AN INVESTIGATION INTO THE FACTORS INFLUENCING ESCAPEMENT ESTIMATION FOR CHINOOK SALMON (*Oncorhynchus tshawytscha*) ON THE LOWER SHUSWAP RIVER, BRITISH COLUMBIA

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ABSTRACT

The area-under-the-curve (AUC), method based on helicopter visual enumeration, is a commonly used technique to estimate escapement of chinook salmon (*Oncorhynchus tshawytscha*) for the Fraser River and its tributaries. Two key factors associated with this method are survey life and observer efficiency. The survey life currently assumed by Fisheries and Oceans Canada (DFO) for Thompson Basin streams is seven days and for most counting flights the assumed observer efficiency is 100%. Telemetry and tower observations were used to estimate annual (2000-2002) survey lives for male (telemetry) and female (telemetry and tower observation) chinook salmon in the Lower Shuswap River. Mark-recapture based survey lives were directly estimated by dividing the mark-recapture escapement estimate by the AUC estimate of total spawner days. Observer efficiency was estimated by comparing observer counts from helicopters to counts from photographs. Various combinations of total fish counts, observer efficiencies, and survey lives were used in AUC escapement estimates, and compared to mark-recapture and peak count estimates.

Survey lives varied annually. Many of the estimated mean survey lives were significantly less than seven days; mark-recapture based survey lives were generally less than those estimated from telemetry and observations from towers; and mean survey lives for males were higher than for females. The mean observer efficiency of helicopter enumeration was 97% (95% CI is ± 6%), this is not significantly different than the 100% assumed by DFO.

The majority of AUC escapement estimates based on DFO's assumed seven day survey life were lower than or equal to all other AUC escapements. AUC escapement estimates were higher than or equal to peak count estimates, and lower than or equal to independently obtained Petersen mark-recapture estimates.

For determining Lower Shuswap River AUC escapement estimates a 97% observer efficiency, annually determined survey lives, start and end dates determined in the field, and total fish counts calculated using the mean of two experienced observers counts are recommended. The telemetric, combined sex, mean survey life of 5.4 days is recommended for Lower Shuswap River chinook salmon when annual studies of survey lives are not available.

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LIST OF ABBREVIATIONS AND ACRONYMS

AUC = area-under-the-curve

CI = confidence interval

CRD = completely randomized design

DFO = Fisheries and Oceans Canada

Esc = escapement

Est = estimate

Exp = expansion

ID = identification

km = kilometres

m = meters

M/R = mark-recapture

n = sample size

O = observed count

Obs = observer

OE = observer efficiency

OT = observation tower

RT = residence time

s = seconds

SE = standard error

SFU = Simon Fraser University

SL = survey life

Tel = radio telemetry

V = volts

CHAPTER 1
INTRODUCTION

1.1 Introduction

Accurate and precise population escapement estimates are important to the assessment of the status of salmon stocks. Escapement is defined as the number of fish that return to the river to spawn - these mature salmon have escaped the marine and freshwater fisheries and entered the terminal survey area (English *et al.*, 1992). Estimates of Pacific salmon escapement can be generated using a variety of techniques including visual surveys, mark-recapture studies, fence counts, and electronic counters. The vast majority of escapements to upper Fraser and Thompson Basin chinook salmon (*Oncorhynchus tshawytscha*) stocks are estimated using visual surveys, which involve counting fish during multiple visits to a stream over the period of spawning. Estimates are generated by using the area-under-the-curve (AUC) method, by expanding peak counts or by expanding redd counts. Such data are frequently used as an indicator of production for future generations, and to provide an index of the success of management of the fishery (Neilson and Geen, 1981).

Because of financial, geographic and other constraints helicopter-based visual counting is likely to remain the most efficient method to survey spawner abundance for many upriver Fraser chinook salmon populations. There are significant issues surrounding the quality of many visual escapement estimates, especially those based on peak counts; therefore, the Department of Fisheries and Oceans (DFO) is moving toward use of the AUC method and is attempting to compare estimates derived from that method to estimates from other methods such as mark-recapture.

In the Upper Fraser Basin, there are approximately 80 systems surveyed annually to estimate the escapement of chinook salmon at three levels of effort: 1) intensive estimates – estimates of known precision undertaken on indicator stocks that permit determination of escapement by age and sex, 2) extensive estimates – estimates that provide indices of escapement; and 3) random surveys – estimates that provide information on the presence of spawners in seldom sampled habitats. There are three intensive indicator stocks in the Upper Fraser Basin, two of which are surveyed by Petersen mark-recapture programs and the remaining one, Dome Creek, is surveyed using a counting fence or a Petersen mark-recapture when the fence washed out. The Lower Shuswap River chinook salmon stock, one of the intensive indicator stocks, was studied from 2000-2002 to compare escapement estimates from mark-recapture studies and aerial survey data expanded using the AUC and the Peak Count methods.

1.1.1 AUC Method

English *et al.* (1992) and Bue *et al.* (1998) state, "The AUC is a method used to convert periodic counts of mature salmon in streams into an estimate of escapement". This method is considered to be efficient and robust when used with valid observer efficiency and residence time data (Perrin and Irvine, 1990).

The AUC estimation procedure consists of two basic components: estimates of the total aggregate residence time (e.g. estimated total fish days) and estimates of the average stream residence time (stream life; English *et al.*, 1992). The total population size is then estimated as:

$$\hat{N}_{AUC,stream} = \frac{AUC_{stream} * OE}{stream\_residence\_time} \qquad \text{Equation 1}$$

where $\hat{N}_{AUC,stream}$ is the estimated population size of the escapement to the stream computed using AUC and residence time of fish for the entire stream, AUC_{stream} is the total number of fish days in the stream calculated using the AUC method, and OE is the observer efficiency expansion factor related to the fraction of actual fish observed during the periodic surveys. Stream residence time is defined as the duration of time in days from a fish's entrance into its natal stream until death (Table 1).

For Fraser River chinook salmon, an AUC is generally calculated for spawning fish alone (not holding fish or carcasses) and divided by an estimate of survey life to yield an estimate of escapement. Survey life is the duration of time in days from the onset of spawning until a female vacates her redd or until a male dies (Table 1). The mark-recapture based survey life may be approximated by survey life. Mark-recapture based survey life is defined as the duration of time in days fish spent in the spawning area and were countable as spawners during aerial surveys air

– this includes all fish that are on the shallows and clearly associated with spawning habitat (Table 1).

Table 1. Residence time and survey life terminology, as defined in this study.

Term	Definition
Stream Residence Time	the duration of time in days from a fish's entrance into its natal stream until death
Survey life	the duration of time in days from when a fish begins to spawn (onset of spawning) until a female vacates her redd or until a male dies (completion of spawning) - estimated using telemetry and observations from towers - can be used to approximate mark-recapture based survey life when estimating spawner escapement
Mark-recapture based survey life	the duration of time in days fish spent in the spawning area and were countable as spawners during aerial surveys air - includes all fish that are on the shallows and clearly associated with spawning habitat - can be derived from aerial spawner counts and independent estimates of total abundance

Holding fish are not used in the estimate because arrival in the terminal area can proceed spawning by up to several months. Thus, surveys would have to be conducted over much wider time spans. Additionally, it is much more difficult to estimate numbers of holding fish, which are typically schooled and pool-resident as opposed to spawners, which are spread out on shallower habitats. Visual count data are reported separately for spawners, holders and carcasses. Only counts of chinook spawners taken during the spawning period are used for this estimation technique – not holder or carcass counts. From the air, chinook salmon were identified as spawners if they were on the shallows and clearly associated spawning habitat. Chinook salmon were identified as holders if they were holding in pools and not associated with spawning habitat (Faulkner and Ennvor, 1995).

For a spawner escapement estimate, total spawner days is used in place of total fish days and survey life is used in place of stream residence time. The total spawner population size can be estimated as:

$$\hat{N}_{AUC,spawner} = \frac{AUC_{spawner} * OE}{spawner\_residence\_time} \qquad \text{Equation 2}$$

where $\hat{N}_{AUC,spawner}$ is the estimated spawner population size from the AUC method, $AUC_{spawner}$ is the total number of spawner days, and OE is the observer efficiency factor. This population estimate does not include fish that die just prior to spawning (pre-spawn mortalities).

Survey life is a key component in the AUC estimate of escapement. Currently DFO assumes a value of 7-days for survey life in the Thompson Basin. Better estimates of survey life will allow for less biased Pacific salmon escapement estimates using the AUC method. Ultimately, this will lead to better management of these salmon stocks. Imprecision in estimates of escapement will result from the uncertainty in the mean redd residence time; therefore, further analysis of survey life to reduce error in the estimate would be very valuable (Anon. 1997 and Hill 1997). Further work is needed on many populations to improve estimates of survey lives. These could be determined using various methods including telemetry, tower observation, or from mark-recapture programs (Bailey *et al.*, 2000; Manske and Schwarz 1999). This study used radio telemetry and tower observation to estimate survey lives. The mark-recapture based survey life was calculated by dividing the AUC total spawner days by the mark-recapture escapement estimate.

Another key component of the AUC method is the observer efficiency coefficient. The observer efficiency coefficient is used to adjust the spawner counts, for the inability of the observers to count all the salmon present during a visual survey. Currently, DFO assumes 100% observer efficiency for most counting flights. In this study, aerial photography was used to estimate the observer efficiency of counts of chinook salmon made during overflights of the Lower Shuswap River from helicopters (Chapter 2).

The most common method used to estimate AUC (total spawner days) is the trapezoidal approximation:

$$AUC_{spawner} = \sum (t_i - t_{i-1}) * \left[\frac{(x_i + x_{i-1})}{2} \right] \qquad \text{Equation 3}$$

where t_i is the *i*th day of the year and x_i is the number of spawners observed for the *i*th survey (English *et al.* 1993; Bue *et al.* 1998; Hilborn *et al.* 1999). The first and last day that ground crews observed chinook salmon spawning in the Lower Shuswap River each year were selected as the start and end dates of spawning for the AUC escapement curve; no flights were conducted on those dates. The spawner curve was temporally bounded by the first day that fish began to spawn and the first day that there were no longer any spawners (Parken *et al.*, 2003). An example of the AUC estimate of total spawner days for Lower Shuswap chinook salmon in 2000 is presented in Figure 1 and Table 2.

In this study, AUC estimates were derived using various approximations of the total spawner days, the observer efficiency, and the survey lives. These estimates were then compared to each other and to estimates derived from Petersen mark-recapture studies and the Peak Count method.

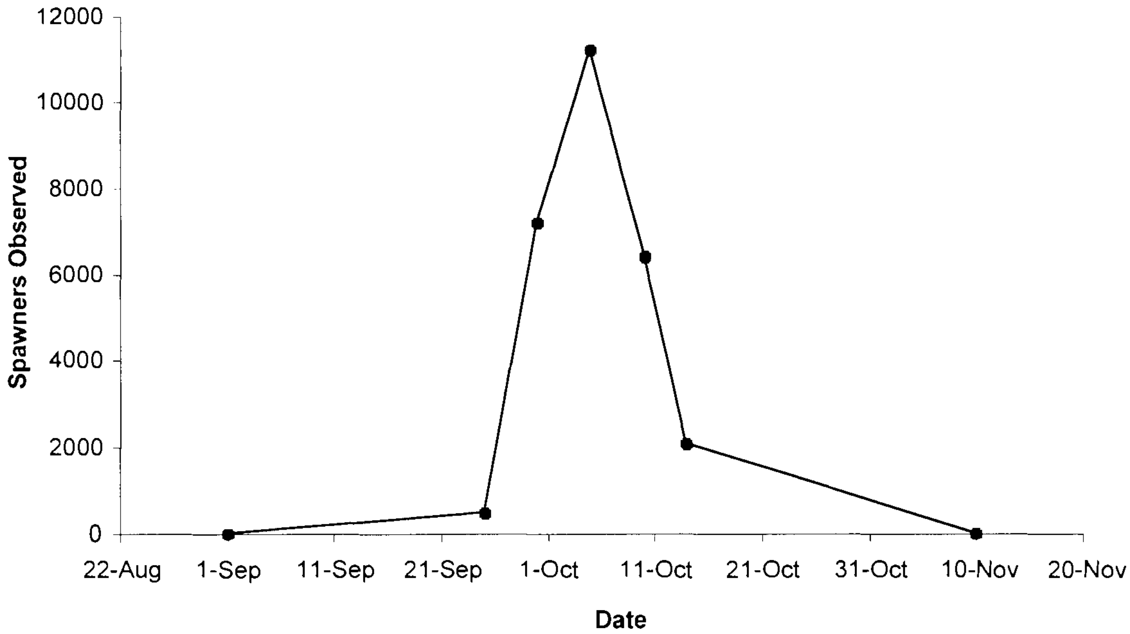


Figure 1. The 2000 chinook salmon data from the Lower Shuswap River is an example of spawner count data and the AUC estimation technique for calculating total spawner days using the trapezoidal method. The points indicate the number of spawners counted during each survey. The areas of the polygons are summed to estimate the total spawner days.

Table 2. The number of chinook salmon spawners counted from the helicopter and the calculated trapezoidal area for the Lower Shuswap River in 2000.

Count Number	Date Observed	Spawners Observed	Trapezoidal Area
1	1-Sep	0	-
2	25-Sep	473	5676
3	30-Sep	7187	19150
4	5-Oct	11190	45943
5	10-Oct	6374	43910
6	14-Oct	2071	16890
7	10-Nov	0	27959
		Total	159527

When AUC estimates of spawner escapement were calculated using mean total spawner counts and extrapolated and observed survey lives, the variance of the function g(x,y)=x/y when x and y are independent was estimated using the delta method (p. 7, Seber, 1982):

$$V(g(x,y))=(dg(x,y)/dx)^2*V(x) + (dg(x,y)/dy)^2*V(y) \qquad \text{Equation 4}$$

where V(x) is the variance of x (mean total spawner days) and V(y) is the variance of y (survey life).

The standard error of the total spawner days is zero when calculating the AUC estimate of spawner escapement using the best count method. Therefore, variance in the extrapolated and observed survey lives was used to determine the total spawner day variances. The delta method was used to estimate variance of the function x, g(x) (p. 7, Seber, 1982):

$$V(g(x))=(dg(x)/dx)^2*V(x) \qquad \text{Equation 5}$$

where V(x) is the variance of x (survey life).

When calculating the AUC estimate of spawner escapement using mean fish counts and DFO's current 7-day survey life, the delta method was used to estimate variance of the function y, g(y) (p. 7, Seber, 1982):

$$V(g(y))=(dg(y)/dy)^2*V(y) \qquad \text{Equation 6}$$

where V(y) is the variance of y (total spawner days).

As seen above, only some of the sampling variability of certain components of the equation can be estimated. When using a mean count method for spawner days and DFO's assumed 7-day survey life (Equation 6), only variability for total fish days can be estimated and there is no estimate of variability for the 7-day survey life. The estimated variability may not include total variability in the estimate. The estimates of variability in the AUC estimates of escapement do not account for systematic biases. For example, if the AUC flights straddle the peak, the straight line between them will cause a downward bias in the estimate of total spawner days and the resultant estimate of escapement. Another example may be that the use of radio tags may have also caused a negative bias in the survey lives estimated for radio tagged chinook salmon, due to stresses on chinook salmon caused by the insertion and carrying of a radio tag. A negatively bias estimate of survey life would result in a positively bias estimate of escapement, as survey life is the denominator of the AUC escapement equation.

1.1.2 Mark-recapture Method

"The Petersen mark-recapture method of population estimation is based on the general principle that the number of individuals in a population of unknown size may be estimated by marking or tagging a representative sample of individuals, releasing these to become distributed throughout the population, then obtaining a second sample at random for examination." (Cousens *et al.*, 1982:33). The design of this mark-recapture study was similar to that used on the Harrison River (Farwell *et al.*, 1999). Chinook salmon holding in pools throughout Reaches 1 to 8 (Figure 2) were beach seined for tagging and spawning ground surveys were conducted to recover carcasses (Chapter 4).

The adult chinook salmon population ($\hat{N}$) within the Lower Shuswap River study area was estimated using the Chapman modification of the Petersen estimator (Ricker, 1975 and Cousens *et al.*, 1982):

$$\hat{N}_{M/R} = \frac{(M+1)(C+1)}{(R+1)} \qquad \text{Equation 7}$$

where M is the original number of individuals marked, C is the number of carcasses examined for marks, and R is the number of marked carcasses recovered. This adjusted Petersen estimate is the most commonly used mark-recapture formula and provides an approximately unbiased estimate of N (Cousens *et al.*, 1982).

The standard errors of the Lower Shuswap River mark-recapture escapement estimates of chinook salmon were estimated as:

$$SE_{M/R} = \sqrt{\frac{(N*C)*(N-R)*(C-R)}{R^3}} \qquad \text{Equation 5}$$

Relative precision of the estimate is approximately proportional to the square root of the number of marks that are recovered. Therefore, higher precision can be achieved by increasing the number of marks applied to increase the proportion of the population that is tagged, or by increasing the recovery effort to get more marks back (Schwarz *et al.*, 1993). In each year of this study (2000-2002), large numbers of tags were released and recovered (Table 3).

Table 3. The original number of individuals marked (M), the number of carcasses examined for marks (C), and the number of marked carcasses recovered (R) during the Lower Shuswap River chinook salmon mark-recapture study annually from 2000-2002.

Year	M	C	R
2000	734	12,801	249
2001	1,803	17,988	798
2002	3,743	25,042	1,690

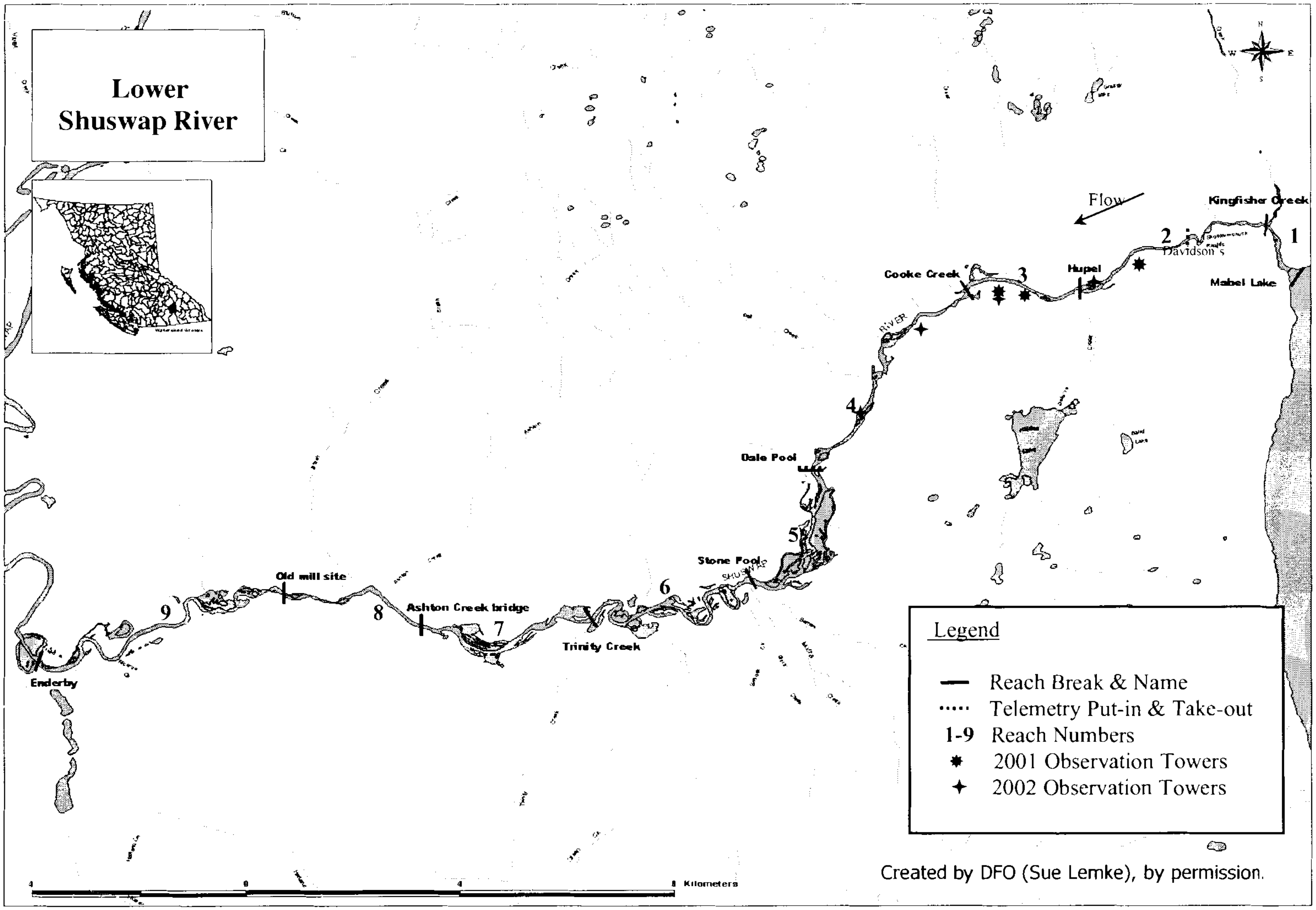


Figure 2. Lower Shuswap River survey life study area reach breaks and names; telemetry put-in and take-out; and observation tower locations.

1.1.3 Peak Count Method

Visual surveys were conducted as close to the time of peak spawning as possible each year and the survey with the highest combined count of holders, spawners and carcasses was used to estimate escapement. The Peak Count method (as used for Fraser River chinook salmon) assumes that observers count 65% of the true population, when the count occurs at the peak of spawning (Dickson in Farwell *et al.*, 1999) and assumes a 100% observer efficiency. Peak of spawning is the date with the highest number of spawners annually. The escapement is estimated as:

$$\hat{N}_{PeakCount} = \frac{Total\_Fish\_Observed}{0.65} \qquad \text{Equation 6}$$

where $\hat{N}_{PeakCount}$ is the estimated spawner population size for the stream using the Peak Count method.

1.1.4 Thesis Objectives

For streams in the Thompson Basin, DFO assumes a 7-day survey life and 100% observer efficiency for calculating an estimate of escapement for chinook salmon using the AUC method. Both the assumed survey life and observer efficiency are based on very limited data and need to be quantified for different systems and across fish species to reduce biases in AUC escapement estimates. There is a need to investigate the factors influencing survey lives and observer efficiencies. Estimates of escapement generated using the AUC method will also be compared to estimates determined from other methods to determine whether the values assumed currently are acceptable.

The objectives of this thesis are:

1) To investigate the observer efficiency of spawner counts conducted during helicopter surveys,
2) To estimate the total spawner day component of the AUC equation using the best and mean count methods,
3) To estimate the mean survey lives of males and females annually, and determine if survey lives are stable across years,
4) To compare the current survey life used by DFO to the survey lives determined in this study,
5) To estimate some of the factors that may cause variation in survey life, observer efficiency, and the resultant AUC estimates of escapement,
6) To calculate and compare escapement estimates based on the AUC method using a various estimates of total spawner days, observer efficiencies, and survey lives,
7) To compare AUC-based escapement estimates with those determined using peak count and mark-recapture methods.

1.2 Study Area

The Lower Shuswap River is part of a complex system that drains a mountainous watershed in southern interior British Columbia. Initially, the Lower Shuswap River flows southwest from Mabel Lake for approximately 40km until it reaches the town of Enderby. The flow then changes to a northerly direction until the river enters Mara Lake and ultimately Shuswap Lake at Sicamous. Many tributaries enter the Lower Shuswap River below Mabel Lake including Kingfisher Creek, Cooke Creek, Trinity Creek and Ashton Creek. There is no known spawning of chinook salmon in these tributaries. The survey area lies mainly in rural agricultural land and is affected by bank erosion, loss of riparian habitat, and other effects of farming.

Annual and spawning season mean discharge (m^3s^{-1}) were measured at Environment Canada's Water Survey Station on the Lower Shuswap River near Enderby (Lynne Campo, pers. comm., Environment Canada, unpublished data). The mean annual daily flows were 88.5±0.9 m^3s^{-1} with spawning season mean daily flows during spawning season ranged from 31.8-52.2 m^3s^{-1}. Maximum flows approached 350 m^3s^{-1} and typically occurred in June. Water temperatures ranged from 13-20 °C during the spawning season (September-November).

The Lower Shuswap River supports populations of four species of Pacific salmon; pink (*O. gorbuscha*), coho (*O. kisutch*), sockeye (*O. nerka*), and chinook. The majority of the chinook salmon spawn between the outlet of Mabel Lake and Trinity Creek (Figure 2) in coarse gravel substrate, from mid-September to late-October. The Lower Shuswap River has 8 km of good, 19 km of moderate and 47 km of poor quality spawning habitat (Parken *et al.*, 2002). Other salmonid fish species inhabiting the Lower Shuswap River include rainbow trout (*O. mykiss*), Rocky Mountain whitefish (*Prosopium williamsoni*), and bull trout (*Salvelinus confluentus*). Non-salmonid fish include suckers (*Catastomus* spp.), Peamouth Chub (*Mylocheilus caurinus*), sculpins (*Cottus* spp.), and Northern pikeminnows (*Ptychocheilus oregonensis*).

The Lower Shuswap River supports a summer-run chinook salmon population that spawns between late-September and early-November. Prior to the onset of spawning, some of the chinook salmon move through the Lower Shuswap to spawn in the Wap and Middle Shuswap Rivers, which both flow into Mabel Lake. Some of the chinook salmon hold in Mabel Lake for up to 8 weeks before moving downstream to spawn in the Lower Shuswap River. Others hold in Mara Lake and move upstream to spawn in the Lower Shuswap River. Some chinook salmon also hold in-river before spawning and some move directly onto spawning habitat upon arrival. Different combinations of these behaviors may also occur. Peak spawning for this stock occurs typically around October 12 each year.

For mark-recapture and aerial escapement estimation purposes, the Lower Shuswap River study area encompasses the upper portion of the river from Enderby bridge upstream to Mabel Lake. The 40 km long study area is divided into 9 reaches (Figure 2), which were already established by previous aerial enumeration crews. These areas appear to be divided by large visual landmarks.

From 2000 – 2002, the Stock Assessment Division of the Department of Fisheries and Oceans Canada operated the Lower Shuswap River chinook salmon mark-recapture program and survey life studies. DFO partnered with a local community group, the Kingfisher Interpretative Centre Society (KICS). KICS allowed the use their facilities, offered community support, and provided other in-kind services. DFO and the Secwepemc Fisheries Commission (SFC) conducted the aerial counts. The program was conducted from September 13 to the beginning of November each year to encompass the entire chinook salmon spawning period in Reaches 1-6 (Figure 2).

CHAPTER 2
OBSERVER EFFICIENCY OF AERIAL ENUMERATION

Knowledge of observer efficiency is an essential component of the AUC method for estimating fish abundance from periodic spawner counts. Observer efficiency is defined as the proportion of fish counted relative to the actual number of fish present in the stream during the survey (Korman *et al.*, 2002). Historically when using either the AUC or the Peak Count method to estimate escapement, DFO staff have assumed 100% observer efficiency. Aerial enumeration is the main visual count method used to count chinook salmon in the Fraser Basin. Occasionally, it is also employed to count coho salmon in larger, more remote streams.

2.1 Methods

Aerial observer efficiency of chinook salmon was estimated for the Lower Shuswap River based on two surveys conducted in one day. To estimate observer efficiency, observer counts from helicopters were compared to counts from photographs. At the time of the survey (October 5, 2001), the Lower Shuswap River study sites were approximately 25-60 meters wide and 50-200 cm deep. The discharge was approximately 26.2 m^3s^{-1} (Table 20, Appendix 1). The counting conditions were near optimal; the sections had good light with little shading, very low turbidity, little overhanging vegetation, good weather (calm winds and no rain) and low abundance of other species (i.e. sockeye salmon). Chinook salmon are also relatively large, making them easy to identify from the air.

Three sections of 150 meters in length and three other sections of 1000 meters in length, each of which were suitable for aerial photography, were selected in the upper reaches (2-4) of the Lower Shuswap River (Figure 2), where the majority of chinook salmon spawning occurs. The day prior to the initial study flights, observations were made from a Mackenzie River Driftboat and a jetboat to approximately identify high, medium and low density sections for both the 150 meter and the 1000 meter length study sites. Sections had to be straight, jetboat accessible, and have minimal shading on the water at mid-day when photos were to be taken.

A jetboat and three-person crew marked out the sections by placing concrete blocks, spray-painted orange, at the water's edge on both sides of the river - at the upstream and downstream extremity of each section. A hipchain was used to measure the length of the 150 meter sections and a handheld GPS unit was used to measure the length of the 1000 meter sections.

On October 5, 2001 a Bell 206B helicopter equipped with a camera boom took overlapping stereoscopic photographs of designated sections of the Lower Shuswap River. Two regular flights, each with its own experienced counting crew, were conducted to count Lower Shuswap River chinook salmon directly following the photo flight; no communication occurred between the crews (Parken *et al.*, 2003). However, communication did occur between counters on individual flights. While this date was the predicted peak of spawn for the chinook salmon, the peak of spawn did not occur until October 10. The helicopters flew in an upstream direction; therefore, any scattering of spawners occurred behind the helicopters and did not affect fish countability. One-hour periods between flights allowed enough time for fish to move back to the areas that they were occupying before the previous helicopter had passed. Flights were conducted at low levels (50-80 m above the ground) and slow speeds (10-40 km hr^{-1}).

The first helicopter was equipped with a camera boom fitted with two synchronized large format cameras that produced a complete series of stereoscopic photographs of each of the six sections. The next two flights were conducted for direct visual counts of the entire stream and the sections. Fish counting was carried out by two experienced observers each wearing polarized glasses and seated on the opposite side of the helicopter from the pilot. The machine was flown slowly in a "crab" style to provide observers with the best view of the fish. Observers used tally wackers to keep track of their individual counts of chinook salmon. Each observer tallied and recorded chinook salmon spawners, holders and carcasses and recorded their own numbers at the end of each section. Chinook salmon typically hold in pools before moving onto the shallows to spawn; therefore, spawners were distinguished from holding fish by their association with spawning habitat and redd sites (Neilson and Geen, 1981). At lower densities fish were counted individually; however, as the density increased fish were counted or estimated in groups of five's or 10's. This is the standard method used by DFO and partners to count Upper Fraser chinook and coho salmon.

On October 12, 2001 another pair of consecutive counting flights were conducted to count spawning chinook salmon in the Lower Shuswap River. The October 5 and 12 flight data were used to investigate variation in spawner counts from observer-to-observer and flight-to-flight. No photographs were taken on October 12, 2001.

Two different methods were used to determine the total spawner count for each flight. The high (best) count method selects only the highest count of the two observers' counts for each segment on the flight and is the current method used by DFO. It is assumed that the observer with the highest count observed the most fish. The mean count method calculated the mean of the two observers' counts for that flight segment.

During the first helicopter flight on October 5, 2001, multiple overlapping photographs were taken from the helicopter of each section of the Lower Shuswap River using 70 mm moving film. The helicopter flew high enough (60 - 80 m) so the entire width of the river and a small amount of the bank were encompassed in each photo. Overlapping photos were sliced, duplicated, and put on a light table in pairs under a stereoscope for 3D fish counting. For each stereo-photo pair, the number of spawners, holders, and carcasses were counted by three experienced observers and summed for each section. Overlap between photos was taken into account by using distinct objects along the shore as markers. The mean of the three observer counts taken from photographs were used for each section and compared to all individual observer counts from helicopters (not just high counts only).

2.1.1 Calculation of Observer Efficiency

Korman *et al.* (2002) defined observer efficiency as the ratio of total fish seen to total fish present. To determine observer efficiency of chinook salmon aerial flights only spawner counts were used - as holding fish and carcasses are difficult to count and are not used in the AUC estimate of escapement. The counts of spawning salmon made by individual observers from the helicopter were compared to the mean counts of spawners from photographs to determine each individual counter's observer efficiency. The total mean observer efficiency was the mean of all four counter's observer efficiencies. Alternatively, a least-square line with the intercept set to zero was fit to the data and the slope of that line was used to estimate observer efficiency. Aerial counts of the 150 m, low density section and the 1000 m, medium density section were not made by observers on the first counting flight and therefore were not included.

The means of the photographic counts were used as the measure of the actual number of spawners present. The observer efficiency was computed in several ways.

Let $O_{observer,length,density}$ be the observed count by the observer for a segment of a specified length with a certain density class.

Then $$OE_{observer,length,density} = \frac{O_{observer,length,density}}{P_{observer,length,density}}$$ Equation 8

where OE is the observer efficiency, O is the observer count, and P is the photograph count.

Each aerial counter's observer efficiency was computed separately based on the length of the section, by dividing the aerial observer's count for both the 150 meter and 1000 meter sections by the mean photo counts of the corresponding sections. For both the 150 and 1000 m sections, the total mean observer efficiency was computed as the grand mean of all the sections' observer efficiencies.

Each aerial counter's observer efficiency was also computed based on the chinook salmon spawner density (intra-specific abundance) of the section by dividing the aerial counts for high, medium and low density sections by the mean photo counts of the corresponding sections. The total observer efficiency at each spawner density level was calculated by finding the grand mean of all the aerial counters' observer efficiencies for those corresponding sections.

2.2 Results

2.2.1 Spawner Counts

Aerial counts varied among counters and flights for the tested sections lengths and across chinook salmon spawner densities (Table 4). Individual observer counts of spawners from photographs are reported in Table 21 (Appendix 2).

Table 4. Lower Shuswap River helicopter-based and photograph counts of chinook salmon spawners conducted October 5, 2001. The dots indicate missing data. Underneath are the associated observer efficiencies determined for 150 m and 1000 m long sections with low, medium and high spawner densities.

				Flight 1		Flight 2			
Section	Section Length (m)	Density	Mean Photo Count	Obs. 1 Count	Obs. 5 Count	Obs. 2 Count	Obs. 4 Count		
1	150	Low	14	.	.	98	52		
2	150	Medium	181	130	196	173	140		
3	150	High	209	207	198	210	210		
4	1000	Low	252	344	419	282	363		
5	1000	Medium	853	.	.	575	480		
6	1000	High	1,435	1,408	1,335	1,380	1,450		
								Average OE	2SE
150 meter*				86%	101%	119%	100%	102%	13%
1000 meter*				104%	104%	88%	90%	97%	9%
Low Density*				137%	166%	143%	156%	150%	13%
Medium Density*				72%	108%	72%	60%	78%	21%
High Density				98%	93%	97%	101%	97%	3%
All Combined				101%	103%	92%	92%	**97%**	**6%**

*When data points were missing only the one observer count and the associated photo count were used to determine observer efficiency; the missing observer count and its associated photo count were excluded.

Flight data indicated that spawner counts varied from observer-to-observer and flight-to-flight (Tables 5 and 6). Mean spawner counts are materially different than the high (maximum) spawner counts. Table 6 shows how some of the variation (uncertainty) in spawner counts can be taken into account by using mean counts to calculate AUC spawner escapement estimates.

Table 5. Lower Shuswap River helicopter counts for individual observers of chinook salmon spawners from replicate flights on October 5 and 12, 2001. Observers differed from one flight date to the next.

Date	Flight 1		Flight 2	
	First Obs Count	Second Obs Count	First Obs Count	Second Obs Count
05-Oct-01	7,548	8,370	6,883	6,989
12-Oct-01	8,970	8,394	9,216	9,097

Table 6. Lower Shuswap River helicopter counts of chinook salmon spawners from replicate flights on October 5 and 12, 2001 determined using both the high and mean count methods.

Date	Count Method	Flight 1 Count	2SE	Flight 2 Count	2SE
05-Oct-01	High*	8,370		6,989	
05-Oct-01	Mean	7,959	822	6,936	106
12-Oct-01	High*	8,970		9,216	
12-Oct-01	Mean	8,682	576	9,157	119

*for the high count method only the maximum counts were used, so there is no associated standard error.

2.2.2 Observer Efficiency

Total and individual observer efficiencies varied between counters, flights, and spawner densities but not across section lengths (Table 4). The 150 m, low spawner density and 1000 m, medium spawner density sections for Observers One and Five were based on a single data point due to missing data. Counters were focused on the overall reach count and missed the section breaks. Removal of the 150 m, low spawner density count from the data set causes the total mean observer efficiency to drop by 1% to 96%. Mean photograph counts of spawners were compared to observer's helicopter counts of spawners and used to determine each observer's mean observer efficiency (Figures 3-6).

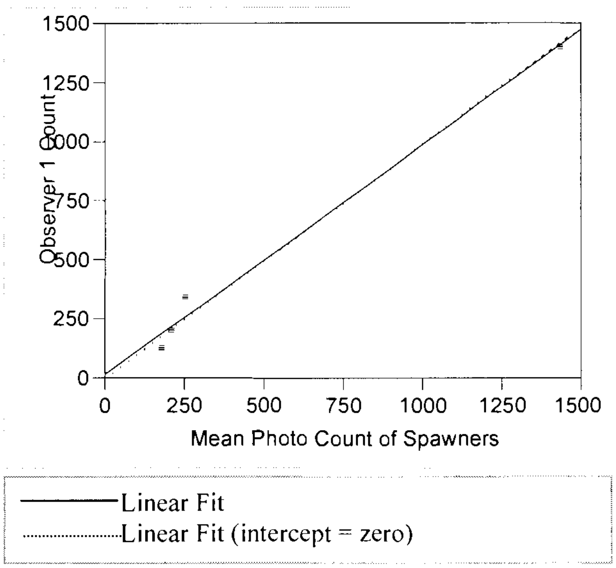


Figure 3. Mean photograph counts of spawners versus Observer One's helicopter counts of spawners for Lower Shuswap River chinook salmon for October 5, 2001.

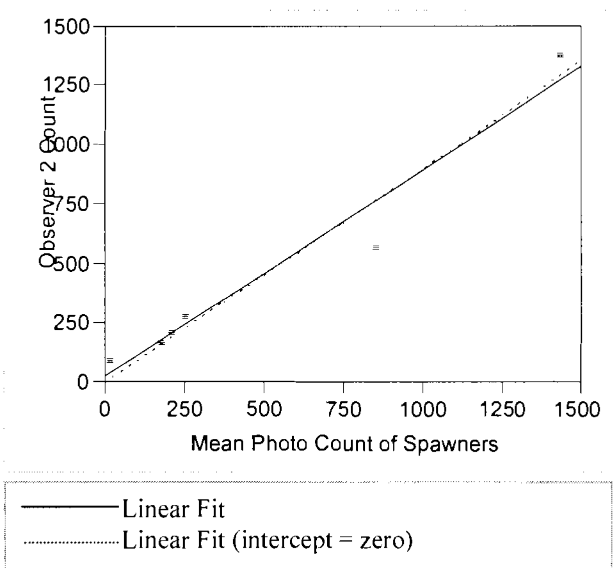


Figure 4. Mean photograph counts of spawners versus Observer Two's helicopter counts of spawners for Lower Shuswap River chinook salmon for October 5, 2001.

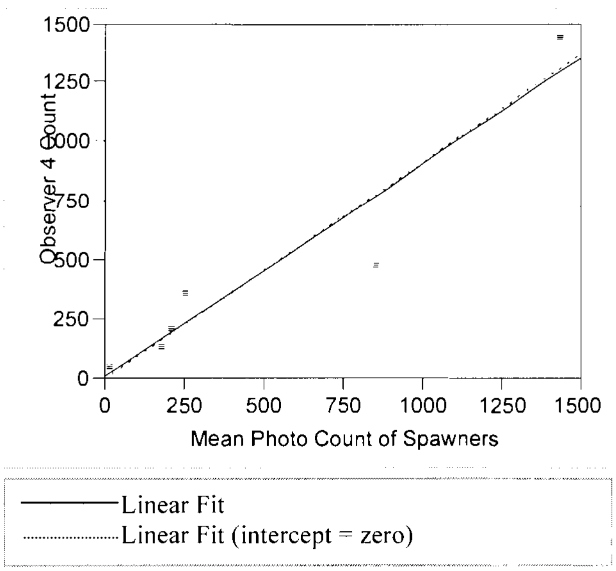


Figure 5. Mean photograph counts of spawners versus Observer Four's helicopter counts of spawners for Lower Shuswap River chinook salmon for October 5, 2001.

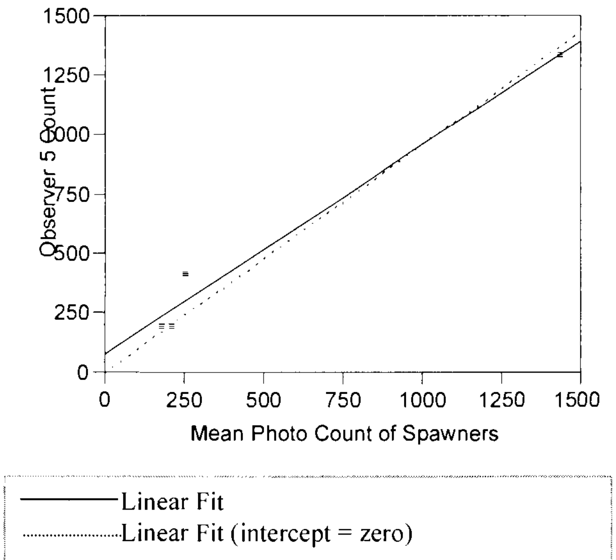


Figure 6. Mean photograph counts of spawners versus Observer Five's helicopter counts of spawners for Lower Shuswap River chinook salmon for October 5, 2001.

The total mean observer efficiency determined as the slope of the line for all counters' observer efficiencies was 0.90 when a slope-intercept model was fit and estimated as 0.93 when the intercept was constrained to zero (Figure 7).

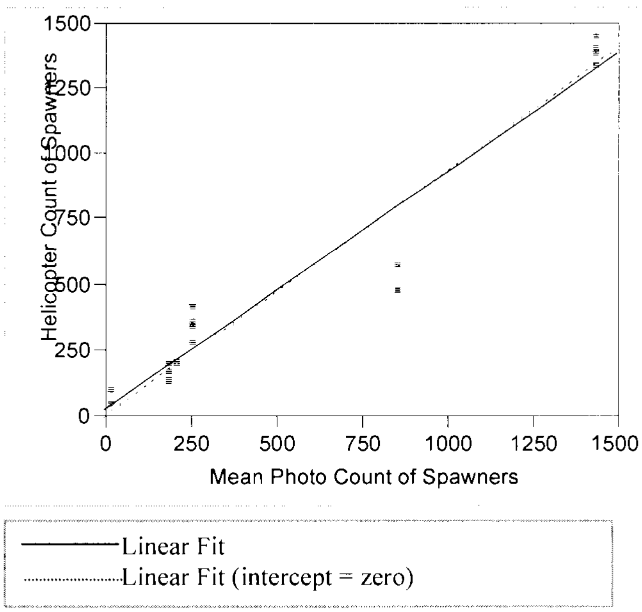


Figure 7. Mean photograph counts of spawners for all observations versus helicopter counts of spawners and used to determine total mean observer efficiency of chinook salmon aerial enumeration on the Lower Shuswap River.

The Lower Shuswap River observer efficiency data from all observers were grouped by section length and density, and the intercepts of the fitted line were constrained to zero to determine the observer efficiencies (Table 7). There was no evidence of different observer efficiencies among the section lengths (p=0.51; Table 8; Figure 8). However, there was strong evidence (p<0.001) that the observer efficiency varied across spawner density (Table 8; Figure 9).

Table 7. Each observer's observer efficiency (slope) and slope ($Slope_0$) when the intercept was constrained to zero.

Observer	Slope	$Slope_0$
One	0.97	0.99
Two	0.87	0.89
Four	0.90	0.91
Five	0.88	0.95

Table 8. Slope of the lines (observer efficiency) for both pooled 150 m and 1000 m long sections and high, medium and low density sections. P-value reports on a test for a common slope and intercept for observer efficiency across length and density.

Section	Slope (OE)	p_{slope}	$p_{intercept}$
150 m	0.95	0.51	0.63
1000 m	0.93		
High Density	0.97	<0.001	<0.001
Medium Density	0.64		
Low Density	1.40		

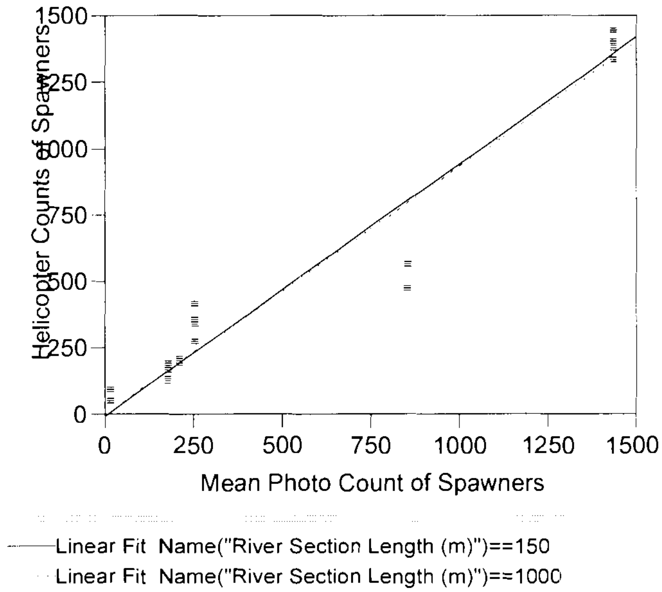


Figure 8. Mean photograph counts of spawners versus each observer's helicopter counts of spawners for Lower Shuswap River chinook salmon using 150 m and 1000 m section lengths.

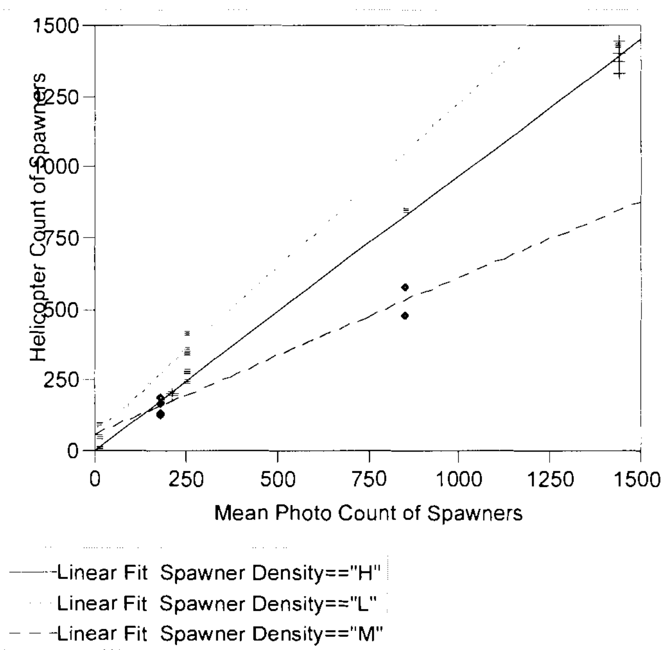


Figure 9. Mean photograph counts of spawners versus each observer's helicopter counts of spawners for Lower Shuswap River chinook salmon using high, medium and low chinook spawner densities.

2.3 Discussion

Visser *et al.* (2002) found that aerial photography counts were much more accurate than fixed wing visual counts of fall-run, chinook salmon redds for the Columbia River's Handford Reach and suggested that helicopter visual enumeration may be even more accurate. Overall, the results of this study indicated that aerial photography produced only marginally larger spawner counts than helicopter visual surveys of summer-run chinook salmon in the Lower Shuswap River: Mean observer efficiency was 97% (95% CI is ± 6%).

In this study, the number of spawning fish counted from photographs was considered to be the actual number of fish present at the time of the survey; however, the accuracy of the photograph counts is unknown. Bevan (1961) recommended that visual surveys should only be used as an index for comparing counts: unless AUC estimates of escapement are corrected using an observer efficiency coefficient, fisheries biologists generally interpret them as negatively biased indexes (Irvine *et al.* 1992, Bevan 1998, Jones *et al.* 1998, Hilborn *et al.* 1998 in Parken *et al.* 2003). Neilson and Geen (1981) found a mean observer efficiency of 96% when fixed wing spawner counts were compared to photograph spawner counts for the Morice River. This result is similar to the 97% observer efficiency determined in this study although helicopters were used in place of fixed wing aircrafts. Higgins and Peterman (1990) found that fixed wing aerial surveys were within ± 4% of weir counts when compared to tower counts and underestimated the abundance of sockeye spawners in Bristol Bay, Alaska.

This one-day study only looked at the influence of survey stratum length and intra-specific abundance factors on observer efficiency. Many other factors could cause variation in observer efficiency, including movement of fish into and out of surveyed sections between flights.

For determining the mean observer efficiency, the fit of mean photo counts to observer counts was lower than those calculated directly from the counts. This is an artifact of the estimation method when the “mean of ratios” is not equal to the “ratio of means”. For example $(10/11+90/100)/2 = 0.904 < 0.909 = (10 + 90)/(11+100)$.

Replicate flight data and section counts showed variation in counts from observer-to-observer and flight-to-flight. However, factors that cause observer-to-observer and flight-to-flight differences in spawner counts were not investigated in this study.

Factors that could cause differences in spawner counts from observer-to-observer may include the observer's position in the helicopter (front or back seat), experience, eye sight, polarized glass shape and colour, and motor skills or ability to punch the tally wacker at the same rate fish are being seen - especially at high densities. Bevan *et al.* (1961) found an observer:count interaction that indicated a difference between an observer's ability to count by 100's or 1000's and that the ability to count by 100's or 1000's will differ with the magnitude of the count. Therefore, Bevan *et al.* (1961) suggested using one counting unit only (1's, 5's, 10's, 10's or 1000's) and using the same observer whenever possible to reduce systematic error. When observers have similar counting experience, some of the uncertainty in spawner counts may be taken into account by using the mean of the two observers counts to calculate AUC spawner escapement estimates.

Observer efficiency most likely varies within most river systems, indicating that a single observer efficiency for an entire stream may not be appropriate. English *et al.* (1992) recommended investigation of more survey conditions within systems but recognize that such studies will be limited to few streams due to the high amount of effort and associated cost of conducting these types of surveys. Higgins and Peterman

(1990) also recognized the high costs but noted that mangers need to be made aware of the study design options available.

This study found that medium and high spawner density sections had similar observer efficiencies (78% and 97%) but the observer efficiency was higher for the low spawner density section (150%; Table 4). The higher observer efficiency for the low density section may have been caused by observers overestimating the number of spawners present in the low density sections because more fish may have moved into the low density section after the photo was taken but before the count for the second flight was made (approximately three hours later). This could not be verified by the counts from the first flight, as the observers on flight one did not count this low density section in isolation from the reach as a whole. The similarity of photo estimates and overflight counts infers high observer efficiency, if we assume all fish present were counted in the photographs. We found different efficiencies for photo counts and helicopter counts at high, medium and low chinook salmon spawner densities (intra-specific abundance). Higgins and Peterman (1990) agreed that intra-specific abundance may affect observer efficiency and that this correlation needs further investigation.

When individual observer efficiencies were examined, there was a strong agreement between the flight and the two observer's counts. The most likely reason for this agreement was that the river was flown simultaneously by the two observers on each flight and these two observers were able to converse about the fish they were counting. Flight One observer counts may have been closer to mean photograph counts than Flight Two observer counts because they flew closer to when the photographs were taken. Other factors that may have affected spawner counts between these flights or surveys might include speed and height of helicopter, pilot performance, time of day, aircraft, light (i.e. position of the sun), shading, wind (i.e. wind ripple), and fish movement between flights. Factors that influence observer-to-observer spawner counts such as physical counting may also cause flight-to-flight differences in spawner counts. Bevan *et al.* (1961) found that similar aircraft and pilot changes from flight-to-flight did not have an effect on observer efficiency between flights. However, Bailey *et al.* (2000) reported the interflight count differences may have resulted from differing pilot experience, as well as light and wind factors. Parken *et al.* (2003) reported variation in counts between replicate flights due to reflection and rippling caused by sun and wind.

Neilson and Geen (1981), Solazzi (1984), and Higgins and Peterman (1990) found that observer efficiency varies from system-to-system due to stream size (length, width or discharge), weather (i.e. surface disturbance by wind), turbidity or water clarity, hideable cover, intra- and inter-specific abundance and the migration's spatial and temporal distribution in the survey area. This study did not investigate these factors. Higgins and Peterman (1990) found that each of the three streams they studied required separate bias correction factors (i.e. observer efficiency) and suggest that these bias correction factors be applied cautiously among different stocks. "Ideally, managers should be collecting the data required to fit separate bias correction functions for each stock and technique, because if may be incorrect to assume standard correction procedures apply among stocks, and this may bias analyses and the subsequent decisions based upon them." (Higgins and Peterman, 1990:19).

CHAPTER 3
SURVEY LIVES

Survey life is another key factor in the AUC method for estimating escapement of Pacific salmon (Perrin and Irvine, 1990). In this study, survey life is defined as the duration of time in days from when a fish begins to spawn (onset of spawning) until a female vacates her redd or until a male dies (completion of spawning, Table 1). The completion of spawning is normally marked by a female fish vacating the vicinity of her redd and by death for a male fish. AUC estimates based on survey lives are often more reliable than other methods such as peak counts (Hill and Irvine, 2001). This study estimated the survey life of Lower Shuswap River chinook salmon for 2000-2002 using telemetric monitoring and observation from towers.

The mark-recapture based survey life is defined as the number of days a fish is countable as a spawner from the air – this includes all fish that are on the shallows and clearly associated with spawning habitat (Table 1). When estimating spawner escapement, survey life can be used to approximate the mark-recapture based survey life (Table 1). Observers identify spawners as fish on the spawning grounds (shallows) - not fish holding in pools, unless they are in a pool tail-out and associated with redds or spawning gravel. The mark-recapture based survey life was computed from the total spawner counts and the mark-recapture spawner estimates of escapement. By assuming an unbiased mark-recapture and AUC, the mark-recapture based survey life should represent the true survey life. The mark-recapture based survey lives will be shorter than the observed survey lives, as the mark-recapture based survey life includes fish that are moving through the spawning grounds (migrators), fish that are gaming but not yet spawning, and fish that have vacated their the redd but have not yet died; whereas, survey life includes established spawning fish only. This is an artefact of observers not being able to distinguish resident spawners from migrators or near dead fish from helicopters.

3.1 Methods

3.1.1 Telemetric Monitoring

3.1.1.1 Radio Tag Application

Chinook salmon were captured for radio tag (transmitter) application during the mark-recapture seining operations (Chapter 4). This telemetric study of Lower Shuswap River chinook salmon was approved by Simon Fraser University's (SFU) Animal Care Department (Appendix 3). After a successful set, salmon randomly selected for radio transmitter application were tagged before the remaining salmon were tagged for the mark-recapture study, as decreased holding time minimizes stress on the radio tagged fish. Chinook salmon were also angled from shore to capture salmon from holding inaccessible to powerboat seining. Angled fish were held for a minimum of 30 minutes before tagging in 1.25 m x 0.3 m diameter vinyl flow-through holding tubes, anchored along shore to allow suitable flow of water through the tube (Farwell *et al.*, 1999).

Lotek MBFT pulsing transmitters (radio tags) were activated by removing the magnet taped to the outside of the tag and tapping it a couple of times on a solid surface such as a rock. Each captured chinook salmon was placed into the canvas sling of the tagging tray that was submerged in shallow water, and were quickly tagged, inspected for health, recorded, and released without being lifted from the water. To insert the radio tag, the fish was held in the tagging box while another person held the fish's mouth open and a third person inserted the radio tag. The radio tags were inserted using a 20 cm long x 10 mm diameter plastic pipe with the antenna of the tag threaded through the tube and then pulled tight. By firmly holding onto the end of the antenna, the pipe was used to push the tag down the throat of the fish and into the stomach. Then the pipe was removed, leaving the tag in the fish's stomach and the antenna hanging out of the fish's mouth. The radio tagged fish were also Peterson disk tagged with numbered, sex-specific coloured tags. Tag colours were different in colour from those being used for the mark-recapture program to permit visual identification. The females were marked with numbered orange or pink disk tags and the males were marked with numbered green or blue disk tags. Release time, radio tag channel and code were recorded in addition to the regular data obtained during Peterson tagging. All other procedures implemented during regular Peterson disk tag application were also conducted (Section 4.1.1 and Farwell *et al.*, 1999).

Radio-tagged fish were released throughout Reaches 1-6 in 2000 and Reaches 1-4 in 2001 and 2002 (Figure 2). These reaches contain the majority of chinook salmon spawning habitat and suitable areas for capturing chinook salmon by beach seining on the Lower Shuswap River.

Radio tags were inserted into 32 male and 29 female chinook salmon in 2000; 36 males and 38 females in 2001; and 73 females, 73 males and one jack (two year old precocious males) in 2002. All channels/frequencies used had radio tags with individual codes; therefore, identification of individual fish was known as soon as the channel and code registered on the receiver. This study utilized both new and used radio tags. Radio tag recovery conducted during mobile tracking and regular recovery facilitated re-use after removal from carcasses. Radio tags were re-used up to three times in one season.

Various sized chinook salmon were tagged throughout the run. Tagging commenced on September 13 annually and continued until the majority of fish had moved onto the spawning grounds and very few fish were left holding (approximately the end of October). This allowed for the tagging and monitoring of fish that had arrived in the terminal area throughout the spawning period.

3.1.1.2 Spawning Ground Survey

During mark-recapture spawning ground surveys (carcass recovery), deceased radio tagged fish were identified, recorded, and the radio tags were collected by cutting the fish's body cavity open and pulling the radio tag out of the fish's stomach. Sex, Petersen tag number and colour, post-orbital to hypural plate (POH) length, radio tag number, number of eyes, recovery method, adipose presence, percent spawn, carcass condition, and approximate time of death information were recorded for each radio tagged chinook salmon recovered. Radio tagged fish were also recovered during telemetric mobile tracking and two floats were made at the end of the study each year, after all fish were assumed to be dead - specifically to retrieve radio tags.

3.1.1.3 Monitoring

A combination of fixed station and mobile tracking systems were used to locate chinook salmon, monitor their movement, and estimate survey lives.

At two locations on the river annually, Lotek SRX_400 (www.lotek.com) data logging fixed station receivers were encased in a waterproof, locked aluminum boxes and powered by 12 V RV batteries. Each station was equipped with two directional antennas attached to the receiver and positioned adjacent to river areas with relatively shallow water to ensure that the receiver would detect every tagged fish that passed by. At each station one antenna pointed upstream and the other pointed downstream. These directional antennas allowed for determination of the fish's movement (upstream or downstream) and also facilitated detection of the radio tagged fish entering and leaving the study areas.

In 2000 and 2002, fixed telemetry stations were set-up at the upstream and downstream extremities of the study area: one at the Old Mill Site (approximately 27 km downstream of Mabel Lake) and one Mabel Lake Outlet (approximately 500 m downstream of Mabel Lake) in 2000; and one just below Skookumchuck Rapids (approximately 2 km downstream of Mabel Lake) and one at Dale Pool (approximately 15 km downstream of Mabel Lake; Figure 2) in 2002. In 2001, the fixed stations were located at the upstream and downstream extremities of the highest density spawning area on the river: one at Hupel (approximately 5 km downstream of Mabel Lake) and one just above Cooke Creek outlet (approximately 7 km downstream of Mabel Lake; Figure 2).

Radio tagged chinook salmon were tracked daily using a portable telemetry receiver, Lotek SRX_400, while floating in a Mackenzie River drift boat. A telescopic pole, adjustable from 1.8 to 3.6 m, with a Yagi 2-element antenna attached was placed at the front of the drift boat. This antenna was connected to the portable receiver that was monitored and controlled by one person in the boat while a second person rowed. During peak of spawn, a third person was required to record registered radio tag signals, control the direction of the antenna, and watch for radio tagged chinook salmon with coloured Petersen tags. Daily records of time, location, channel, code, habitat type and signal power were kept for each of the registered radio tag signals.

When the receiver detected a tag at a high power level this indicated that the tag was within close proximity, time permitting the researchers would row the boat to shore and walk up and down the river bank until the strongest signal was obtained. This allowed for closer determination of the radio tagged salmon's location and the associated habitat type. However, at periods of peak abundance, it was not always possible to investigate the exact location of every tag detected.

Floats were made daily in Reaches 2-6 (Figure 2), between Davidson's and Dale's, throughout the spawning period. This area contains the majority of the high quality spawning habitat. Skookumchuk Rapids, a section of Reach 1 (Figure 2), could not be floated due to the narrow passage and steep grade of the river in this section. Where accessible, this area was monitored weekly by walking the river shore with the portable receiver.

3.1.1.4 Survey Life Determination

Survey lives (Table 1) were estimated from telemetric monitoring data by counting each consecutive day that a fish was recorded on spawning habitat. Fish encountered only once on spawning habitat were excluded, because these fish may have been migrating through and not spawning. No survey lives were determined for cases where the time of death estimated at recovery pre-dated the start date of spawning; where the radio tag was observed to have punctured the fish's stomach; or where the fish was never recorded on spawner habitat inside the study area. Some fish may have expelled radio tags; therefore, data were not considered for radio tag signals that registered in the same location throughout the entire study period and continued to register in the same location after all chinook salmon spawning had ceased.

Mean annual survey lives were determined separately for male and female chinook salmon. A 50:50 sex ratio (male to female) and actual sex ratios determined from mark-recapture estimates were used when estimating combined sex survey lives from telemetric monitoring. The delta method was used to estimate the standard error of the estimates (Seber, 1982). General spawning behaviour of male and female chinook salmon is summarized in Table 22 (Appendix 4).

3.1.2 Observation Tower Monitoring

3.1.2.1 Study Area

Temporary observation towers were constructed along the Lower Shuswap River to permit observations of spawners. Three observation towers were located in Reach 2 in 2001 and four observation towers were located in Reaches 2-4 in 2002. Selection of observation tower locations was based on river bank features and spawning habitat suitability. The riverbank had to be accessible by drift boat, wide enough to safely place scaffolding and have trees present to anchor the scaffolding. The spawning habitat adjacent to the observation tower location had to be suitable for chinook salmon spawning, known to be used historically by spawning chinook salmon, and shallow enough to clearly observe salmon and their redds. Historical spawning locations were determined by experienced crewmembers. After selecting the observation tower location, a 6 to 8 meter high scaffolding tower was erected on the riverbank and securely anchored to nearby trees. Observation towers were then equipped with a tarp roof, a 3-person sitting area and a "*No Trespassing*" sign. Depending on the height of the riverbank, observers typically sat 9 to 10 meters above the water's surface.

After each observation tower was constructed, a 30 meter by 20 meter grid was established on the river bottom parallel to the flow, adjacent to the tower, and approximately 2 to 5 meters away from the river bank (Figure 10). Concrete bricks were spray painted orange and placed on the river bottom by hand to outline the grid and divide it into six 10 meter by 10 meter sections (Figure 10). Gridding off the observed river sections facilitated the identification of individual redds and the females occupying them. At the end of each study period, bricks not buried in redds were removed from the river bottom.

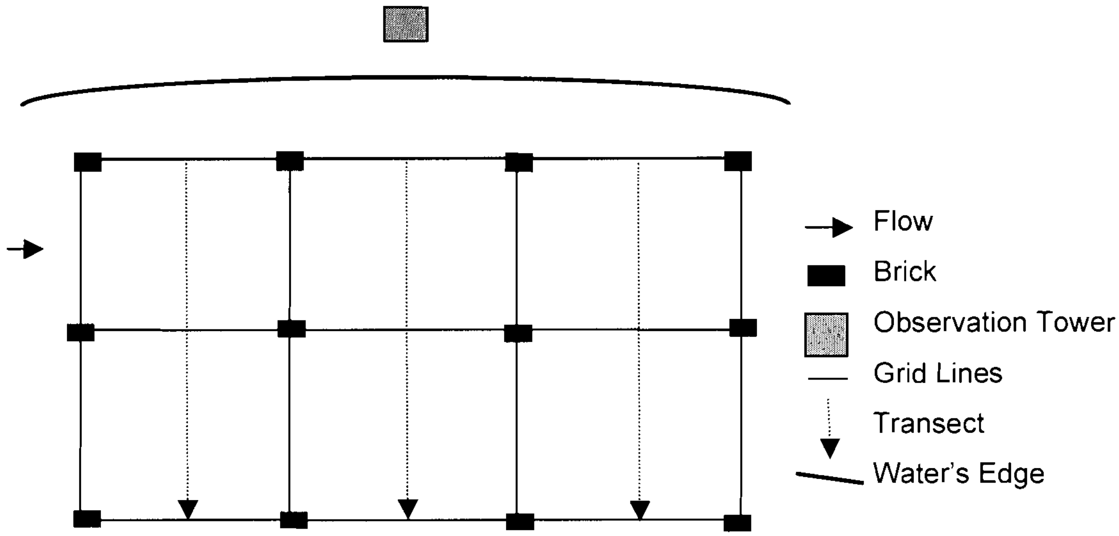


Figure 10. The layout of each 20 by 30 meter grid and transects at each observation tower study area, as part of the survey life study.

3.1.2.2 Monitoring

Daily tower observations of spawning salmon were conducted from mid-September to late-October of each year. Observers remained on each tower long enough to sketch and record all chinook salmon in the grid (10 to 90 minutes). Individual females were identified using natural body markings and redd position. Sketches of chinook salmon redd distribution and associated spawners were made and each female chinook salmon was assigned an individual number. For example 3-51, would be assigned to the 51st female chinook salmon observed at observation tower number three. Redds and fish inside or bordering the grid were observed and recorded.

Female behavioural and physical characteristics were recorded to help determine if the fish was a spawner. For example if a female had a white tail and was observed digging a redd, a digging comment was recorded and that individual was automatically considered to be an active spawner. As some females will dig "test pits" before establishing a redd, only survey lives greater than one day were included.

A test pit is a small hole dug by some females prior to establishment of a permanent redd site. Males and jacks were sketched and counted but not individually identified, as they were too hard to distinguish and appeared to move considerably from day-to-day. Total numbers of male and female salmon present within the grid were recorded daily. If time permitted, an estimate of the total number of sockeye salmon present in the grid was also made.

3.1.3 Survey Life Determination

Male survey lives could not be determined from tower observations because males are transient and spawn with multiple females in an area larger than the 20 x 30 m study area. After spawning, males frequently abandon their mates in search of other active females (Briggs, 1953). Therefore, the observation tower study design did not allow for the monitoring of males throughout their entire spawning period and it was not possible collect sufficient data to estimate representative male survey lives.

Tower observations were used to determine female chinook salmon survey lives. Females usually remain on one redd throughout the entire spawning period, and spawn multiple times in a series of nests, usually resulting in a single redd (Berejikian *et al.*, 2000). Nests and completed redds are defended by females against superimposition by other females (Briggs, 1953).

Survey lives (Table 1) determined from observations made at towers were calculated as the number of days that a female chinook salmon was observed to be associated with a redd inside the study area. Spawning start and end dates for each female chinook salmon spawning in the study area were recorded to determine individual survey lives. The start date was identified as the first day an individual female was observed on a redd or digging a redd within the grid. The last day of residence was the last day an individual female was observed to be associated with her original redd.

3.1.4 Survey Life Comparisons

Telemetric monitoring data were used to compare male versus female survey lives. A two-factor completely randomized design (CRD) analysis of variance was conducted to investigate the effects of sex, year, and this interaction upon the mean survey life. Inter-annual variation in mean, female survey lives was determined from telemetry and observation tower results. Inter-annual variation in mean male and combined sex survey lives was determined using telemetry results only. Inter-annual variation in mark-recapture survey lives was also investigated.

Spawners were divided into two groups, early and late, to determine if arrival timing affected the survey lives. The early-arrival group was defined as having a mid-point spawning date before the peak of spawn. The late-arrival group was defined as having a mid-point spawning date after the peak of spawn. The mid-point spawning date was the middle day of an individual salmon's total spawning period. The peak of spawn was estimated as the date that the highest number of spawning females was observed from towers.

Fukushima and Smoker (1997) suggested that residence time increased with immigration date. Therefore, the relationship between survey life and spawning date (mid-point of residence) was investigated for all three years (2000-2002) for both males and females. This relationship was also examined by pooling the data across all three years. A two-factor CRD analysis of variance was conducted to investigate the effect of spawning date, year, and their interaction upon mean survey life. To standardize annual spawning dates, the first day chinook salmon were observed spawning in the Lower Shuswap River for each year was assigned to be Day 1 of the spawning period.

The relationship between survey life and length (body size) was examined for both males and females. Lengths were only obtained for fish monitored using telemetry, as fish observed from towers were not captured. This relationship was also examined by pooling the survey life data for all three years (2000-2002). A two-factor CRD analysis of variance was conducted to investigate the effect of spawning date, year, and their interaction upon mean survey life.

3.1.5 Mark-recapture Based Survey Life

Mark-recapture based survey life is the mean time fish spent in the spawning area and were countable as spawners during aerial surveys, derived from aerial spawner counts and independent estimates of total abundance (Table 1). The mark-recapture based survey life was estimated using total spawner days and the mark-recapture estimate of escapement:

$$\text{Survey Life}_{M/R} = \frac{\text{Total Spawner Days x Observer Efficiency}}{\text{M/R Spawner Esc Estimate}} \qquad \text{Equation 9}$$

Total spawner days were calculated using both the mean count and the current best count method (Chapter 3), as well as using, DFO's current 100% and this study's 97% observer efficiencies. The best count method uses only the highest of the two observer's spawner counts and the mean count method uses the mean of the two observer's spawner counts. Four different combinations of total spawner counts and observer efficiencies were used to compute mark-recapture based survey life for each year. The delta method was used to estimate the variance of the estimates (Seber, 1982).

Mark-recapture based survey lives were compared among years and to the combined sex, radio-telemetrically, and tower observed survey lives. The difference between the mark-recapture based survey lives calculated using high counts for total spawner days were compared to those using mean counts. No significant difference was found between mark-recapture based survey lives calculated using 97% and 100% observer efficiency.

3.2 Results

Survey lives could only be determined for 20-28% of the total radio tagged fish released each year due to radio tag loss, movement from the study area, pre-spawn mortality, and radio tagging mortality (Table 9). The individual survey lives estimated from telemetric monitoring are presented in Table 23 (Appendix 5).

Table 9. Numbers of radio tags released, numbers of radio tags that produced valid survey lives (SL), mean survey lives and associated standard errors for Lower Shuswap River chinook salmon from 2000-2002 determined by radio-telemetric monitoring. All of the 2002, female survey lives from radio telemetry were exactly three days, resulting in a standard error of zero. Below are the survey lives determined from observations made at towers.

	Females				Males			
Year	Radio's Released	Valid SL's (n)	Mean SL	2SE	Radio's Released	Valid SL's (n)	Mean SL	2SE
2000*	29	2	4.8	0.5	32	10	6.2	1.2
2001	38	10	4.8	0.9	36	11	8.1	1.3
2002	73	6	3.0	0.0	73	24	6.3	0.5

*The start and end dates of the survey life were a range of days and the midpoint of that range was used as the start and end dates. The result was mean survey lives of 4.8 and 6.2.

Both a 50:50 male-to-female sex ratio and the mark-recapture determined sex ratios were used to calculate combined sex survey lives (Table 10).

Table 10. Combined sex, mean survey lives for Lower Shuswap River chinook salmon from 2000-2002 determined by telemetric monitoring. A 50:50 male to female ratio is assumed for the first set of combined survey lives. The sex ratios determined from mark-recapture data were used to calculate the second set of combined male and female survey lives.

Year	50:50 Sex Ratio		M/R Ratio		
	SL	2SE	Sex Ratio (M/F; %)	SL	2SE
2000	5.5	0.6	42/58	5.3	0.7
2001	6.4	0.8	51/49	6.5	0.8
2002	4.6	0.2	41/59	4.3	0.3

The 2001 mean survey life of female chinook salmon determined by observations made from towers is significantly higher than that for 2002 ($p=0.001$; Table 11). The individual survey lives estimates from tower observations are presented in Table 24 (Appendix 5).

Table 11. Sample sizes and mean survey lives of female chinook salmon for the Lower Shuswap River from 2001-2002 determined by observations made from towers.

Year	Total (n)	Mean SL	2SE	Arrival Timing Early (n)	Late (n)
2001	40	6.5	0.72	12	28
2002	133	4.8	0.35	72	61

Telemetric monitoring suggests that mean survey lives differed among years ($p<0.001$, Figure 11), and that males had longer survey lives than females ($p<0.001$) by a difference of 2.7 (95% CI is ± 0.6) days. The interaction between sex and year was not significant ($p=0.42$).

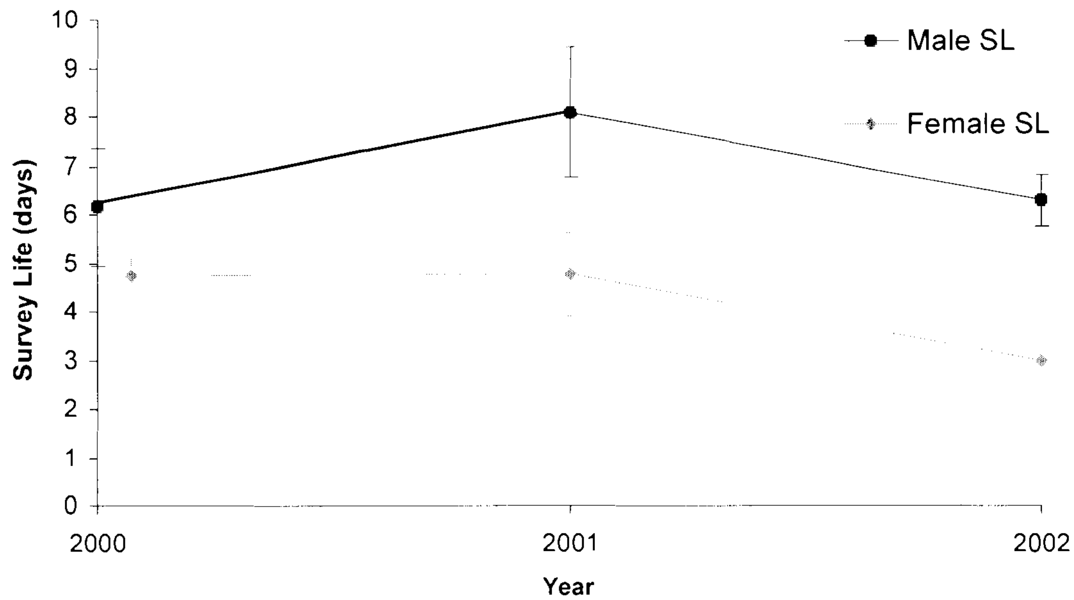


Figure 11. 2000-2002 mean survey lives with 95% CI of Lower Shuswap River male and female chinook salmon determined using telemetric monitoring.

Telemetric monitoring suggested that the mean survey life of early arrival male spawners was significantly greater than those that arrived late (Table 12 and Figure 12). When compared for each year separately and for all years combined, there was no evidence of a relationship between spawning date and male survey life (Table 13 and Figure 13). There was evidence that the relationship differed among years. The 2001 mean survey life of male chinook was higher than for 2000 by 2.9 (95% CI is ±0.8) days. The 2001 mean survey life of male chinook was higher than for 2002 by 2.6 (95% CI is ±0.6) days.

Telemetric monitoring suggested that the mean survey life of early arrival female spawners was greater than or equal to those that arrived late (Table 12 and Figure 12). When the relationships between female survey lives and spawning date were compared for each year separately and for all years combined, there was evidence of a negative relationship between spawning date and female survey life (Table 13 and Figure 14).

There was no evidence of an interaction between spawning date and mean survey life of female chinook salmon, and no evidence of a year effect (Table 13).

Table 12. Mean survey lives, 95% confidence intervals and sample sizes (n) for Lower Shuswap River male and female chinook salmon that arrived early and late - determined using telemetric monitoring and observations from towers.

Sex:	Male					
Study Method:	Telemetry					
Arrival:	Late			Early		
Year	n	SL	2SE	n	SL	2SE
2000*	5	7.0	1.6	5	5.3	1.5
2001	6	9.5	2.4	9	7.2	1.3
2002	7	6.7	1.5	19	6.1	0.5

Sex:	Female											
Study Method:	Telemetry						Observation Tower					
Arrival:	Late			Early			Late			Early		
Year	n	SL	2SE	n	SL	2SE	n	SL	2SE	n	SL	2SE
2000*	1	4.5	0	1	5.0	0	na	na	na	na	na	na
2001	1	4.0	0	8	4.9	1.0	36	6.9	0.9	12	5.7	1.4
2002	4	3.0	0	2	3.0	0	61	5.1	0.6	71	4.7	0.5

*No observations from towers were made in 2000.

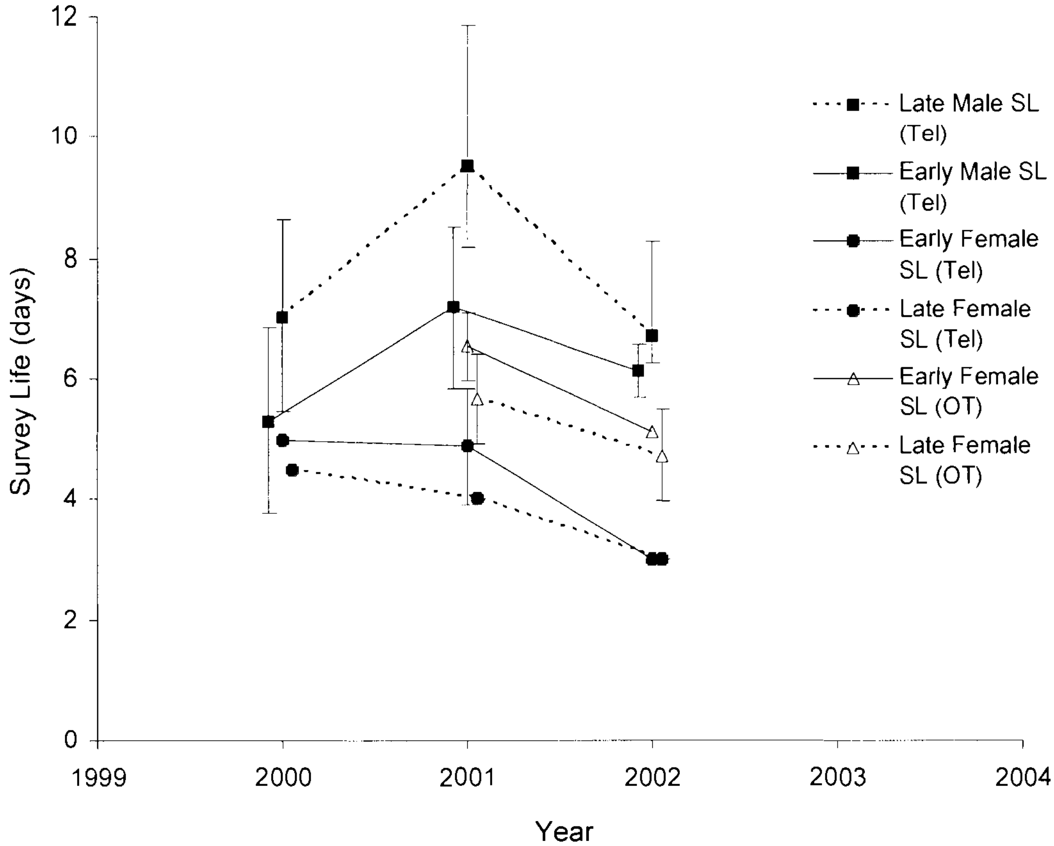


Figure 12. Mean survey lives (days) with 95% CI of early and late arrival chinook salmon based on radio telemetry and observations made from towers.

Table 13. P-values for tests of equality of mean survey lives of male and female chinook salmon determined using radio telemetry versus arrival timing, spawning date, and fish length of Lower Shuswap River chinook salmon for each year (2000-2002) and for all years pooled. Year effects and interactions for male and female pooled data versus spawning date and fish length are shown below.

Sex:	Female				Male			
Year:	2000	2001	2002	Pooled	2000	2001	2002	Pooled
SL versus:								
Spawning Date	na	0.55	1.00	0.01	0.40	0.03	0.98	0.59
Fish Length	na	0.26	1.00	0.08	0.22	0.38	0.72	0.81
Late or Early Arrival	na	0.56	1.00	0.08	0.17	0.09	0.33	0.01

Sex:	Female		Male	
	Year Effect	Interaction	Year Effect	Interaction
SL versus:				
Spawning Date	0.28	0.77	<0.001	0.04
Fish Length	0.03	0.84	0.003	0.30

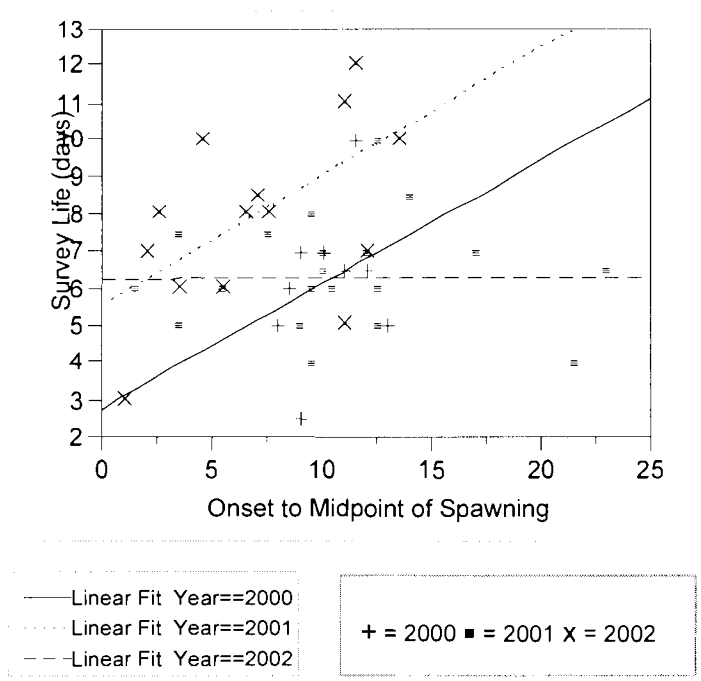


Figure 13. 2000-2002 bivariate fit of telemetric, male survey life versus timing of spawning, the number of days from the population's onset of spawning to an individual fish's mid-point of survey life.

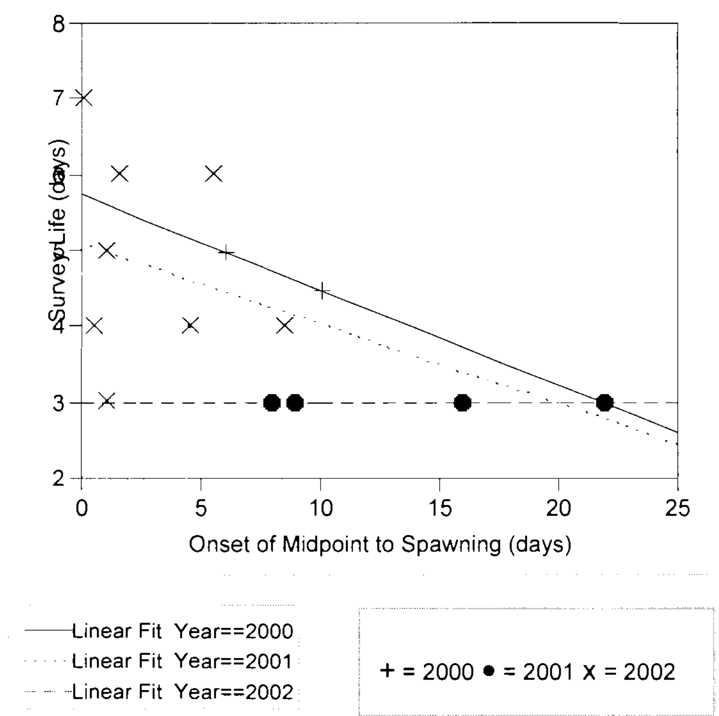


Figure 14. 2000-2002 bivariate fit of female survey life versus timing of spawning, the number of days from the population's onset of spawning to individual fish's mid-point of survey life.

Tower observations suggested that the mean survey life of early arrival female chinook salmon was significantly lower than late-arrival for pooled data only (Table 14 and Figure 12). When 2001 and 2002 data were tested separately, no difference was found between mean survey lives of female chinook salmon that arrived early than those that arrived late. When the relationship between female survey lives and spawning dates were compared for each year and for both years pooled, there was evidence of a negative relationship between spawning date and female survey life in 2001 and for both years pooled (Table 14). The mean survey life of female chinook salmon in 2001 was higher than 2002 by a difference of 1.41 (95% CI is ±0.39) days.

When the relationship between female survey life and fish length were compared for each year separately, there was evidence of a negative relationship between length and female survey life (Table 13 and Figure 15). When all years of data were combined, there was evidence of a negative relationship between length and female survey life (Table 13). The 2002 mean survey life of female chinook salmon was higher than for 2000 by 1.74 (95% CI is ±0.85) days. The 2001 mean survey life of female chinook salmon was higher than for 2002 by 1.69 (95% CI is ±0.57) days.

When the relationship between male survey lives and length were compared for each year separately and for all years combined, there was no evidence of a relationship between length and male survey life (Table 13 and Figure 16). The two-factor ANOVA failed to detect an interaction; however, there was a year effect (Table 13). The 2001 mean survey life of male chinook salmon was higher than for 2000 by 2.76 (95% CI is ±0.89) days. The 2001 mean survey life of male chinook salmon was higher than for 2002 by 2.09 (95% CI is ±0.65) days.

Table 14. P-values for tests of equality of mean survey lives of female chinook salmon determined using observations from towers versus arrival timing and spawning date of Lower Shuswap River chinook salmon for each year (2001-2002) and for both years pooled. P-values for year effects and interactions of male and female pooled survey life data versus spawning date and fish length.

Year:	2001	2002	Pooled	Pooled	
				Year Effect	Interaction
SL versus:					
Spawning Date	0.05	0.25	0.01	<0.001	0.21
Late or Early Arrival	0.12	0.29	0.02	na	na

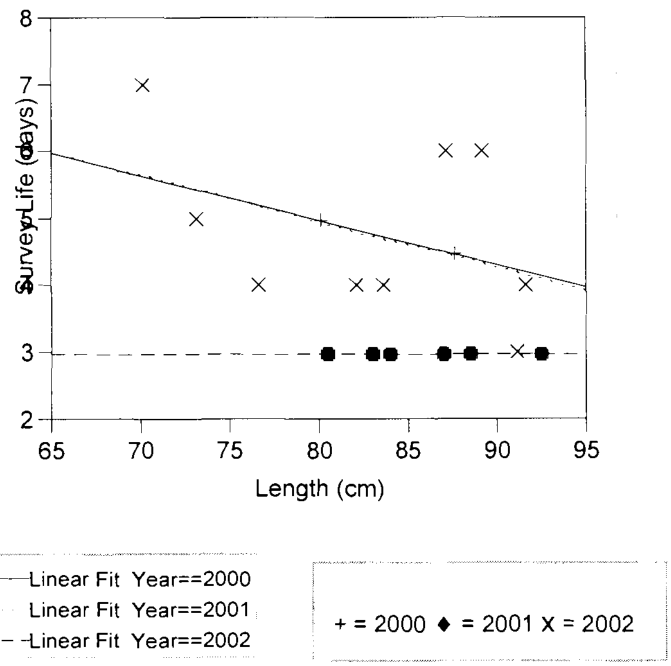


Figure 15. 2000-2002 bivariate fit of female survey life versus length (body size).

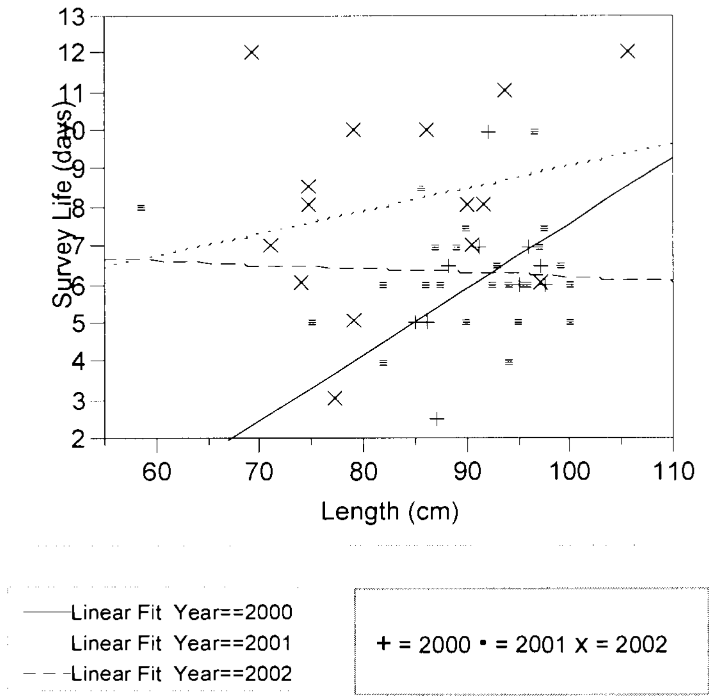


Figure 16. 2000-2002 bivariate fit of male survey life (days) versus length (body size).

The mark-recapture based survey lives for Lower Shuswap River chinook salmon had the same pattern of annual variation for all combinations of count method (best and mean) and observer efficiency (97% and 100%; Table 15 and Figure 17). Over the three years examined (2000-2002), the mark-recapture based survey life was the highest in 2001 and the lowest in 2002.

The mark-recapture based survey lives calculated using mean counts were materially less than mark-recapture based survey lives calculated using best counts by an average of 5%. In 2000 and 2001, there was no evidence that mark-recapture based survey life using 100% observer efficiency was different than the mark-recapture based survey life calculated using 97% observer efficiency (Table 15 and Figure 17). In 2002, the mark-recapture based survey life calculated using 100% observer efficiency was materially greater than the mark-recapture based survey life calculated using 97% observer efficiency by 11%.

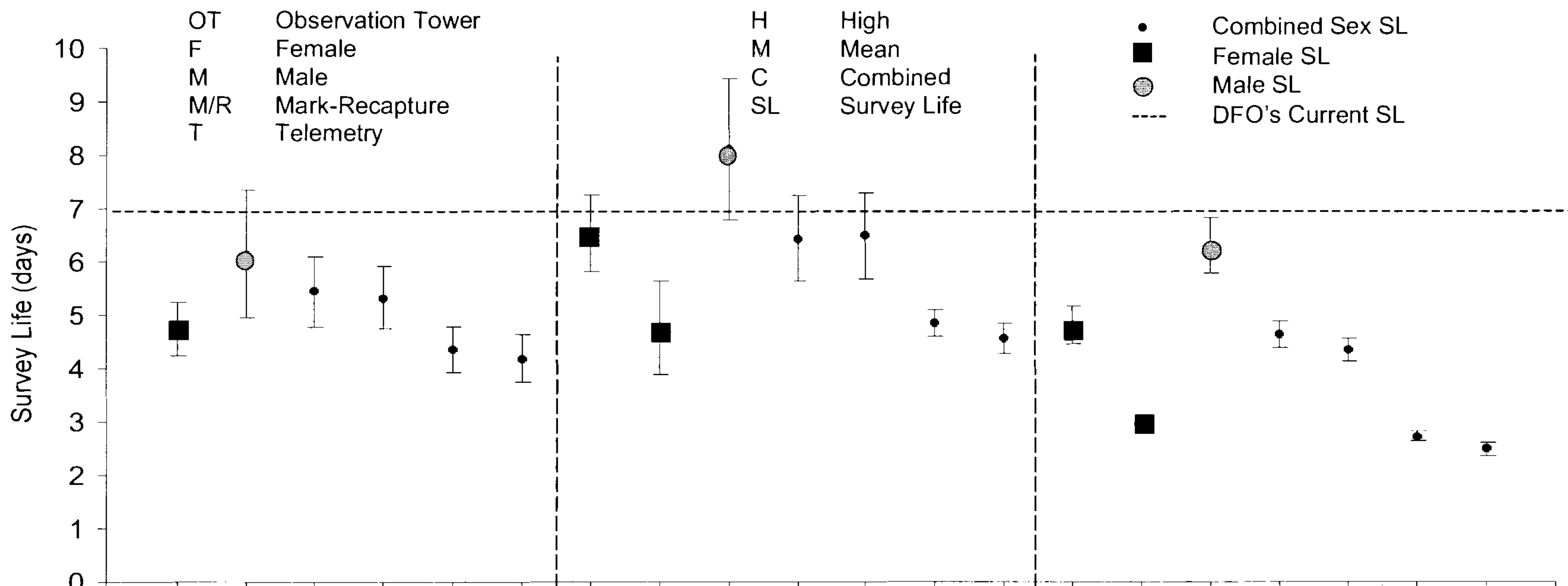
Table 15. The mark-recapture based survey lives for Lower Shuswap River chinook salmon determined by dividing the best and mean total spawner days (counted) by the mark-recapture escapement estimate (Equation 7) using both the DFO's original 100% and this study's 97% observer efficiencies.

Count Used	Observer Efficiency	Survey Life	2SE
2000			
Best	100	4.23	0.43
Mean	100	4.07	0.44
Best	97	4.36	0.44
Mean	97	4.19	0.45
2001			
Best	100	4.70	0.24
Mean	100	4.42	0.27
Best	97	4.85	0.25
Mean	97	4.56	0.28
2002			
Best	100	2.44	0.08
Mean	100	2.41	0.10
Best	97	2.73	0.09
Mean	97	2.48	0.11

Table 16. Summary of potential factors influencing survey lives for Lower Shuswap River chinook salmon from 2000-2002.

	Possible Factors			
Year	Sex Ratio (M/F; %)	Mean Daily Discharge (m^3s^{-1})	Chinook Abundance (M/R)	Sockeye Abundance
2000	42/58	52.2	37,682	50
2001	51/49	36.3	40,666	1,071
2002	41/59	31.8	55,462	780,655

Mean survey lives of female chinook salmon calculated from telemetric monitoring data were significantly lower than mean survey lives determined by observations made from towers for 2001 and 2002 (p=0.036 and p=0.034).



Sex	F	M	C	C	C	C	F	F	M	C	C	C	C	F	F	M	C	C	C	C
Total Fish Count	na	na	na	na	H	M	na	na	na	na	na	H	M	na	na	na	na	na	H	M
Male %	na	na	50	42	na	na	na	na	na	50	51	na	na	na	na	na	50	41	na	na
Data Collection Method	T	T	T	T	M/R	M/R	OT	T	T	T	T	M/R	M/R	OT	T	T	T	T	M/R	M/R
Year	←		2000			→	←			2001			→	←			2002			→

Figure 16. Mean survey lives and survey lives with 95% CI determined for Lower Shuswap River chinook salmon from 2000-2002 using a 97% observer efficiency (OE) and all study methods. A 7-day spawner residence time is currently used by DFO. The estimated escapement using a 100% OE will not be materially different than the estimate using 97% OE.

3.3 Discussion

There are several definitions of survey life in use. In this study we define survey life as the duration of time in days from when a fish begins to spawn (onset of spawning) until a female vacates her redd or until a male dies (completion of spawning), redd residence time is synomyn for this term (McPhee & Quinn, 1998; Table 1). In this study, the completion of spawning was marked by a female fish vacating the vicinity of her redd and by death for a male fish. McPhee & Quinn (1998) define female survey life by the redd residence which is the number of days from date of establishment until a female has left her redd. Other similar terms are breeding life, which has been defined as the interval between entry into the natal stream and death by van den Berghe and Gross (1986) and spawning (or female) longevity defined by Morbey (2001) as the period between arrival to the spawning grounds and death. Reproductive life span, another synonym, is defined as the time spent between arrival at the spawning area and death. Survey life is defined by Perrin and Irvine (1990) as "the number of days that the average spawner is alive in a survey area." Survey life is redefined by its spatial limits from survey areas as small as a redd (redd residence time) to as large as an entire stream (stream life). In this study, mark-recapture based survey life is defined as the number of days a fish is countable as a spawner from the air – this includes any fish that are on the shallows. Observers can not differentiate between fish that have started spawning and those that are just passing through (migrators). The survey life was approximated using observed survey lives and mark-recapture based survey lives, which are calculated by dividing the AUC estimated total spawner days by the mark-recapture estimate (Equation 7). Observed survey lives would not include those fish that were migrating or scouting for spawning habitat, or those fish that had vacated their redds just before death, as survey lives only included for fish that were spawning; however, these fish would be identified as spawners from the air. Therefore, mean survey lives determined from telemetric and tower observations may be a positively bias estimate of the mark-recapture based survey life. Other similar terms include stream life, which is defined as time between entrance to the creek and death (Willis, 1952) or the period between tagging and death (Fukushima & Smoker, 1997 and McPhee & Quinn, 1998). A clear, concise definition of survey life or residence time is required for all AUC studies.

Figure 17 is a summary plot of the survey lives computed from a number of sources and using a variety of methods. These were compared to the "7-day" survey life used by DFO in its current operations. Most of the estimated survey lives were significantly less than the assumed 7-day value; mark-recapture based survey lives were generally less than those calculated from other methods; and mean survey lives of male chinook salmon are higher than mean survey lives of female chinook salmon.

Consistent with predictions made by Perrin and Irvine (1990) and English *et al.* (1992), survey lives exhibit considerable annual variation. The mean survey life of female chinook salmon was lower in 2002 than in 2000 or 2001. One possible explanation for this variation may be inter-specific competition, as female survey life was negatively correlated with sockeye abundance (Table 16). Inter-specific competition (van den Berghe and Gross, 1989) and territoriality (Foote, 1990) are common for spawning female salmonids. In 2002, there was a large concurrent escapement of sockeye salmon (Table16). Overlapping habitat and timing of spawning between the two salmon species may have caused high inter-specific competition between female chinook salmon and sockeye salmon. Morbey (2000) observed that higher spawner density causes an increase in female kokanee residence time, because increased nest defense decreases the chance of egg dig-up and increases fitness through decreased offspring mortality. Female chinook salmon may have expended high levels of energy guarding their nests from sockeye in 2002 which potentially caused female survey life to be lower in 2002 than the other two years. Contrary to predictions made by Perrin and Irvine (1990), no relationship was found between mean survey lives of female chinook salmon and sex ratio, intra-specific (chinook) density, or spawning season discharge (Table 16). The effect of chinook salmon abundance on survey life may have been minimal in comparison to the effect of sockeye salmon abundance in 2002, making it difficult to determine the relationship between intra-specific (chinook salmon) abundance and survey life.

A positive relationship between mean survey life of male chinook salmon and sex ratio was found. The mean survey life of male chinook salmon and the ratio of male to female chinook salmon was higher in 2001 than 2000 or 2002. Contrary to predictions made by Perrin and Irvine (1990), no relationship was found between mean survey life of male chinook salmon and inter-specific or intra-specific competition (abundance) or spawning season discharge (Table 16). Sockeye abundance (inter-specific competition) may not have affected mean survey life of male chinook salmon because chinook salmon are much larger than sockeye or because available evidence is not sufficient for comparison.

Males were found to have significantly longer mean survey lives than females for the Lower Shuswap River chinook salmon population. This finding is in accordance to Korman *et al.*'s (2002) telemetric observations of Cheakamus River steelhead survey life. Willis (1952) also observed that males have higher mean residence times than females for the Wilson River chinook salmon population. In a stream flowing into Puget Sound, Ames (1984) found that male chum had lower mean survey life than female chum. Lady and Salski (1998) estimated stream residence times from mark-recapture data and found that mean stream residence time was lower for males than females for the Iliamna Lake sockeye salmon population.

In some salmon populations, mean female residence time decreased with the timing of arrival to the spawning grounds (van den Berghe and Gross 1989; English *et al.* 1992; McPhee and Quinn 1998; Hendry *et al.* 1999; Morbey 2001; Korman *et al.* 2002). In other words, there was a negative relationship between reproductive life span and breeding date. Concurrent with these findings, female chinook salmon mean survey life was found to decrease linearly throughout the spawning period. No relationship was found between mean survey life of male chinook salmon and timing of spawning. The mean survey life of male chinook salmon for 2001 was higher than for 2000 and 2002.

Other studies, based mainly on females, reported that mean residence time decreased from early-arrival to late-arrival fish (Willis 1952; Neilson and Banford 1983; van den Berghe and Gross 1989; Perrin and Irvine 1990; English *et al.* 1992; Anon. 1997; Hendry *et al.* 1999; Morbey 2001). Using telemtetry, this study also found that early-arrival females had longer mean survey lives than late-arrival females. Early-arrival salmon have more redd sites to chose from, a progeny selective advantage, that allows them to select more favorable spawning sites (Larkin 1977 in Morbey 2001; Neilson and Banford, 1983), usually building large redds in relatively slow, deep water (Neilson and Banford 1983; McPhee and Quinn 1998). Another selective advantage to longer survey lives for female chinook salmon that arrive early is decreased superimposition (dig-up avoidance). Female chinook salmon that arrive late have a shorter period of vulnerability to superimposition, as few female chinook salmon will arrive after them; therefore, female chinook salmon that arrive and spawn late do not need to survive as long to defend their redd sites as those that arrive and spawn early. Late-arrival female salmon are also forced to fast flowing, relatively shallow water that takes more energy to maintain position. This increased allocation of energy to maintaining position may also reduce survey life. Using observations from towers, this study found that early-arrival females had shorter mean survey lives than late-arrival females – the reasoning for this finding is unknown.

Early-arriving male chinook salmon were found to have shorter mean survey lives than late-arrival male chinook salmon in this study. Further research is needed to determine the reasoning for this relationship between male survey lives for Pacific salmon and arrival timing.

Fukushima and Smoker (1997) and van de Berge and Gross (1986) found that body size is one of the major determinants of survey life. Van de Berge and Gross (1986) also found that coho longevity increased with body size (length). McPhee and Quinn (1998) found no relationship between female sockeye body length and longevity. Survey life of female chinook salmon in the Lower Shuswap River system had a weak negative correlation with body size (length): the correlation was not statistically significant when a single data point was removed. No relationship was found between mean survey lives of male chinook salmon and length.

Morbey (2001) found that female body size of kokanee was positively correlated to arrival timing. In this study, there was no evidence of a relationship between body size (length) of male and female chinook salmon and arrival timing.

The annual variation in the mark-recapture based survey lives is a function of both the total spawner count and the mark-recapture estimate. As expected, the mean spawner count produced mark-recapture based survey lives less than or equal to high (best) count mark-recapture based survey lives. Total spawner days is the numerator of the mark-recapture based survey life equation; therefore, lower total spawner day counts result in lower mark-recapture based survey lives. Mark-recapture based survey lives calculated from high counts were closer to survey lives determined from telemetric monitoring and observations from towers. All the mark-recapture based survey lives were lower than the observed survey lives. Total spawner days may also be negatively biased if the observer efficiency of fish counts was actually lower than 97% determined in this study (Chapter 3); a positively biased observer efficiency would result in an under-estimation of the total number of spawner days and thus an under-estimate of the mark-recapture based survey life. Another explanation for the negative bias in the mark-recapture based survey life compared to survey life may be attributed to differences in their definitions. Survey life includes established spawning fish only; whereas, the mark-recapture based survey life includes fish that are moving through the spawning grounds (migrators), fish that are gaming but not yet spawning, and fish that have vacated their the redd but have not yet died. This is an artefact of observers not being able to distinguish resident spawners from migrators or near dead fish. If the mark-recapture based survey life includes migrators and gaming fish, then it makes sense that mean mark-recapture based survey lives were shorter than mean survey lives.

Previous studies show that when the closed population Petersen mark-recapture method is used to calculate salmon spawner escapement, the result is usually a positively biased estimate (Cousens *et al.*, 1982). A positively biased mark-recapture estimate would lead to an underestimate of the mark-recapture based survey life, as it is the denominator of the mark-recapture based survey life equation.

Mean survey lives of female chinook salmon determined through telemetric monitoring were lower than those determined from observations made at towers. Stresses associated with application and carrying of radio tags may have decreased the life of fish, thus negatively biasing telemetrically based survey lives. If observation tower site and grid selection were not representative, resultant survey lives may also have been bias.

Perrin and Irvine (1990) identified data collection method as one of the variables that may affect survey life. The differences reported between telemetric, observation tower, and mark-recapture based survey lives support this statement.

All survey lives determined in this study were lower than or equal to the current spawner 7-day survey life used by DFO for calculating AUC estimates of escapement for Thompson Basin chinook salmon stocks. Survey lives lower than 7-days will result in higher AUC estimates of escapement, as survey life is the denominator of the AUC equation (refer to Chapter 4 for more details).

CHAPTER 4
LOWER SHUSWAP RIVER ESCAPEMENT ESTIMATES

Various combinations of total fish counts, observer efficiencies, and survey lives were used in AUC escapement estimates. The estimates using the AUC method were compared to each other and to the mark-recapture and peak count estimates for 2000-2002.

4.1 Methods

4.1.1 Chinook Salmon Mark-recapture

Mark-recapture studies are used when estimates of escapement by age and sex are required for management purposes. Mark-recapture studies are undertaken annually on a small number of "indicator" stocks in the Pacific Region such as the Lower Shuswap River chinook salmon.

For this study, chinook salmon were captured for tag application by seining throughout Reaches 1-8 (Figure 2); however, seining operations were most successful in Reaches 1-5. A seine net was set by powerboat, drift boat or raft in a downstream crescent and drawn from the river to enclose a small area of water along the riverbank. Captured salmon were held in the water until moved to the tray for tagging (Farwell *et al.*, 1999). Peterson disk tags, 2.2 cm diameter clear cellulose acetate disks, were applied to every chinook salmon (Farwell *et al.*, 1999) and radio tags were inserted into selected male and female chinook salmon (Section 3.1.1.1). Sex specific operculum punches, as secondary marks, were applied on the left operculum of every tagged fish: two punches for a female and one for a male. Each fish's tag number, fork length, sex, adipose fin clip status (presence or absence), scarring and release condition were recorded. After tagging and data collection, the salmon were released over a submerged section of the net - at no time were the fish removed from the water. During tag application, any previously tagged chinook salmon and all other fish species captured were recorded and released (Farwell *et al.*, 1999).

Spawning ground surveys and carcass recovery operations were similar to those used on the Harrison River and are described in Farwell *et al.* (1999). To recover tags, crews conducted daily surveys on both river shores from early October to early November. Powerboat and gaff were used to retrieve carcasses from deep pools. Date, reach number, sex, tag number, adipose fin clip, post-orbital to hypural plate (POH) length, secondary mark status, carcass condition, number of eyes, and recovery method (shore or gaff) were recorded for each carcass recovered. Examined carcasses were cut in half to prevent re-counting. Heads of adipose clipped fish were collected and scales were taken from every 20^{th} adult fish and every 10^{th} jack encountered during carcass recovery. Heads were collected for coded wire tag removal and decoding, and scales were removed and read to determine fish ages.

Male (including jacks) and female estimates were calculated separately in anticipation of sex related differences in abundance (Farwell *et al.*, 1999) and for determination of sex ratios used in survey life calculations. Mark-recapture estimates were not corrected for factors such as sex identification errors or pre-spawn mortality.

4.1.2 Peak Count

The Peak Count method was used to estimate chinook salmon escapement for the Lower Shuswap River using aerial flight data (Section 1.1.3).

4.1.3 Chinook Salmon AUC

4.1.3.1 Survey lives

Radio telemetry, observations from towers, and mark-recapture methods were used to determine the annual survey lives for males, females and both sexes combined (Chapter 3). All the mark-recapture and observed mean survey lives were used to calculate annual estimates of escapement using AUC and compared to AUC estimates determined using the 7-day survey life assumed by DFO. Both male and female survey lives were used to calculate AUC estimates of escapement because in many circumstances it is only possible to observe female survey lives.

4.1.3.2 Total Spawner Days

Total spawner days were determined using observed spawner counts from multiple overflights (4-5) conducted throughout the spawning period annually. Aerial counts were performed in an upstream direction using low level (50-80 m) overflights in a Bell 206B helicopter, at speeds between 10 and 40 km per hour (Farwell *et al.*, 1999). Four to five flights were made annually at three to six day intervals starting September 25 in 2000 and October 1 in 2001 and 2002. An attempt was made to have the second or third flight occur at the peak of spawn. Two observers, seated in the helicopter opposite the pilot, counted and discussed all chinook salmon observed and recorded the number of spawners, holders and carcasses for each reach. At the end of each reach, observers recorded their individual counts and discussed their observations to determine a "best" spawner count estimate (Farwell *et al.*, 1999). When observers had the similar counting experience, the higher count (maximum) was usually selected as the best estimate because it is assumed that that observer saw more fish. A study of chinook salmon escapement on the Nechako River also uses the same system, the maximum count obtained by the two observers in each section was used in calculations to estimate escapement as it was considered to most accurately reflect the subsequent actual population present (Faulkner and Ennevor, 1995). The mean counts, not conventionally used, were also used to calculate determine total spawner days for this study.

4.1.3.3 Observer Efficiency

As seen in Chapter 2, the total number of spawner days is corrected for observer efficiency to reduce bias of the AUC escapement estimate (Hilborn *et al.*, 1999). The total population size of spawners can be estimated using the AUC estimate of spawners corrected for fish visibility, as shown in Chapter 1.

In this study, observer efficiency was determined by comparing spawner counts from helicopters to spawner counts from photographs. AUC escapement estimates were compared using this study's observer efficiency of 97% to DFO's current observer efficiency of 100%. The use of 100% observer efficiency assumes that the AUC escapement estimate does not need to be corrected for observer bias.

4.1.4 Sockeye Salmon

Sockeye salmon estimates of escapement were determined by DFO's Sockeye Stock Assessment Division. Multiple visual counts were made from a powerboat throughout the spawning season to estimate sockeye salmon escapement for 2000 and 2001. In 2002, the Shuswap River sockeye salmon mark-recapture program determined a combined escapement estimate for the Lower and Middle Shuswap Rivers. To calculate a Lower Shuswap River sockeye escapement for 2002, the Middle Shuswap visual count escapement estimate was subtracted from the combined Lower and Middle Shuswap River mark-recapture escapement estimate (Keri Benner, pers. comm., 2003).

4.2 Results

4.2.1 Lower Shuswap River Salmon Escapement Estimates

4.2.1.1 M/R and Peak Count Escapement Estimates

Preliminary estimates of escapement are tabulated in Table 17 and individual observers' spawner counts are reported in Table 25 (Appendix 6). The escapement appears to have increased from 2000-2002 - this trend was also observed in most other chinook systems in the South Thompson, which have been increasing since the early 1990's. The standard errors of the Peak Count escapement estimates could not be determined as only one count was used.

Table 17. Lower Shuswap River chinook and sockeye salmon estimates of escapement for 2000-2002.

Year	Chinook M/R	2SE	Chinook Peak Count*	Sockeye
2000	37,682	3,840	20,409	50
2001	40,666	2,102	18,349	1,071
2002	55,462	1,930	19,332	780,655

*Peak Count is the estimate of escapement determined by dividing the highest total number of fish counted (estimated peak of spawn) by 0.65.

4.2.1.2 AUC Chinook Salmon Escapement Estimates

4.2.1.2.1 Escapement Estimate

Table 18 tabulates estimates of escapement computed using the AUC methods with various combinations of observer efficiencies, total spawner counts, and survey lives. Escapement estimates varied from 22,567 to 37,682 in 2000; from 19,473 to 40,666 in 2001; and from 17,607 to 55,462 in 2002 (Table 18 and Figure 18).

Table 18. AUC escapement estimates calculated using 97% observer efficiency for Lower Shuswap River chinook salmon from 2000-2002. AUC estimates of escapement were calculated using both mean and high total spawner counts and survey lives determined using different methods and sex ratios.

Total Spawner Count Method	**High**						
Survey life Method	DFO (7-days)	Telemetry		M/R*	Telemetry		Obs Tower
Sex of Fish	Combined				Male	Female	
Sex Ratio (Male/Female)	50/50	50/50	Annual Basis	50/50	na	na	na
	2000						
AUC	23,494	30,176	30,806	37,682	26,742	34,623	na
2SE	na	3,224	3,757	3,840	5,228	3,645	na
	2001						
AUC	28,153	30,606	30,393	40,666	24,329	41,247	26,188
2SE	na	3809	3,725	2,151	4,000	7,492	5,997
	2002						
AUC	21,624	32,592	34,841	55,462	24,070	50,455	26,002
2SE	na	1,499	2,089	1,930	1,994	0	6,033
Total Spawner Count Method	**Mean**						
	2000						
AUC	22,567	28,986	29,591	37,682	25,686	33,257	na
2SE	745	3,242	3,739	4,397	5,093	3,669	na
	2001						
AUC	26,497	28,806	28,605	40,666	22,898	38,821	19,473
2SE	879	3,710	3,632	2,839	3,840	7,168	7,639
	2002						
AUC	19,673	29,651	31,697	55,462	21,899	45,903	17,607
2SE	515	1,569	2,073	1,408	1,902	1,201	7,557

* This estimate is circular, as the mark-recapture based survey life is calculated by dividing the total spawner days by the mark-recapture estimate and then the AUC escapement estimate is calculated by multiplying the mark-recapture based survey life by the total spawner days; therefore, the resulting AUC escapement estimate is always equal to the mark-recapture estimate.

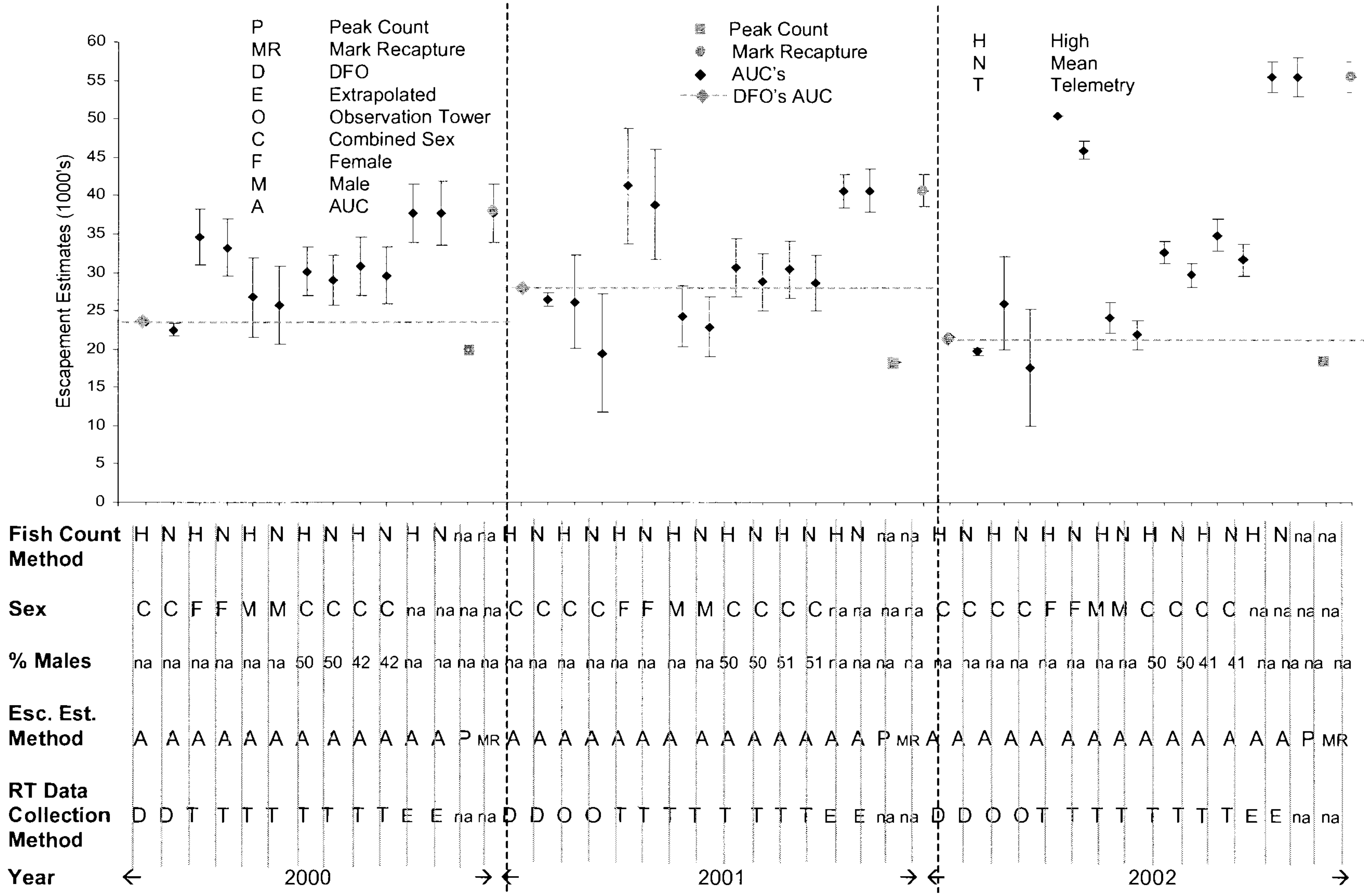


Figure 16. Escapement estimates with 95% CI determined for Lower Shuswap River chinook salmon from 2000-2002 using a 97% observer efficiency and various escapement estimation techniques, survey lives and total fish count methods.

4.2.1.2.2 Survey Lives

Differences between escapement estimates calculated using male, female, combined sex, mark-recapture based, telemetric or observation tower survey lives are seen in Tables 18 and Figure 18. Telemetric male and observer tower female mean survey lives were higher than other survey lives; therefore, the resulting AUC escapements were lower. Mean female survey lives determined through telemetric monitoring and mean mark-recapture based survey lives were lower than other observed survey lives and DFO's assumed 7-days; therefore, the resulting AUC escapements were generally higher.

AUC estimates calculated using the mean survey lives of female chinook salmon determined using telemetry were lower than estimates for males. AUC estimates calculated using female, mean survey lives determined using telemetry were lower than or equal to estimates using observations from towers. AUC estimates calculated using the mark-recapture survey lives were higher than those calculated using observed survey lives. AUC estimates calculated using the 7-day survey life assumed by DFO were lower than or equal to mark-recapture based and observed survey lives – except when 2001 and 2002 mean survey lives of male chinook salmon were used.

Combined survey lives determined using a 50:50 sex ratio were not materially different than survey lives calculating using the actual sex ratio.

4.2.1.2.3 Total Spawner Days

AUC escapement estimates determined using the high count method for the total spawner days were higher than or equal to escapement estimates determined using the mean count method (Tables 18 and Figure 18).

4.2.1.2.4 Observer Efficiency

AUC escapement estimates calculated using the 97% observer efficiency were not materially different than the AUC's calculated using DFO's original 100% observer efficiency. AUC estimates of escapement based on 97% observer efficiency are presented in Table 18 and Figure 18 - those based on 100% observer efficiency were not reported.

4.3 Discussion

Figure 18 summarizes the various estimates of escapement.

4.3.1 Mark-recapture Chinook Salmon Escapement

The mark-recapture was the largest estimate of escapement annually (Table 18 and Figure 18). Previous studies have shown that closed population Petersen mark-recapture method often exhibits a positive bias (Cousens *et al.,* 1982) caused by various violations of assumptions. For example, tag loss, emigration and tags overlooked during carcass recovery may cause an overestimation of the population size. The potential for this bias was reduced by more thoroughly examining carcasses and the use of secondary marks, which reduced the number of missed tags during recovery (Cousens *et al.,* 1982). Other biases such as temporal, spatial, sex and size will be addressed as per Farwell *et al.* (1999) in the final mark-recapture estimates. Properly designed, executed and analysed mark-recapture studies can produce reliable estimates of escapement (Nelson *et al.*, 2000).

4.3.2 AUC Chinook Salmon Escapement Estimates

The AUC estimates varied annually and with different assumed survey lives. The AUC escapement estimate changes inversely to changes in the survey life estimate because survey life is the denominator of the AUC escapement calculation. Change in the escapement estimate will be proportional to changes in total spawner days and observer efficiency, which appear as the numerator of the AUC escapement calculation.

4.3.2.1 Survey Lives

AUC escapements estimated the using the 7-day survey life assumed by DFO were generally lower than all other AUC estimates (Figure 18). This not surprizing as the 7-day survey life was greater than or equal to all other survey lives estimated in this study. Factors influencing survey lives were discussed in Chapter Three. AUC escapements estimated using mean survey lives observed from towers were the lowest estimates annually, as these survey lives were the longest.

Total survey lives for Pacific salmon typically assume equal sex ratios; however, the actual sex ratios differed annually from 50:50. Therefore, the annual sex ratios determined from annual mark-recapture estimates were used to calculate combined-sex survey lives determined using telemetry, the resultant AUC escapements differed materially by an average of 3% from those derived assuming equal sex ratios. Mark-recapture data is not typically available when the AUC escapement estimation technique is being used; therefore, 50:50 sex ratios will be used unless a way to estimate the actual sex ratios is available.

4.3.2.2 Total Spawner Days

Some of the factors influencing estimates of total spawner days were discussed in Chapter Two. Two other factors that may influence total spawner days and resultant AUC escapement estimates include the frequency of counts and timing of counts with respect to peak spawn date (Neilson and Geen, 1981). A coho calibration study produced spawner curves that differed in shape depending on the frequency of surveys selected (e.g. every other day versus every 3 days and 7-days) (Richard Bailey, pers. comm., 2000). However, resultant estimates of total spawner days were very similar, indicating that the method may be robust to reduced survey frequency. In the annual Nechako River Study of chinook salmon, Anon. (1990) reported that reducing the number of surveys from 29 to four did not materially alter the estimated total number of spawner days. For this study, failure to count all spawners through inadequate flight scheduling may have resulted in an underestimate of the total number of spawner days, thus resulting in an underestimation of the mark-recapture based survey life. Hill (1997) found that the precision in the annual estimate of escapement decreased as flight frequency increased for Nechako River chinook salmon; therefore, the balance between flight costs and lost precision has to be chosen by fisheries managers.

Total spawner counts determined using the mean count method might more explicitly incorporate uncertainty into AUC estimates of escapement than the high count method.

4.3.2.3 Observer Efficiency

The observer efficiency determined in this study was only 3% less than the previously assumed 100%, this did not lead to materially different estimates of escapement. It is important to remember that the 97% observer efficiency determined was based on a single survey (October 5, 2001), when optimal counting conditions were optimal. Generic application of the 0.97 correction factor for chinook salmon aerial enumeration on the Lower Shuswap River should be applied cautiously. Further investigations into observer efficiency are recommended.

4.3.3 Peak Count Chinook Salmon Escapement Estimates

The Peak Count estimates were the lowest annually (Figure 18). "It has long been recognized that peak counts usually produce serious underestimates of total escapement and represent an index at best." (Cousens *et al.,* 1982:5). In a study of sockeye salmon, Tschaplinski and Hyatt (1991) found that peak aerial counts seriously underestimated sockeye populations in all instances under near optimum viewing conditions.

The Peak Count method is based on several unsubstantiated assumptions, including the 65% expansion factor which came from two ad-hoc studies on the Chilcotin River and the Blackwater River (Farwell *et al.*, 1999). These two systems were counted once from the air and once from the ground on the same day. The ground count was considered the true abundance and compared to the aerial count: the result was a 65% expansion factor that was generically applied to all systems in the Fraser Basin.

The factors leading to negative bias in visual escapement estimates using the AUC method or Peak Count method may include insufficient flights (resulting in missed "peak" spawn or failure to describe the spawner curve) and variability in spawner behaviour. For example, 2001 and 2002 Lower Shuswap aerial surveys missed the peak of spawn by 4-5 days annually.

4.3.4 Summary

Aerial escapement estimates are known to typically underestimate abundance of spawners (Bevan 1961; Cousens *et al.* 1982; Higgins and Peterman, 1990; Neilson and Geen 1981). AUC escapement estimates were lower than independently obtained Petersen mark-recapture estimates. There are many potential reasons for this discrepancy including visual survey data underestimating the true area-under-the-spawner-curve; and estimates of survey life or Petersen estimates being positively biased. As mark-recapture estimates often overestimate the true escapement (Cousens *et al.,* 1982), it was not surprizing that the mark-recapture estimate of escapements were higher than the AUC and Peak Count estimates.

A benefit of the AUC method compared to the Peak Count method is that the fish do not have to be counted at the peak spawning period in order to be used in the calculation of an escapement estimate (English *et al.,* 1992). This is one of the reasons that this method is more effective than the Peak Count method: the exact timing of peak spawn, which is difficult to predict, does not have to be known exactly. The AUC methods are relatively inexpensive compared to mark-recapture studies. Visual surveys are mostly conducted from helicopters because of the ability to fly over geographically widespread areas in a relatively short period of time. Helicopters allow almost simultaneous counting of all areas of interest. Aerial observation also facilitates counting of areas with no road access and difficult terrain (Farwell *et al.* 1999; West and Goode 1987).

CHAPTER 5
CONCLUSION

5.1 Observer Efficiency (Objective 1 & 6, Section 1.1.4)

The mean observer efficiency of helicopter enumeration of summer-run, chinook salmon in the Lower Shuswap River was 97% (95% CI is ± 6%), as helicopter spawner counts were only marginally less than aerial photograph spawner counts. This observer efficiency is not materially different than DFO's assumed 100% observer efficiency or Neilson and Geen's (1981) 96% or Higgins and Peterman's (1990) correction error of ± 4%.

Broad application of this 97% observer efficiency may not be warranted, as it was based on one study of one system, the Lower Shuswap River. This study's methodology can be used to investigate observer efficiencies for surveys within a season, across years, and across systems. The factors found to have an influence on observer efficiency could then be used to develop models for predicting observer efficiency.

Effects of variation in survey segment length and density on observer efficiency were investigated. Similar observer efficiencies were found for the 150 m and 1000 m sections of the Lower Shuswap River. As many flight or survey areas are much longer than 1000 m, observer efficiency for longer sections should be investigated. Research into the effects of flight duration on observer efficiency is recommended, as observer efficiency may decrease throughout a flight or survey due to observer fatigue - especially during very long flights or surveys (i.e. 3+ hrs). Low abundance (chinook salmon density) segments had a mean observer efficiency closer to 100% than medium and high density segments. For medium density sections the observers generally counted less fish than the mean photograph counts and for low density sections observers generally counted more fish than the mean photograph counts. Experimental segments that are countable from the air could be manipulated to investigate the effect of density on observer efficiency and survey life. Fish may have moved into the low density section after the photo flight and before the counting flights, this would have caused an overestimate of observer efficiency for the low density sections. Therefore, the impact of various fish behaviour on estimating observer efficiency should be investigated. Very high abundance of sockeye salmon (intra-specific abundance), as seen in 2002 (Table 16, p. 52), may also have decreased observer efficiency and could be investigated using the same methodology as recommended for intra-specific abundance.

Korman *et al.* (2002) determined seasonal variation in observer efficiency by comparing diver counts of steelhead to the actual number of steelhead present in sections of the Chekamous River. In Korman *et al.* (2002) the observer efficiency was found to vary considerably from survey-to-survey, decreased with migration date due to increasing discharge and turbidity, and was influenced by the distribution of spawners. Korman *et al.* (2002) developed relationships predicting observer efficiency as a function of physical river conditions that will allow future estimation of numbers present. Models such as this one should be developed to investigate relationships between the bias correction (i.e. observer efficiency) values and a stream's physical and biological variables (Higgins and Peterman, 1990).

Stream-to-stream variation in observer efficiency exists (Perrin and Irvine, 1990) and needs to be investigated to determine how to extrapolate observer efficiency from one stream to another, as it is not economically feasible to independently determine the observer efficiency for every stream surveyed. Impacts of factors such as stream size (length, width or discharge), weather (i.e. surface disturbance by wind), turbidity or water clarity, hideable cover, intra- and inter-specific abundance and the migration's spatial and temporal distribution in the survey area may cause stream-to-stream variation and should be included in future studies.

Replicate flight data and section counts showed variation in counts from observer-to-observer and flight-to-flight. Possible factors that could cause differences in spawner counts from observer-to-observer may include the observer's position in the helicopter (front or back seat), experience, eye sight, polarized glass shape and colour, and motor skills or ability to punch the tally wacker at the same rate fish are being seen - especially at high densities. Possible factors that could cause differences in spawner counts from flight-to-flight may include speed and height of helicopter, pilot performance, time of day, aircraft, light, shading, water surface ripple (wind) and fish movement between flights.

5.2 Total Fish Days (Objective 2, Section 1.1.4)

When observers have similar counting experience, the use of mean observer counts for determining total fish days is recommended as a way to incorporate some of the observational uncertainty. This study found that escapement estimates based on mean observer counts were lower than those based on high observer counts.

5.3 Survey life (Objective 3, 4 & 6; Section 1.1.4)

Mean survey lives of male and female chinook salmon varied from year-to-year in this study; therefore, survey lives annually determined on a site-specific basis are recommended (Perrin and Irvine, 1990). Most of the mean survey lives determined were significantly less than 7-day value DFO assumes; mark-recapture based survey lives were generally less than those from other methods; and male survey lives were higher than female survey lives. This is a common finding; however, the reasoning for male survey lives being longer than females is not well understood and should be investigated further. As males spawn over a wide spread area and females remain in one location during the spawning period, a larger component of the survey life for males may be spent travelling. This may result in longer survey lives for males than for females.

As mean survey lives of female chinook salmon appear to be correlated with sockeye abundance, an experiment to investigate various levels of sockeye density on survey life of chinook salmon could be conducted. No relationship was found between mean survey lives of female chinook salmon and sex-ratio, inter-specific competition or discharge of this stream. Mean survey lives of male chinook salmon and sex ratio were positively related. No relationship was found between mean survey lives of male chinook salmon and inter- or intra-specific abundance or discharge. Experiments on artificial channels or closed sections of river could be conducted to further investigate the impacts of these factors on the survey lives of male and female chinook salmon. This study indicates that estimates of survey life should not be extrapolated among years or between streams or populations without evidence that it is legitimate to do so. Parken *et al.* (2003) found survey lives were consistent for Nicola River chinook salmon over the 4 years studied and recommended the use of a single, mean survey life across all years. Sockeye abundance may be one of the main factors influencing annual variation in survey life, as it was correlated with female survey life for Lower Shuswap River chinook salmon over the 3 years studied. A possible reason for Parken *et al.* (2003) finding consistent survey lives for Nicola River chinook salmon over the four years may be that the chinook salmon did not have high interspecific competition in any of the four year studied. Stability of survey lives of Lower Shuswap River chinook salmon during low abundance sockeye years should be investigated.

Mean survey lives of female chinook salmon were found to be negatively related with timing of spawn and fish length; there was no apparent relationship for males.

Survey lives determined using direct measurements such as radio telemetry and observation towers are more robust and recommended over mark-recapture based survey lives. Mean survey lives of female chinook determined through telemetric monitoring were lower than those determined from observations made at towers. Stresses caused by radio tag application and carrying may have decreased telemetric survey lives; therefore, a study of the effect of radio tagging and Petersen tagging fish is recommended. Such a study could be conducted in closed channels where all spawners could be monitored from towers. A proportion of the spawners would be radio tagged and marked with coloured Petersen tags for individual identification by observers in towers; another proportion would be marked with Petersen tags only, differing in colour from the radio tagged fish's mark; and a proportion would be left without radio tags or marks. Observers would sketch redds, and record behaviour and tag presence for each fish, to determine individual survey lives and the tagging method used. During the same study, survey lives could be determined using radio telemetry and compared to survey lives determined from the towers; however, an external tagging system for individual identification of tagged fish would need to be established. The effects of using different types of external tags such as jaw, Petersen and spaghetti tags could also be investigated. The external tag that imposes the least impact on the fish and survey life could be selected for use in future study. A study into at the effects of applying different types of radio tags on subsequent survey lives could be conducted such as comparing surgical insertion of radio tags to the gastronal insertion method used in this study.

The use of observation towers to monitor female fish behaviour should be preferred over radio telemetry, as it is less invasive on the fish. The feasibility of using observations from towers to monitor male survey life and behaviour should be investigated. Radio tagging will be necessary when fish bio-physical characteristic information such as length is required.

To facilitate comparison, it is very important that every study and paper provides a clear, concise definition of residence time and survey life, as there are many synonyms and similar terms.

5.4 Estimates of Escapement

5.4.1 AUC (Objective 5, Section 1.1.4)

Robust escapement estimates have the ability to compensate for spatial and temporal variation in survey conditions, and biological and physical factors. To create robust AUC estimates of escapement, survey life and observer efficiency should be determined on an annual, stream specific basis (Perrin and Irvine, 1990 and English *et al.*, 1992).

AUC escapements estimated using the 7-day survey life assumed by DFO were lower than or equal to all other AUC escapements, as most of the survey lives were lower than 7-days. Therefore, AUC escapement estimates using the assumed 7-day survey life are conservative, as the result is an underestimate of escapement.

For determining Lower Shuswap River AUC escapement estimates a 97% observer efficiency, annually determined survey lives, start and end dates determined in the field, and total fish counts calculated using the mean of two experienced observers counts are recommended. The telemetric, combined sex, mean survey life of 5.4 days is recommended for the Lower Shuswap River when annual surveys of survey lives are not available. As seen in Figure 17, survey lives were generally higher than mark-recapture based survey lives; therefore, the recommended 5.4 day survey life may still underestimate the escapement of chinook salmon to the Lower Shuswap River. Extrapolation and broad application of the 5.4 day survey life and the 97% observer efficiency to other streams requires some verification of results, as they were based on one particular study of the Lower Shuswap River only. The optimal choice would be to determine observer efficiency and survey lives for each season and system; however, the large amount of effort required makes this option economically infeasible.

The mean survey lives and other data collected in this study can be used with methodology developed by Hill (1997), to determine the optimal flight interval for Lower Shuswap River aerial counts. Based on the range of survey lives determined in this study, testing of flight intervals between 2-10 days is recommended. An investigation to quantify increases in precision gained by increasing flight frequency close to the peak of spawn is recommended. This approach is currently used by DFO for flights of some Upper Fraser River tributaries (Chuck Parken and Richard Bailey, pers. comm., 2004). Hill (1997) reported that precision increases with increased flight frequency; however, fisheries biologists need to balance gains in precision and cost associated with additional flights. Another approach may be to conduct flights every other day throughout the spawning season and investigate a series of flight schedules and associated error.

When analyzing trends in salmon escapement, for example comparing AUC escapements over time, method standardization is very important – so changes in escapement can reflect change in actual escapement and not changes in methods (Perrin and Irvine, 1990).

5.4.2 AUC versus Peak Count and Mark-Recapture (Objective 7, Section 1.1.4)

AUC estimates of escapement were higher than Peak Count estimates and were lower than independently obtained Petersen mark-recapture estimates. Other methods that could be used to estimate escapement include Higgins and Peterman's (1990) model that accounts for abundance effects on bias and incorporating random counting error and Su *et al.'s* (2001) hierarchical Bayesian approach. Escapement estimates could be calculated using the maximum likelihood method and compared to estimates made using the AUC method (Hilborn *et al.* 1999, Korman *et al.* 2002). "The trapezoidal method is generally more accurate than maximum likelihood methods (Hilborn *et al.*, 1999) for populations arriving on the spawning grounds in a few major pulses" (p. 89, Parken *et al.*, 2003).

5.5 Recommendations for Repeating This Study

As with all studies, if this study were to be repeated a number of approaches are recommended. (a) Increase the number of observation towers from 4 to 8, so that more towers are more evenly distributed throughout the majority of system's spawning habitat. This would allow the investigation of any potential relationship between survey life versus spawning habitat and peak of spawn versus spawning location. For example, do the fish closer to Mabel Lake (upper reaches) spawn earlier than the fish further downstream (lower reaches) or visa-versa. Prior to the spawning period the best time of day, selected based on light, to observe fish from each tower would need to be determined and spawning season observations would be scheduled to maximize visibility at each tower. (b) Collect temperature data within each grid using a thermograph, this would allow an investigation into the relationship between temperature and survey life. (c) Hold radio tagged fish in brood tubes for 30-60 minutes after radio tagging to monitor the fish's condition and tag placement because a number of radio-tags may have been regurgitated soon after insertion. (d) Investigate the observer efficiency for multiple surveys (probably three) throughout the year and from year-to-year to determine if observer efficiency varies throughout the spawning season or from year-to-year; however, this would be very expensive. (e) Collect turbidity data within the counted and photographed sections, as turbidity may affect observer efficiency. (f) Make aerial counts of the fish within the grids at each tower, make grid AUC estimates of escapement, and compare those estimates to tower counts and photograph counts because tower and photo counts may be more representative of the actual spawning population. Closed sections of river or artificial channels, with known numbers of spawners, could be used to compare the actual number of spawners present to AUC escapements estimated from multiple aerial counts of the study area. (g) Conduct more flights each year to try and ensure that the AUC method represents the true spawner curve and to avoid missing the peak of spawn. This information could also be used by fisheries biologists to determine desired flight frequency, by incorporating precision and cost. (h) Conducting this study for multiple years into the future to allow development of observer efficiency and survey life indexes based on physical and biological factors.

APPENDICES

Appendix 1. Depth, Velocity and Gravel Size

Methods

Velocity, depth, and gravel measurements were collected at each tower location before redd construction began. Transect lines were run perpendicular to the flow in the centre of each of the three 10 meter sections of the grid (Figure 10). Measurements were taken at 1-meter intervals along a 20 meter tight chain in 2001 and 2-meter intervals in 2002. The tight chain was to attached to a piece of rebar pounded into the gravel on one end and the opposite end was tied to the river bank. Velocity and depth measurements (facing velocity) were taken with a flow meter. Velocity was taken at 60% depth in the water column. Three separate velocity measurements were taken to make sure the gauge was working properly at each interval, the third measurement was recorded if it was similar to the previous two measurements – usually it was the same or within 0.01 meters per second. Depth and velocity were averaged by transect and then by grid.

The total discharge was measured by extending a 50 m transect across the entire river, just above Cooke Creek's outlet. Measurements started at 0.5 meters out into the water. Depending on the year, a transect was used to divide the river into 1 or 2 meter wide cells transect. The mean cell depth and velocity were determined for each cell by averaging the two measurements on each side of the cell. The discharge for the cell was then determined by multiplying together the mean cell width, depth and velocity. Each cell's discharge was added together to determine the stream's total discharge.

Environment Canada's daily discharges for 1914-2002, measured at the water survey station near Enderby, were used to determine annual mean daily discharge and annual mean daily minimum and maximum. Environment Canada's discharge data for September and October was used to determine the 2000-2002 chinook salmon spawning season mean discharges for the Lower Shuswap River.

Gravel measurements were taken at 1-meter intervals along a transect in 2001 and 2-meter intervals in 2002. A piece of rebar was dropped straight down into the water column and the rock particle that the piece of rebar touched was selected for measurement. The rock particle was measured on two sides in 2001 and three sides in 2002 - the mean length was an average of the measurements. The mean particle size was averaged by transect and then by grid. Sediment-particle sizes were categorized based on Wentworth (1922).

Spawning season water temperature data for the Lower Shuswap River was collected daily from September 13 to mid-October during mark-recapture seining operations using a handheld thermometer. These data were used to calculate annual mean spawning season water temperature. However, the sample locations and depths varied daily and are not consistent enough for comparison. Thermograph datum was only collected for 2001.

Results

Measurements of depth, velocity and gravel size and associated error are shown for each observation tower study area in Table 19. Based on the categories from Parsley and Beckman (1994), the sediment-particle size classification is gravel for all the observation tower study areas for each year. Annual and spawning season mean discharge (m^3/s) measured at Environment Canada's Water Survey Station on the Lower Shuswap River near Enderby are seen in Table 20.

Table 19. Depth, velocity and gravel size measurements taken within the grids located at each observation tower annually.

Year	Tower	Mean Water Depth (m)	2SE	Mean Velocity (m/s)	2SE	Mean Gravel Size (cm)	2SE
2001	1	0.66	0.02	0.85	0.02	10.13	0.55
	2	0.66	0.06	0.85	0.01	8.95	0.08
	3	0.71	0.02	0.84	0.04	10.43	1.46
2002	1	0.55	0.04	0.64	0.03	9.80	1.6
	2	0.63	0.07	0.84	0.04	7.95	0.56
	3	0.80	0.06	1.07	0.07	8.26	1.22
	4	0.57	0.05	1.36	0.08	6.69	0.66

Table 20. Annual and spawning season mean discharge (m^3/s) measured at Environment Canada's Water Survey Station on the Lower Shuswap River near Enderby (Lynne Campo, pers. comm., Environment Canada, unpublished data). In mid-September, discharge was measured just above Cooke Creek using a flow meter. Temperature was taken at various locations within the study area.

Year	Mean Daily	2SE	Mean Daily Maximum	2SE	Mean Daily Minimum	2SE
1914-2002	88.5	0.9	349.0	46.0	29.7	5.4
			Spawning Season			
	Mean Daily	**2SE**	**Flow Meter**		**Temperature (°C)**	**2SE**
2000	52.2	1.55	na		14.9	0.62
2001	36.3	0.94	26.2		16.5	0.64
2002	31.8	0.71	24.4		15.8	0.55

Appendix 2. Spawner Counts of Chinook Salmon from Photographs

Table 21. Lower Shuswap River chinook salmon spawner counts from photographs taken October 5, 2001.

	Observer		
Section	1*	2*	3*
Lower Dale's	205	212	210
Goldfinch's	183	182	179
Prevost	16	12	14
Above Reimer's	804	908	847
Hupel	1,294	1,530	1,481
Brandt's	245	271	240

*Observer 1 = Dean Allan (DFO)
*Observer 2 = Nicole Clark (DFO)
*Observer 3 = Sue Lemke (DFO)

Appendix 3. SFU Animal Care Approval for this Study of Lower Shuswap River Chinook Salmon

To: Carl Schwarz
Statistics
From: R.B.Horsfall
Chair, UACC
Subject: Project # 612S
Date: 4 April, 2002

Your project 612S: "An investigation into the factors influencing escapement estimation for Chinook Salmon (*Oncorhynchus tsawytscha*) on the Lower Shushwap River, British Columbia." Is renewed for a further year.

cc. Susan Sanders (Animal Care)

Appendix 4. Lower Shuswap River Chinook Salmon Behaviour

Methods

Daily telemetry records were used to investigate the general movements of the chinook salmon before, during and after spawning.

Results

In 2001 and 2002, most of the chinook salmon remained in the same pool after radio tag application. The majority of males and females moved downstream after tagging in 2000. However, some fish also moved upstream after tagging each year. Radio tagged fish held in-river for 0-18 days in primary spawning habitat and 0-3 days in secondary holding habitat before the onset of spawning. Chinook salmon moved from upstream, downstream and adjacent areas onto spawning habitat. In 2001 and 2002, most of the fish moved downstream to begin spawning. Throughout the spawning period most of the males moved around and all the females remained in the same location. Most chinook salmon moved downstream after their completion of spawning; however, some remained adjacent to their spawning locations and some even moved upstream to hold and die after spawning (Table 21).

Discussion

As radio tag application may cause stress on the fish, it is not surprizing that most of the fish remained in the same area or moved downstream after being radio tagged. As males are not faithful to a single redd or female and females usually are faithful to a single redd, it makes sense that males were tracked at various locations throughout their spawning period versus females that usually stayed in the same location.

Table 22. Annual numbers of male and female chinook salmon based on movement.

Movement after tagging						
		Male			Female	
Year	U/S	D/S	None	U/S	D/S	None
2000	1	3	1	na	na	na
2001	3	1	7	0	6	2
2002	3	4	19	1	0	5
Movement before spawning						
		Male			Female	
Year	U/S	D/S	None	U/S	D/S	None
2000	2	2	1	1	0	1
2001	2	9	0	3	4	1
2002	7	18	1	2	4	0
Movement during spawning						
			Male			Female
Year		Some	None		Some	None
2000		7	3		0	2
2001		7	4		0	8
2002		20	7		0	6
Movement after spawning						
		Male			Female	
Year	U/S	D/S	None	U/S	D/S	None
2000	0	10	0	0	2	0
2001	0	9	2	1	5	2
2002	6	17	3	0	5	1

Appendix 5. Observed Survey Lives of Chinook Salmon

Table 23. Lower Shuswap River survey lives of chinook salmon determined each year (2000-2002) using telemetric monitoring.

2000		2001		2002	
Sex	SL (days)	Sex	SL (days)	Sex	SL (days)
F	4.5	F	4	F	3
F	5	F	6	F	3
M	6	F	7	F	3
M	5	F	4	F	3
M	6.5	F	5	F	3
M	10	F	6	F	3
M	6	F	4	M	6
M	7	F	3	M	6
M	7	F	4	M	8.5
M	6.5	M	6	M	6
M	5	M	8	M	5
M	2.5	M	12	M	5
		M	10	M	4
		M	12	M	6
		M	7	M	6
		M	5	M	7.5
		M	11	M	7
		M	7	M	6
		M	8	M	5
		M	10	M	6
		M	8	M	6
		M	6	M	4
		M	3	M	6
		M	8.5	M	6
				M	7
				M	10
				M	5
				M	6.5
				M	7.5
				M	8
				M	6.5
				M	7

Table 24. Lower Shuswap River survey lives of chinook salmon determined for 2001 and 2002 using observations from towers.

Fish ID Number	1st Day of Residence	Number of Days Observed	Year
1.18	04-Oct	7	2001
1.26	06-Oct	4	2001
1.39	10-Oct	7	2001
1.41	10-Oct	9	2001
1.44	11-Oct	5	2001
2.24	06-Oct	5	2001
2.25	06-Oct	5	2001
2.33	11-Oct	8	2001
3.12	01-Oct	4	2001
3.13	03-Oct	10	2001
3.20	03-Oct	8	2001
3.22	03-Oct	6	2001
3.28	04-Oct	3	2001
3.39	05-Oct	8	2001
3.43	06-Oct	6	2001
3.46	06-Oct	2	2001
3.52	07-Oct	6	2001
3.118	13-Oct	9	2001
3.60	07-Oct	7	2001
3.67	08-Oct	5	2001
3.70	09-Oct	11	2001
3.72	09-Oct	9	2001
3.73	09-Oct	10	2001
3.75	09-Oct	9	2001
3.77	09-Oct	7	2001
3.84	10-Oct	10	2001
3.86	11-Oct	4	2001
3.88	11-Oct	5	2001
3.91	11-Oct	8	2001
3.94	11-Oct	5	2001
3.120	12-Oct	6	2001
3.96	13-Oct	5	2001
3.97	13-Oct	7	2001
3.118	13-Oct	9	2001
3.102	14-Oct	5	2001
3.105	14-Oct	2	2001
3.106	14-Oct	7	2001
3.109	15-Oct	4	2001
3.116	17-Oct	5	2001
3.117	18-Oct	9	2001
1.1	27-Sep	2	2002
1.3	27-Sep	2	2002
1.5	27-Sep	5	2002
1.6	27-Sep	2	2002

Fish ID Number	1st Day of Residence	Number of Days Observed	Year
1.11	29-Sep	4	2002
1.12	29-Sep	2	2002
1.15	30-Sep	6	2002
1.18	30-Sep	5	2002
1.21	1-Oct	4	2002
1.22	3-Oct	4	2002
1.26	5-Oct	2	2002
1.39	8-Oct	3	2002
1.41	9-Oct	5	2002
2.1	23-Sep	2	2002
2.4	30-Sep	3	2002
2.5	30-Sep	3	2002
2.11	7-Oct	5	2002
2.15	8-Oct	2	2002
2.13	13-Oct	2	2002
3.3	27-Sep	6	2002
3.6	27-Sep	10	2002
3.8	27-Sep	8	2002
3.9	27-Sep	4	2002
3.10	28-Sep	3	2002
3.111	28-Sep	8	2002
3.12	30-Sep	7	2002
3.26	30-Sep	7	2002
3.16	30-Sep	4	2002
3.17	30-Sep	5	2002
3.18	30-Sep	5	2002
3.22	1-Oct	4	2002
3.23	1-Oct	3	2002
3.27	1-Oct	9	2002
3.30	1-Oct	8	2002
3.31	1-Oct	7	2002
3.32	1-Oct	4	2002
3.33	1-Oct	3	2002
3.34	1-Oct	8	2002
3.51	1-Oct	8	2002
3.36	2-Oct	8	2002
3.37	2-Oct	5	2002
3.38	2-Oct	5	2002
3.42	2-Oct	3	2002
3.43	2-Oct	9	2002
3.44	3-Oct	8	2002
3.45	3-Oct	9	2002
3.46	3-Oct	2	2002
3.47	3-Oct	7	2002
3.49	3-Oct	4	2002
3.51	3-Oct	6	2002
3.52	3-Oct	6	2002

Fish ID Number	1st Day of Residence	Number of Days Observed	Year
3.54	4-Oct	8	2002
3.55	4-Oct	8	2002
3.58	4-Oct	6	2002
3.59	5-Oct	8	2002
3.60	5-Oct	7	2002
3.61	5-Oct	6	2002
3.62A	6-Oct	5	2002
3.64	6-Oct	11	2002
3.65	6-Oct	5	2002
3.66	6-Oct	4	2002
3.67	6-Oct	3	2002
3.68	6-Oct	5	2002
3.112	6-Oct	3	2002
3.70	6-Oct	6	2002
3.62B	6-Oct	5	2002
3.72	7-Oct	5	2002
3.26B	7-Oct	5	2002
3.73	7-Oct	4	2002
3.80	7-Oct	6	2002
3.75	7-Oct	7	2002
3.76	7-Oct	2	2002
3.77	7-Oct	6	2002
3.78	8-Oct	5	2002
3.79	8-Oct	4	2002
3.80	8-Oct	6	2002
3.81	8-Oct	5	2002
3.82	8-Oct	9	2002
3.85	8-Oct	5	2002
3.86	5-Oct	6	2002
3.88	10-Oct	5	2002
3.91	12-Oct	4	2002
3.93	12-Oct	3	2002
3.96	13-Oct	4	2002
3.99	14-Oct	2	2002
4.1	25-Sep	4	2002
4.7	26-Sep	4	2002
4.8	27-Sep	4	2002
4.13	29-Sep	5	2002
4.14	29-Sep	3	2002
4.15	30-Sep	7	2002
4.27	30-Sep	6	2002
4.32	30-Sep	2	2002
4.31	30-Sep	4	2002
4.29	30-Sep	5	2002
4.22	1-Oct	8	2002
4.23	1-Oct	4	2002
4.25	1-Oct	2	2002

Fish ID Number	1st Day of Residence	Number of Days Observed	Year
4.33	2-Oct	2	2002
4.48	2-Oct	6	2002
4.51	2-Oct	6	2002
4.36	2-Oct	4	2002
4.37	2-Oct	5	2002
4.38	2-Oct	4	2002
4.39A	3-Oct	5	2002
4.40A	3-Oct	5	2002
4.39B	3-Oct	2	2002
4.41	3-Oct	5	2002
4.42	3-Oct	6	2002
4.43	3-Oct	8	2002
4.45	4-Oct	3	2002
4.61	4-Oct	7	2002
4.47A	4-Oct	3	2002
4.49	4-Oct	2	2002
4.52	4-Oct	4	2002
4.53	4-Oct	7	2002
4.56	4-Oct	4	2002
4.47B	5-Oct	3	2002
4.58	5-Oct	5	2002
4.59	5-Oct	2	2002
4.60	5-Oct	7	2002
4.61	5-Oct	6	2002
4.62	5-Oct	7	2002
4.64	5-Oct	2	2002
4.66	6-Oct	2	2002
4.67	6-Oct	2	2002
4.68	6-Oct	5	2002
4.69	6-Oct	3	2002
4.70	6-Oct	6	2002
4.75	7-Oct	2	2002
4.77	8-Oct	5	2002
4.79	8-Oct	2	2002
4.82	9-Oct	3	2002
4.83	11-Oct	3	2002
4.87	12-Oct	3	2002
4.90	12-Oct	2	2002
4.94	18-Oct	3	2002
10.54	02-Oct	4.5	2000
10.59	28-Oct	5	2000
7.18	02-Oct	4	2001
9.18	02-Oct	6	2001
10.11	22-Sep	7	2001
10.18	06-Oct	4	2001
14.21	28-Sep	5	2001
15.2	28-Sep	6	2001

Fish ID Number	1st Day of Residence	Number of Days Observed	Year
15.23	29-Sep	3	2001
16.18	02-Oct	4	2001
25.21	30-Sep	6	2001
30.232	02-Oct	3	2002
37.233	15-Oct	3	2002
39.202	01-Oct	3	2002
39.282	15-Oct	3	2002
40.103	09-Oct	3	2002
9.18	09-Oct	3	2002

Appendix 6. Lower Shuswap River Chinook Salmon Spawner Counts from Helicopters

Table 25. Individual observer counts of chinook salmon by reach for annual, aerial overflights of the Lower Shuswap River (2000-2002).

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		25-Sep-00				
Enderby to Old Mill	2000	na	na	13	na	12
Old Mill to Ashton Br.	2000	na	na	54	na	44
Ashton Br. To Trinity Cr.	2000	na	na	17	na	23
Trinity Cr. to Stone Pool	2000	na	na	14	na	16
Stone-pool to Dale Pool	2000	na	na	104	na	90
Dale Pool to Cooke Creek	2000	na	na	133	na	146
Cooke Creek to Hupel	2000	na	na	44	na	58
Hupel to Kingfisher Creek	2000	na	na	46	na	47
Kingfisher Cr. to Mabel. L.	2000	na	na	10	na	12
Flight Date:		30-Sep-00				
Enderby to Old Mill	2000	48	na	52	na	na
Old Mill to Ashton Br.	2000	224	na	227	na	na
Ashton Br. To Trinity Cr.	2000	64	na	52	na	na
Trinity Cr. to Stone Pool	2000	154	na	154	na	na
Stone-pool to Dale Pool	2000	1,041	na	1,178	na	na
Dale Pool to Cooke Creek	2000	1,595	na	1,969	na	na
Cooke Creek to Hupel	2000	1,440	na	1,360	na	na
Hupel to Kingfisher Creek	2000	1,402	na	1,677	na	na
Kingfisher Cr. to Mabel. L.	2000	230	na	426	na	na

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		05-Oct-00				
Enderby to Old Mill	2000	na	na	104	na	107
Old Mill to Ashton Br.	2000	na	na	248	na	252
Ashton Br. To Trinity Cr.	2000	na	na	51	na	76
Trinity Cr. to Stone Pool	2000	na	na	58	na	48
Stone-pool to Dale Pool	2000	na	na	1254	na	1,262
Dale Pool to Cooke Creek	2000	na	na	3209	na	3,164
Cooke Creek to Hupel	2000	na	na	2495	na	2,435
Hupel to Kingfisher Creek	2000	na	na	3175	na	2,951
Kingfisher Cr. to Mabel. L.	2000	na	na	552	na	558
Flight Date:		10-Oct-00				
Enderby to Old Mill	2000	na	na	39	na	34
Old Mill to Ashton Br.	2000	na	na	160	na	159
Ashton Br. To Trinity Cr.	2000	na	na	48	na	45
Trinity Cr. to Stone Pool	2000	na	na	21	na	33
Stone-pool to Dale Pool	2000	na	na	674	na	560
Dale Pool to Cooke Creek	2000	na	na	1,679	na	1,731
Cooke Creek to Hupel	2000	na	na	1,503	na	1,469
Hupel to Kingfisher Creek	2000	na	na	1,519	na	1,487
Kingfisher Cr. to Mabel. L.	2000	na	na	515	na	381

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:				14-Oct-00		
Enderby to Old Mill	2000	na	na	3	3	na
Old Mill to Ashton Br.	2000	na	na	32	33	na
Ashton Br. To Trinity Cr.	2000	na	na	16	12	na
Trinity Cr. to Stone Pool	2000	na	na	1	1	na
Stone-pool to Dale Pool	2000	na	na	138	126	na
Dale Pool to Cooke Creek	2000	na	na	477	433	na
Cooke Creek to Hupel	2000	na	na	451	450	na
Hupel to Kingfisher Creek	2000	na	na	777	775	na
Kingfisher Cr. to Mabel. L.	2000	na	na	175	158	na
Flight Date:				01-Oct-01		
Enderby to Old Mill	2001	na	15	na	na	29
Old Mill to Ashton Br.	2001	na	120	na	na	121
Ashton Br. To Trinity Cr.	2001	na	65	na	na	67
Trinity Cr. to Stone Pool	2001	na	107	na	na	105
Stone-pool to Dale Pool	2001	na	454	na	na	515
Dale Pool to Cooke Creek	2001	na	1,570	na	na	1,610
Cooke Creek to Hupel	2001	na	475	na	na	475
Hupel to Kingfisher Creek	2001	na	1,016	na	na	790
Kingfisher Cr. to Mabel. L.	2001	na	150	na	na	85

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		05-Oct-01				
Enderby to Old Mill	2001	na	145	94	na	na
Old Mill to Ashton Br.	2001	na	277	264	na	na
Ashton Br. To Trinity Cr.	2001	na	71	86	na	na
Trinity Cr. to Stone Pool	2001	na	147	157	na	na
Stone-pool to Dale Pool	2001	na	711	815	na	na
Dale Pool to Cooke Creek	2001	na	1,959	2,100	na	na
Cooke Creek to Hupel	2001	na	2,015	1,915	na	na
Hupel to Kingfisher Creek	2001	na	1,378		na	na
Kingfisher Cr. to Mabel. L.	2001	na	180		na	na
Flight Date:		05-Oct-01				
Enderby to Old Mill	2001	106	na	na	na	98
Old Mill to Ashton Br.	2001	328	na	na	na	301
Ashton Br. To Trinity Cr.	2001	125	na	na	na	136
Trinity Cr. to Stone Pool	2001	304	na	na	na	247
Stone-pool to Dale Pool	2001	992	na	na	na	1,007
Dale Pool to Cooke Creek	2001	2,193	na	na	na	2,564
Cooke Creek to Hupel	2001	1,791	na	na	na	1,807
Hupel to Kingfisher Creek	2001	1,387	na	na	na	1,864
Kingfisher Cr. to Mabel. L.	2001	322	na	na	na	346

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		09-Oct-01				
Enderby to Old Mill	2001	161	na	na	na	154
Old Mill to Ashton Br.	2001	406	na	na	na	437
Ashton Br. To Trinity Cr.	2001	68	na	na	na	87
Trinity Cr. to Stone Pool	2001	131	na	na	na	158
Stone-pool to Dale Pool	2001	1,208	na	na	na	1,056
Dale Pool to Cooke Creek	2001	2,902	na	na	na	2,772
Cooke Creek to Hupel	2001	2,156	na	na	na	2,781
Hupel to Kingfisher Creek	2001	2,590	na	na	na	2,602
Kingfisher Cr. to Mabel. L.	2001	469	na	na	na	456
Flight Date:		12-Oct-01				
Enderby to Old Mill	2001	166	na	na	na	140
Old Mill to Ashton Br.	2001	277	na	na	na	353
Ashton Br. To Trinity Cr.	2001	45	na	na	na	58
Trinity Cr. to Stone Pool	2001	55	na	na	na	62
Stone-pool to Dale Pool	2001	793	na	na	na	1,064
Dale Pool to Cooke Creek	2001	2,030	na	na	na	2,194
Cooke Creek to Hupel	2001	2,064	na	na	na	2,244
Hupel to Kingfisher Creek	2001	2,676	na	na	na	2,485
Kingfisher Cr. to Mabel. L.	2001	288	na	na	na	380

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		12-Oct-01				
Enderby to Old Mill	2001	na	120	na	na	157
Old Mill to Ashton Br.	2001	na	329	na	na	305
Ashton Br. To Trinity Cr.	2001	na	57	na	na	70
Trinity Cr. to Stone Pool	2001	na	87	na	na	83
Stone-pool to Dale Pool	2001	na	746	na	na	796
Dale Pool to Cooke Creek	2001	na	2,510	na	na	3,694
Cooke Creek to Hupel	2001	na	2,374	na	na	1,563
Hupel to Kingfisher Creek	2001	na	2,409	na	na	2,134
Kingfisher Cr. to Mabel. L.	2001	na	584	na	na	295
Flight Date:		16-Oct-01				
Enderby to Old Mill	2001	na	na	na	na	117
Old Mill to Ashton Br.	2001	na	na	na	na	194
Ashton Br. To Trinity Cr.	2001	na	na	na	na	29
Trinity Cr. to Stone Pool	2001	na	na	na	na	44
Stone-pool to Dale Pool	2001	na	na	na	na	427
Dale Pool to Cooke Creek	2001	na	na	na	na	1,083
Cooke Creek to Hupel	2001	na	na	na	na	873
Hupel to Kingfisher Creek	2001	na	na	na	na	1,359
Kingfisher Cr. to Mabel. L.	2001	na	na	na	na	178

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		01-Oct-02				
Enderby to Old Mill	2000	na	na	31	na	26
Old Mill to Ashton Br.	2000	na	na	55	na	49
Ashton Br. To Trinity Cr.	2000	na	na	37	na	37
Trinity Cr. to Stone Pool	2000	na	na	81	na	87
Stone-pool to Dale Pool	2000	na	na	300	na	306
Dale Pool to Cooke Creek	2000	na	na	1,740	na	1,619
Cooke Creek to Hupel	2000	na	na	1,390	na	1,435
Hupel to Kingfisher Creek	2000	na	na	1,489	na	1,360
Kingfisher Cr. to Mabel. L.	2000	na	na	90	na	80
Flight Date:		05-Oct-02				
Enderby to Old Mill	2002	62	na	na	na	52
Old Mill to Ashton Br.	2002	61	na	na	na	66
Ashton Br. To Trinity Cr.	2002	27	na	na	na	28
Trinity Cr. to Stone Pool	2002	38	na	na	na	43
Stone-pool to Dale Pool	2002	237	na	na	na	329
Dale Pool to Cooke Creek	2002	1,502	na	na	na	2,109
Cooke Creek to Hupel	2002	3,590	na	na	na	2,514
Hupel to Kingfisher Creek	2002	2,619	na	na	na	2,792
Kingfisher Cr. to Mabel. L.	2002	368	na	na	na	451

Reach Description:	Year	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5
Flight Date:		09-Oct-02				
Enderby to Old Mill	2002	33	na	na	na	44
Old Mill to Ashton Br.	2002	56	na	na	na	55
Ashton Br. To Trinity Cr.	2002	38	na	na	na	42
Trinity Cr. to Stone Pool	2002	50	na	na	na	47
Stone-pool to Dale Pool	2002	258	na	na	na	244
Dale Pool to Cooke Creek	2002	1,550	na	na	na	1,274
Cooke Creek to Hupel	2002	1,842	na	na	na	1,977
Hupel to Kingfisher Creek	2002	1,542	na	na	na	1,776
Kingfisher Cr. to Mabel. L.	2002	400	na	na	na	480
Flight Date:		14-Oct-02				
Enderby to Old Mill	2002	14	na	na	na	14
Old Mill to Ashton Br.	2002	43	na	na	na	38
Ashton Br. To Trinity Cr.	2002	12	na	na	na	13
Trinity Cr. to Stone Pool	2002	10	na	na	na	13
Stone-pool to Dale Pool	2002	67	na	na	na	35
Dale Pool to Cooke Creek	2002	539	na	na	na	395
Cooke Creek to Hupel	2002	744	na	na	na	735
Hupel to Kingfisher Creek	2002	652	na	na	na	628
Kingfisher Cr. to Mabel. L.	2002	154	na	na	na	144
Observer 1 = Dean Allan (DFO)						
Observer 2 = Nicole Clark (DFO)						
Observer 3 = Richard Bailey (DFO)						
Observer 4= Sue Lemke						
Observer 5= Mike Galesloot						
Notes:						
Observers 1 & 2 were in the same helicopter and could communicate with each other						
Observers 4 & 5 were in the same helicopter and could communicate with each other						
Observer 1 & 4 were in the front seat of the helicopter which has better visibility						
Observers 2 & 5 were in the back seat of helicopter which has more limited visibility						

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