	12-Jun	4-Jul	25-Jul
Pitt	Early Summer	48	10-Jul	3-Aug	27-Aug	10	30-Jun	24-Jul	17-Aug
Nahatlatch	Early Summer	55	4-Jul	1-Aug	28-Aug	8	26-Jun	24-Jul	20-Aug
Anderson	Early Summer	55	3-Jul	31-Jul	27-Aug	12	21-Jun	19-Jul	15-Aug
Taseko	Early Summer	55	18-Jul	15-Aug	11-Sep	22	26-Jun	24-Jul	20-Aug
Francois	Early Summer	55	7-Jul	4-Aug	31-Aug	23	14-Jun	12-Jul	8-Aug
Bowron	Early Summer	55	20-Jul	17-Aug	13-Sep	24	26-Jun	24-Jul	20-Aug
Shuswap Complex	Early Summer	55	15-Jul	12-Aug	8-Sep	19	26-Jun	24-Jul	20-Aug
Kamloops	Early Summer	55	15-Jul	12-Aug	8-Sep	19	26-Jun	24-Jul	20-Aug
Chilko	Summer	74	19-Jul	26-Aug	2-Oct	22	27-Jun	4-Aug	10-Sep
Francois/Fraser	Summer	58	18-Jul	17-Aug	15-Sep	22	26-Jun	26-Jul	24-Aug
Quesnel	Summer	66	15-Jul	18-Aug	20-Sep	17	28-Jun	1-Aug	3-Sep
Takla/Trembleur/Stuart	Summer	60	21-Jul	20-Aug	18-Sep	25	26-Jun	26-Jul	24-Aug
Lillooet	Late	62	25-Jul	25-Aug	25-Sep	11	14-Jul	14-Aug	14-Sep
Harrison (D/S)	Late	61	20-Jul	20-Aug	19-Sep	6	14-Jul	14-Aug	13-Sep
Harrison-River	Late	61	20-Jul	20-Aug	19-Sep	6	14-Jul	14-Aug	13-Sep
Cultus	Late-E	24	2-Aug	14-Aug	25-Aug	6	27-Jul	8-Aug	19-Aug
Cultus	Late-M	17	15-Aug	24-Aug	1-Sep	6	9-Aug	18-Aug	26-Aug
Cultus	Late-L	64	15-Aug	16-Sep	17-Oct	6	9-Aug	10-Sep	11-Oct
Harrison (U/S)	Late-E	25	15-Sep	28-Sep	10-Oct	51	26-Jul	8-Aug	20-Aug
Harrison (U/S)	Late-M	19	3-Sep	13-Sep	22-Sep	26	8-Aug	18-Aug	27-Aug
Harrison (U/S)	Late-L	16	13-Sep	21-Sep	29-Sep	11	2-Sep	10-Sep	18-Sep
Widgeon	Late-E	25	27-Jul	9-Aug	21-Aug	1	26-Jul	8-Aug	20-Aug
Widgeon	Late-M	19	9-Aug	19-Aug	28-Aug	1	8-Aug	18-Aug	27-Aug
Widgeon	Late-L	16	3-Sep	11-Sep	19-Sep	1	2-Sep	10-Sep	18-Sep
Seton	Late-E	25	5-Aug	18-Aug	30-Aug	10	26-Jul	8-Aug	20-Aug
Seton	Late-M	19	18-Aug	28-Aug	6-Sep	10	8-Aug	18-Aug	27-Aug
Seton	Late-L	16	16-Sep	24-Sep	2-Oct	14	2-Sep	10-Sep	18-Sep
Kamloops	Late-E	25	13-Aug	26-Aug	7-Sep	18	26-Jul	8-Aug	20-Aug
Kamloops	Late-M	19	26-Aug	5-Sep	14-Sep	18	8-Aug	18-Aug	27-Aug
Kamloops	Late-L	16	19-Sep	27-Sep	5-Oct	17	2-Sep	10-Sep	18-Sep
Shuswap Complex	Late-E	25	28-Aug	10-Sep	22-Sep	33	26-Jul	8-Aug	20-Aug
Shuswap Complex	Late-M	19	10-Sep	20-Sep	29-Sep	33	8-Aug	18-Aug	27-Aug
Shuswap Complex	Late-L	16	30-Sep	8-Oct	16-Oct	28	2-Sep	10-Sep	18-Sep

Table 11. CU-specific timing parameters at Mission and spawning grounds for 2009. Duration is the total number of days from the start of arrival to finish, measured in days) at Mission, Travel Days are the number of days it takes for that CU to move from Mission to the spawning grounds.

		Duration	Arrival Timing at Spawn			Travel	Arrival Timing at Mission		
Stock Name	Timing Group	(Days)	Start	Peak	End	(Days)	Start	Peak	End
Chilliwack	Early Stuart	44	25-Jun	17-Jul	7-Aug	11	14-Jun	6-Jul	27-Jul
Takla/Trembleur	Early Stuart	44	11-Jul	2-Aug	23-Aug	28	13-Jun	5-Jul	26-Jul
Pitt	Early Summer	48	18-Jul	11-Aug	4-Sep	10	8-Jul	1-Aug	25-Aug
Nahatlatch	Early Summer	55	12-Jul	9-Aug	5-Sep	8	4-Jul	1-Aug	28-Aug
Anderson	Early Summer	55	15-Jul	12-Aug	8-Sep	13	2-Jul	30-Jul	26-Aug
Taseko	Early Summer	55	27-Jul	24-Aug	20-Sep	23	4-Jul	1-Aug	28-Aug
Francois	Early Summer	55	19-Jul	16-Aug	12-Sep	24	25-Jun	23-Jul	19-Aug
Bowron	Early Summer	55	29-Jul	26-Aug	22-Sep	25	4-Jul	1-Aug	28-Aug
Shuswap Complex	Early Summer	55	28-Jul	25-Aug	21-Sep	19	9-Jul	6-Aug	2-Sep
Kamloops	Early Summer	55	23-Jul	20-Aug	16-Sep	19	4-Jul	1-Aug	28-Aug
Chilko	Summer	74	27-Jul	3-Sep	10-Oct	25	2-Jul	9-Aug	15-Sep
Francois/Fraser	Summer	58	2-Aug	1-Sep	30-Sep	26	7-Jul	6-Aug	4-Sep
Quesnel	Summer	66	30-Jul	2-Sep	5-Oct	19	11-Jul	14-Aug	16-Sep
Takla/Trembleur/Stuart	Summer	60	21-Jul	20-Aug	18-Sep	28	23-Jun	23-Jul	21-Aug
Lillooet	Late	62	2-Aug	2-Sep	3-Oct	11	22-Jul	22-Aug	22-Sep
Harrison (D/S)	Late	61	28-Jul	28-Aug	27-Sep	6	22-Jul	22-Aug	21-Sep
Harrison-River	Late	61	28-Jul	28-Aug	27-Sep	6	22-Jul	22-Aug	21-Sep
Cultus	Late-E	24	2-Aug	14-Aug	25-Aug	6	27-Jul	8-Aug	19-Aug
Cultus	Late-M	17	15-Aug	24-Aug	1-Sep	6	9-Aug	18-Aug	26-Aug
Cultus	Late-L	64	15-Aug	16-Sep	17-Oct	6	9-Aug	10-Sep	11-Oct
Harrison (U/S)	Late-E	25	15-Sep	28-Sep	10-Oct	51	26-Jul	8-Aug	20-Aug
Harrison (U/S)	Late-M	19	3-Sep	13-Sep	22-Sep	26	8-Aug	18-Aug	27-Aug
Harrison (U/S)	Late-L	16	13-Sep	21-Sep	29-Sep	11	2-Sep	10-Sep	18-Sep
Widgeon	Late-E	25	27-Jul	9-Aug	21-Aug	1	26-Jul	8-Aug	20-Aug
Widgeon	Late-M	19	9-Aug	19-Aug	28-Aug	1	8-Aug	18-Aug	27-Aug
Widgeon	Late-L	16	3-Sep	11-Sep	19-Sep	1	2-Sep	10-Sep	18-Sep
Seton	Late-E	25	7-Aug	20-Aug	1-Sep	12	26-Jul	8-Aug	20-Aug
Seton	Late-M	19	18-Aug	28-Aug	6-Sep	10	8-Aug	18-Aug	27-Aug
Seton	Late-L	16	20-Sep	28-Sep	6-Oct	18	2-Sep	10-Sep	18-Sep
Kamloops	Late-E	25	14-Aug	27-Aug	8-Sep	19	26-Jul	8-Aug	20-Aug
Kamloops	Late-M	19	23-Aug	2-Sep	11-Sep	15	8-Aug	18-Aug	27-Aug
Kamloops	Late-L	16	20-Sep	28-Sep	6-Oct	18	2-Sep	10-Sep	18-Sep
Shuswap Complex	Late-E	25	28-Aug	10-Sep	22-Sep	33	26-Jul	8-Aug	20-Aug
Shuswap Complex	Late-M	19	4-Sep	14-Sep	23-Sep	27	8-Aug	18-Aug	27-Aug
Shuswap Complex	Late-L	16	25-Sep	3-Oct	11-Oct	23	2-Sep	10-Sep	18-Sep

Table 12. Summary of telemetry releases for 2002-2009.

	Release site				
Year	Juan de Fuca	Johnstone Strait	Mission	Total	No. stations
2002	438	873	0	1311	17
2003	.	.	.	0	.
2004	.	.	.	0	.
2005	0	0	411	411	17
2006	236	424	378	1038	24
2007	0	0	381	381	22
2008	0	0	110	110	14
2009	0	0	307	307	21

Table 13. Residence times for each CU in each management area and tributary in 2006. “Trib Time” is the estimated number of days fish reside in a lake or tributary prior to entering the spawning grounds.

CU Name	TTG	TT	Mainstem Fisheries																			Thompson Watershed						
			A29b	A29d	SPM	PMM	MH	HH	HS	ST	T-T	TK	KD	DC	CQ	QN	NN	NB	N	S	C	TB	BK	NT	KLR	LRA	Tot	MS
Chilliwack	E.Stuart	10	1	1	1	1	1																				15	11
Takla/Trembleur	E.Stuart	5	1	1	1	1	1	1	1	2	1	1	1	1	5	2	2		1	4							32	28
Pitt	E.Summer	10	1	1	1	1																					14	10
Nahatlatch	E.Summer	5	1	1	1	1	1	2	1																		13	9
Anderson	E.Summer	5	1	1	1	1	1	2	1	3	1	2															19	15
Taseko	E.Summer	5	1	1	1	1	1	2	1	3	1	2	1	2	4						5						31	27
Francois	E.Summer	5	1	1	1	1	1	2	1	3	1	2	1	2	4	2	2		2								32	28
Bowron	E.Summer	5	1	1	1	1	1	2	1	3	1	2	1	2	4	2	2	3									33	29
Indian/Kruger	E.Summer	5	1	1	1	1	1	2	1	3	1	2	1	2	4	2	2	3									33	29
Shuswap Complex	E.Summer	5	1	1	1	1	1	2	1	3												4	3		2		25	21
Kamloops	E.Summer	5	1	1	1	1	1	2	1	3												4	3	3			26	22
Chilko	Summer	5	1	1	1	1	1	2	1	2	1	2	1	1							9						29	25
Francois	Summer	5	1	1	1	1	1	2	1	2	1	2	1	1	4	2	2		3								31	27
Quesnel	Summer	5	1	1	1	1	1	2	1	2	1	2	1	1	4												24	20
Takla/Trembleur/Stuart	Summer	5	1	1	1	1	1	2	1	2	1	2	1	1	4	2	2			5							33	29
Lillooet	True Late	10	1	2	1	2	1																				17	11
Harrison (D/S)	True Late	5	1	2	1	2	1																				12	6
Harrison-River	True Late	5	1	2	1	2	1																				12	6
Cultus-L-E	Late-E	5	1	2	1	2	1																				12	6
Cultus-L-M	Late-M	5	1	1	1	1	1																				10	6
Cultus-L-L	Late-L	5	1	1	1	1	1																				10	6
Harrison (U/S)-L-E	Late-E	50	1	2	1	2	1																				57	51
Harrison (U/S)-L-M	Late-M	25	1	1	1	1	1																				30	26
Harrison (U/S)-L-L	Late-L	10	1	1	1	1	1																				15	11
Widgeon-L-E	Late-E		1	2	1	2	1																				7	1
Widgeon-L-M	Late-M		1	1	1	1	1																				5	1
Widgeon-L-L	Late-L		1	1	1	1	1																				5	1
Seton-L-E	Late-E		1	2	1	2	1	2	2	3	1	2															17	11
Seton-L-M	Late-M		1	1	1	1	1	2	1	3	2	3															16	12
Seton-L-L	Late-L		1	1	1	1	1	2	1	4	2	3															17	13
Kamloops-L-E	Late-E		1	2	1	2	1	2	2	3												5	8				27	21
Kamloops-L-M	Late-M		1	1	1	1	1	2	1	3												5	7				23	19
Kamloops-L-L	Late-L		1	1	1	1	1	2	1	4												6	4				22	18
Shuswap Complex-L-E	Late-E		1	2	1	2	1	2	2	3												5	8		3	12	42	36
Shuswap Complex-L-M	Late-M		1	1	1	1	1	2	1	3												5	7		3	9	35	31
Shuswap Complex-L-L	Late-L		1	1	1	1	1	2	1	4												6	4		3	6	31	27

Note. TG = Timing Group, TT = Trib Time, A29b = Area 29b GN-E, A29d = Area 29d GN-E, S-PM = Stev-P.Mann, PMM = P.Mann-Mission, MH = Mission-Harrison, HH = Harrison-Hope, HS = Hope-Sawmill, ST = Sawmill-Thompson, T-T = Thompson-Texas, TK = Texas-Kelly, KD = Kelly-Deadman, DC = Deadman-Chilcotin, CQ = Chilcotin-Quesnel, QN = Quesnel-Naver, NN = Naver-Nechako, NB = Nechako-Bowron, N = Nechako, S = Stuart, C = Chilcotin, TB = Thompson-Bonaparte, BK = Bonaparte-Kamloops, NT = North Thompson, KLR = Kamloops-LittleR, LRA = LittleR-Adams, Tot = Total, MSA = Mission-Spawn Area.

Table 14. Total in-river reconstructed CU-specific harvest (2002 – 2009).

CU Name	2002	2003	2004	2005	2006	2007	2008	2009
Chilliwack	10	8	1858	47	5	2	372	25
Takla/Trembleur	3185	673	40227	24299	1967	326	1798	2888
Pitt	12387	10560	17561	2394	7773	976	1365	139
Nahatlatch	1816	1456	672	309	593	319	193	36
Anderson	530	8181	30236	2980	3892	687	9079	1060
Taseko	452	426	1174	316	3046	70	47	6
Francois	500	1557	78573	12805	7962	419	26012	2308
Bowron	2914	7271	7751	1009	3144	665	1030	202
Shuswap Complex	66685	29449	45760	5048	247269	2647	1770	509
Kamloops	7300	22091	62405	18452	25531	3431	5898	450
Chilko	126508	358181	151612	135532	278338	77627	146781	27796
Fraser	114456	64558	162834	34356	75592	16885	99109	5430
Quesnel	1083144	194917	80024	378586	146416	15896	19933	4008
Takla/Trembleur/Stuart	68903	31657	206689	57326	32197	3468	83947	10968
Lillooet	17726	43136	6944	3680	86264	4044	4473	492
Harrison (D/S)	1873	1588	3633	298	6931	249	584	58
Harrison-River	2657	1197	386	25895	54753	6669	1622	2931
Cultus	211	131	3	5	558	6	18	5
Harrison (U/S)	3632	9070	4751	1626	9104	1527	4934	63
Widgeon	119	130	78	15	26	5	78	5
Seton	1322	1848	3439	2349	6803	433	157	10
Kamloops	1498	3108	13871	6825	1568	3338	21217	340
Shuswap Complex	447896	116927	7402	5430	742255	14158	334	962
Total	1965724	908120	927883	719582	1741987	153847	430751	60691

Table 15. Total CU-specific arrival abundances (2002-2009) at Mission, BC reconstructed from in-river catch and escapement.

CU Name	2002	2003	2004	2005	2006	2007	2008	2009
Chilliwack	3851	4964	42187	3454	1102	1967	68194	5612
Takla/Trembleur	57512	29273	153555	212789	47631	12093	30804	76693
Pitt	102667	88789	78503	64441	46589	42805	18286	31173
Nahatlatch	9120	4526	1770	2478	2271	4172	766	1475
Anderson	2703	26843	74278	23263	13321	3801	30037	27294
Taseko	1751	1171	2750	1691	10175	356	132	116
Francois	2426	7484	185156	71713	36469	2550	119159	33012
Bowron	11685	20918	19119	5657	10499	3279	3018	4773
Shuswap Complex	281363	76957	101048	30895	882854	28696	12102	14568
Kamloops	32868	58905	161271	98475	94608	33275	18575	13084
Chilko	509261	1079106	378392	868557	872163	383480	418750	258745
Fraser	437167	176143	417130	209655	222781	58213	258846	43293
Quesnel	5537218	616219	222415	2983996	491929	87705	64697	185248
Takla/Trembleur/Stuart	272940	79390	531888	330672	100918	10142	219954	118697
Lillooet	298789	353015	71311	133846	495522	97524	50133	59078
Harrison (D/S)	32365	13136	38007	10714	39530	6059	6553	6839
Harrison-River	45930	9897	4036	932273	312294	162490	18197	348043
Cultus	5351	2317	91	204	4342	666	501	841
Harrison (U/S)	372365	178794	120718	135745	75175	154585	100018	55886
Widgeon	982	885	594	310	197	252	891	1560
Seton	19526	9296	10702	14431	31357	4750	4299	2641
Kamloops	23775	18060	38599	33281	9276	36512	104906	17405
Shuswap Complex	7103607	683738	20597	26478	4391741	154890	1654	49135
Total	15165222	3539826	2674117	6195018	8192744	1290262	1550472	1355211

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2: Validation of the Fraser River Salmon Management Model (FRSMM)

2.1 Abstract

Simulation and stock assessment models are often used by resource managers before being adequately validated. In this chapter, I provide an initial validation of the Fraser River Salmon Management Model (FRSMM) using the best available data on arrival timing at Mission, B.C. and in-river harvest of 20 Fraser river sockeye CUs. Simulated arrival timing of each CU at Mission differs from PSC estimates by +/- 2.5 days for 55% of CUs at the 25th percentile, 90% at the 50th percentile, and 80% at the 75th percentile. Simulated harvests differ from reconstructed estimates by +30%, -32%, -30% and +21% for the Early Stuart, Early Summer, Summer, and Late run timing groups, respectively, with differences in CU specific harvest ranging from -83.5% (Cultus.L) to 70.9% (Takla.Estu). Differences are likely due to structural differences between FRSMM and the run reconstruction that provided harvest rate estimates. These results suggest that FRSMM adequately simulates arrival timing at Mission for all CUs, while simulated harvest is more variable and dependant on incoming abundance, timing/abundance parameters, and migration distance. Given the complexity of FRSMM, users are encouraged to have a good understanding of its structure, data sources, and parameters prior to use.

2.2 Introduction

Stock assessment models are commonly used by fishery managers to assist in complex decision-making in light of missing, limited, or unknown information. All fishery stakeholders, as well as model developers and users are rightly concerned with whether a model and its results are “correct”. This concern can be addressed through model validation, whereby model outputs are compared to known (empirical) data, or to outputs of another, independent model, with the “correctness” being the degree to which results agree with one another. Here, we attempt to quantify the relative “correctness” of two models, the run reconstruction developed in Chapter 1 and an independently developed simulation model, the Fraser River Salmon Management Model (FRSMM). We use statistical measures to represent model differences, opposed to model error, as no set of estimates is known to be the most reliable.

Fishery models need to be rigorously assessed, and outputs need to be compared to established performance benchmarks (Gordon et al. 2004) prior to their use. Techniques for assessing model performance include comparing outputs to other models, comparing modeled "events" to actual events, and assessing realism of the model under extreme conditions (Sargent, 2004). Ultimately, the objective of such validation techniques is to "substantiate that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (Schlesinger, 1979). With the exception of PSC arrival timing data at Mission, a lack of fine scale empirical data implies that neither the run reconstruction nor FRSMM can be validated by comparing modelled events to actual events, and therefore we must compare outputs of the two models’ against one another. Run reconstruction methods are well documented (Starr and Hilborn 1988; Cave and Gazey 1994; English et al. 2007) and therefore we use outputs from the run reconstruction as the basis for comparison, while recognizing its potential shortcomings.

The run reconstruction approach developed in Chapter 1 ultimately needs to be tested for reliability because it makes several simplifying assumptions that could lead to persistent biases in abundance and exploitation rate estimates. For instance, the run reconstruction model assumes equal vulnerability for each stock present in a fishery, and the spatio-temporal pattern of stock-specific parameters such as migration speeds, and en route mortality rates, are known exactly and are uniform within FMAs in the Fraser River. Although each of these factors is known to vary among some conservation units (CUs), spatial areas within the river, and time periods within a migration season (Cass and Wood, 1994; Cox and Hinch, 1997; Hamon et al. 2000; Cooke et al. 2004; Hanson et al. 2008; and Kendall et al. 2009), a lack of fine-scale empirical data for each CU limits our ability to include these processes in run reconstruction models. Collection of fishery catch on coarse weekly time-scales further limits our ability to examine the consequences of aggregating catch statistics on abundance and exploitation rate estimates.

A simulation modeling approach is an effective way to ultimately assess reliability of stock assessment models when values of the true variables (e.g., stock-specific abundance, exploitation, migration parameters) cannot be measured directly (Hilborn and Walters 1992). For example, simulation models of arbitrary complexity can be developed to represent fine-scale details in any of the factors affecting Fraser River sockeye during their spawning migration. Such complex models can then be used to generate the types of data (e.g., total sockeye catch aggregated by week) we would normally have available for assessment. Analyzing this artificial data and comparing the results to what occurs in the run reconstruction model provides a direct and unambiguous means of comparing model outputs.

Management of salmon fisheries in the Fraser River is challenged by a complex array of fisheries, harvesting rights, environmental change, and fish migration pathways (Pearse and Walters 1992; Holt and Peterman 2006; Pestal et al. 2008; Price et al. 2008). Given these complexities, DFO requires a tool that can help evaluate different management options for Fraser River sockeye fisheries that arise from i) new First Nation treaty obligations, ii) new conservation requirements and management units (CUs) under the WSP, and iii) climate change (Cox and Holt, 2007).

The Fraser River Salmon Management Model (FRSMM) provides a modeling platform for evaluating scientific and management questions related to harvest policies and stock assessment procedures while accounting for biological complexity and uncertainty. The model is a spatially explicit, individual-based, multi-stock model that simulates fisheries, monitoring, and management systems along with the spatial and temporal abundance dynamics of an arbitrary number of co-migrating salmon populations as they move from ocean areas through fisheries and upriver to their spawning grounds within the Fraser River watershed. Key FRSMM features include, but are not limited to: any number of populations and their abundances, population-specific timing of arrival to any "node" (area of interest along the migration - e.g. PSC hydroacoustic site at Mission), population-specific migration and survival rates, time- and area-specific harvest rates, population and individual-based survival and movement (stochastic vs. deterministic) in response to environmental conditions.

In this chapter, I examine how well FRSMM outputs compare to existing harvest rate estimates and timing of arrival to Mission. Specifically, my research objectives are to quantify modeled differences of: (i) simulated arrival timing at Mission, B.C., and (ii) simulated CU-specific in-river harvests. These objectives provide an initial validation of FRSMM to establish the coarse-level "realism". Estimates of FRSMM harvests differ from those provided by the run reconstruction, though this is likely due to fundamental assumptions and structural differences between the two models. Differences in arrival timing to Mission between the two models are very small, and likely due to a combination of input data being of a high quality, and selecting a timing “node” within FRSMM that is spatially proximate to Mission.

2.3 Methods

2.3.1 General Description of the FRSMM

The FRSMM simulates migration of co-migrating populations of Fraser River sockeye through a series of sequential fisheries before escaping to spawning areas. Along their riverine migration route, sockeye are exposed to geographic bottlenecks (e.g., Hells Gate), as well as localised environmental conditions (i.e., river discharge and temperature) that can have both acute and cumulative effects on movement rates and survival (Macdonald et al. 2000; Macdonald, 2000; Naughton et al. 2005; Rand et al. 2006; and Farrell et al. 2008). The FRSMM permits the user to modify any number of parameters including natural mortality, migration rates, initial abundance, arrival timing, etc, as well as parameters that quantify relationships between these processes and environmental factors. Full documentation of FRSMM is beyond the scope of this chapter and the reader is referred to the FSmod help files in 'R' for further documentation. Here I focus on describing FRSMM components that are directly relevant to my research questions including data sources used to develop FRSMM, spatial and temporal scales upon with FRSMM operates, migration of sockeye in river, management area harvest rates, and arrival timing to Mission.

2.3.2 Data Sources

The baseline configuration and data for FRSMM includes 20 of 23 lake-type CUs of Fraser River sockeye for which escapement, spawning locations, and arrival timing data to Mission are available (DFO, 2009). Information on management area- and daily-specific harvest rates and CU-specific arrival abundances to the mouth of the Fraser River (Area 29) are provided from the run reconstruction I developed in Chapter 1. For FRSMM validation, the run reconstruction was run without en-route mortality, and with first, mean and last date of passage at Mission being identical to that of the PSC passage data at Mission. Therefore, CU abundance, and arrival timing inputs to FRSMM will differ from those presented in Chapter 1.

In-river migration rates are based on LGL Limited tracking studies (English et al. 2005; Karl English, LGL Limited, Sidney, B.C. V8L 3Y8) of radio tagged sockeye from Mission, B.C., through the Fraser to spawning areas. River flow and water temperature come from data-loggers operated and maintained by the Department of Fisheries and Oceans (DFO) and/or the Ministry of Environment of B.C. (MOE). The base map for all rivers and streams of the Fraser River was derived from the MOE Fisheries Information Summary System (FISS), with additional data on Fraser River watersheds, spawning streams, nursery lakes and Conservation Units provided by DFO (Blair Holtby, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, B.C., V8L 4B2).

2.3.3 Spatial and temporal scale

FRSMM operates on a 12 hr time step over 10 km segments, or "reaches", beginning at tidal areas (reaches 1 : 13) and extending throughout the Fraser River watershed (reaches 13 : 394). The timeframe extends from 1 June to 31 October, which encompasses the complete in-river migration of all 20 CUs, and spatially, the model includes spawning areas for all 20 CUs considered (Figure 15). Sequential reaches are used to define CU-specific migration paths from entry areas to spawning grounds. Areas of particular interest are identified as "nodes" and include *inter alia* junctions of major tributaries and Hells Gate. Fishery management areas (FMAs) include 16 along the Fraser River mainstem, 4 within the Thompson River Watershed, and one for each of the Nechako, Stuart and Chilcotin river tributaries. FMAs are uniquely defined by combining the reaches contained within each fishery management area. For this chapter, Area 29b represents the starting point of the map and is comprised of the first three reaches (Table 16, Figure 15).

2.3.4 Late Run Sockeye

Late-run Fraser River sockeye are unique among the four timing groups of Fraser River sockeye because it is composed of two distinct classes, the "Lates" and the "True Lates" (PSC, 2008a). The former group include all CUs that spawn in the Lillooet River system (Lillooet, Birkenhead and Harrison (D/S)) and return to the river in a pattern similar to a normal probability density function, while the latter group includes all other late timed CUs (Seton, Shuswap, Harrison (U/S), Cultus, and Kamloops) and return to the river in a multi-modal pattern approximated by a mixture of two or three normal distributions (Hague and Patterson 2007). Earlier than expected river entry of some True Late sockeye has resulted in increased en-route mortality of those early entrants, which also migrate at a faster rate than later entrants (English et al. 2005). For these reasons, in Chapter 1, True Late run CUs were modelled as three overlapping normal distributions, each with a different migration rate and estimate of en-route mortality. Using FRSMM, I simulated the True Late CUs using the same three overlapping distributions, outputting catch and timing results for each of the three distributions. For assessment purposes, I averaged errors in arrival timing at Mission, and summed simulated catch for each of the three distributions prior to calculating errors for each CU.

2.3.5 Migration rates

Despite application of more than 1000 tags per year in 2002 and 2006 (English et al. 2005; Robichaud and English, 2007), sample sizes of radio tagged sockeye are not large enough in any year to establish migration rates specific to most individual CUs. Therefore, I assumed that migration rates are the same for each CU within a particular run timing group, between sexes, and among times within a season. Note, however, that Hanson (2008) provides evidence for differences in migration rate between the sexes, though it is small. Each of the three components to the True Late run CUs were given an estimate of migration rate based on radio telemetry. I use up to a maximum of seven different migration rates for each FMA, one for each of the 4 run-timing groups and one for each of the 3 True Late components (Table 17).

Migration rate estimates are available only on the scale of FMAs, and not for each 10 km reach. Therefore, to move fish upriver, FRSMM converts the migration rates from km/day to km/time step, and then to reaches/time step. At each time step, fish are moved upriver by the appropriate number of reaches, rounding to the nearest whole number. For example, a CU that migrates through a 110 km (11 reach) long FMA at an average 34 km/day (17km/time step, 2 reaches/time step) will do so in 3 days within the run reconstruction, and within 6 time steps (3 days) within FRSMM.

Movement between reaches is simulated via a "jumping distribution" that allows for variation of individual fish movement rates, while ensuring that FMA migration rates are, on average, equal to expected migration rates. The jumping distribution parameter ("sc") can be set to a high or low level (but not zero), with high values allowing fish from a CU to, on average, reside in an FMA for the exact length of time expected (i.e. not rounded to the nearest 12 or 24 hours), with low values simulating deterministic movement (i.e., all fish move upriver at the same rate). However, deterministic movement severely limits FRSMM's ability to match FMA migration rates to the expected rates. A deterministic approach, commonly known as a boxcar model, is employed in this chapter (sc = 0.0001) to best mimic the movement assumptions made in the run reconstruction model. Further details on the methods used to simulate fish migration in FRSMM can be found in the FSmod 'R' help files.

2.3.6 In-river fishery catch

Fishery catches in each time/area combination are simulated using the time- and FMA-specific harvest rates estimated in the run reconstruction (Chapter 1). Differences in both temporal and spatial scales between the run reconstruction and FRSMM required the following conversion of daily, FMA harvest rates (h_f) from the run reconstruction to 12-hour, 10-km reach-specific harvest rates, D_f;

$D_f = 1 - \sqrt{(1 - h_f)}$

2.3.7 Arrival timing and abundance

Steveston, B.C. was selected as the node to which timing and abundance data would be input, as it is the area for which the run reconstruction generates non-normalized, CU specific daily arrival abundances (Table 18). Daily estimates of arrival abundance (as opposed to normally distributed abundances) were used to ensure that initial daily abundances in FRSMM were identical to those from the run reconstruction. This allowed FRSMM to replicate the arrival patterns estimated from the run reconstruction at Steveston, approximately 70 km from Mission, the node where we compare FRSMM arrival timing to that of the PSC hydroacoustic site.

The dates of 25th, 50th and 75th percentile passage at Mission were calculated directly from timing/abundance data provided by the PSC, and date of passage for each percentile is the date at which 25%, 50% and 75% of fish for each CU were estimated to have passed Mission. The PSC does not generate timing/abundance profiles for all CUs at Mission, therefore “indicator” CUs were identified which best represent timing profiles for these missing CUs, as was done in the run reconstruction (Table 1). For each early, middle and late component of True Late CUs, the 25th, 50th and 75th percentiles were estimated from normalized arrival curves.

2.3.8 Validating FRSMM Performance

There is no standard, broadly accepted theory on validating simulation model performance (Kleijnen, 1995, Gordon et al. 2004). Therefore, I used the following heuristic approach (Punt et al. 2002):

1. Select quantities of interest (CU specific harvest and arrival timing at Mission) for validation.
2. Select the best available data (run reconstruction estimated harvests, and PSC arrival timing at Mission) to compare to model estimates.
3. Use FRSMM to generate data used for assessment purposes.
4. Compare model estimates to empirical data using appropriate summary statistics.
5. Correct errors and/or improve model specifications.
6. Repeat 1- 6

Three statistical methods commonly used to evaluate forecasting models for Pacific Salmon (Willmott et al. 1985, Haeseker et al. 2008), were used to compare FRSMM outputs to those from the run reconstruction. Mean percent error (MPE), mean error (ME), and Root Mean Square Error (RMSE), were selected to represent three alternative measures of difference between the outputs of the two models. Positive (or negative) values of MPE indicate FRSMM outputs are positively (or negatively) different from the run reconstruction, whereas positive (or negative) values of ME indicate the size and direction of differences, while RMSE is always positive in value, and used to report the average difference between estimates.

All statistics calculated depend on the base discrepancy or residual error, calculated as:

$$e_s = \hat{A}_s - A_s$$

where $\hat{A}_s$ is the FRSMM simulated estimate, and A_s is the run reconstruction (or PSC) estimate for each CU, *s*. To reflect relative magnitude and direction of FRSMM catch and arrival timing I use MPE, calculated as:

$$\mathrm{MPE}=100^{*}\left(\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{\mathrm{e_s}}{\mathrm{A_s}}}{\mathrm{n}}\right)$$

where n is the number of simulations.

Mean error (ME) is calculated using the mean value of residual error (i.e. $\sum e_s/n$), while RMSE is calculated as $□□□□ = \sqrt{\frac{(\sum_{□=1}^{□} □_{□})\text{^}2}{□}}$

2.4 Results

2.4.1 Harvest

Harvest differences between FRSMM and run reconstruction estimates varied for each CU. FRSMM harvests were lower than reconstructed estimates for 18 of 20 CUs, with the magnitude of difference increasing with abundance. Similarly, RMSE of all harvests was highly variable, and dependent upon abundance (Table 19).

Total harvests simulated via FRSMM are lower than estimates from the run reconstruction. Harvest of the Early Summer and Summer run timing groups are lower than expected with average differences of -32.6%, -30.5%, respectively. Average difference in harvest of the Early Stuart and Late timed groups was positive, with differences of 70.6% and 21.2%, respectively. CU specific MPE values are negative for 18 of 20 CUs, and range from a minimum difference of -2.9% to a maximum of -83.5% for Kamloops.L and Cultus.L, respectively (Table 19). CUs with similar run timing and migration distance have similar differences, as evidenced by Harrison.DS.L, Harrison.River.L and Lillooet.L (-42.7%, - 42.0% and -41%, respectively) and Kamloops.ES and Shuswap.ES (-31.9% and -33.0%, respectively) (Table 19). Takla.Estu and Shuswap.L were the only two CUs where difference was positive, with MPE values of 70.9% and 25.4%, respectively (Table 19).

Harvest of the Early Summer and Summer timed groups is simulated to be 27,584 and 472,300 less than expected, respectively, while harvest of the Early Stuart and Late timed groups is 1,067 and 67,207 larger than expected, respectively. The latter two values are driven by one CU in each group (Takla.Estu and Shuswap.L) where harvest was simulated with large, positive difference (1,062 and 75,257, respectively) relative to other CUs of that group. CU specific simulated harvest differs from run reconstructed estimates by between -386,591 and 75,257 for Quesnel.S and Shuswap.L respectively (Table 19), while simulated harvest of Chilliwack.Estu, Kamloops.L and Francois.ES is the least different, with average differences of -1, -29, and -31, respectively (Table 19). CUs of higher initial abundance are simulated to have more differences in harvests relative to CUs of smaller abundance (Table 19).

2.4.2 Timing

Arrival timing to Mission is simulated with little difference, from expected values at the 50th percentile, and with varying degrees of difference at the 25th and 75th percentiles. With the exception of Anderson.ES, all CUs, at all percentiles, are simulated to arrive within +/-10% of their expected date. CU specific difference, measured by MPE, at the 25th, 50th and 75th percentiles range between -5.1% (Harrison.DS.L and Harrison.River) and 10.4% (Chilliwack.Estu), -2.8% (Lillooet.L, Harrison.DS.L and Harrison.River), and 7.2% (Chilliwack.Estu) and -11.5% (Anderson.ES) and 3.6%, respectively (Table 20).

CU specific difference, measured by ME, at the 25th, 50th, and 75th percentiles (measured in units of timesteps) range between -8.7 (Harrison.DS.L and Harrison.River.L) and 8.7 (Harrison.US.L), -5.1 (Lillooet.L, Harrison.DS.L and Harrison.River) and 5.7 (Chilliwack.Estu), and -16.2 (Anderson.ES) and 3.9 (Harrision.DS.L and Harrison.River.L) (Table 21). Average difference, as measured by RMSE, across all CUs and percentiles is highly variable (Table 22), and highly dependent on ME, and will not be discussed individually here.

2.5 Discussion

FRSMM offers managers of Fraser River salmon a flexible tool for assessing management and monitoring options under a variety of biological and environmental scenarios. Our results indicate that CU specific FRSMM catch and arrival timing is simulated with varying degrees of difference from run reconstructed, and PSC estimates, respectively. Across all measures, difference in FRSMM outputs is greater with respect to catch than to arrival timing, which is generally simulated with little difference from PSC hydroacoustic estimates (Table 19 - Table 21). Findings presented here will be useful for managers using FRSMM as I provide CU-specific estimates of differences relative to model-estimated harvests from the run reconstruction and empirical timing/abundance data from the PSC.

It is important to address the two types of data to which we are comparing FRSMM results: 1) estimates of CU specific catch provided by another, independent, statistical model, the run reconstruction, and; 2) empirical, independent, and validated observations of arrival timing at Mission, provided by the PSC. The former data are estimates from a (yet) non-validated model, which have the potential to, themselves, be biased and inaccurate (Cass and Wood, 1994). Results of the run reconstruction will only be as reliable as it assumptions are true: 1) all fish in a fishery are equally vulnerable to harvest; 2) all fish from a CU have identical FMA residence times; 3) fish arrive on spawning grounds according to a normal probability density function, and; 4) total weekly catch (where reported) is known exactly, and can be distributed equally amongst all seven days of that week. At the moment, validating the run reconstruction using empirical data would be a near-impossible task given the logistical complexities and financial cost. In spite of this, it remains the best (and only) source of data to compare FRSMM harvest results to. PSC arrival timing/abundance data, however, is based on observations of fish passage at Mission using a split - beam hydroacoustic program (PSC 2005) in concert with DNA testing to assess sockeye population composition throughout the season. In estimating passage timing and abundance, certain assumptions are made about fish behaviour and technological shortcomings, many of which have been independently validated by Xie et al. 2005, providing a great degree of certainty to the timing data used in the FRSMM assessment.

In addition to assumptions regarding the data, the fundamental structural differences between FRSMM and the run reconstruction may also be responsible for the observed differences in simulated catch. In particular, the run reconstruction operates over a spatial scale equal to the size of each FMA, and a temporal scale of 24 hours, whereas FRSMM operates on a 10 km, 12 hour scale. While every attempt was made to minimize differences between FRSMM and the run reconstruction, it is not possible to exactly simulate the conditions and assumptions under which the run reconstruction operates, and for these reasons, differences in harvest must be interpreted cautiously. Nevertheless, simulated harvests of 90% of CUs are less than estimated from the run reconstruction (Table 19). One potential reason for these differences is that simulated movement through FMAs in FRSMM is faster than expected, and therefore, fish are not exposed to fisheries as long as they are in the run reconstruction, which could lead to lower harvests.

Fish movement within FRSMM is simulated with a jumping distribution, and its defining parameter ("sc") was set to a very low level in order to best mimic deterministic, box-car like movement, as occurred in the run reconstruction. However, even with deterministic movement, FRSMM is unable to exactly replicate movement as it occurred in the run reconstruction. Unlike the run reconstruction, which rounds residence time in an FMA to the nearest 24 hours, with a small jumping distribution, FRSMM rounds to the nearest 12 hours. Consequently, some fish move through FMAs faster than they do in the run reconstruction (i.e. in 12 hours, not 24 hours), which leads to reduced harvests, as fish will be exposed to a fishery for a shorter period of time. Summer run CUs, for example migrate between Mission and Harrison (30 km, or 3 reaches long) at a rate of 44 km/day (22km/time step). FRSMM will therefore advance these fish upriver 2.0 reaches every time step. However, due to rounding, these fish will stay in this FMA for 0.5 days (1 time step), when, according to the run reconstruction, they should remain here for 1 day (2 time steps). This type of advancement occurs in any FMA where the number of reaches is not a near exact multiple of migration rate (km/reach). Furthermore, each time this occurs, fish are advanced up river 1 time step from where they would be expected to be on their migration (compared to the run reconstruction), possibly exposing them to different fishery openings. When this occurs multiple times for a CU, it can result in both lower than expected harvests and earlier than expected arrival to the spawning grounds. Unfortunately, there is no easy way to simulate FMA residencies of 24 hour multiples within FRSMM.

At all percentiles, and over all CUs, differences in FRSMM timing to Mission tends to be low relative to timing estimates from the PSC, with MPE of all CUs falling within a relatively narrow range of -11.5% to 10.4% (Table 20 and Table 21). These values compare favourably to results from Haeseker et al. (2008) who retrospectively evaluate preseason forecasting models for salmon and report a minimum bias of 16% and a maximum of 356%. FRSMM arrival at Mission is slightly "earlier" than expected, likely due to the previously discussed possibility that FRSMM moves fish faster than the run reconstruction.

The small differences between arrival timing at Mission is likely due to: 1) initiating the model with well defined, validated arrival timing data (as previously discussed), and; 2) the relatively close proximity of Steveston (our timing node used to seed the model) to Mission (~ 70 km) (our timing node at which we assess differences). This last point is important because FRSMM can simulate arrival timing at any defined node along the migration path, including spawning escapement areas, and differences may change depending upon which node is used to time arrival, as well as migration distance from the beginning of the map to the arrival node. A small migration distance between the starting node, and the node used to evaluate timing limits the ability for differences (due, for example, to migration rate) to accrue, which is likely why we see small differences in arrival timing despite the “faster” simulated movement than occurred in the run reconstruction as previously discussed. We purposely avoided using spawn escapement arrival timing in our assessment, as it is not validated (Bailey et al. 2000). Furthermore, some CUs are known to "hold" for up to three weeks in larger tributaries or lakes prior to spawning (English et al. 2005). These "holding periods" are currently not accounted for in FRSMM, and would lead to errors in arrival timing in areas downstream of the holding areas is escapement timing was used. We recommend that any future application of FRSMM use Mission as the timing node for arrival.

In assessing ME of arrival timing, we draw two conclusions: 1) FRSMM has the ability to simulate mean arrival timing to within +/-1.0 days of expected arrival for 90% of all CUs, and; 2) error is not constant across percentiles for each CU (Table 20, Table 21). The first conclusion is important, as it indicates that FRSMM is capable of simulating arrival timing of most CUs with little mean error, a critical factor for managers using FSMM as a tool for pre-season planning. However, as the second point suggests, this level of error does not hold constant across all percentiles. This is likely due to the fact that PSC arrival timing data at Mission were not normalized (except for True Lates) prior to calculating the 25th, 50th, and 75th percentiles of arrival (i.e. these were calculated from the raw data, as it was reported). The large difference of Anderson.ES timing best exemplifies this point. In 2002, Anderson arrival at Mission was not normal, and is punctuated by 10 and 12-day gaps where no Anderson fish were assessed to pass Mission. Without normalizing the data this results in the 25th percentile of fish arriving 5 days prior to the 50th, while the 75th percentile arrives 15 days after the 50th. Within

FRSMM, however, these values would be nearly equidistant from the date of arrival for the 50th percentile. For all other CUs, these differences are less, and consequently, so too are the errors.

In my validation of FRSMM, I have shown that arrival timing can be simulated with little difference, while difference from run reconstruction estimated harvest is much more variable, and likely due to differences in fish movement between the two models. I have provided three different measures of model difference, with the intention that managers can decide which type/combination of difference is most important in evaluating FRSMM, while keeping in mind possible errors and biases in other models upon which our validation is based. For future work, I suggest: 1) validating FRSMM's many other functions including en-route mortality calculations and its application of in-river flow and temperature, and; 2) validating the run reconstruction using simulation – estimation where FRSMM simulates a fishing season, and the run reconstruction is used to estimate that season. Despite wide-spread application of run reconstruction models in fisheries management (Starr and Hilborn 1988; Cave and Gazey 1994; Templin et al. 1996; English et al. 2007), they have never been adequately tested. With the development of FRSMM, managers have a tool that can adequately assess each assumption in a run reconstruction, and quantify its effect on harvest, timing, and natural mortality of each CU. As discussed, assumptions in migration rate/residence time and their effects on harvest need to be adequately assessed. I therefore propose increasing the sc parameter within FRSMM so fish residency within an FMA is simulated exactly as the migration rate data describes (i.e. not rounding to the nearest 12 or 24 hours), and then comparing harvest estimates to those from the run reconstruction, with the difference being due to residence time rounding errors in the run reconstruction. The resulting outcomes would subsequently lead to improvements in run reconstruction methods, data collection, or both, and therefore to improved fishery management.

2.6 Figures

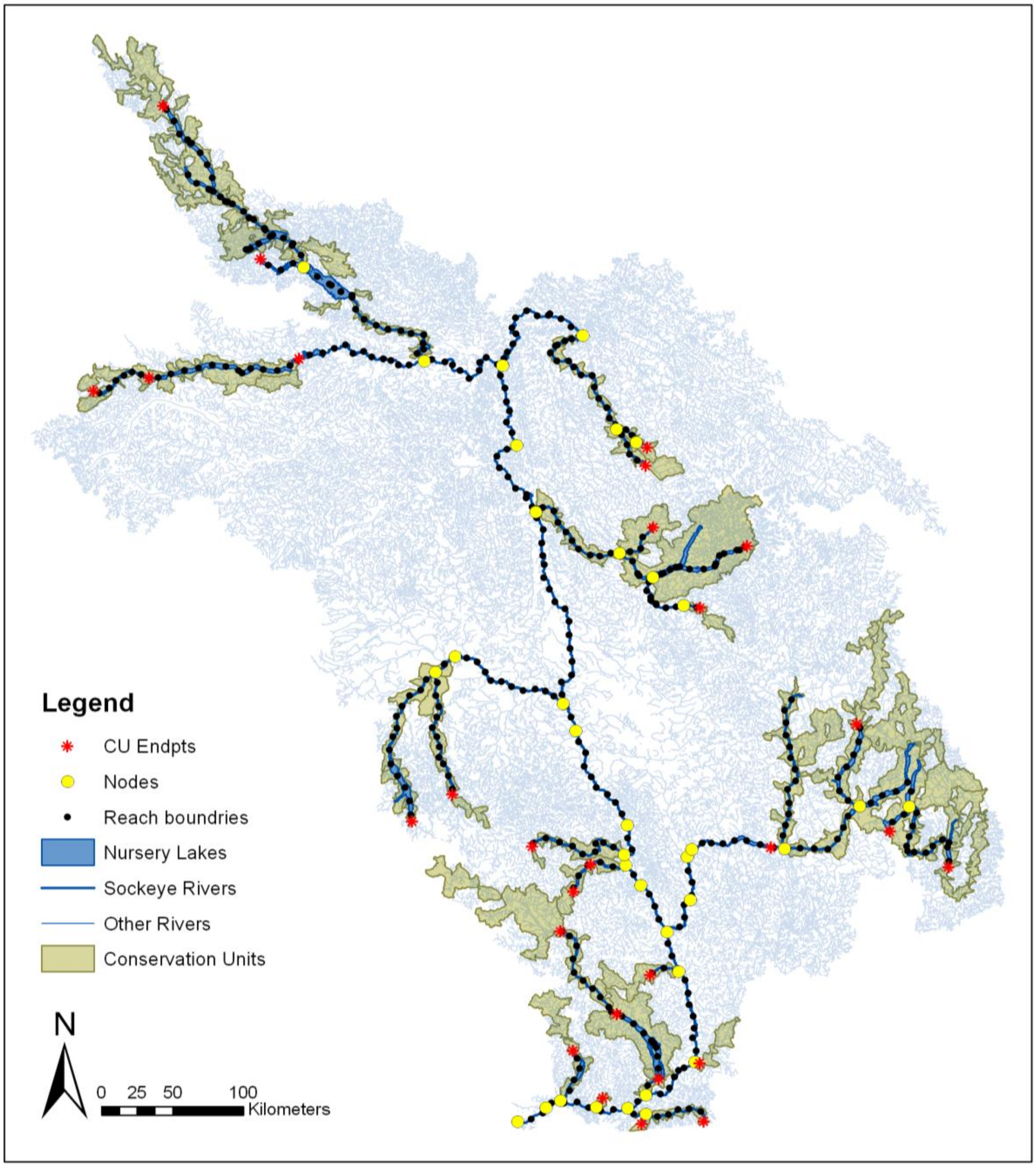

Figure 15. Watershed map of the Fraser river used in FRSMM, with each 10 km reach, node, and CU endpoint identified. Map provided by Brett Zuehlke.

2.7 Tables

Table 16. Fishery Management Area mapping definitions. FRSMM length indicates the length of each FMA as simulated with FRSMM, while LGL Run Recon length represents the actual, measured distance of each FMA.

Fishery No.	Short Name	Description	Reaches	FRSMM Length (kms)	LGL Run Recon length
1	Statistical Area 29b - estuary to Vancouver	Area 29b GN-E	18:22	50	n.a.
2	Statistical Area 29d - estuary to Vancouver	Area 29d GN-E	38:39	20	n.a.
3	Steveston to Port Mann bridge	Steveston : Port Mann	40:42	30	33
4	Port Mann bridge to Mission	Port Mann : Mission	43:46	40	42
5	Mission to Harrison River confluence	Mission : Harrison River	47:49	30	32
6	Harrison river confluence to Hope	Harrison River : Hope	50:54	50	51
7	Hope to Sawmill creek	Hope : Sawmill	55:57	30	29
8	Sawmill creek to Thompson river confluence	Sawmill : Thompson River	58:65	80	77
9	Thompson river confluence to Texas creek	Thompson River : Texas Creek	66:69	40	43
10	Texas creek to Kelly creek	Texas Creek : Kelly Creek	70:75	60	59
11	Kelly creek to Deadman creek	Kelly Creek : Deadman Creek	76:80	50	49
12	Deadman creek to Chilcotin river confluence	Deadman Creek: Chilcotin River	81:86	60	59
13	Chilcotin river confluence to Quesnel river confluence	Chilcotin River : Quesnel River	87:102	160	160
14	Quesnel river confluence to Naver creek	Quesnel River : Naver Creek	103:111	90	87
15	Naver creek to Nechako river	Naver Creek : Nechako River	112:117	60	65
16	Nechako river to Bowron river confluence	Nechako River : Bowron River	118:129	120	121
17	Nechako river	Nechako River	200:209	100	100
18	Stuart river	Stuart River	210:225	160	180
19	Chilcotin river	Chilcotin River	165:178; 322:325	180	180
20	Thompson confluence to Bonaparte river	Thompson confluence: Bonaparte River	132:142	100	79
21	Bonaparte river to Kamloops lake	Bonaparte River : Kamloops Lake	143:148	70	77
22	North Thompson river	North Thompson River	406:428	220	135
23	Kamloops to Shuswap lake	Kamloops : Shuswap Lake	165:163	80	81

Table 17. CU specific migration rates (km/day) for each of the 23 Fishery Management Areas for 2002. Periods (".") indicate that fish do no pass through this area.

	Management Area																		
CU Name	Area 29b GN-E	Area 29d GN-E	Steveston : Port Mann	Port Mann : Mission	Mission : Harrison River	Harrison River : Hope	Hope : Sawmill	Sawmill : Thompson River	Thompson River : Texas Creek	Texas Creek : Kelly Creek	Kelly Creek : Deadman Creek	Deadman Creek : Chilcotin River	Chilcotin River : Quesnel River	Quesnel River : Naver Creek	Naver Creek : Nechako River	Nechako River : Bowron River	Nechako River	Stuart River	Chilcotin River
Chilliwack	38	38	38	38	38	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tak/Trem	38	38	38	38	38	38	34	44	47	47	45	45	31	40	40	.	74	45	.
Anderson	46	46	46	46	46	43	30	29	44	44	.	.	.	.	.	.	.	.	.
Taseko	46	46	46	46	46	43	30	29	44	44	44	44	.	.	.	.	.	.	35
Francois	46	46	46	46	46	43	30	29	44	44	44	44	52	39	39	.	65	.	.
Bowron	46	46	46	46	46	43	30	29	44	44	44	44	52	39	39	39	.	.	.
Chilko	44	44	44	44	44	44	36	36	42	42	45	45	.	.	.	.	.	.	.
Fraser	44	44	44	44	44	44	36	36	42	42	45	45	53	53	53	.	53	.	.
Quesnel	44	44	44	44	44	44	36	36	42	42	45	45	53	.	.	.	.	.	.
Stuart	44	44	44	44	44	44	36	36	42	42	45	45	53	53	53	.	.	35	.
Tak/Trem	44	44	44	44	44	44	36	36	42	42	45	45	53	53	53	.	.	35	.
Lillooet	31	31	31	31	31	31	.	.	.	.	.	.	.	.	.	.	.	.	.

Table 17 cont'd. CU specific migration rates (km/day) for each of the 23 Fishery Management Areas for 2002. Periods (".") indicate that fish do no pass through this area.

	Management Area													
CU Name	Area 29b GN-E	Area 29d GN-E	Steveston : Port Mann	Port Mann : Mission	Mission : Harrison River	Harrison River : Hope	Hope : Sawmill	Sawmill : Thompson River	Thompson River : Texas Creek	Texas Creek : Kelly Creek	Thompson confluence: Bonaparte River	Bonaparte River : Kamloops Lake	North Thompson River	Kamloops : Shuswap Lake
Shuswap Cmplx	46	46	46	46	46	43	30	29	.	.	19	31	.	27
Kamloops	46	46	46	46	46	43	30	29	.	.	19	31	41	.
Harrison (D/S)	31	31	31	31	31	31	.	.	.	.	.	.	.	.
Cultus - E	34	34	34	34	34	34	25	23	23	23	15	11	.	40
Cultus - M	35	35	35	35	35	35	23	25	25	25	15	20	.	28
Cultus - L	29	29	29	29	29	29	21	13	13	13	17	23	.	43
Harrison (U/S) - E	34	34	34	34	34	34	25	23	23	23	15	11	.	40
Harrison (U/S) - M	35	35	35	35	35	35	23	25	25	25	15	20	.	28
Harrison (U/S) - L	29	29	29	29	29	29	21	13	13	13	17	23	.	43
Lower Fraser - E	34	34	34	34	34	34	25	23	23	23	15	11	.	40
Lower Fraser - M	35	35	35	35	35	35	23	25	25	25	15	20	.	28
Lower Fraser - L	29	29	29	29	29	29	21	13	13	13	17	23	.	43
Seton - E	34	34	34	34	34	34	25	23	23	23	15	11	.	40
Seton - M	35	35	35	35	35	35	23	25	25	25	15	20	.	28
Seton - L	29	29	29	29	29	29	21	13	13	13	17	23	.	43
Kamloops - E	34	34	34	34	34	34	25	23	23	23	15	11	.	40
Kamloops - M	35	35	35	35	35	35	23	25	25	25	15	20	.	28
Kamloops - L	29	29	29	29	29	29	21	13	13	13	17	23	.	43
Shuswap Cmplx - E	34	34	34	34	34	34	25	23	23	23	15	11	.	40
Shuswap Cmplx - M	35	35	35	35	35	35	23	25	25	25	15	20	.	28
Shuswap Cmplx - L	29	29	29	29	29	29	21	13	13	13	17	23	.	43

Table 18. Arrival abundance and timing to Steveston for each CU in 2002. “First”, “Mean”, and “Last” are the timestep at which the first, mean and last sockeye from that CU arrives at Steveston. Values are in "time steps" from the first simulated model day (June 1) where two time steps = one day, or a 24 hr period.

		PSC Estimated Arrival Timing Parameters to Steveston		
CU Name	Abundance	First	Mean	Last
Chilliwack	3845	53	86	110
Takla/Trembleur	24812	53	86	110
Anderson	2659	71	113	152
Taseko	1746	77	121	166
Francois	2352	69	109	150
Bowron	11633	77	124	66
Shuswap Cmplx	287931	83	129	176
Kamloops	32829	77	121	166
Chilko	526072	69	137	206
Fraser	448165	79	137	196
Quesnel	5712827	83	153	224
Takla/Trembleur	50530	69	131	194
Lillooet	296052	115	179	224
Harrison (D/S)	30988	155	179	244
Harrison-River	43757	115	179	244
Cultus - E	856	121	147	170
Cultus - M	329	163	183	200
Cultus - L	4187	195	213	228
Harrison (U/S) - E	1448	119	145	168
Harrison (U/S) - M	15021	163	183	200
Harrison (U/S) - L	85055	195	213	228
Seton - E	1568	119	145	168
Seton - M	5125	163	183	200
Seton - L	9161	195	213	228
Kamloops - E	1818	119	145	168
Kamloops - M	6282	163	183	200
Kamloops - L	11260	195	213	228
Shuswap Cmplx - E	543210	119	145	168
Shuswap Cmplx - M	1876992	163	183	200
Shuswap Cmplx - L	3364187	195	213	228

Table 19. Harvest bias (MPE), average error (ME), and precision (RMSE) of FRSMM compared to estimates provided by the run reconstruction. MPE and RMSE are unit-less, while units of ME are fish. CUs are presented in increasing abundance within their group.

CUname	Group	MPE	ME	RMSE
Chilliwack.Estu	Early Stuart	-27.5	-1	1
Takla.Estu	Early Stuart	70.9	1062	1062
Taseko.ES	Early Summer	-70.8	-315	315
Anderson.ES	Early Summer	-56.4	-271	274
Francois.ES	Early Summer	-26.6	-113	113
Bowron.ES	Early Summer	-12.2	-348	348
Kamloops.ES	Early Summer	-31.9	-2318	2318
Shuswap.ES	Early Summer	-33.0	-24205	24205
Takla.S	Summer	-17.0	-3372	3372
Fraser.S	Summer	-25.1	-31552	31552
Chilko.S	Summer	-35.4	-50741	50741
Quesnel.S	Summer	-30.7	-386591	386591
Kamloops.L	Late	-2.9	-29	29
Cultus.L	Late	-83.5	-193	193
Harrison.US.L	Late	-19.3	-95	95
Seton.L	Late	-3.4	-31	31
Harrison.DS.L	Late	-42.7	-670	670
Harrison.River	Late	-42.0	-929	929
Lillooet.L	Late	-41.0	-6142	6142
Shuswap.L	Late	25.4	75257	75257

Table 20. Difference of FRSMM timing as represented by Mean Percent Error (MPE) relative to PSC data for the 25th, 50th, and 75th percentiles of arrival abundance. (+/-) values indicate FRSMM arrival earlier/later than expected. CUs are presented, within their group, in increasing abundance.

CUname	Group	25th Percentile	50th Percentile	75th Percentile
Chilliwack.Estu	Early Stuart	10.4	7.2	2.2
Takla.Estu	Early Stuart	9.0	6.3	2.0
Taseko.ES	Early Summer	0.9	0.4	3.4
Anderson.ES	Early Summer	5.4	2.4	-11.5
Francois.ES	Early Summer	7.6	1.1	-4.7
Bowron.ES	Early Summer	0.7	0.6	3.6
Kamloops.ES	Early Summer	0.5	0.4	3.4
Shuswap.ES	Early Summer	-0.5	2.0	3.1
Takla.S	Summer	1.8	3.8	-2.6
Fraser.S	Summer	-1.7	1.1	-4.2
Chilko.S	Summer	-3.4	0.6	-3.6
Quesnel.S	Summer	0.4	-2.2	-1.7
Kamloops.L	Late	5.0	0.5	0.1
Cultus.L	Late	4.8	0.4	0.0
Harrison.US.L	Late	5.1	0.5	0.5
Seton.L	Late	5.0	0.5	0.4
Harrison.DS.L	Late	-5.1	-2.8	2.0
Harrison.River	Late	-5.1	-2.8	2.1
Lillooet.L	Late	-5.0	-2.8	2.0
Shuswap.L	Late	5.1	0.5	0.1

Table 21. Average difference (ME) of FRSMM timing compared to PSC data at the 25th, 50th, and 75th percentiles. Units in ME are "time steps", where 2 time steps = one 24 hour period, and (+/-) values indicate FRSMM arrival earlier/later than expected according to PSC data. CUs are presented, within their group, in increasing abundance.

CUname	Group	25th Percentile	50th Percentile	75th Percentile
Chiliwack.Estu	Early Stuart	7.4	5.7	2.0
Takla.Estu	Early Stuart	6.4	5.0	1.8
Taseko.ES	Early Summer	1.0	0.5	4.4
Anderson.ES	Early Summer	5.4	2.7	-16.2
Francois.ES	Early Summer	7.4	1.3	-6.0
Bowron.ES	Early Summer	0.8	0.7	4.7
Kamloops.ES	Early Summer	0.6	0.5	4.5
Shuswap.ES	Early Summer	-0.6	2.6	4.4
Takla.S	Summer	2.2	5.2	-4.0
Fraser.S	Summer	-2.2	1.5	-6.7
Chilko.S	Summer	-4.5	-0.9	-5.8
Quesnel.S	Summer	0.6	-3.5	-3.0
Cultus.L	Late	8.2	0.6	-0.1
Kamloops.L	Late	8.6	0.9	0.2
Seton.L	Late	8.6	0.9	0.8
Harrison.US.L	Late	8.7	0.9	0.9
Harrison.DS.L	Late	-8.7	-5.1	3.8
Harrison.River	Late	-8.7	-5.1	3.9
Lillooet.L	Late	-8.6	-5.1	3.9
Shuswap.L	Late	8.6	0.9	0.2

Table 22. RMSE values of FRSMM timing compared to PSC data at the 25th, 50th, and 75th percentiles. CUs are presented, within their group, in increasing abundance.

CUname	Group	25th Percentile	50th Percentile	75th Percentile
Chiliwack.Estu	Early Stuart	7.3	5.7	2.1
Takla.Estu	Early Stuart	6.4	5.0	1.8
Taseko.ES	Early Summer	1.1	0.7	4.5
Anderson.ES	Early Summer	5.4	2.6	16.1
Francois.ES	Early Summer	7.3	1.5	5.9
Bowron.ES	Early Summer	0.9	0.7	4.7
Kamloops.ES	Early Summer	0.6	0.5	4.5
Shuswap.ES	Early Summer	0.6	2.6	4.4
Takla.S	Summer	2.3	5.2	4.0
Fraser.S	Summer	2.2	1.5	6.7
Chilko.S	Summer	4.5	0.8	5.8
Quesnel.S	Summer	0.6	3.5	3.0
Cultus.L	Late	8.2	0.6	0.1
Kamloops.L	Late	8.6	0.9	0.2
Seton.L	Late	8.6	0.9	0.8
Harrison.US.L	Late	8.7	0.9	0.9
Harrison.DS.L	Late	8.6	5.1	3.8
Harrison.River	Late	8.7	5.1	3.9
Lillooet.L	Late	8.6	5.1	3.9
Shuswap.L	Late	8.6	0.9	0.2

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