Enumeration of Chilko River Chinook Salmon Escapement (Mark-Recapture) 2012

Completion Report

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As requested by local First Nation Communities:

NOTICE TO READERS REGARDING CONTENT AND ABORIGINAL TITLE AND RIGHTS

WHEREAS existing Aboriginal and treaty rights are recognized and affirmed in section 35(1) of the *Constitution Act*, *1982*;

AND WHEREAS in entering into agreement to undertake this collaborative work, the Parties are not seeking to determine the existence, nature or scope of Aboriginal or treaty rights but rather are seeking to collaborate in aquatic resource management;

AND WHEREAS the Parties confirm their commitment to a relationship based on mutual respect and understanding;

(a) This cooperative research study:

- (i) does not, and is not intended to, define or extinguish any Aboriginal or treaty rights and is not evidence of the nature or extent of any Aboriginal or treaty rights;
- (ii) is made without prejudice to the positions taken by either Party with respect to Aboriginal or treaty rights;
- (iii) does not affect any Aboriginal or treaty rights of any other Aboriginal group.

The Parties agree that participation in this cooperative study is not, and shall not be construed as, evidence that the Tsilhqot'in National Government nor its member Bands acknowledge or consent to Crown jurisdiction or any infringement of the Aboriginal title within areas subject to Aboriginal title, including the area under consideration of BC Supreme Court in Tsilhqot'in Nation v. Canada, 2007 BCSC 1700 and November 2010 BC Supreme Court of Appeals.

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ABSTRACT

The 2012 escapement of summer-run Chinook salmon to the Chilko River was estimated using a two event mark-recapture study, and the Peak Count method based on concurrent aerial visual surveys. Petersen tags and sex-specific secondary marks were applied to 679 adult Chinook salmon captured using a combination of seining and angling (one male was removed during the First Nation fishery and eight heavy bleeders were removed), of which 266 were recovered. A total of 1,489 adult carcasses were recovered. The age composition of the recovery sample was 2% age 3, 36% age 4, 60% age 5, and 2% age 6. All samples showed a two-year freshwater growth pattern (sub2). There were only four jacks sampled during carcass recovery and of the two tags applied to jacks none were recovered; therefore, a valid estimate of the jack escapement could not be calculated.

The results of the bias testing indicated that measurable sources of stress including holding time, marking, number of times recaptured, and release condition did not have a significant impact on the subsequent behaviour of the marked fish. The mark-recapture assumption of closure was likely met based on the mark-recapture field observations, aerial survey data, and the 2010 radio telemetry study. There was no evidence of spatial bias in the recovery sample for both sexes. There was evidence of temporal bias in the application and recovery samples both sexes and spatial bias in the female recovery sample. The Stratified Population Analysis System (SPAS) results showed no evidence of an unequal ratio of marked to marked between spatial recovery and temporal application strata; therefore, the temporal stratification was tested. There was evidence of inconsistent recovery probabilities and an unequal ratio of marked to unmarked between the temporal strata for females; therefore, the maximum likelihood (ML) Darroch method was recommended as the most reliable escapement estimation model for females. As SPAS results showed no evidence of incomplete mixing or unequal proportions between temporal strata for males, the Petersen estimator was used. The total estimate of escapement for adults was 4,255 adult Chinook salmon (lower 95% CI=3,707; upper 95% CI=4,803). Sex-specific escapement estimates were 2,161 males (Petersen, lower 95% CI=1,747; upper 95% CI=2,575) and 2,094 females (Darroch, lower 95% CI=1,960; upper 95% CI=2,228). The estimated escapement based on aerial counts and the Fraser River Chinook peak count expansion factor was 3,845; 10% less than the mark-recapture estimate.

INTRODUCTION

For the purposes of management under the Pacific Salmon Treaty, Fraser River Chinook salmon (*Oncorhynchus tshawytscha*) have been grouped into five stock aggregates on the basis of life history, migration timing and ocean distribution. Summed aggregate escapements are reported annually for the Fraser River stock aggregates in the Chinook Technical Committee (CTC) Catch and Escapement Report (PSC 2002; 2011). Aggregate escapements consist of summed estimates for the constituent streams, and individual estimates vary in quality; however, collectively they represent long term indices of abundance. Estimates are often derived from visual survey data, although some are produced from direct counts (e.g. at a fishway or as they pass an electronic resistively counter).

In addition to spawning ground escapement estimates, preseason forecasting and management of the stock aggregates require time series of estimates of survivals and exploitation rates. Over a number of years, an indicator study can be used to generate these aggregate-specific estimates of survival and exploitation. Indicator studies are ongoing for three of the five Fraser River Chinook salmon aggregates; Lower Shuswap (Fraser 0.3 Summer), Nicola (Fraser 1.2 Spring) and Harrison (Fraser 0.3 Fall) rivers. Ultimately, survival and exploitation rate indicator stock programs are required for each Chinook aggregate in the Fraser River, thus programs are needed for the Fraser River 1.3 Spring and 1.3 Summer Chinook salmon aggregates.

To develop a survival and exploitation indicator program requires that the candidate stock be assessable by a high precision method (usually mark recapture) to yield: (a) reliable annual estimates of escapement by age and sex and (b) carcass sampling rates that are high enough to yield precise estimates of return by CWT code. In order to produce precise CWT return estimates, indicator stocks require substantial annual releases of CWT'd juveniles to provide stock and age specific markers for subsequent identification in fisheries and escapement. Annual provision of marked juveniles may be achieved by hatchery supplementation or by extensive juvenile trapping and tagging programs. However, prior to initiation of any CWT program, a stock should first be assessed to determine whether it is feasible to determine accurate and precise estimates of escapement annually and to measure carcass sampling rates.

Chilko River has been identified as the preferred system for development of an indicator program to represent the Fraser River 1.3 Summer Chinook salmon stock aggregate, based on historical escapement data, the physical characteristics of the river, the importance of the stock to fisheries, and historical CWT data during the CTC base period. The Chilko River is one of the largest of the Summer-run age 1.3 populations in the Fraser River watershed with a recent mean annual escapement (1991-2012) of 9,800 (3,845-21,625) based on peak count escapement estimation methods (Bailey et al. 2000, Parken et al. 2003). Last year (2012) had the lowest annual aggregate escapement recorded since 1989. The total estimated escapement to the stock aggregate has ranged between 10,000 and 45,000 since 1975 (PSC 2011). The Fraser River Summer-run 1.3 stock aggregate contributes catch to AABM and ISBM fisheries from SEAK to Washington, and returning Chilko River Chinook salmon are significant contributors to First Nations and recreational fisheries within the Fraser River. The aggregates importance in fisheries facilitates the recovery of CWT information and the production of exploitation rates.

The Sentinel Stocks Program (SSP) was created as a part of the 2008 Pacific Salmon Treaty Agreement. The SSP was created to provide additional sources of high quality escapement information for stocks with five geographic areas that are of particular importance to the Pacific Salmon Commission (PSC), thus strengthening the biological basis of the Chinook regime, increasing confidence in management, and better informing the development of future regimes.

Funding for this project was provided by the SSP to estimate the Chinook salmon escapement to the Chilko River in 2012, while providing an opportunity to investigate in-river behavior and evaluate the study design for possible future use. The primary objectives of this study were:

1) To produce an estimate of the spawning abundance by age and sex that meets or exceeds the CTC data standard for escapement indicator stocks;

2) To produce an estimate of an annual calibration factor to correct for biases in peak count salmon escapement estimates in the Chilko River and other Fraser River tributaries that have similar visual counting conditions.

The design of the Chilko River Chinook salmon mark-recapture study was similar to that used on the Harrison River (Farwell et al. 1998) and Nicola River (Farwell *et al*. 1999). The project was also conducted in 2010 and 2011; and an additional Chilko River Chinook salmon study is planned for 2013. If the ongoing studies indicate that it is feasible to generate high precision estimates of escapements to the Chilko River annually and sufficient carcass sampling rates, then it may be feasible to develop an indicator stock program on the Chilko to represent the Fraser River Summer-run Age 1.3 Chinook aggregate.

STUDY AREA

The Chilko River is a large (stream order 7) tributary of the Chilcotin River located on the eastern edge of the Coast Mountain Range in Central British Columbia (Figure 1). The river flows from Chilko Lake northeast for 82 km before entering the Chilcotin River, 106 km upstream of the Fraser River.

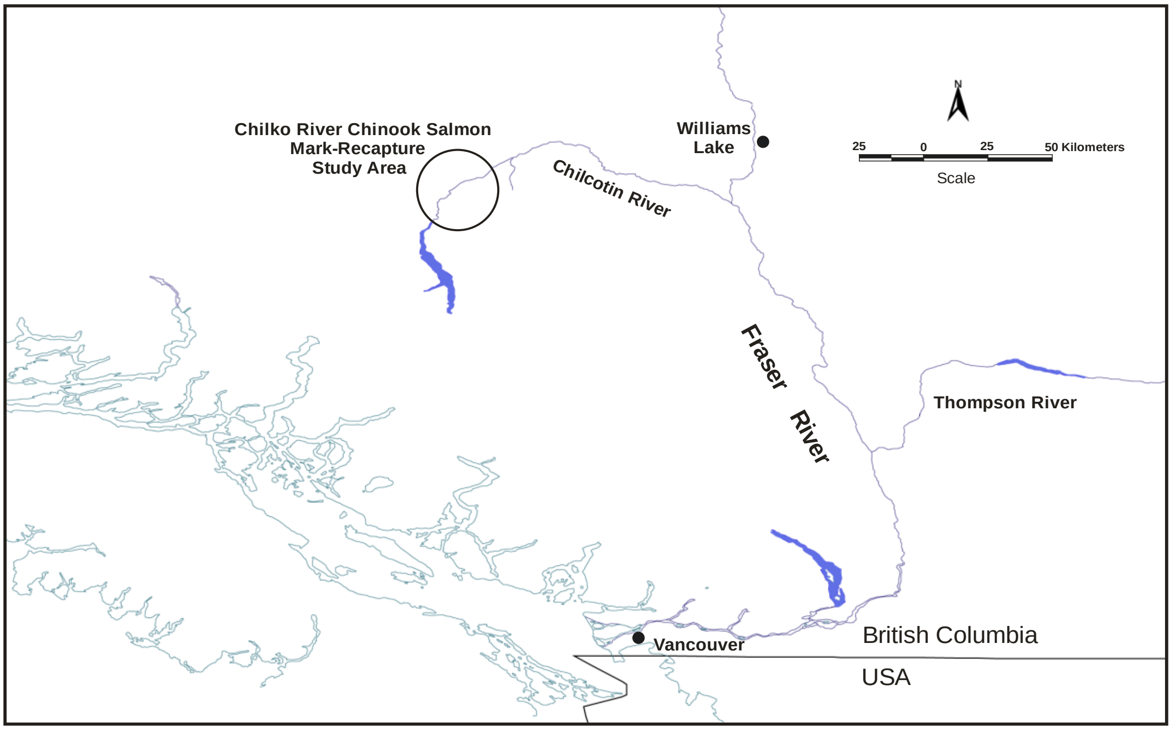

Figure 1. The Chilko River is located about 135 km west of Williams Lake and about 300 km north of Vancouver, B.C.

The Chilko River Chinook salmon population returns to the mouth of the Fraser River from late June to early August, with a peak in migration during mid July (Parken et al. 2008). The time for this mid-summer-run stock to migrate from the Fraser River mouth to the spawning grounds has not been measured directly, but the migration may take about three to five weeks since adult Chinook salmon first appear in the Chilko River during late July. Chinook salmon spawning occurs from late August to late September.

Virtually all Chinook salmon spawn in the Chilko River between the outlet of Chilko Lake and a canyon below its confluence with Brittany Creek; approximately 30 km downstream of the lake. The Chilko River downstream of the Brittany Creek confluence is very high gradient and constrained within a lava bedrock canyon. Based on previous assessment studies, the study area was divided into eight reaches, from the lake outlet to the upper end of Bidwell Canyon (Figure 2 & Table 1). This study area was selected because it is where virtually all the Chinook salmon spawn. Lingfield Creek and Brittany Creek are minor tributaries that enter the Chilko River study area (Figure 2), and there is no reported spawning of Chinook salmon in either one.

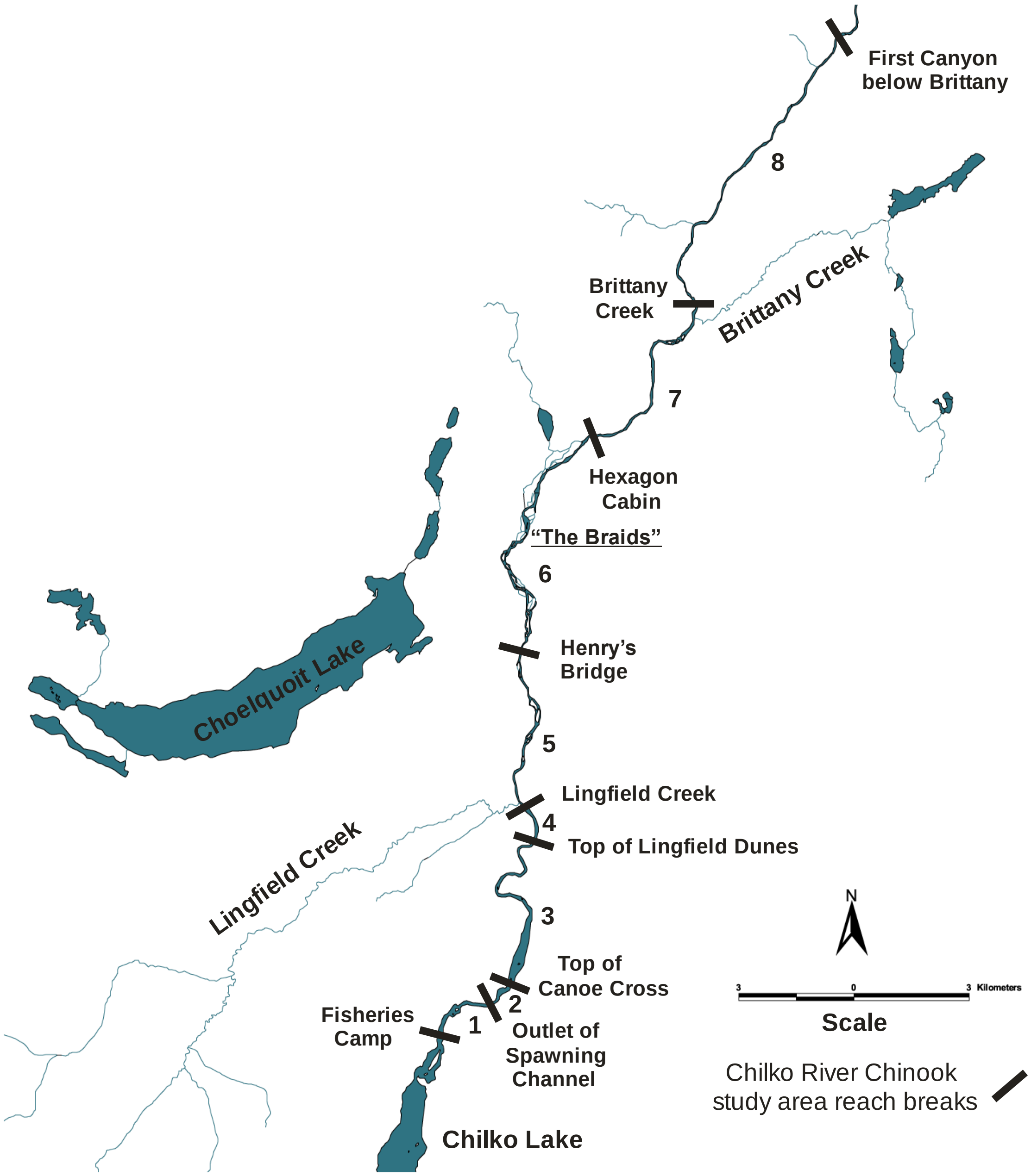

Figure 2. The Chilko River study area with reach breaks, tributaries, seining location and other sites referred to in this report.

Table 1. Chilko River reaches, coordinates, associated reach designations and length.

Reaches	Upstream Coordinates[a]	Reach Number	Reach Length (km)

Fisheries Cabin to Outlet of Spawning Channel	51 37 34 N 124 08 32 W	1	1.6
Outlet of Spawning Channel to Top of Canoe Cross	51 37 55 N 124 07 27 W	2	1.0
Top of Canoe Cross to Top of Lingfield Dunes	51 38 26 N 124 06 48 W	3	5.3
Top of Lingfield Dunes to Lingfield Creek	51 40 09 N 124 06 19 W	4	0.9
Lingfield Creek to Henry's Bridge	51 40 43 N 124 06 35 W	5	4.5
Henry's Bridge to Hexagon Cabin (Kye's)	51 42 55 N 124 06 25 W	6	7.0
Hexagon Cabin (Kye's) to Brittany Creek	51 45 46 N 124 04 25 W	7	4.4
Brittany Creek to First Canyon Below Brittany Creek	51 47 22 N 124 02 22 W to 51 51 15 N 123 58 45 W	8	9.3

a. NAD83 map datum.

The greatest densities of Chinook salmon spawners are in the "Lingfield Dunes" directly upstream of Lingfield Pool (reach 4) and in the "Braids" below Henry's Crossing (reach 6; Figure 2).

Annual and spawning season mean discharge data (m^3s^{-1}) were estimated for Chilko River by Environment Canada (Lynne Campo, pers. comm., Environment Canada, unpublished data). In 2012, discharge based on preliminary data ranged from 47-153 m^3/s during the project (August-October; Figure 3). Historical maximum flows approach 205 m^3s^{-1} and occur in early-August, but a secondary peak can occur later in the summer when sudden warming causes rapid melting of high elevation snow and glaciers. In 2012, the discharge steadily decreased throughout the study period and water temperatures ranged from 12-16°C with a mean of 14°C during the application period.

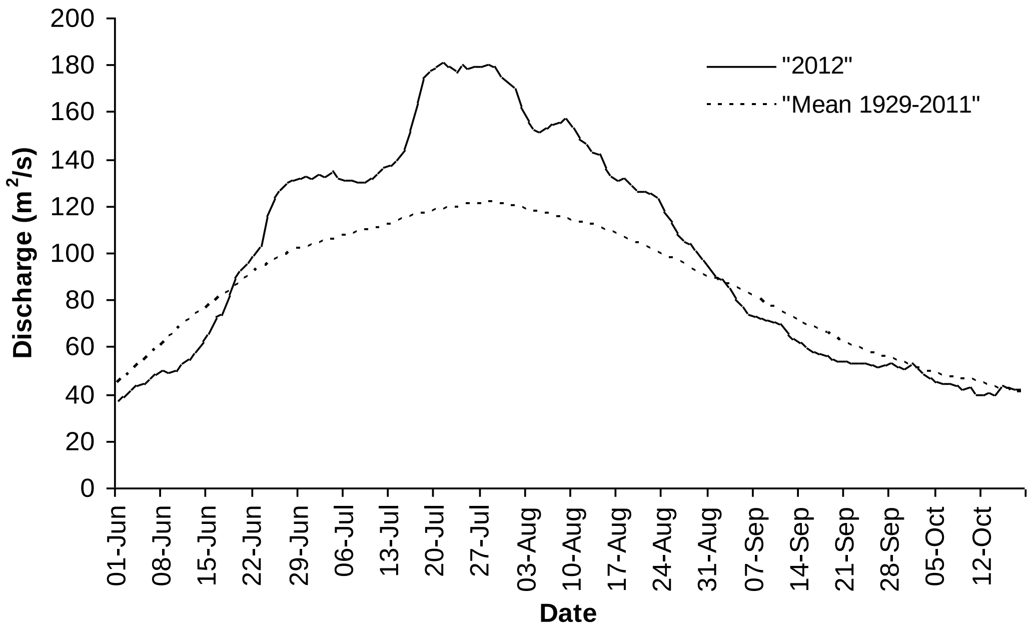

Figure 3. Preliminary mean daily discharge (m^3/s) for 2012 and the mean daily discharge for 1928-2012 for Chilko River from June – October using Environment Canada's Water Survey Station information near the outlet of Chilko Lake (Lynne Campo, pers. comm., Environment Canada, unpublished data).

The Chilko River supports populations of three species of Pacific salmon; Chinook, Coho (*O. kisutch*), and Sockeye (*O. nerka*). Other salmonid fish species inhabiting the Chilko River include rainbow/steelhead 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*.

METHODS

MARK-RECAPTURE FIELD STUDY

The initial study design was developed to meet Petersen mark-recapture assumptions; including closure, and equal application and recovery probabilities.

Fish Capture and Mark Application

Chinook salmon were captured for mark application by beach seining and angling from 8 August 2012 to 6 September 2012. Seining was conducted at Lingfield Pool (Reach 4), the only suitable holding pool identified for seining (Figure 2). Other seining sites were investigated and found to be unsuitable due to flows, substrate types, and/or a lack of holding fish. Fish were successfully angled at 13 locations downstream of Henry’s Bridge throughout reaches 6-8 (Figure 4).

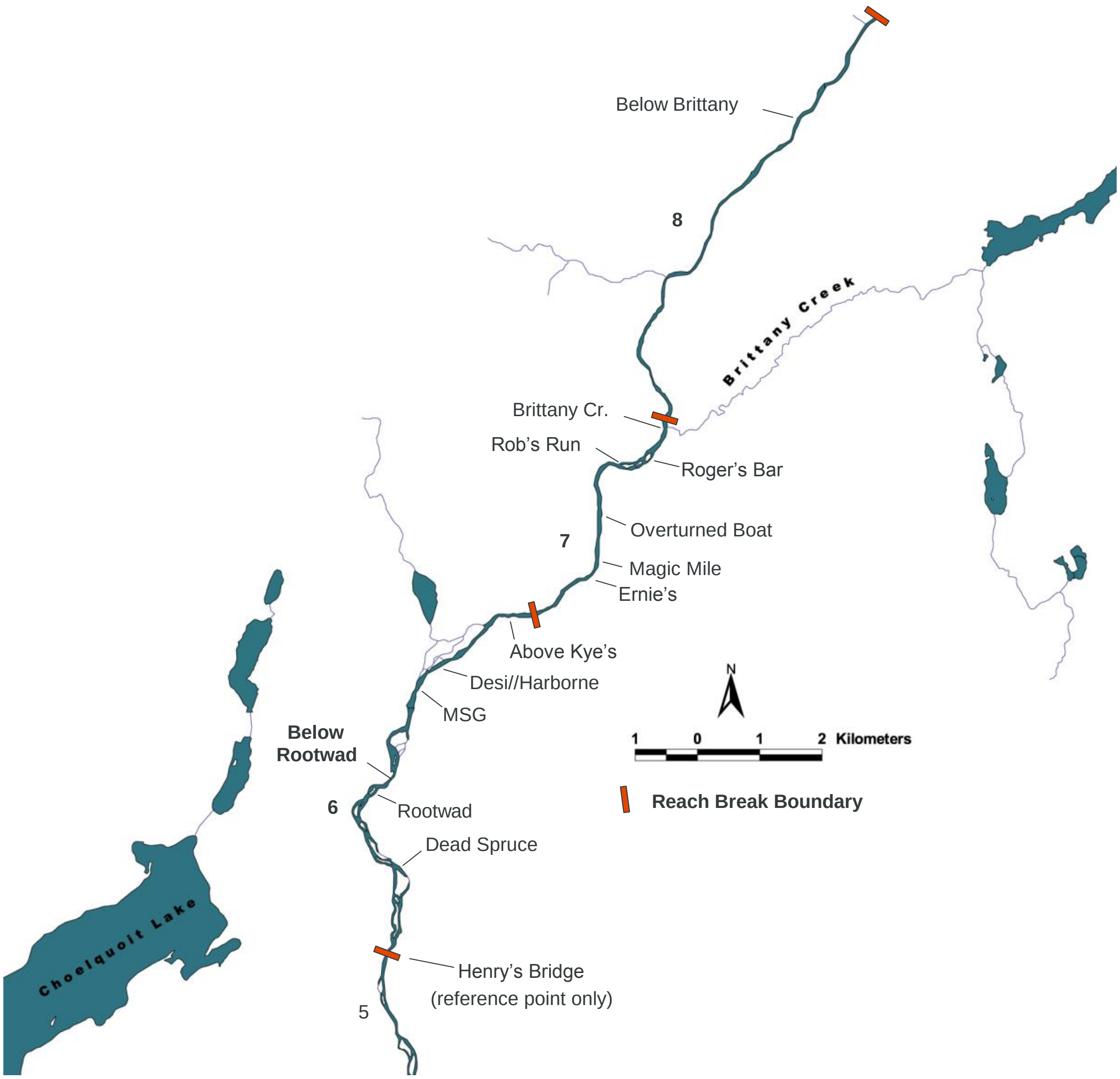

Figure 4. Chilko River Chinook angling locations, 2012.

Fish were caught on single barbless hooks of sizes 3/0 or 4/0 that were baited with roe (salmon eggs) treated with Pro-Cure and borax, and fish were also caught on spinners and spoons equipped with equal sized hooks. Chinook salmon were landed into a dip net, processed (marked) immediately in an onboard marking tray with flowing water or portable marking tray placed in the water, and held for up to 15 min in 1.25 m x 0.3 m diameter vinyl flow-through holding tubes that were anchored instream in a manner that permitted suitable water flow. Hooking location and amount of bleeding from the hook wound were recorded. The relative amount of bleeding from the area of the hook wound was recorded as none, slight, moderate, or heavy. The location where the fish was hooked was recorded and later categorized as either critical (roof of mouth, gills, tongue, or eye) or non-critical (all other locations).

For seining, an 80m long X 100 meshes deep seine net constructed with 9cm mesh was set by powerboat in a downstream crescent using a long upstream lead line and drawn from the river to enclose a portion of water along the riverbank. Once the seine and lead line (~50m) were set in an arc they were withdrawn from the river until it enclosed a small area of water along the shore to allow quick capture of the fish for mark application. The upstream lead line was retrieved using a hydraulic winch and the downstream line was retrieved manually. Captured salmon were held in the net in relatively deep water until mark application (Farwell *et al*. 1999).

During mark application, fish were placed in the canvas cradle of the marking tray. The portable marking tray was placed in flowing water and an onboard tray was also used. Onboard trays were mounted in vessels and were supplied with flowing water, pumped from the river during marking operations. Two Peterson tags, 2.2 cm diameter clear cellulose acetate disks, were applied to the captured Chinook salmon (Farwell *et al*. 1999). One Petersen disk tag was uniquely coded with a five digit number and the other was a blank transparent disk. These tags were placed on the fish using a 7.7 cm steel pin inserted through the dorsal musculature and pterygiophore bones approximately 1.5 cm below the insertion of the dorsal fin with the disk arranged one on each side of the fish, and the buffer disk on the pin head side. Petersen disk tags were held tightly against the fish by twisting the pin into a knot. Sex specific operculum punches 0.6 cm in diameter (used as secondary marks), were applied on the left operculum for seined fish and the right for angled fish: two punches for a female and one for a male. Each fish's mark number, fork length (FL, $\pm$ 0.1 cm), sex, adipose fin clip status (adipose fin present or absent), scarring, type of secondary mark, and release condition (1: swam away rapidly; 2: swam away slowly; 3: required ventilation; or 4: died) were recorded. The date, person tagging, tagging location and time were also recorded. After tagging and data collection, seine captured fish were released over the net; however, angled fish were quickly passed from the river to the onboard tagging tray supported in knotless mesh landing nets, and from the tagging tray back to the river and into the flow-through holding tubes to permit complete recovery before release. During mark application, any previously marked Chinook salmon and all other fish species captured were recorded and released (Farwell *et al*. 1999).

Carcass Recovery

Carcass sampling began on 9 September 2012 and continued until 2 October 2012, when no further carcasses were found. Recovery effort occurred in strata 1 to 8 on a two day cycle with each stratum surveyed 12 times. Recovery crews of five to seven people, recovered carcasses from river shores and pools in a downstream direction using a combination of gaffing from boats and walking side channels and the shoreline.

The spawning ground surveys and carcass recovery methods were similar to those used at the Harrison River (Farwell *et al*. 1999). During recovery, Chinook salmon carcasses were removed from the river using peughs or gaffs and were placed on the riverbank for subsequent examination. Complete sample information was collected from marked fish; adipose-absent fish; the 1st unmarked adult in every reach; every subsequent 8th unmarked adult fish; and all unmarked small males (less than 50 cm FL) encountered. Complete sample information consisted of the sampling date, recovery crew members, reach number, sex, Petersen disk tag presence and number, post-orbital to hypural plate (POH) length (± 0.1 cm), secondary mark status, female percent spawn (0% when a pre-spawning mortality, 50% when partially spent, or 100% when virtually no eggs remaining), carcass condition (1: fresh when gills red or mottled; 2: moderately fresh when gills white but flesh still firm; 3: moderately rotten when body intact but soft; or 4: rotten when only skin and bones remaining), adipose fin clip status (present or absent), adipose fin clip (AFC) condition (categorized as 1: complete clip with clip flush with dorsal surface; 2: incomplete clip with a nub of adipose tissue present; and 3: questionable clip that appears to be clipped but fungus or decomposition has obscured the area), number of eyes, and recovery method (shore/beach or pool/gaff) were recorded for each carcass recovered. Scales were collected from every sampled fish and 5 scales from each side of the carcass were placed into scale books. Scale samples were read at the Pacific Biological Station Sclerochronolgy lab in Nanaimo, B.C. Ages were recorded using the Gilbert-Rich and European coding systems. All carcasses examined for the presence of tags were cut in half using a machete to prevent re-counting.

ANALYTICAL PROCEDURES

Sex Identification Correction

Sex identification errors occurred at mark application because sexually dimorphic traits were not fully developed at the time of marking and internal examinations were not possible until carcasses were examined during recovery. For the purposes of estimating sex specific population sizes, the mark application data was corrected for sex identification error using the method described by Staley (1990).

Tests for Sampling Selectivity

Sampling biases were only evaluated for adult males and females because the jack (fish less than 50 cm FL) sample size was too small. All samples were stratified by sex (male and female) before testing.

Tagging Stress

Mark application stress was assessed in a number of ways: by comparing the apparent spawning success for the marked and unmarked females in the carcass recovery sample; by comparing the rates of mark recovery from fifteen minute hold time increments; by comparing the rates of mark recovery from release condition categories; by comparing the rates of mark recovery by bleed code; by comparing the rates of mark recovery by hook location; and by comparing the recovery rates of fish that were captured once to those captured two or more times. As tags were only applied by angling in the lower spatial strata and seining in the upper, the test of recovery rate by application method cannot be differentiated from the spatial test. All of the above mentioned tests were performed using chi-square tests.

Period

Temporal bias was assessed in both the application and recovery samples, using chi-square tests. Application sample bias was examined by comparing the mark incidence among recovery periods. Recovery sample bias was examined by comparing the mark recovery rate among application periods using a chi-square test (Sokal and Rohlf 1981). Samples were stratified by sex prior to testing.

Location

Spatial bias was assessed in both the application and recovery samples, using chi-square tests. Application bias was assessed by comparing the differences in mark incidence among spatial recovery strata. Recovery bias was assessed by comparing the proportion of marks recovered among the spatial application strata.

Size

Size related bias was assessed in both the application and recovery samples, using the Kolmogorov-Smirnov two sample tests (Sokal and Rohlf 1981). Application bias was assessed by comparing POH length frequency distributions in marked and unmarked fish in the recovery sample. Recovery bias was assessed by comparing fork length frequency distributions in the recovered and not recovered portions of the tag application sample. Both samples were stratified by sex prior to performing these tests.

Sex

Sex related bias was assessed in both application and recovery samples, using chi-square tests. Application bias was assessed by stratifying by sex and comparing the differences in mark incidence in the recovery sample. Recovery bias was assessed by comparing the rate of marks recovered by sex in the application sample. In addition, sex specific differences in tag loss were assessed.

Age

Application bias was assessed by comparing the age composition in the marked and unmarked scale samples taken during recovery (chi-square test). In addition, age composition between males and females in the recovery sample was compared using a chi-square test.

Bias Summary

Bias testing results of the adult application and recovery samples for males and females were summarized into one table to inform a decision on the appropriate method to be used to calculate the mark-recapture estimation of escapement.

MARK-RECAPTURE ESTIMATION OF ESCAPEMENT

The mark recapture study design was planned around three estimation strata (adult males, females, and small males) because other Fraser River Chinook salmon escapement programs repeatedly find significant sampling selectivity among these strata; age-specific maturation patterns differ between males and females; and in order to facilitate comparison with past or similar studies.

Petersen Estimator

If no biases were detected, then the adult Chinook salmon population within the Chilko River study area can be estimated using Chapman's modification of the Petersen estimator (Ricker 1975).

Darroch Estimator

If biases were detected, population estimates were generated using the Stratified Population Analysis System (SPAS), a statistical software package developed by Arnason *et al*. (1996). This software package performs a number of statistical tests and generates the Darroch maximum likelihood estimate of escapement. The study area was stratified by pooling animals that exhibited approximately homogeneous capture and migration encounters. The data were entered into SPAS according to the directions in Arnason *et al*. (1996). The SPAS program uses a "complete mixing" test, to determine whether all animals have an equal probability of recovery across all strata, and an "equal proportions" test, to determine whether the ratio of marked to unmarked animals is equal across all strata. Passing either of these tests ($p>0.05$) is sufficient for the validity of full pooling; thus it is appropriate to use the pooled Petersen method. Otherwise the Darroch/Plante maximum likelihood (ML) method should be used to produce the most accurate population estimate (Arnason *et al*. 1996).

Escapement by Age

Escapement by age was determined by applying the estimated age composition of the recovery sample to the estimate of escapement based on the ML Darroch estimator. As sex specific escapement estimates were calculated, age data were also stratified by sex.

PEAK COUNT ESCAPEMENT ESTIMATION

Aerial counts were performed at low levels (50-80 m above the ground) using a Bell 206B helicopter, flown at slow speeds (10-40 km hr^{-1}). The helicopter flew in a downstream direction to minimize scattering of spawners and glare. 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 helicopter was flown slowly in a “crab” style to provide observers with the best view of the fish. Observers used tally counters for their individual counts of Chinook salmon. Fish were recorded as spawners, holders, or carcasses by stratum. Spawners were observed in the shallow water and clearly associated spawning habitat, whereas holders were observed in pools or migrating through areas not associated with spawning habitat. Where carcasses had been cut in two by the recovery crew, only posterior sections including tails were counted carcasses. At lower densities, fish were counted individually. However, as the density increased, fish were counted or estimated in groups of five or 10.

For each stratum, observers discussed the groups of fish that were being counted and noted when a fish or group was counted by only one observer. At the end of each stratum count, the observers recorded their individual tallies, discussed their observations, and determined the best count for the stratum. Frequently, but not exclusively, the best count was the higher count of the two observations because it is assumed that the observer with the highest count observed the most fish (typically front seat). This methodology is used at many locations throughout the Fraser River watershed (Faulkner and Ennevor 1995; Bailey *et al*. 2000; Parken *et al*. 2003; Trouton 2004).

Peak Count Estimate of Escapement

For the peak count method, the annual escapement is calculated by multiplying the maximum total daily count of spawners, holders and carcasses by the species- and area-specific expansion factor to account for fish not observed (McPherson *et al*. 1999). The maximum total daily count usually occurs closest to the peak of spawning (comparatively few holding fish or carcasses; most of the fish actively spawning). Visual surveys were conducted throughout the spawning period with two or three surveys scheduled as close to the predicted time of peak spawning as possible (Parken *et al*. 2003). The survey with the maximum daily count of spawners, holders and carcasses was then multiplied by 1.54 to generate an estimate of the escapement. The expansion factor used for Fraser River Chinook salmon estimation, 1.54, assumes that observers count 65% of the true population when that count occurs at or very close to the peak of spawning (Dickson in Farwell *et al*. 1999).

RESULTS

Mark-Recapture

Fish Capture and Mark Application

Six hundred and seventy nine (679) Chinook salmon adults were captured for mark application between 9 August and 6 September 2012 (Appendix 1). Of those, 307 were captured by seine net and 372 by angling. There were six mortalities observed during the angling portion of application, resulting in an estimated instant mortality rate for angling of <2%. Heavy bleeding from hooking injuries was observed in eight fish, moderate bleeding was observed on 13 fish and slight bleeding was observed on 92 fish. One marked male (mark number: 96074) was recovered in the First Nation fishery. The eight heavy bleeders and the one First Nation Recovery were removed from the data set.

Mark application was conducted in four of the eight reaches (**Error! Reference source not found.**). Over half of the marks (55%) were applied by angling in reaches 6, 7 and 8. The remaining tags were applied in reach 4 at the Lingfield seine site. Of the 372 marks applied by angling 171 (46%) were applied at the Rogers Bar application site. The application sites Bellow Brittany and the Root Wad resulted in 60 (16%) and 49 (13%) marks applied respectively. The final 94 (25%) marks were applied at the Above Kye’s, Rob’s Run, Ernies, MSG, Overturned Boat, Dead Spruce, Below Root Wad, Desy Harborne, Brittany Creek, and Magic Mile application sites. Peak angling application in the lower river was 45 Chinook on August 23. Peak seining application in the upper river was 159 Chinook on September 5.

Within the mark application sample, females averaged 80.2 cm FL (range 59.3 to 96.5 cm; Figure 5) while males averaged 82.0 cm FL (range 50.5 to 103.5 cm; Figure 6) and jacks averaged 46.1 cm FL (range 42.8 to 49.5 cm; Figure 6; Appendix 1).

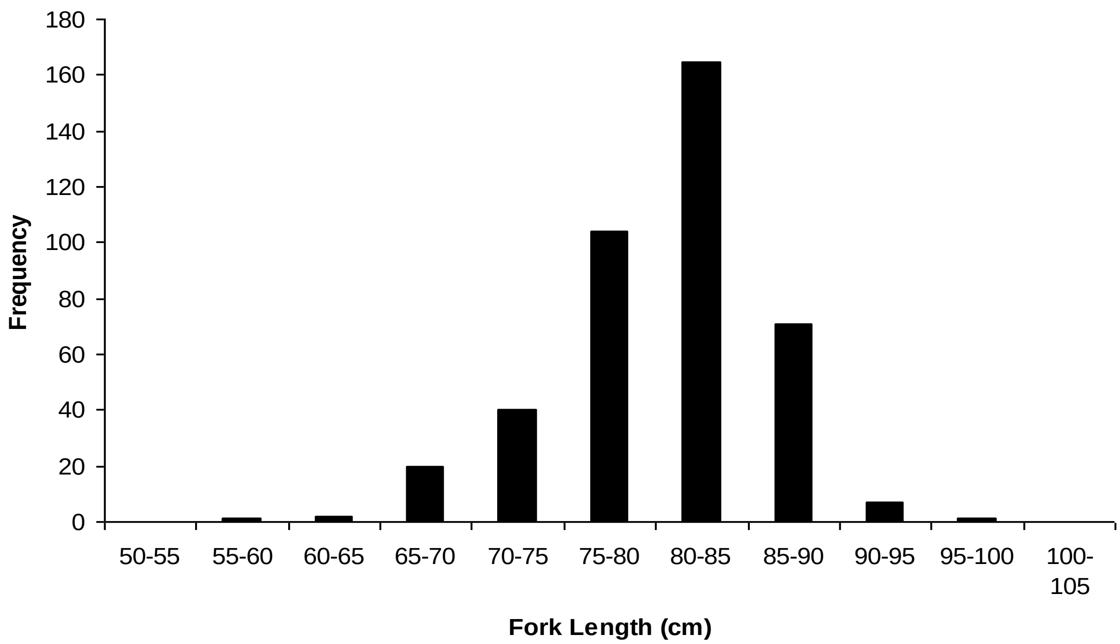

Figure 5. The fork length distribution of female Chinook salmon captured during mark application at Chilko River 2012.

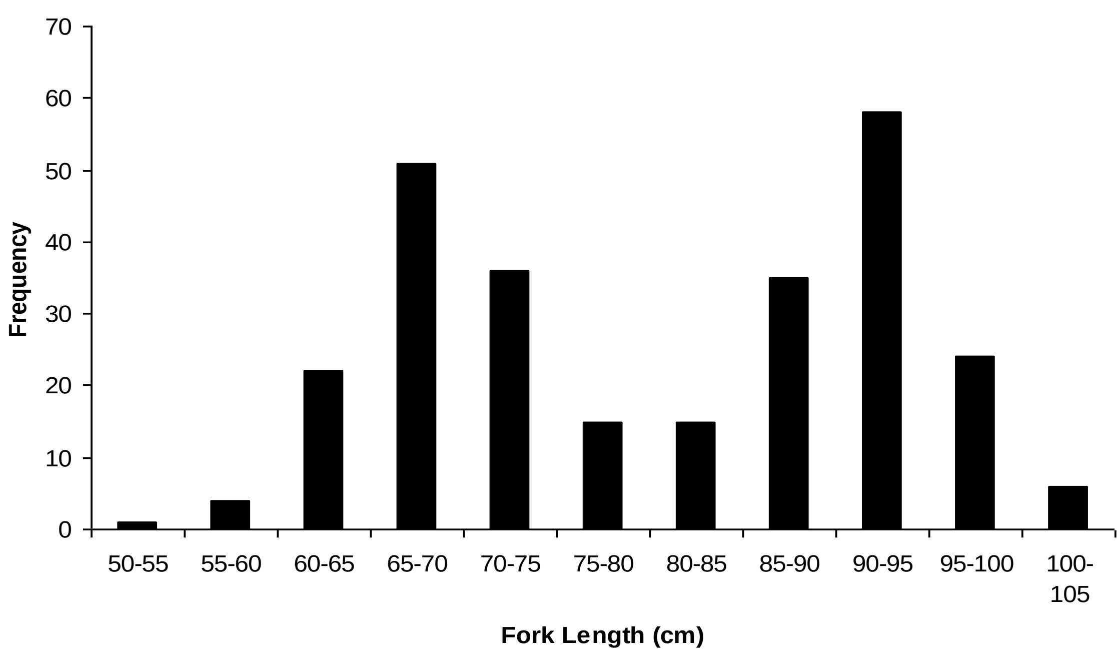

Figure 6. The fork length distribution of male Chinook salmon captured during mark application at Chilko River 2012.

`Carcass Recovery

A total of 1,531 carcasses were examined between 8 September 2012 and 2 October 2012 (Appendices 2 & 3). Of this sample, 1,490 were of known sex and used in the mark-recapture data analysis. Within this recovery sample, 267 Chinook salmon carcasses were marked and 1,223 were unmarked (Table 2). Within the marked group, there were 68 males and 199 females (Appendices 1& 2). The mean elapsed time (days out) between mark application and the subsequent mark recovery was 21 days (Appendix 1).

Table 2. Summary of carcass recovery for Chinook salmon in the Chilko River, 2012.

Sex	Total Carcasses	Primary Mark	Secondary Mark Only	Marked Total
Male	534	64	4	68
Female	956	193	6	199
Jack	4	0	0	0
Unknown	39	7	0	9
Total	1,533	264	10	267

Reach 6 had the most carcasses recovered (30%) while reach 1 and 2 had the fewest (0%). Peak recovery occurred on the recovery cycle from September 19 to September 20. Of the 1,489 sexed adult carcasses examined, 36% were males and 64% were females. Within the recovery sample, males averaged 69.1 cm POHL (range 49.9 to 84.0 cm; Figure 8) while females averaged 67.7 POHL (range 54.8 to 79.0 cm; Figure 7) and small males averaged 36.7 cm POHL (range 35.0 to 38.0 cm; Figure 8).

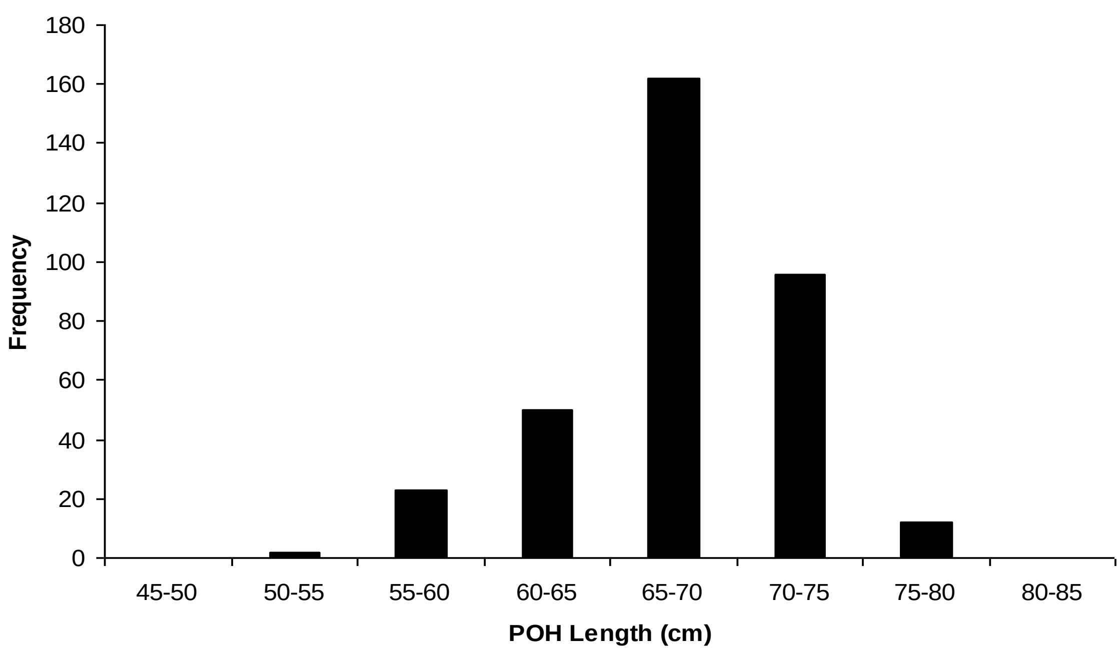

Figure 7. The post-orbital to hypural plate (POH) length distribution of female Chinook salmon sampled during carcass recovery at Chilko River 2012.

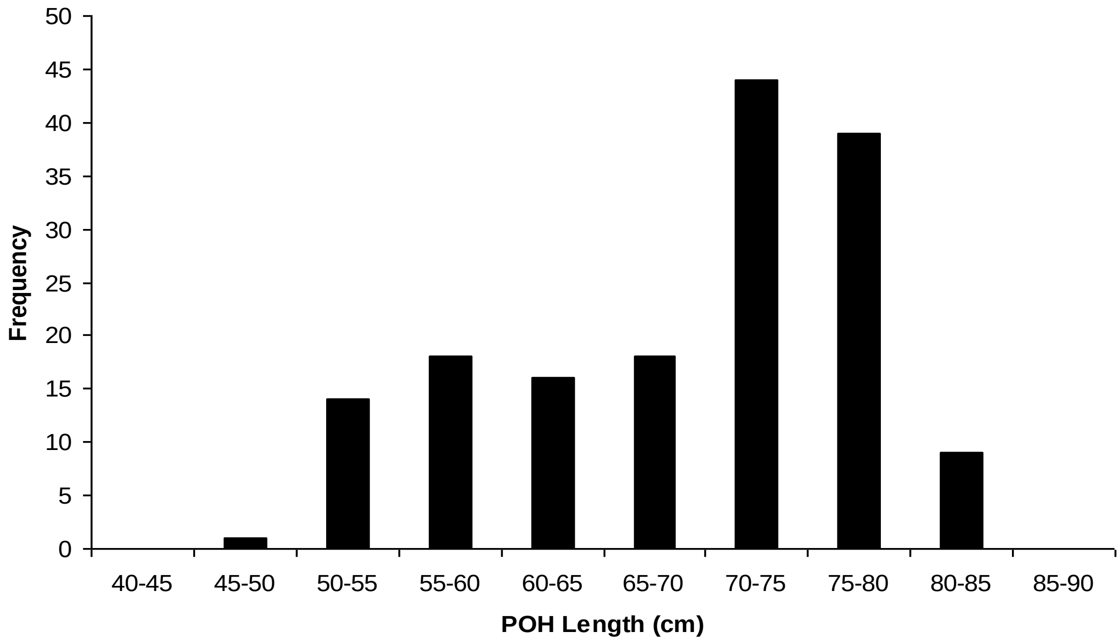

Figure 8. The post-orbital to hypural plate (POH) length distribution of male Chinook salmon sampled during carcass recovery at Chilko River 2012.

At carcass recovery, the sub-sample of scale ages showed this population has stream-type life history, and the scales all had one freshwater annulus, with total ages of four to six years (Appendix 3). The Chinook were primarily age 3.1. **Table 3** shows the age composition by sex of the scale sub-sample with complete ages.

Table 3. Age structure for adult Chilko River Chinook salmon for 2012, collected during carcass recovery.

Age		Male		Female		Total	
European	Gilbert Rich	Sample Size	Percent	Sample Size	Percent	Sample Size	Percent
1.1	32	9	7	1	0	10	2
1.2	42	47	34	105	36	152	36
1.3	52	80	58	177	61	257	60
1.4	62	2	1	6	2	8	2

ANALYTICAL

Sex Identification Correction

Of the 679 marked Chinook salmon in the application sample, 280 were identified as male, 399 as female, and two were identified as small male at the time of release (Table 4). There were six sex identification errors among recovered marked fish: two fish identified as males at mark application were actually females and four females were actually males (Appendix 1). After application of the sex identification correction, the corrected mark releases were 280 (41%) males and 399 (59%) females.

Table 4. Marks applied by sex, including Staley's sex correction factors and sex corrected totals, to Chilko River Chinook salmon, 2012.

	Mark Application		
Sex	Total	Sex Correction Factor[a]	Sex Corrected
Male	267	+0.02	280
Female	412	-0.02	399
Jacks	2	0	2

a. Staley's sex correction factor. Adjust application totals by adding/subtracting male/ female factors for each of the total male and female marks applied.

Sampling Selectivity

Small males, less than 50 cm FL, identified as jacks in the field were not analyzed due to inadequate sample sizes.

Marking Stress

There was no evidence of a difference in spawning success between marked and unmarked female recovery samples (p=0.24; Table 5; Appendix 2).

Table 5. Spawning success rates of marked and unmarked female Chinook salmon for Chilko River 2012.

	Unsuccessful	Successful	Percent Successful (%)
Marked	1	171	99.4
Unmarked	12	683	96.5

There was no evidence detected for stress related to the length of time male or female Chinook salmon were held until marking (p=0.09 and p=0.20, respectively; Table 6; Appendix 1).

Table 6. Proportion of marks recovered by sex and hold time strata during seining mark application of Chilko River Chinook salmon, 2012.

	Marked Recoveries				Marks Applied [a]				Percent Recovery (%)			
Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
0-45 Minutes	11	50	0	61	44	81	0	125	25	62	-	49
46-90 Minutes	6	63	0	69	59	121	0	180	10	52	-	38
Total	17	113	0	130	103	202	0	305	17	56	-	43

a. Corrected for sex identification error.

Of the 679 fish marked, the majority (99%) swam away rapidly (release condition 1) after mark application and very few (0.7%) swam away slowly (release condition 2 +3; Appendix 1). The sample size of Chinook that swam away slowly was too small to use chi-square tests. Even if a bias did exist within that group, the small sample size would make any possible effects to the estimate negligible.

Of the 374 fish marked during angling, eight had heavy bleeding observed after mark application; 13 had moderate; 92 had slight, and 271 had no bleeding. The eight heavy bleeders were removed from the analysis. Due to small sample sizes, slight and moderate bleeders were grouped for comparison to fish with no bleeding. There was no evidence of difference detected for stress related to bleeding for male or female Chinook salmon (p=0.88 and p=0.44, respectively; Table 7; Appendix 1).

Table 7. Proportion of marks recovered by sex and hook location strata during angling mark application of Chilko River Chinook salmon, 2012.

	Marked Recoveries				Marks Applied [a]				Percent Recovery (%)			
Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
Bleeding	15	22	0	37	46	58	0	104	33	38	-	36
No Bleeding	35	64	0	99	117	142	0	259	30	45	-	38
Total	50	86	0	136	163	200	0	363	31	43	-	37

a. Corrected for sex identification error.

Of the 365 fish marked during angling (used in analysis), 126 were hooked in a critical location, 218 in a non-critical location and 21 unknown. There was no evidence of difference detected for stress related to hook location for male or female Chinook salmon (p=0.54 and p=0.64, respectively; Table 9; Appendix 1).

Table 8. Proportion of marks recovered by sex and hook location strata during angling mark application of Chilko River Chinook salmon, 2012.

	Marked Recoveries				Marks Applied [a]				Percent Recovery (%)			
Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
Critical	17	26	0	43	53	72	0	126	32	36	-	34
Non-Critical	27	46	0	73	104	113	0	218	26	41	-	33
Total	44	72	0	116	157	185	0	344	28	39	-	34

a. Corrected for sex identification error.

Of the 679 fish marked, 307 were captured by seine net and 372 were captured by angling. The test to determine differences between the marked recovery rates of capture methods (angling versus seining) was the same as the spatial recovery test (Table 13).

Following release, 61 previously marked adult Chinook were recaptured during subsequent mark application periods (**Table 9**; Appendix 1). Four Chinook were recaptured twice during the application period. There was no evidence of a difference in marked recovery rate between recaptured and non-recaptured fish for males or females respectively (*p=0.99 and p=0.38*; chi-square test).

Table 9. Effect of recapture on recoverability by sex for Chilko River Chinook salmon, 2012.

	Marked Recoveries				Marks Applied [a]				Percent Recovery			
Times Recap'd	M	F	J	Total	M	F	J	Total	M	F	J	Total
0x	63	179	0	242	260	352	2	614	24%	51%	0	39%
1x +	5	20	0	25	18	47	0	65	27%	43%	-	38%
Total	68	199	0	267	278	399	2	679	24%	50%	0	39%

a. Corrected for sex identification error.

Period

Temporal bias in the application sample was examined by comparing mark incidences among three recovery periods. When the period was stratified to contain approximately equal numbers of carcass recoveries, each stratum contained between 6 and 8 days. The greatest amount of pooling (8 days) was in the first period when sample sizes were smallest. The mean mark incidence was 13% (range 12% to 15%) for males and 21% (range 15% to 23%) for females (Table 10). There was no evidence of a difference in mark incidence throughout time for males or females (p=0.66 and p=0.11). When the application period was stratified into two periods, there no evidence of a difference in mark incidence for males or females (p=0.92 and p=0.06).

Table 10. Incidence of primary or secondary marks in Chilko River Chinook salmon, by recovery period and sex, 2012.

	Marked Recoveries				Total Recoveries				Percent Recovery			
Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
09-Sep	17	25	0	42	113	165	2	280	15%	15%	0	15%
17-Sep	35	114	0	149	299	499	2	800	12%	23%	0	19%
23-Sep	16	60	0	76	122	292	0	414	13%	21%	-	18%
Total	68	199	0	267	534	956	4	1,494	13%	21%	0	18%

a. Corrected for sex identification error.

Temporal bias in the recovery sample was examined by comparing recovery rates among two application periods. When the period was stratified to contain approximately equal numbers of marks applied, each stratum contained between 4 and 14 days. The greatest amount of pooling (14 days) was in the later period when daily sample sizes were smaller. The mean percentage recovered was 24% for males and 47% for females (**Table 12**). There was no evidence of a difference in recovery rate among periods for females (p=0.16). There was evidence of a difference in recovery rate among periods for males (p=0.03). The recovery rate in the early period was higher than the late period for males (Table 9).

Table 11. Primary marks applied and recovered in Chilko River Chinook salmon, by application period and sex, 2012.

	Marked Recoveries				Marks Applied [a]				Percent Recovery			
Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
09-Aug	19	23	0	42	54	59	0	113	35%	39%	-	37%
23-Aug	45	170	0	215	224	339	2	565	20%	50%	0	38%
Total	64	193	0	257	278	398	2	678	23%	49%	0	38%

a. Corrected for sex identification error.

Location

Spatial bias in the application sample was examined by comparing mark incidences among reaches two to eight, as no carcasses were recovered in reach one. Reaches were pooled into two strata: the upper stratum consisted of reaches two through five and the lower stratum consisted of reaches six, seven and eight. The mark incidence in the lower stratum was 12% for males and 19% for females (Table 12). The mark incidence in the upper stratum was 13% for males and 22% for females. There was no evidence of a difference between mark incidence in the upper and lower spatial recovery strata for males or females (p=0.84 and p=0.34).

Table 12. Incidence of primary or secondary marks in Chilko River Chinook salmon, by recovery strata and sex, 2012.

Marked Recoveries	Total Recoveries	Mark incidence

Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
Lower	42	86	0	128	344	444	3	791	12%	19%	0	16%
Upper	25	113	0	138	189	512	1	702	13%	22%	0	20%
Total	67	199	0	266	533	956	4	1,493	13%	21%	0	18%

Spatial bias in the recovery sample was examined by comparing the recovery rate between different spatial application strata. All marks were applied by seining in the upper reaches and angling in the lower reaches. Due to this application procedure, the spatial application strata cannot be separated from application method (angling, seining). There was no evidence of a difference in the percentage of marked fish that were recovered between application method strata for males (p=0.06). There was strong evidence that seined females were recovered at a higher rate than those angled (p<0.01; Table 13).

Table 13. Primary marks applied and recovered in Chilko River Chinook salmon, by application method and sex, 2012.

	Marked Recoveries				Marks Applied [a]				Percent Recovery			
Stratum	M	F	J	Total	M	F	J	Total	M	F	J	Total
Angling	46	80	0	126	170	193	2	365	27%	41%	0	35%
Seining	17	113	0	130	104	203	0	307	16%	56%	-	42%
Total	63	193	0	256	274	396	2	672	23%	49%	0	38%

a. Corrected for sex identification error.

Size

Size-related bias in the application sample was examined by comparing the POH length-frequency distributions in the measured sample of marked and unmarked carcasses in the recovery sample. There was no evidence of a difference in POH length between marked and unmarked recoveries for both males and females (p=0.20 and p=0.12).

Size related bias in the recovery sample was examined by comparing the male and female fork length frequency distributions of recovered and not recovered fish marked at application. There was no evidence of a difference in fork length between recovered and not recovered samples for both males and females (p=0.20 and p=0.12).

Sex

Sex bias in application was assessed by comparing mark incidence between males and females in the recovery sample. Mark incidence was 13% for males and 21% for females (**Table 14**). There was strong evidence of a difference between male and female mark incidence (p<0.001); therefore, there was a sex bias at application.

Table 14. Percent recovery and mark incidence of secondary only and primary marks recovered by sex for the 2012 Chilko River Chinook salmon mark-recapture project.

Sex	Marks Applied[a]	Secondary Marked Recoveries[b]	Total Marked Recoveries[c]	Total Recoveries	Percent Recovery	Mark Incidence
Male	274	4	67	533	25%	13%
Female	396	6	199	956	46%	21%
Total	670	10	266	1,489	40%	18%

a. Corrected for sex identification error.
b. Carcasses recovered with secondary mark only.
c. Total carcasses recovered (primary and secondary only).

Sex bias in recovery was assessed by comparing percent recovery between males and females in the application sample. There was strong evidence of a sex bias in the recovery sample ($p<0.001$), the percent recovery of males was 13% and of females was 21% (Table 14). Primary mark loss was 2% for males and 2% for females, these estimates were not materially different.

Age

Age bias on application was assessed by comparing the age composition of the marked and unmarked recovery sample. Due to small sample sizes, age 3_2 were removed for female analysis and 6_2 were removed for male analysis. There was no evidence of a difference in age composition between marked and unmarked samples for males or females (p=0.26 and p=0.34; **Table 15**).

At carcass recovery, all scale samples showed this population has stream-type life history, and the scales all had one freshwater annulus, with total ages of three to six years (Appendix 3). Table 15 shows the age composition by sex for scale samples with complete ages that were collected during the recovery sample. The one jack sample was a 3_2. Due to small sample sizes, age 3_2 and 6_2 were removed. There was no evidence of a difference in age composition between the males and females (p=0.7). Both sexes were composed of a higher proportion of age 5_2 than 4_2.

Table 15. Age structure for adult Chilko River Chinook salmon for 2012 samples collected during carcass recovery.

	Male		Female	
Age	Sample Size	Percent[a]	Sample Size	Percent[a]
3_2	13	9%	1	0%
4_2	47	34%	105	36%
5_2	80	58%	177	61%
6_2	2	1%	6	2%

a. Where percentages do not sum to 100, differences are due to rounding error.

Table 16. Comparison of age samples taken from marked and unmarked adult Chinook salmon during recovery in the Chilko River, 2012.

		Male		Female	
	Age	Sample size	Percent[a]	Sample Size	Percent[a]
Marked	3_2	4	7%	0	0%
	4_2	21	39%	59	39%
	5_2	28	52%	89	59%
	6_2	1	2%	3	2%
Unmarked	3_2	5	6%	1	1%
	4_2	26	31%	46	33%
	5_2	52	62%	88	64%
	6_2	1	1%	3	2%

a. Where percentages do not sum to 100, differences are due to rounding error.

Bias Summary

Bias testing results of the adult application and recovery samples for males and females are summarized in Table 17.

Table 17. Results of statistical tests for bias in the 2012 Chilko River Chinook salmon escapement estimation study.

Bias type	Application sample [a]	Recovery sample [a]
Stress	No bias	Capture method for females
Period	Female bias	Female and male bias
Location	No bias	Female bias
Fish size	n/a	No bias
Fish sex	Higher rate for females.	Higher rate for females.
Fish age	n/a	No bias.

a. No bias indicates that bias was not detected; undetected bias may be present.

MARK-RECOVERY ESTIMATE OF ESCAPEMENT

Significant sex related bias were evident at application and recovery; therefore, the data were stratified by sex.

Males: Petersen Estimate

There was insufficient data to generate an estimate of jack escapement using a mark-recapture method (**Table 18**), as no tagged jacks were recovered. A total of two tags were applied to jacks and four jack carcasses were recovered; therefore, a minimum of four jacks were handled during sampling events. In the future, as the scale sample sizes become larger for Chilko River Chinook salmon with fork lengths less than 50cm then a valid estimate of escapement may be able to be generated for these small fish.

Due to evidence of temporal bias in the male recovery data, the recovery data was stratified into early and late recovery periods based on equal tag proportions. The program SPAS reported no evidence of incomplete mixing ($p=0.21$) or an unequal ratio of marked to unmarked males between the strata ($p=0.84$). Considering these results, a pooled Petersen estimator was used to calculate male escapement. Therefore, the 2012 male spawning escapement of Chilko River Chinook salmon was estimated to be 2,176 ± 417 (Table 18).

Table 18. Male escapement estimate derived from 2012 mark-recovery data using a Petersen estimator for Chilko River Chinook salmon.

	Sex	
	Male	Jack [b]
Carcasses Sampled	533	4
Marks Applied [a]	274	2
Marks Recovered	67	0
Percent Recovered	25%	0
Population Size	2,161	na
Coefficient of Variation	10%	na
Lower 95% Confidence Limit	1,747	na
Upper 95% Confidence Limit	2,575	na

a. Corrected for sex identification error.
b. Insufficient data to generate valid estimate of escapement.

Females: Darroch Estimate

There was spatial and temporal bias at recovery and temporal bias at application for females. The recovery data were stratified into early and late recovery periods based on equal tag recovery proportions. The early period for recovery data was September 9th to 18th and the late period was September 19th to October 1st. The application data were stratified into early and late periods based on equal tag application proportions. For temporal stratification at application, the early period was

August 9th to September 2nd and the late period was from September 3rd to September 6th. For spatial stratification at recovery, the river was divided into upper and lower segments.

For temporally stratified application and spatially stratified recovery data, the program SPAS reported no evidence of an unequal ratio of marked to unmarked females between strata (p=0.30). For temporally stratified application and recovery data, the program SPAS reported strong evidence of incomplete mixing of marked and unmarked females ($p<0.01$) and an unequal ratio of marked to unmarked females between strata (p=0.05). These results further support the use of the ML Darroch estimator for females instead of the Petersen estimator. Therefore, the 2012 female spawning escapement of Chilko River Chinook salmon was estimated to be 2,094 ± 177 using the Darroch estimator in SPAS (Table 19).

Table 19. Female escapement estimate derived from 2012 mark-recovery data using the ML Darroch estimator for Chilko River Chinook salmon.

	Female
Carcasses Sampled	956
Marks Applied [a]	396
Marks Recovered	199
Percent Recovered	50%
Population Size	2,094
Coefficient of Variation	8%
Lower 95% Confidence Limit	1,960
Upper 95% Confidence Limit	2,228

a. Corrected for sex identification error.

Combined Total

The 2012 total adult spawning escapement of Chinook salmon to Chilko River was 4,255 ± 388 (Table 20).

Table 20. The total adult escapement estimate derived from 2012 mark-recovery data using the Petersen estimator for males and the ML Darroch estimator for females for Chilko River Chinook salmon.

	Total Adult
Carcasses Sampled	1,489
Marks Applied [a]	670
Marks Recovered	266
Percent Recovered	35%
Population Size	4,255
Coefficient of Variation	6%
Lower 95% Confidence Limit	3,707

Upper 95% Confidence Limit	4,803

a. Corrected for sex identification error.

Escapement by Age

The majority of male and female Chinook salmon returning to the Chilko River in 2012 were age 1.3 (**Table 21**). The male age composition consisted of 7% age 1.1, 34% age 1.2, 58% age 1.3 and 1% age 1.4. The female age composition consisted of 0% age 1.1, 36% age 1.2, 61% age 1.3 and 2% age 1.4.

Table 21. Escapement estimates by sex and age for 2012 Chilko River Chinook salmon.

Age		Male			Female		
European	Gilbert Rich	Sample Size	Escapement Estimate	Percent[a]	Sample Size	Escapement Estimate	Percent[a]
1.1	32	9	141	7%	1	7	0%
1.2	42	47	736	34%	105	761	36%
1.3	52	80	1,253	58%	177	1,282	61%
1.4	62	2	31	1%	6	43	2%

a. Where percentages do not sum to 100, differences are due to rounding error.

PEAK COUNT ESCAPEMENT ESTIMATION

In 2012, five aerial surveys were conducted on September 1, 7, 12, 17 and 21. The highest spawner count (2,303) occurred on the September 12 (Figure 9). The peak count of Chinook salmon was 2,499 (2,303 spawners, 100 holders and 96 carcasses) also on September 12. The expanded peak count estimate was 3,845.

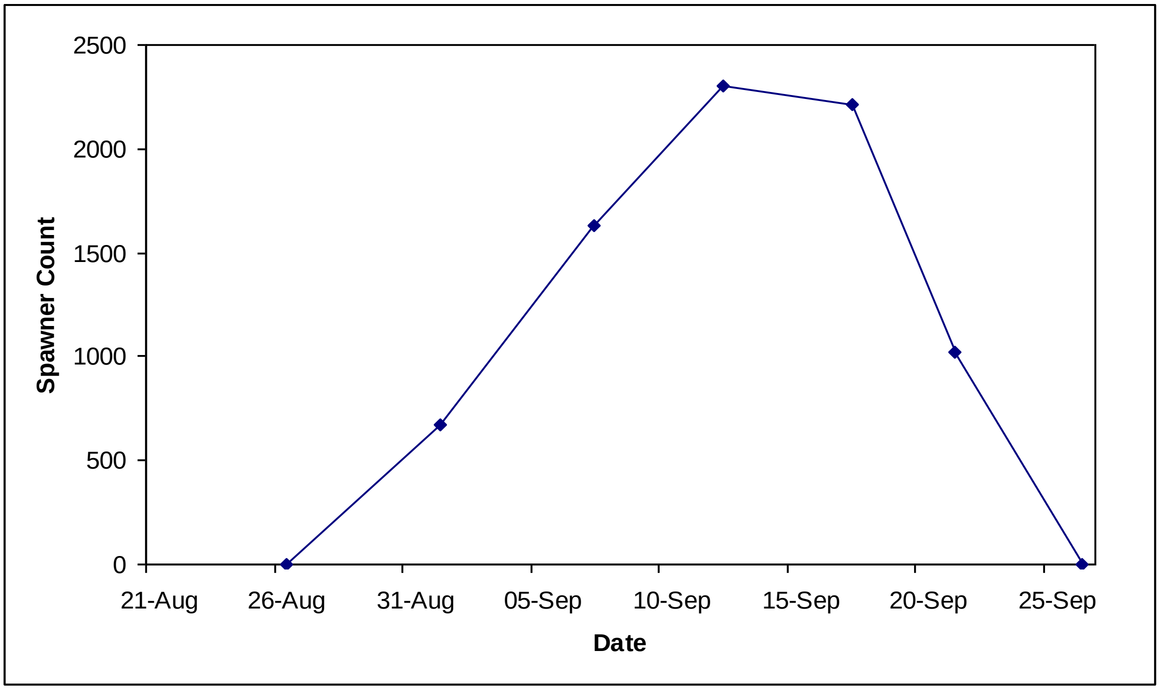

Figure 9**.** Chinook salmon spawners counted by date for the Chilko River, 2012.

DISCUSSION

Properly designed, executed and analyzed mark-recapture studies produce reliable estimates of escapement (Nelson et al. 2000). A high precision mark-recapture estimate can be achieved by applying a large number of marks and by implementing an appropriate recovery effort to recover a large number of those marks (Schwarz et al. 1993). During the 2012 Chilko River Chinook salmon mark-recapture study, large numbers of marks were applied and recovered producing a CV of 6% for the total spawner abundance, and it is likely that the CTC data standard for precision should be attainable in the future. To account for differences in tag incidence, recovery rate, and length distribution between males and females, the estimation of the spawning population was stratified by sex.

Females were recovered at a higher rate than males, as expected due to the behavioural differences between males and females after spawning. Just before death, spawning males continue to move downstream looking for additional spawning opportunity; therefore, males are more likely to be recovered lower in, or lost completely from, the study area. Females guard their redds while able to maintain position, then move into slower flows close by just before death, subsequently they are more likely to be recovered in close proximity to their spawning location; therefore, females are more likely to be recovered within the study area than males. As females tagged at Lingfield Pool tended to spawn just upstream in the Lingfield Dunes, and they tend to be recovered at a high rate by gaffing at the downstream end of the Lingfield pool, females were recovered at a very high rate in this area compared to males. Males were likely moving downstream in search of more spawning opportunities, and were more likely to get washed out of the study area.

In 2012, age data indicated a higher proportion of age-5 fish for both sexes. In 2010 and 2011, there were a higher portion of 4_2 males and 5_2 females. The age composition for 2012 does not align with the 2010 and 2011 Chilko River Chinook salmon age composition and other studies that found Fraser stream-type Chinook salmon females were most abundant at age 5 and males were most abundant at age 4 (Groot & Margolis 1991).

The mark-recovery method will produce an accurate estimate of the actual population size if the capture and tagging process do not significantly influence subsequent fish behaviour (Ricker 1975). The results of the bias testing indicated that measurable sources of stress including holding time, number of times recaptured, hook location, bleeding, and release condition did not have a significant impact on the subsequent behaviour of the marked fish. There was no measurable source of stress between application methods (angling versus seining) for males. There was a higher recovery rate for females captured by seining than those angled. This difference is discussed in the spatial section as the seining only occurred in the upper portion of the river and the angling only occurred in the lower.

Ricker (1975) stated that an important criterion for producing accurate population estimates from the mark-recovery method is that the mark application and carcass recovery samples should be representative of the population. In 2012, we assessed the representativeness of the sampling process by looking for bias in temporal, spatial, fish size, and sex composition patterns of the application and recovery samples. No biases were detected in the fish size distribution or age composition in application or recovery data. No significant spatial biases were detected in the application for either sex or recovery for males. However, a spatial bias in the female recovery data was detected. There was a higher rate of recovery in the upper section of the river. As the majority of the spawning occurs in the upper portion of the river at Lingfield Dunes and there is a large pool (Lingfield Pool) immediately downstream that collects many of the carcasses, large numbers of females were recovered at this location. Female carcasses in the lower section of the river may be more likely to drift out of the study area, as there a no large pools for carcasses to collect in.

There was a significant temporal bias detected in the recovery sample for females, as there was a lower proportion of tagged females recovered in the early period. This bias may have been driven by a delay in the start date of capture by seining; therefore, we recommend starting seining earlier in future studies. There was also a significant temporal bias detected in the recovery sample for males, as there was a lower proportion of tagged males recovered in the later period. This bias may have been driven by males not being available for capture later in the application period; therefore, we recommend seining and angling as late as possible. To minimize temporal biases in future studies we recommend evenly distributing application effort throughout the time to reflect the migration of Chinook salmon into the Chilko River.

As there was evidence of temporal bias at application and recovery for both sexes and spatial bias at recovery for females; stratifying the application samples by period, recovery by time for males, recovery time and space for females was recommended. For males, SPAS did not identify a need to use a temporally stratified estimator. Based on this result, we employed the Petersen estimator to generate an escapement estimate of 2,161 males. For females, SPAS did not identify a need to use a spatially stratified estimator. However, SPAS did identify a need to use a temporally stratified estimator for females. Based on these results, we employed the temporally stratified ML Darroch for females to generate an escapement estimate of 2,094 females. The total escapement estimate is 4,255 (CV = 6%) adults.

Based on the results of the Chilko River Chinook salmon mark-recapture project and data analyses over the last three years, recommendations include continuing to apply marks evenly in the two spatial strata (upper/seining and lower/angling); apply tags low in the system and early including starting seining earlier; apply tags in primary holding only (angling); applying tags throughout time (entire migration) at Lingfield (seining) and ensure that no marks are applied to spawning fish.

Visually derived estimates of spawning escapement throughout the Fraser watershed are generally biased low: Bailey et al. (2000) and Parken et al. (2003) reported negative biases of 5 to 51% during calibration studies in the Nicola watershed. The mark-recapture estimate of adult escapement of 4,255 (range

3,707-4,803) was slightly higher than the Peak Count estimate of 3,845; however, they were not materially different. Fish visibility during aerial counts can be influenced by fish behaviour, weather, and the physical conditions at the time of counting such as flow and turbidity (Bevan 1961). Other factors influencing aerial estimates include fish density, the experience of the pilot and observers, flight scheduling and frequency of counts (Bevan 1961; Neilson and Geen 1981).

When we assume that the mark-recapture estimate represents the true population, expansion factors of 1.28, 1.12, and 1.11 (2010, 2011, and 2012 respectively) of the Peak Count were necessary to meet the mark-recovery escapement estimate. Therefore, the mean expansion for Chilko River Chinook salmon is 1.17 (range 1.11-1.28). The 1995 Nicola River study noted a much larger mean expansion factor (2.04) of the Peak Count aerial estimates over a five year period (Bailey et al. 2000). That large expansion factor was reported from abnormally turbid waters during the 1995 Nicola River enumeration flights and because counts of live fish were not recorded as spawners or holders. Using the mean expansion factor of 4 years, peak count estimates of Nicola River Chinook salmon spawners ranged from -14% to +21% of the mark recapture estimates (Parken et al. 2003). Even with optimal counting conditions for all aerial surveys in 2010, 2011 and 2012; the Chilko River Chinook salmon estimate was still slightly lower than the mark-recapture estimate. On the Lower Shuswap River the spawning area and timing of spawn between Chinook and sockeye salmon overlaps; therefore, the ability to count Chinook salmon decreases with the presence of large numbers (>500,000) of sockeye salmon. In 2010, the ability to count Chinook at Chilko River was not highly affected by the large return of sockeye; however, more years with measured expansion factors are necessary to represent different counting conditions. A Chilko River Chinook salmon expansion factor for optimal aerial counting conditions may be recommended if the 2013 expansion factor is similar to 1.17. Until more calibration information is collected, we recommend continuing to use the 1.54 expansion factor that is currently used to expand raw count data to peak count estimates for Fraser Chinook salmon.

The results of the Chilko Chinook salmon assessment projects over the last three years indicate that the spawning escapement can be estimated with high precision. This study produced precise (CV) escapement estimates for males (10%) and females (7%), which is consistent with the PSC CTC data standards (CV<15%). Also, a high percentage of male (24%) and female (50%) carcasses were sampled, which indicates there is very good potential to collect sufficient numbers of CWTs on the spawning grounds to represent the ages for adult males and females and produce high quality CWT statistics. However, another part of the PSC CTC data standards specifies that the escapement estimates should be asymptotically unbiased, but in this study, sampling biases have been detected in the application and recovery samples. The ML Darroch estimator was used to reduce the influence of the bias, yet further refinement of the study design is needed to produce more representative samples. Also, the abundance of small males that were less than 50 cm could not be estimated due to insufficient samples. A size threshold of 50 cm fork length was based on the results of the Lower Shuswap River mark-recapture program from 2000-2009; however, as more data becomes available from successive studies on the Chilko River the relationship between recovery probabilities and fish length can be evaluated to determine appropriate size stratification. Nonetheless, estimation of the spawning escapement of all ages is a desirable attribute for CWT indicator stock programs. Overall, the results from the three years of the escapement estimation strongly indicate that suitable data can be collected from the Chilko River to support a CWT indicator program, and additional years of study will help refine the study design to improve the quality of escapement estimates.

SUMMARY

1. The Chinook salmon escapement to the Chilko River in 2012 was estimated by mark-recapture.

2. Marks were applied to 680 Chinook salmon: 307 of them were captured by seining and 373 by angling. Two of those marks were applied to jack (<50 cm FL) Chinook salmon, both captured by angling. One marked male was recovered in First Nation fisheries and were subsequently removed from bias testing and escapement estimates. Therefore, 679 adult marks were used for mark-recapture purposes.

3. After correction for sex identification errors, the application sample consisted of 280 males, 399 females, and 2 jacks.

4. In the recovery sample, 1,494 Chinook carcasses were sampled and 1,455 were identified by sex and 267 were marked.

5. The recovery sample had 534 males; 956 females; 4 jacks; and 36 that could not be identified for sex. The male age composition consisted of 6.5% age 1.1, 34.1% age 1.2, 58.0% age 1.3 and 1.4% age 1.4. The female age composition consisted of 0.3% age 1.1, 36.3% age 1.2, 61.2% age 1.3 and 2.1% age 1.4. All age samples showed the population has stream-type life history, as indicated by a two-year freshwater growth pattern (sub2).

6. Sampling selectivity related to temporal and spatial patterns, as well as fish size and sex, were assessed in both mark and recovery samples. Temporal biases were detected.

7. Based on the radio telemetry from 2010 and aerial survey data from 2010-2012, the mark-recapture assumption of closure was met.

8. There was evidence of temporal bias in the application and recovery sample for both sexes. Due to these biases, the Stratified Population Analysis System (SPAS) was used. The results confirmed that due to incomplete mixing and unequal proportions of marked to unmarked females in the strata the maximum likelihood (ML) Darroch estimate would be more appropriate than the Petersen estimate for females. The program SPAS found no evidence of incomplete mixing or an unequal ratio of marked to unmarked males between the strata; therefore, a pooled Petersen estimator was used to calculate male escapement.

9. The 2012 total adult spawning escapement of Chinook salmon to Chilko River was 4,255 with lower and upper 95% confidence limits of 3,707 and 4,803 respectively. The male escapement (Petersen) was estimated to be 2,161± 414 and the female estimate (ML Darroch) was 2,094± 134.

10. Aerial surveys of Chinook salmon spawners, holders, and carcasses were conducted between 1 September 2012 and 21 September, 2012. The September 12 flight was the peak count with 2,499 (2,303 spawners, 100 holders and 96 carcasses).

11. The peak count on 12 September 2012 produced an escapement estimate of 3,845 Chinook salmon using the Fraser River Chinook peak count expansion factor (1.54). This escapement estimate was 92% of the mark-recapture escapement estimate. The measured peak count expansion factor was 1.10 based on the peak count and mark-recapture estimate.

12. The residence time was 9.1 days (CV=1%) based on the spawner surveys and the mark-recapture estimate.

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REFERENCES

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences 2106.

Bailey, R.E., C.K. Parken, J.R. Irvine, B. Rosenberger, and M.K. Farwell. 2000. Evaluation of utility of aerial overflight based estimates versus mark-recapture estimates of Chinook salmon escapement to Nicola River, BC. Fisheries and Oceans Canada, CSAS. 2000:152.

Bevan, D.E. 1961. Variability in aerial counts of spawning salmon. J. Fish. Res. Bd. Can. 18: 337-348.

Faulkner, G. and B. Ennevor. 1995. Nechako and Stuart Rivers Chinook spawner enumeration 1994. Fisheries and Oceans Canada. Nechako Fisheries Conservation Program. Data Report No. M94-1.

Farwell, M.K., R. Diewert, L.W. Kalnin, and R.E. Bailey. 1998. Enumeration of the 1995 Harrison River Chinook salmon escapement. Can. Manuscr. Rep. Fish. Aquat. Sci. 2453: 32 p.

Farwell, M.K., R.E. Bailey, and B. Rosenberger. 1999. Enumeration of the 1995 Nicola River Chinook Salmon Escapement. Can. Man. Report of Fish. Aquat. Sci. 2491.

Groot, C. and L. Margolis. 1991. Pacific salmon life histories. UBC Press, Vancouver, British Columbia, Canada: 564 pages.

McPherson, S.A, D.R. Bernard, R.J. Yanusz, P.A. Milligan, and P. Timpany. 1999. Spawning abundance of chinook salmon in the Taku River in 1998. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 99-26.

Neilson, J.D., and G.H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Trans. Am. Fish. Soc. 110: 554-556.

Nelson, T.C., R.C. Bocking, and D.E. Miller. 2000. Chinook escapement to the Chuckwalla River 1999: a comparison of mark-recapture and area-under-the-curve estimates based on biotelemetry, aerial surveys, and carcass recoveries. Prepared for the Fisheries and Oceans Canada and Rivers Inlet Restoration Society by LGL Ltd. 83p.

Pacific Salmon Commission. 2002. Catch and escapement of Chinook salmon under Pacific Salmon Commission jurisdiction 2001. TCCHINOOK (02)-1.

Pacific Salmon Commission. 2011. 2010 Annual report of catches and escapements. TCCHINOOK (11)-2.

Parken, C.K. J.C. Candy, J.R. Irvine, and T.D. Beacham. 2008. Genetic and coded wire tag results combine to allow more-precise management of a complex Chinook salmon aggregate. North American Journal of Fisheries Management 28:328-340.

Parken, C.K., R.E, Bailey, and J.R. Irvine. 2003. Incorporating uncertainty into area-under-the-curve and peak count salmon escapement estimation. North American Journal of Fisheries Management 23:78-90.

Ricker, W.E. 1975. Computations and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382 p.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry, the principles and practices of statistics in biological research. Second edition. W.H. Freeman and Company. San Francisco. 859 p.

Staley, M.J. 1990. Abundance, age, size, sex and coded wire tag recoveries for Chinook salmon escapements of the Harrison River, 1984-1988. Can. Manuscr. Rep. Fish. Aquat. Sci. 2066: 42 p.

Schwarz, C.J., R.E. Bailey, J.R. Irvine and F.C. Dalzeil. 1993. Estimating salmon spawning escapement using capture-recapture methods. Can. J. Fish. Aquat. Sci. 50: 1181-1197.

Trouton, N.T. 2004. An investigation into the factors influencing escapement estimation for Chinook salmon (*Oncorhynchus tshawytscha*) on the Lower Shuswap River, British Columbia. Simon Fraser University. MSc Thesis.

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APPENDICES

-Included in separate document –