Calibration of Assessment Methods for Fraser River Sockeye Salmon *(Oncorhynchus nerka)* Spawning Populations (25,000 to 75,000) in the Horsefly, Stellako and Adams River Systems.

2007

by

Paul Welch, Keri Benner and Brian Leaf

Fisheries and Oceans Canada
Fraser River Stock Assessment
985 McGill Place
Kamloops, BC
V2C 6X6

Project Completion Report

For

Southern Boundary Restoration and Enhancement Fund
Pacific Salmon Commission
600-1155 Robson Street
Vancouver, BC.
Canada V6E 1B5

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

Enumeration of Fraser River sockeye *(Oncorhynchus nerka)* spawning escapement has historically followed a well established two-tiered protocol developed by the former International Pacific Salmon Fisheries Commission (IPSFC). An abundance threshold of 25,000 spawners determined the methodology employed, with low precision visual techniques for escapements <25,000, and high precision techniques (fences or mark-recaptures) for escapements >25,000. However, recent pressures on financial resources coupled with an increasing number of larger populations have strained capacity to meet these standards. This resulted in an increase of the threshold level to 75,000 spawners in 2004, with the objective of maintaining coverage on as many populations as possible while realizing minimal negative precision related impacts to the enumeration program overall. As a result of the threshold change, visual methods are now being used to enumerate much larger populations than they were ever intended to estimate. The standard expansion factor currently applied to visual counts (to account for the consistent underestimation of live counts) was developed for small stream populations in the Fraser system. Its application to larger populations (>25,000) will lead to substantial negative bias in spawning estimates.

Large populations (>25,000) tend to spawn in larger streams where the relative proportion of the sockeye population vulnerable to survey crews is much different than in smaller systems. By way of example, the only simultaneous comparisons of high and low precision methods that have occurred for large Fraser River sockeye escapements indicate indexes reaching as high as 17.5 (Schubert 1998). These are much higher than the current standard of 1.8 and its improper application could lead to estimates that are only 10% of a high precision estimate. As the proportion of the total Fraser sockeye escapement that is enumerated using visual techniques increases as a result of the change in enumeration threshold, it is crucial that structured calibration studies are undertaken to produce system, method and abundance specific expansion factors to avoid serious negative bias in future escapement estimates.

In 2007, a study was implemented at Horsefly, Stellako, and Adams Rivers to develop appropriate system specific expansion factors for larger river systems with populations ranging between 25,000 and 75,000. The Adams River was originally not planned as a calibration study location and was added late in the season when large numbers of sockeye failed to materialize. Overall, the study had the following objectives:

1. Develop an appropriate system specific visual expansion factor (index) by calibrating aerial live counts to mark-recapture estimates on the Horsefly, Stellako, and Adams Rivers.
2. Compare the high precision estimation methods that were employed on the Horsefly River (i.e. Mark/Recapture, DIDSON, Fence).
3. Compare and calibrate simultaneous aerial based live counts to ground based live counts.
4. Compare traditional live counts (aerial and ground based) to simultaneous aerial video based counts in an attempt to determine observer efficiency.
5. Compare differences and variability of individual observer counts between habitat types and visual methods.

STUDY AREA

HORSEFLY RIVER

Originating from Wells Grey Provincial Park within the Cariboo Mountains, the Horsefly River is a large tributary (110 km) entering the southwest corner of the main arm of Quesnel Lake draining a watershed of 2,756 km^2. The Horsefly River system consists of three main tributaries: Little Horsefly River, McKinley Creek and Moffat Creek (Fig. 1).

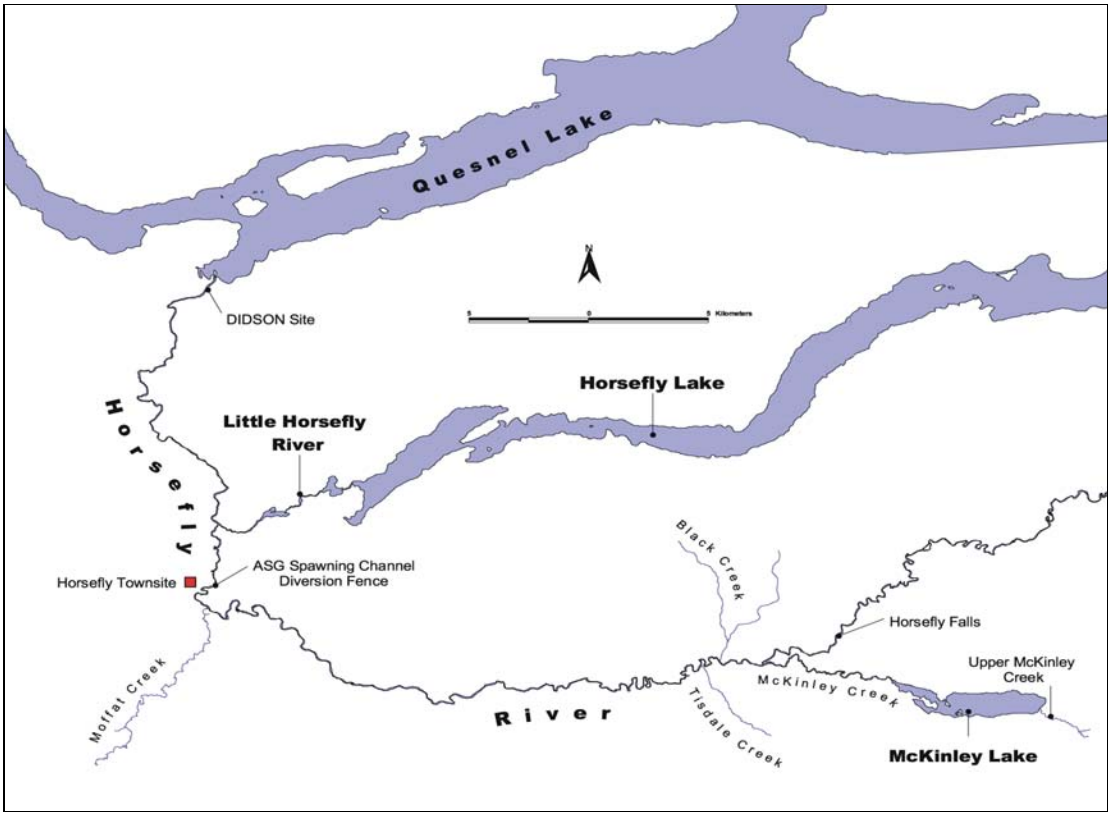

Figure 1. Overview map of the Horsefly River system.

The upper most areas of the Horsefly River near the McKinley Creek confluence are characterized by riffles, pools and cobble and gravel substrate within a well defined, low to moderate gradient channel. Further downstream the river meanders through a broad flood plain and has primarily a mud, silt and sand substrate before transitioning back to larger substrates and moderate gradients. The flow regime of the lower river differs from the upper river due to the increased discharge from Little Horsefly River. The gradient is below the townsite then increases as it flows though a series of small steps in exposed bedrock. Further downstream the river decreases in gradient and substrate size and braids frequently as it extends to Quesnel Lake. The Horsefly River is accessible to sockeye upstream to an impassable falls approximately 62.6 km above the mouth (Houtman and Cone 2000).

Daily discharge of the Horsefly River above McKinley Creek averages 19.5 m^3s^{-1} with a mean daily maxima of 180 m^3s^{-1} and mean daily minima of 1.59 m^3s^{-1} occurring in July and March, respectively (Environment Canada 2007a). The 2007 calibration study on the Horsefly River included the entire accessible spawning area of the river from the mouth at Quesnel Lake upstream to the impassable falls (Fig.1).

STELLAKO RIVER

The Stellako River originates from Francois Lake and flows northeast for 13 km before entering the western end of Fraser Lake (Fig. 2). The river has a generally shallow, well defined, and stable channel with a predominately boulder substrate. The uppermost sections of the river are primarily wide (approximately 35 m in channel width) with rapids and riffles separated by isolated pools and runs with a boulder and cobble substrate. A 1.5 m high, passable falls is located approximately 7.0 km upstream from Fraser Lake. Downstream of the falls the river flows out of the broad canyon and into an open plain where it becomes more sinuous, with discrete gravel bars as it meanders through increasingly prevalent gravel substrate. The river enters a vegetation-filled lagoon before flowing through a deep, slow moving channel into Fraser Lake (Schubert 2000). The majority of the sockeye spawning is located in the lower sections of the river between an area known as “Grassy Banks” and the traditional site of the DFO sockeye enumeration fence located approximately 1 km upstream of the Highway 16 bridge.

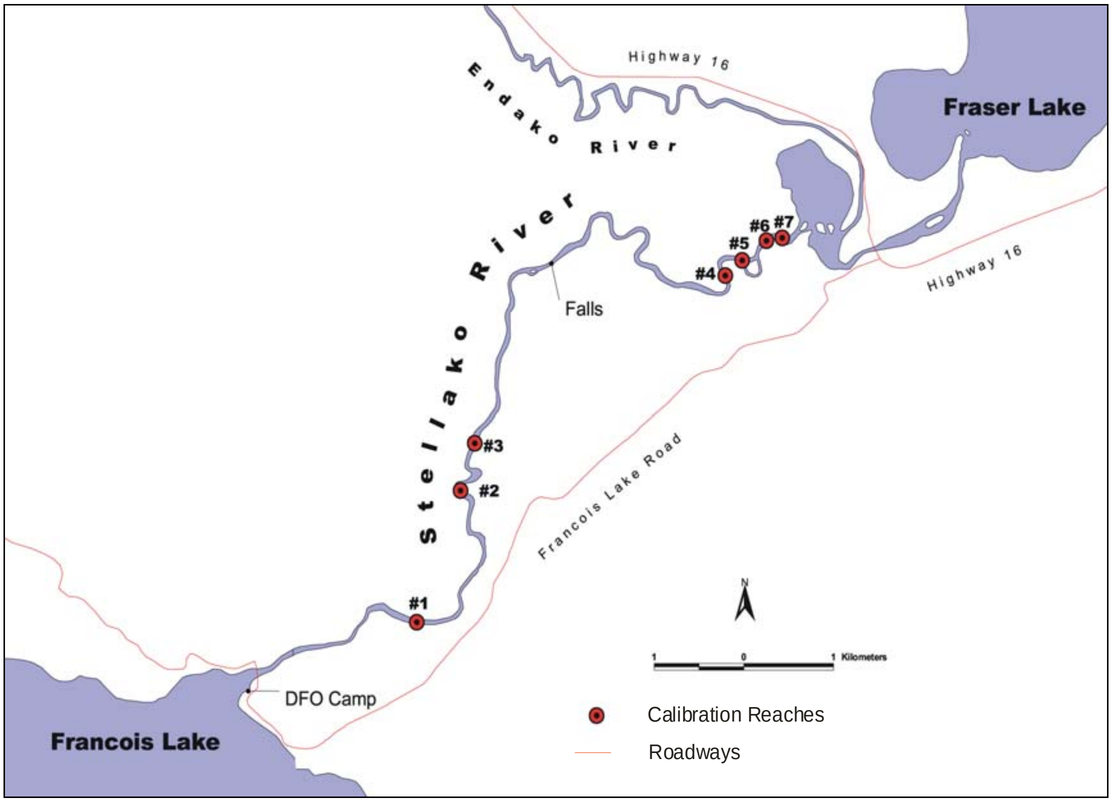

Figure 2. Stellako River system study area location map.

Daily discharge of the Stellako River averages 20.4 m^3s^{-1} (monitored at Glenannan) with a mean daily maxima of 166 m^3s^{-1} and mean daily minima of 1.98 m^3s^{-1} occurring in June and January, respectively (Environment Canada 2007b). The 2007 calibration study on the Stellako River included the entire river from the mouth at Fraser Lake upstream to its origin at the outlet of Francois Lake (Fig. 2).

ADAMS RIVER

The Adams River is situated in the South Thompson River system with headwaters originating from the Columbia Mountains flowing south for 117 km before entering Shuswap Lake, near Squilax, BC. The river downstream and upstream of Adams Lake is referred to as the Lower and Upper Adams River, respectively (Fig. 3).

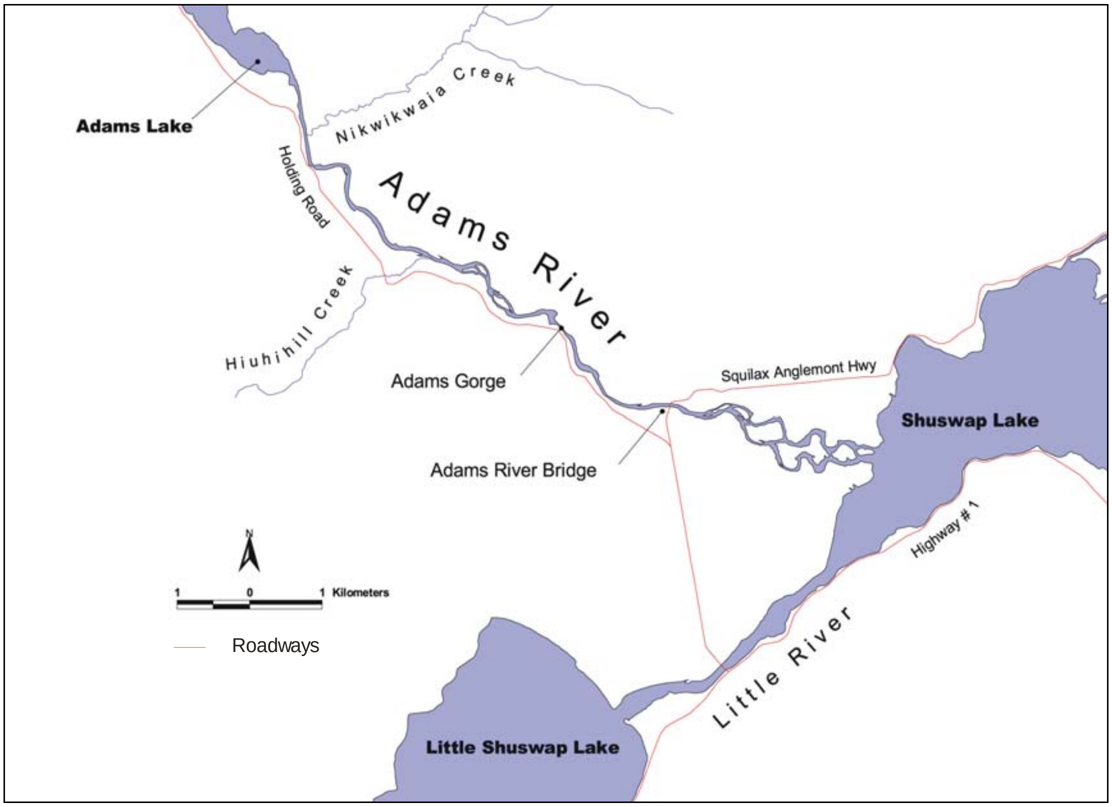

Figure 3. Adams River system study area location map.

The river morphology in the Lower Adams River changes frequently within its short 11 km length. Upstream from the Highway Bridge, the river mainly consists of a single channel with moderate flow and a cobble/boulder substrate. Within this area, the river channel narrows down to 15 m in width through a 100 m long canyon. Downstream of the bridge, the river is heavily braided with gravel bars and treed islands. Gravel and cobble substrates predominate in this section of the lower river. Sockeye spawning is typically heavier here than any other section of Adams River (Houtman and Fanos 2000); however, the amount of available spawning in the lower river has been reduced in the last 10 years due to constantly changing river morphology (Adams River Habitat Assessment 2005). Daily discharge of the Adams River averages 70.4 m^3s^{-1} (near Squilax, BC) with a mean daily maxima of 396 m^3s^{-1} and mean daily minima of 2.41 m^3s^{-1} occurring in June and April, respectively (Environment Canada 2007c). The 2007 calibration study on the Lower Adams River included the entire river from its mouth at Shuswap Lake upstream to the outlet at Adams Lake.

METHODS

This section describes the field methods and analytical procedures for the enumeration (high and low precision) and calibration techniques (observer efficiency and index calculation) employed in this study. Due to project logistics, financial constraints and late developments regarding sockeye abundance in the Fraser watershed, each river system experienced varying levels of survey intensity. The Horsefly River was the most intensively studied followed by the Stellako and the Adams Rivers. Due to this variation in study design, comparisons and subsequent analysis could not be consistently extended across all locations.

HIGH PRECISION METHODS

Mark-Recapture

Mark-recapture methods were used to generate high precision sockeye escapement estimates on the Horsefly, Stellako and Adams Rivers. The precision objective of a mark-recapture study for management purposes is to estimate the sex specific escapement with 95% confidence limits of ± 25%. The accuracy of a mark-recapture escapement estimate depends on how well the study satisfies the mark-recapture assumptions as outlined in Seber 1982. The field methods employed in the three mark-recaptures in this study are complex and will not be detailed in this report, but are similar to those described in Schubert 2007. The following is a general overview of the procedures used to analyze the 2007 mark-recapture studies.

To address the population closure assumption, the data are first examined and adjusted (if required) for tag emigration from the mark-recapture study area. Next, since the tagging procedure can induce stress that can influence post-tagging behaviour and the timing and probability of recovery, the data are evaluated (using chi-square tests) to determine whether specific tags should be excluded from the application sample as a result of tagging.

To address the equal opportunity of capture and recapture assumption, statistical tests are then performed to determine whether application and recovery were proportional and whether complete mixing occurred (Seber 1982). The data are examined for temporal, spatial and fish sex biases at application and recovery using chi-square tests. Application bias (non-proportional application and incomplete mixing) is assessed by stratifying the recovery sample and comparing the mark incidence (the proportion of carcasses with disk tags and/or secondary marks) among strata. Similarly, recovery bias (non-proportional recovery and incomplete mixing) is assessed by stratifying the application sample and comparing the proportion recovered among strata. The data are further examined for a size bias in recovery using a Kolmogorov-Smirnov two-sample test (application bias cannot be assessed since unmarked carcasses are not measured). The data are also examined for interactions among tag status, location of recovery relative to the tag site and female spawning success as indicators of further tagging induced stress using chi-square tests. Finally, the data is examined and adjusted (if required) for tag loss, tag recognition error and sex identification error.

Sex specific escapements to Horsefly, Stellako and Adams Rivers were estimated using the Pooled Peterson mark-recapture estimator ("PPE"; Seber 1982). The use of sex specific data avoids potential biases resulting from differences between males and females in arrival timing and behaviour on the spawning grounds (Schubert, 2007).

Fence

Based on pre-season forecasts, the 2007 escapement to the Horsefly River was expected to exceed the 75,000 threshold. Therefore, to allow for the calibration of visual estimates on the Horsefly River in 2007, the study design included the installation of the Spawning Channel diversion fence, located 22 km upstream from the mouth to obtain a total count of sockeye into the upper portions of the Horsefly River with the expectation that escapement to the upper river would fall somewhere between 25,000 and 75,000 spawners. The Horsefly River Spawning Channel (ASG) diversion fence is constructed of a series of aluminum panels spanning the entire wetted width (approximately 50 m) of the Horsefly River along a permanent concrete sill. The fence was installed prior to sockeye arrival to the upper river then remained closed until the first sockeye were observed holding below the fence. The diversion fence operated daily from sockeye arrival until its permanent closure on September 6, 2007 to facilitate the loading of Horsefly Spawning Channel.

Daily fence operation varied due to fish behaviour, fish migration patterns and environmental conditions. Sockeye were counted through the fence by 1 or 2 crew members per shift with as many as 3 or 4 crew members per shift during heavy migration periods. Split shifts were commonly used to allow for fish passage during optimal migration times which were generally sunrise and sunset. During periods of heavy migration, the fence would be opened from approximately 0600 hrs to approximately 2100 hrs. Crew members generally counted fish through the fence by removing 1 to 4 aluminum dowels. Sockeye counts were recorded by direction (upstream and downstream) and tag status (tagged and untagged) hourly during fence operation. Weather conditions, fish visibility, and water temperature was recorded twice a day. When possible, approximate counts of fish holding below the fence were noted. Any significant activity in or around the fence site that could affect fish behaviour was also noted.

The total net upstream fence count provided a census of the total escapement to the upper portions of the Horsefly River in 2007. Sex ratios were obtained from the total river carcass recovery sample. An independent mark-recapture estimate (PPE) of the upper Horsefly escapement (above the diversion fence) was also calculated using the total number of Petersen disc tags counted upstream through the fence and the carcass recovery sample above the fence. Since it was not feasible to collect the individual Petersen disc tag numbers by sex through the fence, bias testing and sex specific estimates for the upper river mark-recapture was not possible.

DIDSON

In 2007, Dual Frequency Identification Sonar (DIDSON) was used as an additional high precision method in order to obtain a total adult sockeye escapement to the Horsefly River system, including all of its major tributaries and the Horsefly River Spawning Channel (ASG). DIDSON is an underwater acoustic camera that produces near video quality images utilizing multiple sound beams focused through a movable lens. Objects within the field (also known as the ensonified area) reflect sound back to the sonar where the echoes are used to develop an image. It has the ability to provide images in turbid or dark water. When proper protocols and procedures are followed, DIDSON estimates of fish passage can be as accurate as enumeration fence counts (Holmes *et al.* 2006). DIDSON was previously used on the Horsefly River in conjunction with a broader feasibility study in 2004 identifying potential sites for adult sockeye enumeration in the Fraser River watershed (Holmes *et al.* 2005) and finally utilized for salmon escapement estimation on the Horsefly River in 2005 (Cronkite *et al.* 2006) and 2006.

The site chosen for DIDSON on the Horsefly River in 2007 was approximately 400 m upstream from the river mouth (Fig. 4). Approximately 55 m of fish deflection weir was used to direct migrating adult sockeye through an 11.7 m opening in the weir. DIDSON set-up (including weir construction) and operation follows procedures outlined in Cronkite *et al*. 2006; Enzenhofer and Cronkite 2005; and Enzenhofer *et al.* 2005. The DIDSON data collection and analysis protocols followed in 2007 are described in detail by Cronkite *et al.* 2006. The following is a general overview of the field methods and analytic procedures employed at the 2007 Horsefly DIDSON project.

The DIDSON system was programmed to record the first twenty minutes of every hour over the entire sockeye arrival period. All files were manually counted and recorded into a MS Excel spreadsheet that expanded for the total hourly upstream migration. A minimum of 5 files per day were randomly counted by 2 or more different observers (the average count used to calculate the hourly net upstream migration). A minimum of 4 simultaneous visual and DIDSON counts were collected daily during daylight hours throughout the study period to ensure that sockeye were not passing the DIDSON system undetected. The sum of the expanded hourly net upstream migration past the DIDSON site provided an estimate with known precision of the total Horsefly River system sockeye escapement in 2007.

Figure 4. Aerial view of the 2007 Horsefly River DIDSON site.

LOW PRECISION METHODS

Aerial Counts

One aerial survey was conducted at the Horsefly, Stellako and Adams Rivers during the peak of spawn as indicated by mark-recapture crew members. A second aerial survey was carried out below the Horsefly River diversion fence approximately one week after the first survey to coincide with the later peak of spawn that is typical of the lower Horsefly River spawners. Flights were scheduled for the best possible lighting and weather conditions during the day to minimize surface glare. All aerial counts were conducted by experienced (greater than 3 years) observers. Horsefly aerial counts consisted of 2 to 4 observers (1 replicate flight) while Stellako and Adams aerial counts had 2 observers (single flight). The same two observers were present for all aerial surveys to address consistency issues. All aerial surveys covered the entire length of spawning with each observer recording individual counts of live and dead sockeye by reach. All observers wore polarized sunglasses and used mechanical counters to keep track of their individual counts of sockeye salmon.

Counts between individual aerial observers were averaged to produce mean aerial counts by reach. The use of 4 observers on the Horsefly River allowed for comparisons between observer counts.

Ground Counts

The aerial surveys were paired with ground surveys (conducted within 24 hours of the aerial survey) to permit direct comparisons of the ground and aerial counts. Ground surveys, which were performed in an inflatable raft (one observer; one rower per survey), were conducted in designated sections or “calibration reaches” (see description below) at Horsefly and Stellako rivers due to river length and program logistics; whereas, the ground survey of the Adams River covered the entire length of the river. Subsequently, the aerial to ground visual comparisons of the Horsefly and Stellako rivers were of the sub-sampled calibration reaches only, while the entire length of river was used for comparison at the Adams River. Individual counts of live and dead sockeye were recorded by reach. All ground counts were conducted by experienced (greater than 3 years) observers. All ground observers wore polarized sunglasses and used mechanical counters to keep track of their individual counts of sockeye salmon.

One replicate ground survey of the Horsefly River was conducted to allow for the comparison between observer counts. Individual counts from the two observers were averaged to generate a mean ground count by calibration reach at Horsefly. Replicate ground surveys were not conducted on the Stellako and Adams Rivers.

Video Counts

During aerial surveys of the Horsefly and Stellako rivers, designated sections or “calibration reaches” (see description below) were video recorded to directly compare aerial, ground and video (post-processing) counts. These video files attempted to provide an accurate baseline for the comparison of observer live counts in order to obtain accurate observer efficiencies. A Sony® Digital HD (High-Definition) video camera recorder (Sony® Handycam™ Model HDR-SR7) with a polarized lens and a 60 gigabyte hard drive was used to video tape calibration reaches from start to finish. Care was taken to schedule helicopter flights during favourable weather and light conditions. Videotaping was taken as parallel as possible to the river channel while encompassing the channel width. Each video taped calibration reach was individually identified by file name, date and time for cross-referencing to the appropriate aerial and ground counts in post-season analysis.

Recorded video files stored on the camera’s hard drive were played back on a 91 cm (36 inch) Panasonic® TAUW/HD television. A grid pattern (10 cm x 11.5 cm squares) made from a clear acetate sheet was taped in front of the television screen along the edge to aid in counting. Each of the selected files (21 in total) were independently counted by two people to allow for comparisons between observers. The counts were averaged to produce a mean count between the two video observers for each calibration reach. Each videotaped reach was rated for visibility as either poor, moderate or good. Video footage that was deemed by the project supervisor to be of poor quality was not used in the analysis.

CALIBRATION REACHES

Calibration reaches were developed at the Horsefly and Stellako rivers to permit the evaluation of the effect of stream morphology on observer efficiency and to directly compare aerial counts to ground counts. Nine major habitat types were chosen as representative on the Horsefly and Stellako rivers with each calibration reach identified by habitat type (i.e. riffles, glides, deep pools, etc., Table 1). Since water depth, substrate size, substrate colour, type and amount of overhanging riparian vegetation and spawning densities collectively influence observer efficiencies, replicated reaches representing different habitat types were chosen. The start and end of each reach was georeferenced using a Garmin® 60CSx GPS and were identified with white markers (approximately 1 m x 1 m signs) so that they were visible from the ground and air. The reach breaks never occurred in the middle of spawning riffles/runs; instead, they were located in transition areas or natural breaks where sockeye were not likely to spend any time except to migrate through (i.e. a corner pool that transitions from deep, slow moving water to a shallow, fast moving riffle). In 2007, due to the low abundance of sockeye relative to the total available spawning habitat, especially at Horsefly, only the optimal primary spawning habitats were utilized. Consequently, only habitat types 1 to 4 were thoroughly utilized and subsequently assessed. Very few or no spawning sockeye were observed in other habitats (Habitats 5-9) and as a result were not assessed for calibration purposes. Overall, a total of 14 calibration reaches were assessed at Horsefly (Figs. 5-7) and 7 at Stellako (Fig. 2) ranging from 99 m to 836 m in length (Appendix 1).

Table 1. Habitat type number and description used for Horsefly and Stellako River calibration reaches, 2007.

Habitat Type #	Habitat Type Description
1	Bank to bank cobble/gravel; shallow (0.25m-1m) glide
2	Bank to bank cobble/gravel; shallow (0.25m-1m) glide with large boulders interspersed throughout
3	Bank to bank cobble/gravel; moderate depth (1m-3m) glide with shallower "tail-out"
4	Bank to bank cobble/gravel; moderate depth (1m-3m) glide (trough or U-shaped throughout)
5	Bank to bank boulders; deep glide
6	Cut bank glides
7	Deep cut bank glides
8	Boulders, pools, riffles, Class 1 rapids, large canopy (canyon)
9	Deep pools

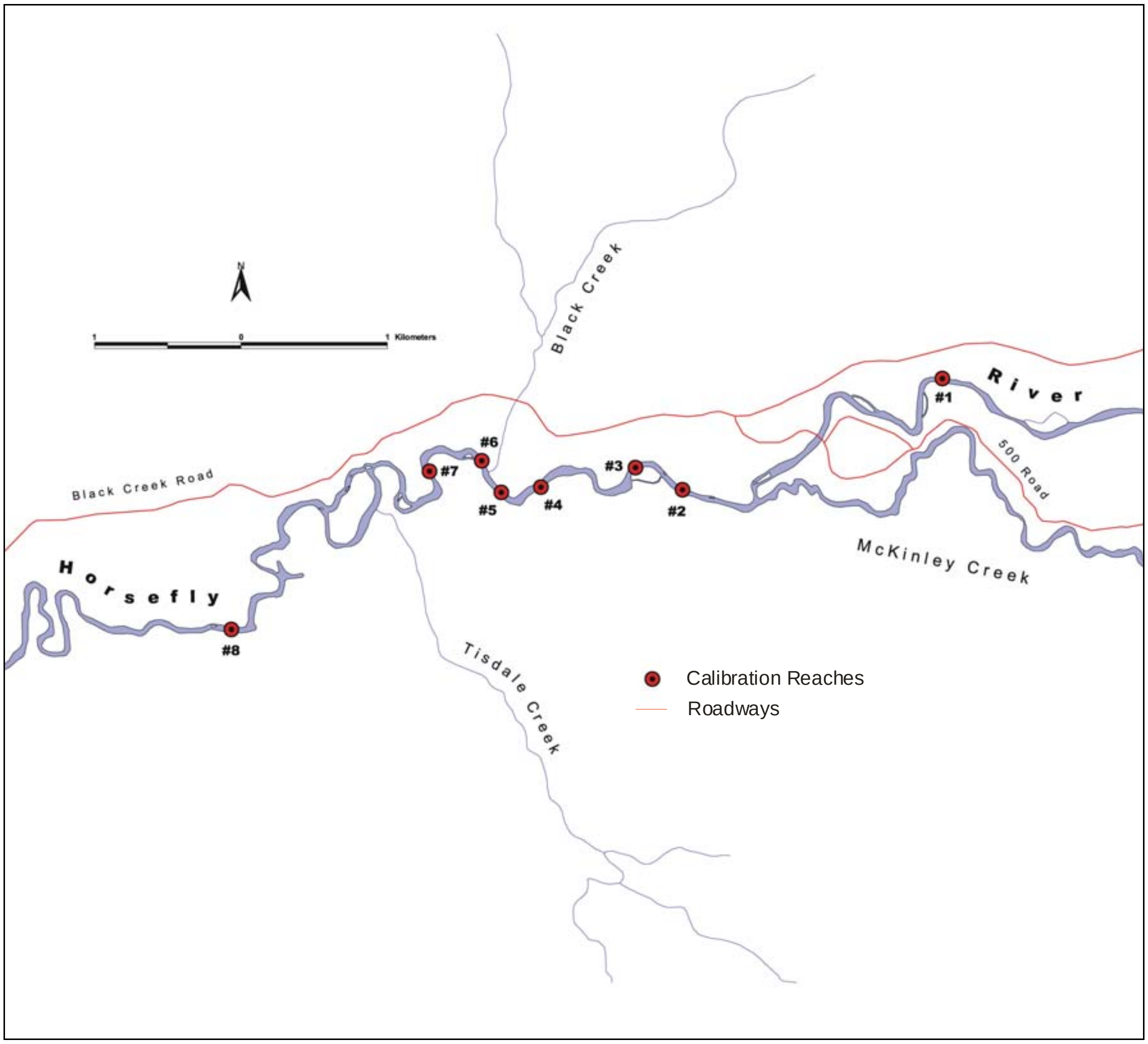

Figure 5. Upper Horsefly River study area map showing calibration reaches.

Analysis comparing variance between counters within specific habitat types (calibration reaches) was conducted using JMP software Version 7.0.1 (SAS Institute Inc. 2007). The precision of the observer counts (repeatability of counts between observers) was assessed using the average percent error (APE). Analysis of Variance (ANOVA) was used to compare the average percent error between observers and habitat types as well as between aerial, ground and video counts. Differences in counts amongst observers were tested using the Least Squares Means Differences Student's *t*-test (log scale). Individual variability in observer counts was assessed by plotting a One-way Analysis of residual log counts by observer.

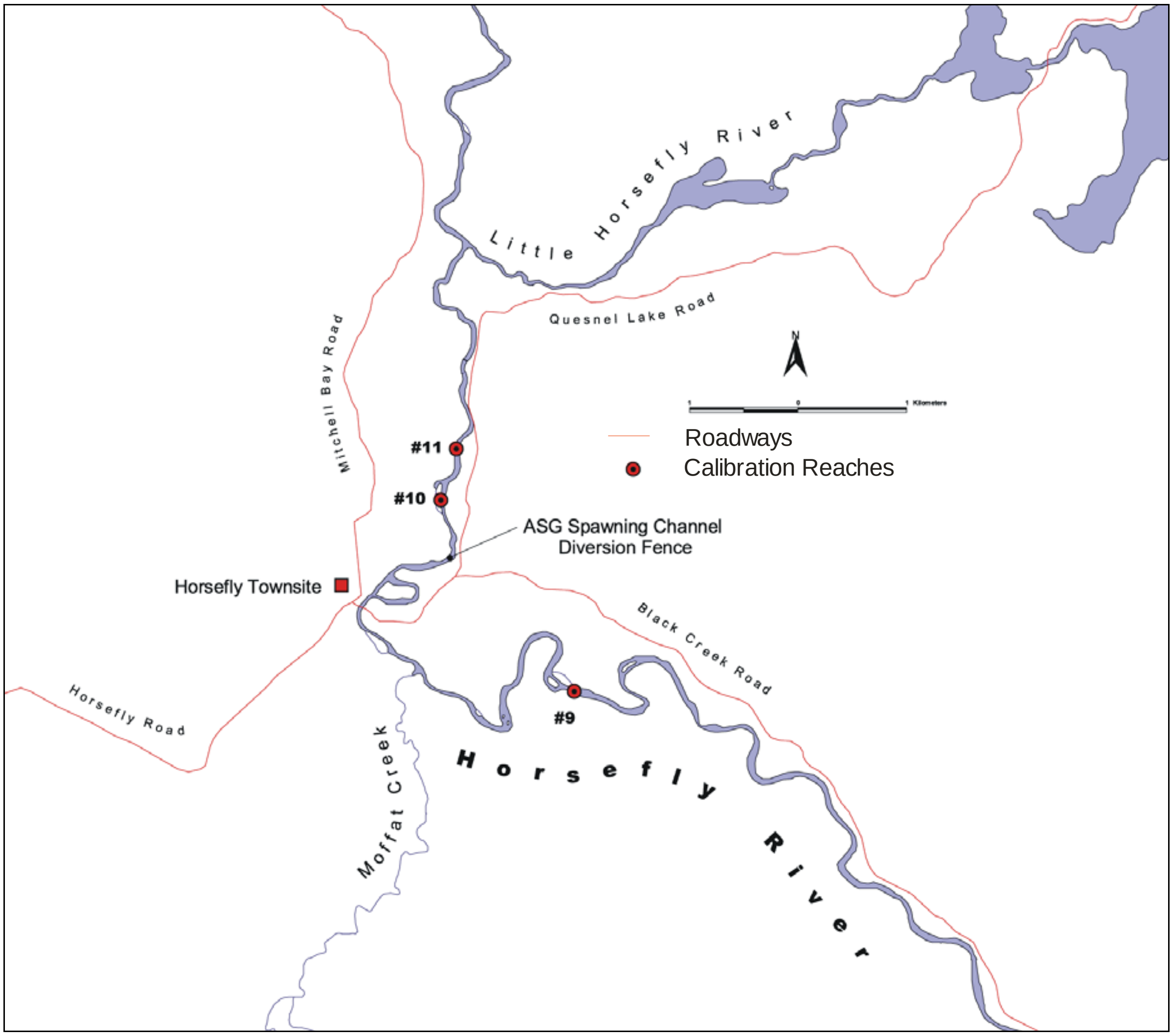

Figure 6. Middle Horsefly River study area map showing calibration reaches.

OBSERVER EFFICIENCY AND INDICES

Observer efficiency is an essential component in determining the corrective indices for estimating sockeye escapements for all visual surveys in the Fraser River watershed. Observer efficiency is defined as the proportion (or ratio) of fish counted relative to the actual number of fish present in the stream during the survey (Korman *et al.* 2002). An index is developed by dividing a high precision population estimate by the peak live count plus the cumulative count of recovered carcasses through the date of the peak live count.

Aerial counts were compared directly to mark-recapture, fence and DIDSON estimates at Horsefly River and mark-recapture estimates at Stellako and Adams rivers. System specific indices were produced by dividing the high precision estimate by the aerial count (live plus dead). Three indices for aerial to mark-recapture were produced for the Horsefly River – upper, lower and total. The upper Horsefly River aerial to mark-recapture index was generated by dividing the upper mainstem mark-recapture estimate by the upper mainstem aerial count.

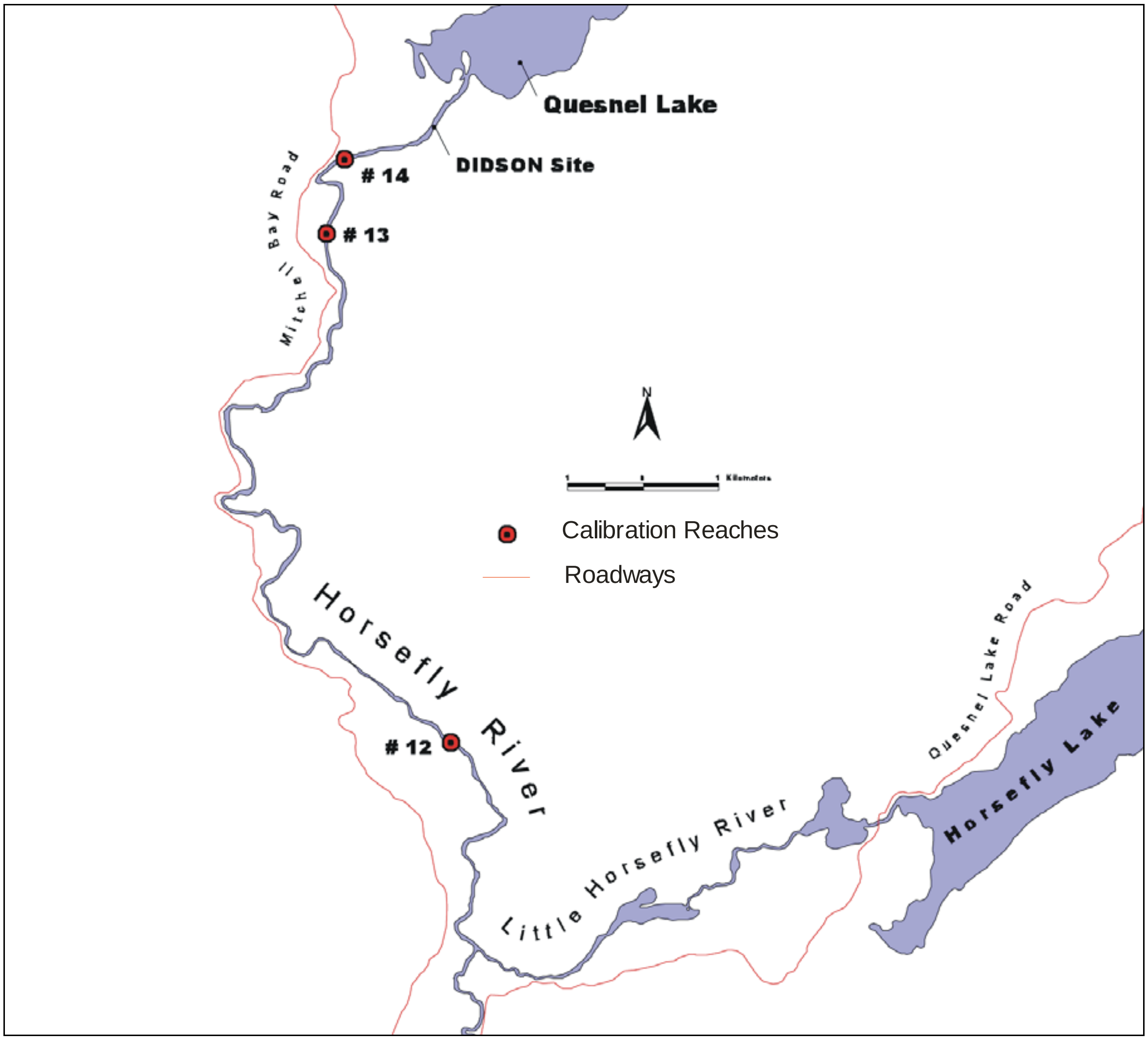

Figure 7. Lower Horsefly River study area map showing calibration reaches.

The lower Horsefly River aerial to mark-recapture index was produced by dividing the lower mainstem mark-recapture estimate (the total mainstem mark-recapture estimate minus the fence count) by lower mainstem aerial count. The total Horsefly River aerial to mark-recapture index was generated by dividing the total mainstem mark-recapture estimate by the total mainstem aerial count. Similarly, indices were generated by calibrating the aerial counts against the DIDSON and fence estimates.

Aerial counts were compared to ground counts for the Horsefly, Stellako and Adams rivers by dividing the aerial count by the ground count. Similarly, video counts from the Horsefly and Stellako rivers were compared to ground counts by dividing the video counts by ground counts.

RESULTS

HIGH PRECISION METHODS

Horsefly Mark-Recapture

Tag application began August 22, 2007 and continued until September 23, 2007, with a total of 1,079 sockeye tagged. Recovery began August 29, 2007 and continued until October 2, 2007, with a total of 9,599 carcasses recovered, of which 189 were tagged. After adjustments the final application, carcass recovery and tagged recovery samples totaled 945, 7,180 and 122, respectively (Table 2). The 2007 Horsefly River sockeye escapement, based on the PPE and adjusted data, is 29,314 adult males and 25,867 adult females with 95% confidence limits of ± 7,182 (24.5%) and 5,536 (21.4%), respectively (Table 2). The total river escapement, produced by summing the sex specific estimates, is 55,181 ± 9,050 (16.4%) adult sockeye. The total system estimate, which includes the visually generated estimates of the main spawning tributaries (Little Horsefly River and McKinley Creek) and the absolute count into the Horsefly Spawning Channel is 60,792 adult sockeye.

Detailed examination of the Horsefly River mark-recapture data indicate that the tagging process was relatively stress-free (no indication of differences in recovery probabilities between tagged and untagged sockeye) and that application and/or recovery was proportional with respect to sex, size, time and space in both sexes (Table 3). Therefore there is no indication that the male or female PPE estimates are biased.

Table 2. Total (unadjusted) and adjusted application and recovery samples with resulting Pooled Petersen estimates (+/- 95% c.l.) by sex for the total Horsefly, upper Horsefly, Stellako, and Adams Rives, 2007.

	Total (unadjusted)			Adjusted					
Mark-Recapture	Tags Applied	Carcass Recoveries	Tagged Recoveries	Tags Applied	Carcass Recoveries	Tagged Recoveries	Population Estimate (N)	95% c.l.	Percent of N
Horsefly (Total)									
Male	528	4,493	97	483	3,327	54	29,314	7,182	24.5%
Female	551	5,106	92	462	3,853	68	25,867	5,536	21.4%
Total	1,079	9,599	189	945	7,180	122	55,181	9,050	16.4%
Horsefly (Upper)									
Total	354	5,204	70	334	5,080	68	24,668	5,106	20.7%
Stellako									
Male	1,704	4,890	409	1,707	4,889	408	20,425	1,654	8.1%
Female	2,042	6,294	612	2,024	6,288	609	20,903	1,317	6.3%
Total	3,746	11,184	1,021	3,731	11,177	1,017	41,328	2,108	5.1%
Adams									
Male	714	2,358	71	679	2,223	65	22,830	5,114	22.4%
Female	759	3,778	93	767	3,626	92	29,883	5,588	18.7%
Total	1,473	6,136	164	1,446	5,849	157	52,713	7,591	14.4%

Stellako Mark-Recapture

Tag application began September 5, 2007 and continued until October 3, 2007, with a total of 3,746 adult sockeye tagged. Recovery began September 11, 2007 and continued until October 24, 2007, with a total of 11,184 adult carcasses recovered, of which 1,021 were tagged. After adjustments the final application, carcass recovery and tagged recovery samples totaled 3,731, 11,177 and 1,017, respectively (Table 2). The 2007 Stellako River sockeye escapement, based on the PPE and adjusted data, is 20,425 adult males and 20,903 adult females with 95% confidence limits of ± 1,654 (8.1%) and 1,317 (6.3%), respectively. The total river escapement, produced by summing the sex specific estimates, is 41,328 ± 2,108 (5.1%) adult sockeye (Table 2).

Detailed examination of the Stellako River mark-recapture data indicated several biases (Table 3). Four of the seven tests for tagging related stress suggested that tagged sockeye were potentially behaving differently than untagged sockeye. Additional identified biases include: i) a temporal application bias in both sexes ii) a temporal recovery bias in males and iii) a spatial application bias in both sexes (Table 3). Note that spatial recovery bias could not be tested for and thus could not be ruled out. Consequently, both the male and female PPE estimates for the Stellako River are potentially biased in 2007.

Adams Mark-Recapture

Tag application began September 26, 2007 and continued until October 26, 2007, with a total of 1,473 adult sockeye tagged. Recovery began October 2, 2007 and continued until November 7, 2007, with a total of 6,136 adult carcasses recovered, of which 164 were tagged. After adjustments the final application, carcass recovery and tagged recovery samples totaled 1,446, 5,849 and 157, respectively (Table 2). The 2007 Adams River sockeye escapement, based on the PPE and adjusted data, is 22,830 adult males and 29,883 adult females with 95% confidence limits of ± 5,114 (22.4%) and 5,588 (18.7%), respectively. The total river escapement, produced by summing the sex specific estimates, is 52,713 ± 7,591 (14.4%) adult sockeye (Table 2).

Detailed examination of the Adams River mark-recapture data indicate that the tagging process was relatively stress-free (no indication of differences in recovery probabilities between tagged and untagged sockeye) and that application and/or recovery was proportional with respect to sex, size, time and space in both sexes (Table 3). Therefore there is no indication that the male or female PPE estimates are biased.

Horsefly Diversion Fence

A total of 25,706 sockeye, 354 of which were tagged were counted into the upper Horsefly River from August 24, 2007 to September 6, 2007 (Appendix 2). Of these, an estimated 1,245 sockeye migrated to McKinley Creek (upper and lower) leaving an estimated 24,461 in the upper river mainstem (Table 4).

Of the 354 tagged sockeye counted upstream of the diversion fence, 20 were estimated to have emigrated to McKinley Creek (upper and lower), leaving an estimated 334 tagged sockeye in the upper river mainstem (Table 2). Adjusted carcass recoveries in the upper river mainstem totaled 5,080, of which 68 were tagged. The resulting independent mark-recapture estimate of the upper Horsefly mainstem based on the PPE and adjusted data is 24,668 ± 5,106 (20.7%) adult sockeye (Table 2).

Table 3. Bias profile for the Horsefly (total), Stellako and Adams river mark-recapture studies, 2007.

		Test results [a.]		
Bias type	Sample Stratification	Horsefly (Total)	Stellako	Adams
Application sample				
Temporal	Recovery period	No Bias	Bias	No Bias
Spatial	Recovery Areas	Female Bias	Bias	No Bias
Fish sex	Males vs Females	No Bias	Bias	No Bias
Stress				
% spawn success	Tagged vs Untagged	No Bias	Bias	No Bias
% spawn success	Above vs below the tag site	n/a	Bias	n/a
Tag Incidence	Above vs below the tag site	n/a	Bias	n/a
Recovery sample				
Temporal	Application period	No Bias	Male Bias	Bias
Spatial	Tag Sites	No Bias	n/a	Bias
Fish sex	Males vs Females	No Bias	Bias	No Bias
Fish size	Recovered vs Nonrecovered	No Bias	No Bias	No Bias
Stress				
Recapture	# times recaptured	No Bias[b]	Female Bias	No Bias
Release Code	Condition on release	No Bias[b]	No Bias[b]	No Bias[b]
Tag Status	# of tags applied (single vs. double)	No Bias	No Bias	No Bias
Holding Time	Length of time held in the net	No Bias	No Bias	No Bias

[a.] A " no bias" test result indicates that bias was not detected; undetected bias may be present.

[b.] Test result may be biased due to small sample size.

n/a = test not applicable.

Horsefly DIDSON

The 2007 sockeye salmon migration into the Horsefly River began mid-August and finished in late September (DIDSON operated from August 13 to September 26, 2007). Figure 8 displays the daily sockeye salmon migration past the Horsefly River DIDSON site in 2007. The daily escapement plot displays multi-modal run timing with a maximum daily net upstream escapement estimate of 6,974 sockeye salmon on August 26, 2007. Total sockeye escapement to the Horsefly system estimated using DIDSON was 60,721 with 95% confidence limits of ± 11,930 (± 20%). The width of this interval reflects errors associated with 1) counting the DIDSON data sets (accuracy), 2) the repeatability of counts between different individuals for the same data sets (precision), and 3) temporal sub-sampling (representativeness of the sampling). The error in counting the DIDSON data sets can be considered overall to be zero for this population estimate as the DIDSON data are not biased by fish moving past the site undetected (Holmes *et al.* 2006). The repeatability of counts (APE) contributed an overall error of ±19% and the temporal sub-sampling of 20 minutes out of every hour contributed an overall error of ±5%. Daily expanded and cumulative DIDSON counts are presented in Appendix 3.

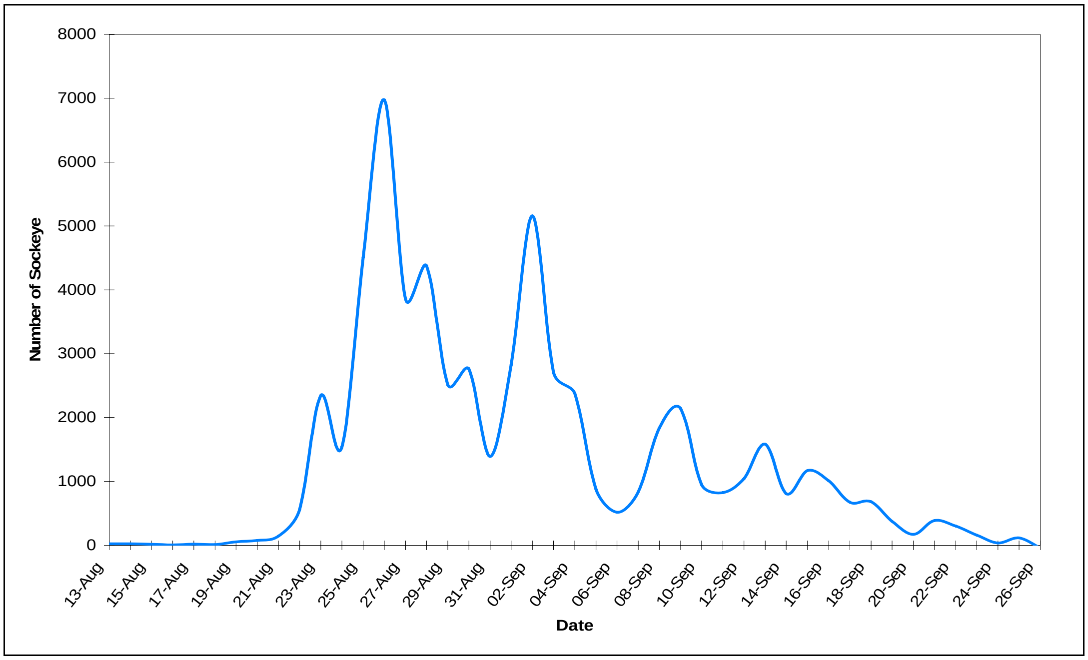

Figure 8. Daily net upstream sockeye counts past the Horsefly River DIDSON site, 2007.

LOW PRECISION METHODS

Horsefly River

An aerial survey of the entire Horsefly mainstem was conducted on September 9, 2007 with a total of 22,406 sockeye (live + dead) enumerated (Table 4). Of this, 13,943 and 8,463 sockeye (live + dead) were enumerated above and below the diversion fence, respectively (Appendix 4.) Independent aerial counts of the nine upper river calibration reaches were also conducted during the same flight with an average total of 4,270 sockeye enumerated. Ground surveys of the nine upper river calibration reaches were conducted on September 8-9, 2007, with an average total count of 5,613 sockeye enumerated. A second aerial survey of the lower Horsefly River (below the diversion fence) was conducted on September 15, 2007 with an average total count of 7,097 sockeye (live + dead) enumerated (Appendix 4). Independent aerial counts of the 5 lower river calibration reaches were also conducted during the same flight with an average total count of 2,194 sockeye enumerated. Ground surveys of the 5 lower river calibration reaches were conducted on September 14 and 15, 2007, with an average total count of 2,351 sockeye enumerated. An average total of 4,016 and 1,546 sockeye were enumerated during post-season video analysis of the upper and lower calibration reaches, respectively (Table 4).

Aerial counts of the calibration reaches in the upper, lower and entire Horsefly River were 76%, 93% and 81% of the ground counts, respectively (Table 4). Video counts of the calibration reaches in the upper, lower and total Horsefly Rivers were 72%, 66%, and 70% of the ground counts, respectively. The indices generated from comparing the peak aerial live count (September 9th flight) to the mark-recapture estimates for the upper, lower and total Horsefly River are 1.77, 3.63, and 2.46, respectively. The index generated from the comparison of the average aerial count above the diversion fence (13,943) to the absolute count through the fence (24,461) is 1.75. The indices generated from comparing aerial live counts to the DIDSON estimates for the lower and total Horsefly River are 3.62 and 2.46, respectively (Table 4). Aerial counts for the entire Horsefly River are presented by reach and observer in Appendix 4. Aerial, ground and video counts for individual calibration reaches on the Horsefly River are presented in Appendix 5.

Stellako River

An aerial survey of Stellako River was conducted on September 29, 2007 with an average total count of 13,100 sockeye (live + dead) being enumerated (Table 4). Independent aerial counts of the 7 calibration reaches were also conducted during the same flight with an average total of 10,110 sockeye enumerated. Ground surveys were conducted on September 28 and 29, 2007 on the seven calibration reaches with a total of 12,489 sockeye being counted. A total of 8,417 sockeye were counted on the seven calibration reaches during post-season analysis of video footage (Table 4).

Aerial and video counts of the calibration reaches in the Stellako River were 81% and 67% of the ground counts, respectively (Table 4). The index generated from comparing the aerial live count to the mark-recapture estimate for the Stellako River is 3.15. Stellako River aerial counts by reach and observer are presented in Appendix 6. Aerial, ground and video counts for individual calibration reaches on the Stellako River are presented in Appendix 7.

Table 4. Summary of estimates by method with resulting indices for all calibration study stocks, 2007.

					Indices			Calibration Reaches				
Stock	M/R estimate	DIDSON estimate	Diversion Fence	Aerial estimate	Aerial to M/R	Aerial to DIDSON	Aerial to Fence	Aerial estimate	Ground estimate	Video estimate	% Aerial to Ground	% Video to Ground
Adams	52,713	-	-	16,050	3.28	-	-	-	18,788[f]	-	82%	-
Stellako	41,328	-	-	13,100	3.15	-	-	10,110	12,489	8,417	81%	67%
Horsefly												
Upper	24,688[a]	-	24,461[d]	13,943	1.77	-	1.75	4,270	5,613	4,016	76%	72%
Lower	30,720[b]	30,649[c]	-	8,463	3.63	3.62	-	2,194	2,351	1,546	93%	66%
Total	55,181	55,110	-	22406[e]	2.46	2.46	-	6,464	7,964	5,563	81%	70%

a. Independent M/R estimate

b. Mainstem river M/R estimate minus upper river absolute count (diversion fence)

c. Mainstem river DIDSON estimate minus upper river absolute count (diversion fence)

d. Calibration fence count minus McKinley Creek and Upper McKinley Creek estimates.

e. Peak Count (September 9th flight)

f. Total river estimate

Adams River

An aerial and ground survey of the entire Adams River was conducted on October 15, 2007 with an average total of 16,050 and 18,788 sockeye (live + dead) being enumerated, respectively (Table 4). The average total aerial count was 82% of the ground count (Table 4). The index generated from comparing the aerial live count to the mark-recapture estimate for the Adams River is 3.28 (Table 4). Adams River aerial and ground counts by observer and reach are presented in Appendix 8.

HABITAT AND OBSERVER VARIABILITY

Aerial Surveys

The mean Average Percent Error (APE) of observer aerial counts of all calibration reaches on the Horsefly and Stellako rivers was 12.17%, ranging from 9.03% to 13.42% when stratified by habitat type (Table 5). Although there was no significant difference (p = 0.60, ANOVA) in observer percent error between habitat types, those representing shallow glides (types 1 and 2) revealed a lower mean APE than habitats of moderate depth (types 3 and 4).

Table 5. Mean average percent error (APE) of aerial counts with associated standard error (SE), 95% confidence limits amongst habitat types at Horsefly and Stellako Rivers, 2007.

Habitat Type	(n)	Mean APE (%)	SE	Lower 95%	Upper 95%
1	3	9.98	3.27	3.08	16.87
2	3	9.03	3.27	2.13	15.92
3	10	13.15	1.79	9.38	16.93
4	5	13.42	2.53	8.08	18.76
Mean	21	12.17	2.72	5.67	17.12

Test for Significant Differences in APE between Habitat Types (p = 0.60).

The Least Squares Means Differences Student's t-test outlines the relative differences (log scale) of counts between observers (Table 6). Aerial counts between the four observers at Horsefly were significantly different from each other (p < 0.01, ANOVA; Table 7). Results indicate that the average aerial counts from observer #4 were consistently lower than the other observers. For example, observer #4 has on average, approximately 81% (exp(-0.211)), 79% (exp(-0.231)) and 77% (exp(-0.256)) of the counts of observer #1, #2 and #3, respectively. Upon removal of observer #4 the significant value was eliminated (p = 0.95, ANOVA; Table 7). With the remaining 3 observers the estimated difference is quite small with approximately 2% to 5% difference among these 3 observer counts (Table 6). There was no significant difference between counts from the same 2 observers that were present at all aerial surveys (p = 0.15, ANOVA; Table 7).

Table 6. Least Squares (LS) Means Differences Student's t-test (log scale) comparing observer mean aerial counts with associated standard error (SE) and 95% confidence limits at Horsefly River, 2007.

	Observer 1	Observer 2	Observer 3	Observer 4
Observer 1				
Mean[i]-Mean[j]	0	-0.0208	-0.0456	0.21103
SE Difference	0	0.06844	0.07818	0.06674
Lower CL Difference	0	-0.1601	-0.2047	0.07525
Upper CL Difference	0	0.11841	0.11341	0.3468
Observer 2				
Mean[i]-Mean[j]	0.02082	0	-0.0248	0.23185
SE Difference	0.06844	0	0.08016	0.06844
Lower CL Difference	-0.1184	0	-0.1879	0.09262
Upper CL Difference	0.16006	0	0.13828	0.37108
Observer 3				
Mean[i]-Mean[j]	0.04563	0.02481	0	0.25666
SE Difference	0.07818	0.08016	0	0.07818
Lower CL Difference	-0.1134	-0.1383	0	0.09761
Upper CL Difference	0.20468	0.1879	0	0.41571
Observer 4				
Mean[i]-Mean[j]	-0.211	-0.2318	-0.2567	0
SE Difference	0.06674	0.06844	0.07818	0
Lower CL Difference	-0.3468	-0.3711	-0.4157	0
Upper CL Difference	-0.0752	-0.0926	-0.0976	0

Table 7. Test for significant differences (ANOVA; p-values) between observer counts for visual estimation methods for the Horsefly, Stellako and Adams Rivers, 2007 (level of significance: $\alpha = 0.05$).

Stock	Estimation Method	Number of Observers	P-Value
Horsefly	Aerial	4	<0.01
Horsefly	Aerial[a]	3	0.95
Horsefly/Stellako/Adams	Aerial	2	0.15
Horsefly	Ground	2	0.88
Horsefly/Stellako	Video[b]	2	0.74

a. Removal of observer #4 - same flight

b. Does not include Habitat # 2

Figure 9 displays the variability of individual observer aerial counts at the Horsefly River. Results indicate that there is very little difference in variability among the observers.

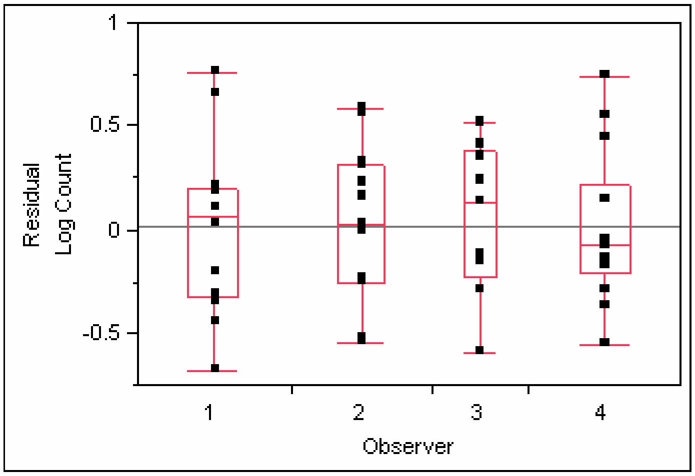

Figure 9. One-way analysis of residual log aerial counts of observers at the Horsefly River, 2007.

Ground Surveys

The mean APE of observer ground counts of all calibration reaches on the Horsefly River was 6.95%, ranging from 3.85% to 14.75% when stratified by habitat type (Table 8). Although there was no significant difference (p = 0.17, ANOVA) in observer percent error between habitat types, type #2 revealed a much higher mean APE (14.75%) than the other three habitat types (Table 8). Additionally, ground counts amongst observers at Horsefly did not differ significantly (p = 0.88, ANOVA; Table 7).

Table 8. Mean average percent error (APE) of ground counts with associated standard error (SE), 95% confidence limits and p-value amongst habitat types at Horsefly River, 2007.

Habitat Type	(n)	Mean APE (%)	SE	Lower 95%	Upper 95%
1	3	3.85	3.60	-4.17	11.87
2	3	14.75	3.60	6.74	22.77
3	5	4.58	2.79	-1.63	10.79
4	3	6.19	3.60	-1.83	14.21
Mean	14	6.95	3.40	-0.22	14.91

Test for Significant Differences in APE between Habitat Types (p = 0.17).

Video Counts

The mean APE of observer video counts of the calibration reaches on the Horsefly and Stellako rivers was 8.41%, ranging from 3.63% to as high as 12.15% when stratified by habitat type (Table 9). Although there was no significant difference (p = 0.17, ANOVA) in observer percent error between habitat types, type #4 revealed a higher mean APE (12.15%) than the other two habitat types (Table 9). Additionally, video recorded counts did not differ significantly amongst observers (p = 0.74, ANOVA; Table 7). Note that habitat #2, which was represented by three calibration reaches, was excluded from the analysis due to the extremely poor quality video files for these particular reaches.

Table 9. Mean average percent error (APE) of video recorded counts with associated standard error (SE), 95% confidence limits and p-value amongst habitat types at Horsefly and Stellako rivers, 2007.

Habitat Type	(n)	Mean APE (%)	SE	Lower 95%	Upper 95%
1	3	3.63	5.98	-9.04	16.30
3	10	7.98	3.27	1.04	14.92
4	5	12.15	4.63	2.33	21.96
Mean	18	8.41	4.63	-1.89	17.73

Test for Significant Differences in APE between Habitat Types (p = 0.17).

DISCUSSION

All three mark-recaptures in this study provided escapement estimates with a precision within 95% confidence limits of ± 25%. All assumptions of the Petersen mark-recapture method were addressed and satisfied at the Horsefly and Adams Rivers indicating that the PPE estimates for these systems are unbiased. However, a number of biases were identified in the Stellako River mark-recapture data including indications that tagged fish may have been behaving differently than untagged fish. As a result, the PPE estimates for the Stellako River may be biased; although, it is difficult to determine the direction of the bias due to the unknown affects of tagging-induced stress on recoverability. Overall, it is believed that the estimates from all three mark-recaptures are able to serve as accurate baselines through which the visual estimates (aerial and ground) can be calibrated and indices generated.

The 2007 enumeration at Horsefly was extremely unique since three independent high precision techniques were employed simultaneously. The point estimate for the upper river mark-recapture was extremely close to the absolute count generated from the diversion fence count and the upper river estimate was relatively precise (± 21%) despite the smaller sample size. When comparing the mark-recapture estimate for the entire Horsefly system to the DIDSON estimate, the point estimates were nearly identical. The close agreement between these high precision estimates lends additional credibility and reliability to the Horsefly River mark-recapture estimate as a suitable standard for comparison purposes with visual methods.

FACTORS AFFECTING OBSERVER EFFICIENCY

Accuracy and variance with visual estimates can be influenced by multiple factors such as river morphology, water colour and clarity, weather (including light conditions), riparian vegetation, intra- and interspecific abundance and the migration's spatial and temporal distribution in the survey area (Trouton 2004).

River morphology and habitat are distinctively different between the upper and lower sections of the Horsefly River. In contrast to the lower Horsefly River, the upper Horsefly River is much smaller in average depth, width and overall discharge. This is largely due to the influence of Little Horsefly River which drains Horsefly Lake (5868 ha in area) before entering the Horsefly River approximately 4km downstream of the diversion fence. In addition, substrate size is generally smaller and lighter in colour (i.e. small gravels and cobbles with reduced algae growth) in the upper Horsefly River. The overall morphology of the upper river primarily consists of shallow riffles and glides; whereas, the lower river is predominantly deeper riffles, rapids, deep pools and canyon areas. Consequently, sockeye are much more easily observed in the upper Horsefly, which is partially verified by the lower index (1.77) as opposed to the lower Horsefly (3.63).

River morphology on the Stellako is very similar to the lower Horsefly where deeper riffles, rapids, deep pools and canyon areas are common. These characteristics combined with tannic- coloured water and algal growth on the Stellako River could potentially decrease observer efficiency and increase the mark-recapture to aerial ratio index (3.15) since sockeye are able to naturally blend into the surroundings. In addition, the average depth of spawning in Stellako in 2007 was considerably greater than at Horsefly and Adams Rivers and contributed to difficulties in counting. It should be realized that water levels at Stellako were abnormally high during the 2007 sockeye spawning period and that the counting conditions at water levels typical to most years would most likely be significantly improved.

River morphology on the Adams is similar to areas throughout the Horsefly. Spawning primarily occurs in relatively shallow riffles and glides; however, the mean monthly discharge of the Adams (70.4 m^3/s) is considerably greater when compared to the Horsefly River (30.4 m^3/s) (Environment Canada 2008) and likely reduces observer efficiency on the Adams. In spite of this, when compared to the Stellako River, the water clarity and colour of the Adams River is much more conducive to counting. The average substrate size on the Adams River is smaller with considerably less algal growth and the combination of these characteristics can lead to increased observer efficiency. Unique to the Adams is the close proximity of a large lake to the spawning grounds. Since most of the spawning in the Adams (75% in 2007) occurs within 2 km of the mouth, many carcasses and moribund sockeye (especially males) are removed (via drift) from the river at a higher rate than other systems. Depending on the severity of the out-migration and the timing of the visual survey, these fish may not be available to the visual survey to the same extent as in other systems which would lead to a higher index

(3.28). Also of considerable significance is the total length of spawning habitat at each location. Spawning at the Horsefly River is spread out over 62 km compared to only 11 km and 13 km at the Adams and Stellako Rivers, respectively. When observing populations of similar sizes at these locations, the spawning densities are obviously much higher at Adams and Stellako Rivers and likely lead to a decrease in observer efficiency.

Although aerial surveys were conducted during the best possible conditions in 2007, poor weather can be encountered at any time and can be largely unavoidable. This may have negatively biased aerial observer efficiency during the Stellako River overflight that encountered weather conditions that varied from light rain to heavy snow. Even during favourable weather conditions, the amount of cloud cover and the location of the sun in the sky can result in poor counting conditions due to serious shading and glare. These conditions were encountered during the filming of the some of the Horsefly calibration reaches in 2007, which required several passes upstream and downstream to find the best possible view for video recording. Future studies should strive to schedule flights with the sun in the best location in the sky as possible in order to minimize shading and glare.

Survey frequency and timing also represent important aspects that influence the development of indices. Surveys that begin too late or are not conducted frequently enough will most likely underestimate the population because the early carcasses will not be available for counting and the true peak of spawn may occur before or in between surveys. While the carcass count influences the estimate, typically only a small percent (~5%) die before the peak, and therefore has a minimal effect. However, the possibility of missing the peak of spawn can potentially introduce a substantial negative bias (Schubert, 2007). This bias was minimized during this study by conducting the aerial flights during the peak of spawn as confirmed by the mark-recapture crews.

EFFECTS OF MIGRATION DURATION

The absolute count of sockeye into the upper Horsefly River (through the diversion fence) provided a baseline count for comparing to an independent mark-recapture estimate for the upper Horsefly River. It also offered a solid platform to calibrate upper river aerial live counts. However, the indices derived from calibrating the upper river aerial counts to the high precision estimates (fence or mark-recapture) may be slightly biased low since the natural migration of sockeye was halted by the fence closure on September 6, 2007 for ASG loading. Ideally, the development of indices are best suited to small, clear systems with a relatively short migration timing that is normally distributed (Schubert 2007). Since migration into the upper river was possibly delayed at the beginning of the run and abruptly terminated near the end of migration as a result of the fence, an unnatural, truncated migration distribution curve occurred. Consequently, the relatively low indices that were produced for the upper river (1.77 and 1.75 based on mark-recapture and fence estimates, respectively) would likely be biased low on other years when fish migration is unobstructed.

Obviously, a system displaying a protracted migration is going to reveal a higher spawner replenishment (spread) compared to a system with a short migration duration. Both systems may share similar peak live counts; however, the population with the higher spawner replenishment and subsequent higher escapement inevitably results in a higher index. Substantial variation in spread between the upper and lower Horsefly has likely contributed to considerable differences in the resulting indices. To further understand the degree of the differences in spawner replenishment between the upper and lower Horsefly River, the mark-recapture tag application and recovery data was examined to observe the pattern of sockeye distribution in the river through time. Figure 10 displays the recovery location (stratified by upper and lower river) of tags that were applied in the lower Horsefly river by application date (representing data of arrival). Not surprisingly, all tags that were recovered in the upper river areas were applied in the earliest arrival period (from August 30 to September 4). However, tags that were recovered in the lower river arrived over a much longer period (from August 30 to September 11), encompassing both the earliest and later arrivals, confirming a much more protracted arrival and spawning period for lower Horsefly River spawners.

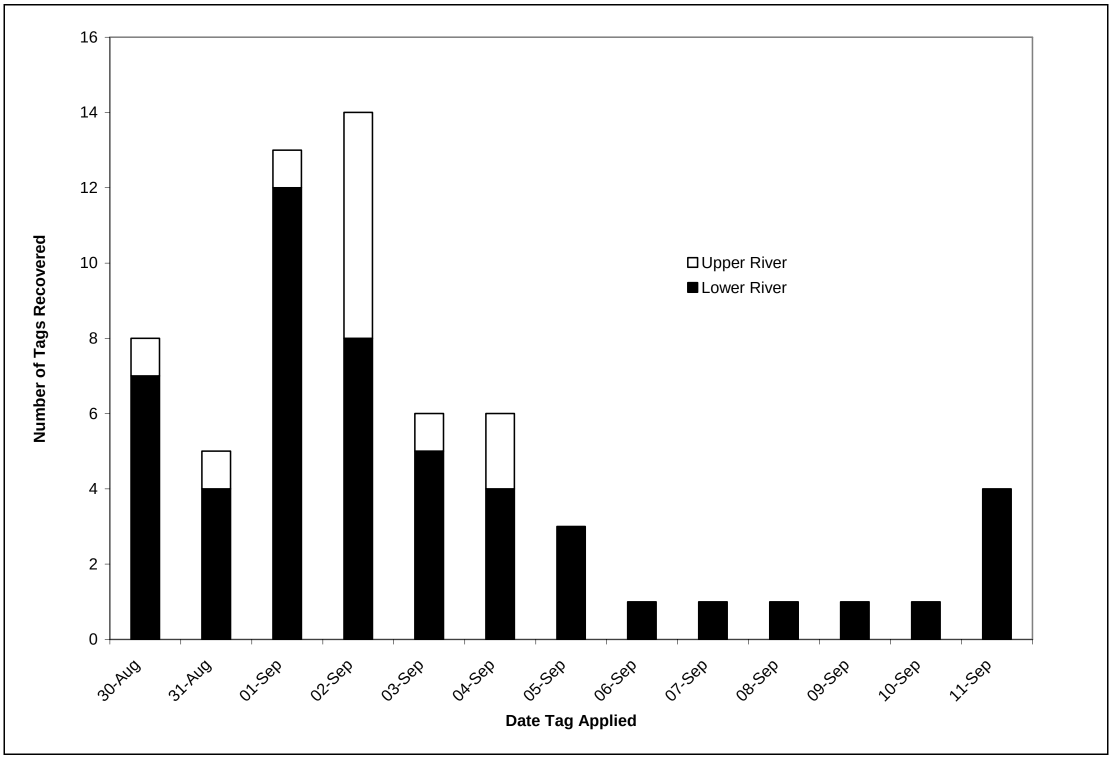

Figure 10. Spawning distribution (upper and lower river) of sockeye tagged in the lower Horsefly River by tag application date.

Although this pattern is typical of the Horsefly River spawners (peak of spawn in the upper river is typically one to two weeks earlier than the lower river), it is possible that it was exaggerated in 2007 due to the presence of the diversion fence throughout the entire duration of the run. Examination of the diurnal migration pattern past the DIDSON site in 2007 indicated the heaviest migration occurred during the late evening and early morning hours with the majority of sockeye (73.3%) migrating between 2000hrs and 0500hrs. Although a similar pattern of migration was observed at the diversion fence (heaviest in the later evening and early morning hours of operation), the fence was generally closed between 2100hrs and 0600hrs. It is plausible that portions of the early component (mostly night migrating sockeye) of the run that would have naturally traveled into the upper river to spawn could have been deterred by the fence and subsequently spawned downstream in the lower river. This is supported by the considerably earlier than normal and more protracted peak of spawn that was observed in the lower Horsefly River in 2007 (September 7 to 23); with sockeye paired up and spawning as early as September 1 in the lower Horsefly River.

In this case, the 3.63 index that was developed in the lower Horsefly, in part by the multi-modal and protracted migration pattern, may not be representative for other years. Overall, the 2.46 index that was generated for the entire Horsefly using the total river mark-recapture estimate as well as the upper and lower aerial estimates combined appears to be the most suitable figure since it may reduce the adverse affects that the diversion fence had on migration and distribution during the study.

AERIAL VS. GROUND COUNTS

When comparing aerial to ground based surveys (rafting) it is assumed that the ground based counts are more accurate in most cases since observers are able to move at a slower and constant rate when counting and view the river from a closer and constant distance. Generally, conditions encountered during ground surveys when compared to aerial surveys are considerably less varied (Johnson *et al*. 2007) which should provide greater standardization and precision in ground survey methodology. Exceptions remain in extremely wide systems, such as the South Thompson or Harrison River, where the ability to view the entire channel from a ground survey is virtually impossible. The comparison of aerial to ground surveys on the Horsefly, Stellako and Adams Rivers revealed that on average ground counts are approximately 20% higher than aerial counts. Since our current calibration index of 1.8 is based on ground counts, aerial counts must be adjusted (increased) accordingly.

Factors that could cause differences in aerial spawner counts between observers may include: the observer's position in the helicopter; fluctuations in helicopter speed and stability; helicopter orientation; height above ground; observer eye sight; polarized glass shape and colour; motor skills or the ability to punch the mechanical counter ("tally-wacker") at the same rate fish are being seen; observer experience and ability; and altering environmental conditions (Trouton 2004). In addition, tally wacker malfunction can be another source of observer error. With the exception of the helicopter factors, ground counts are also subject to similar factors.
In regards to observer experience, it is believed that inexperienced counters tend to underestimate the number of fish and show greater inconsistency in counts (Cousens *et al.* 1982). It also appears likely that this typical underestimation from inexperienced observers is exaggerated with aerial counts, mostly due to speed of the helicopter. This factor, however, likely contributed the least amount to the differences in visual counts between observers in this study because all visual observers were considered experienced (a minimum of 3 years live counting experience).

VIDEO COUNTS

It is difficult to accurately assess observer efficiency with any visual counts since it is nearly impossible to obtain a “true or absolute” estimate for comparison. Aerial photography has been used in the past to obtain the actual number of chinook salmon (Trouton 2004) and chinook salmon redds (Visser *et al.* 2002). In the present study, a similar attempt to obtain a “true or absolute” estimate for comparison purposes was made by video recording sections of varying densities and habitat types (calibration reaches). Unfortunately, video counts proved to be less precise and absolute than hoped for. Horsefly River video counts were approximately 86% of aerial counts and 70% of ground counts and similar trends occurred with the Stellako River video counts. This is likely the result of environmental factors such as shadows, surface glare, substrate colour, water clarity, and weather conditions. Video footage from the Stellako River appeared to focus too much on falling precipitation rather than the water below causing the sockeye to be faint and undefined in deeper water. Counting conditions were much better on the Horsefly River; however, shading from the stream-side riparian vegetation as well as glare from the water surface made some aerial and video footage counting difficult.

The video recording process likely contributed to a majority of the discrepancies between video counts and other visual methods. Modern video recording equipment may provide high resolution, and/or high frame rates, but they do not compare to the adaptability of the human eye to changing conditions. The human eye is an incredibly adaptable device that can focus on distant objects and immediately re-focus on something close by. It is also connected to a brain that has a faster updating and retentive memory than any computer (Constant 2007).

The use of the grid pattern to count video files was challenging since it was difficult to follow the sockeye when the river changed direction or when the video footage would go in and out of focus mid-way though the recording. Although the helicopter was flown slowly in a “crab style” to provide the video recorder the best view of the sockeye often the grid would be orientated at 45° instead of parallel to the river bank. In addition, video counts were originally attempted on 38 cm computer laptop screen (1680 x 1050 pixels) with a grid pattern consisting of 4.0 cm x 3.5 cm squares; however, video counts on a larger, HD television using larger grid patterns (10 cm x 11.5 cm squares) were found to substantially improve counting conditions since it provided greater separation of fish, especially on darker substrates.

Despite advantages with HD video, sockeye were still challenging to count when densities increased or when the video playback was stopped then started again. Some sockeye would only be visible in the video footage if they were moving, but once the playback was stopped the sockeye in question would no longer be detectable to the video counter until the playback was restarted. Experience in video recording and video file analysis should not be underestimated as a possible source of error and a learning period and adjustment to this non-conventional method of enumeration should be expected. Further developments in video technology, video recording procedures and staff experience will inevitably improve which may increase the reliability of the video counts in the future.

VARIANCE BETWEEN OBSERVER COUNTS, METHODS AND HABITAT TYPES

Differences in APE between counters during aerial surveys at both Stellako and Horsefly in relation to habitat types appear to be associated to water depth. In this study, aerial observer counts show reduced variability in shallow glides when compared to deeper glides. Although pools are deeper than glides, similar studies agreed with prior expectations that fish were more visible in riffles than pools (Shardlow *et al.* 1987). Shardlow *et al.* 1987 results showed that habitat type along with species, method of observation and observer experience all affected the probability of observing a fish. It is likely that increasing depth leads to decreased observer efficiency.

As alluded to earlier, the higher precision of ground counts when compared to aerial counts met prior expectations with average percent error of aerial counts (12.17%) almost double that of ground based counts (6.95%). However, slightly different patterns regarding APE and habitat types resulted from ground and aerial counts. Shallow glide sections with interspersed large boulders (habitat #2) displayed the largest APE amongst ground observers (14.75%), which is considerably higher than the other habitat types. This pattern was not observed in the aerial counts where the APE of habitat #2 (9.03%) was similar to habitat #1 (9.98%). It is likely that that the shadows and turbulence caused from the boulders in habitat #2 have a greater effect on ground counts where they are able to physically obstruct vision due to the lower vantage point compared to aerial counts.

The ability to test the effects of factors on variances with adequate statistical power ideally requires larger sample sizes. Unfortunately, the absence of sockeye spawner densities within the other habitat types (5 to 9) as well as the lack of replication of ground counts at Stellako and Adams River resulted in a relatively small sample size for this study. Future calibration studies, ideally with increased replication of all visual survey methodologies, need to be implemented to continue to build on the data collected from this study. Ultimately, additional data gathered from all areas of the Fraser watershed will strengthen the power of the statistical tests and increase the validity of the results.

SUMMARY

Overall, observer efficiency and migration distribution patterns appear to be the drivers regarding the development of a specific index. Systems exhibiting complex river morphology resulting in low observer efficiency will likely contribute to larger indices. Likewise, systems with increased spawner life or protracted spawning, such as Chilko, will undoubtedly have larger indices than those with short spawner life, such as Early Stuart tributaries. Inevitably, indices will be developed and shaped depending on the severity of these characteristics.

Historically, there has been little effort to improve visual methodology since only a small proportion of the total Fraser River escapement was assessed by visual surveys (Schubert

2007). However, since the precision threshold has increased from 25K to 75K, a shift towards developing more accurate system specific indices is imperative. Appling a 1.8 index to larger populations can be highly subjective, and in some cases, this highly unsophisticated method may generate estimates that may be less accurate than an educated guess. These procedures underestimate the variability in population sizes and likely underestimate the true population size, especially among larger populations (Schubert 2007). Therefore, it is recommended that calibration studies be continued over multiple years at many locations to address variation in indices that would invariably occur due to changes in sockeye densities and annual environmental conditions (water levels, light conditions, water clarity, etc). Adopting an analytical procedure that is sufficiently sophisticated to incorporate all necessary criteria to generate relatively accurate visual estimates is essential in providing fishery managers with the most accurate information to make sound decisions.

ACKNOWLEDGEMENTS

We thank the mark-recapture crews from the Horsefly, Stellako and Adams River for their diligent and hard work in helping obtain the data necessary for this extensive study, Mike Savage of Highland Helicopters Ltd., Ken Knight of Pacific Western Helicopters and Kevin Jackson of Cariboo Chilcotin Helicopters Ltd. for piloting the aerial flights in this study. This project was funded through the Pacific Salmon Commission's Southern Boundary Restoration and Enhancement Fund 2007.

REFERENCES

Adams River Habitat Assessment. 2005. Prepared by Summit Environmental Consultants Ltd. for Fisheries and Oceans Canada, Kamloops.

Andrew, J.H., and Webb, T.M. 1987. Review and assessment of adult sockeye salmon enumeration programs on the Fraser River. Prepared by Environmental and Social Systems Analysis Ltd. for the Department of Fisheries and Oceans, New Westminister.

Constant, M. 2008. Lenses. CCTV (Closed Circuit Television) Information from The CCTV Advisory Service website http://www.cctv-information.co.uk/ (accessed February 27, 2008).

Cousens, N.B.F., Thomas, G.A., Swann, C.G., and Healey, M.C. 1982. A review of salmon escapement estimation techniques. Can. Tech. Rep. Fish. Aquat. Sci. 1108: 122p.

Cronkite, G.M.W., Enzenhofer, H.J., Ridley, T., Holmes, J., Lilja, J., and Benner, K. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2647 : vi +47p.

Environment Canada 2007a. Water Level and Streamflow Statistics for the Horsefly River above McKinley Creek (Station ID 08KH010) (accessed on website January 23, 2007).

Environment Canada 2007b. Water Level and Streamflow Statistics for the Stellako River at Glenannan (Station ID 08JB002) (accessed on website January 23, 2007).

Environment Canada 2007c. Water Level and Streamflow Statistics for the Adams River near Squilax (Station ID 08LD001) (accessed on website January 23, 2007).

Enzenhofer, H.J., Cronkite, G.M.W., and Holmes, J.A. 2005. A sectional fish deflection weir and installation boom riverine applications. Can. Tech. Rep. Fish. Aquat. Sci. 2605: iv + 14p.

Enzenhofer, H.J. and Cronkite, G. 2005. A simple adjustable pole mount for deploying DIDSON and split-beam transducers. Can. Tech. Rep. Fish. Aquat. Sci. 2570: iv + 14p.

Holmes, J.A.. Cronkite, G.M.W., Enzenhofer, H.J., and Mulligan, T.J. 2006. Accuracy and precision of fish-count data from a dual-frequency identification sonar (DIDSON) imaging system. ICES J. Mar. Sci. 63 (543-555).

Holmes, J.A., Cronkite, G.M.W., and Enzenhofer, H.J. 2005. Feasibility of implementing a dual-frequency identification sonar (DIDSON) imaging system to estimate sockeye salmon escapement in major tributary systems of the Fraser River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2592: xii + 51p.

Houtman, R. and Cone, T.E. 2000. Estimation of the 1995 Horsefly River system sockeye salmon *(Oncorhynchus nerka)* escapement. Can. Manuscr. Rep. Fish. Aquat. Sci. 2535: 45p.

Houtman, R. and Fanos, B.P. 2000. Estimation of the 1995 late run sockeye salmon *(Oncorhynchus nerka)* escapement to the Adams River study area. Can. Manuscr. Rep. Fish. Aquat. Sci. 2533: 73p.

Johnson, D.H., Shrier, B.M., O'Neal, J.S., Knutzen, J.A., Augerot, X., O'Neal, T., and Pearsons, T.N. (plus 37 contributing authors) 2007. Salmonid Field Protocols Handbook: Techniques for Assessing Status and Trends in Salmon and Trout Populations. American Fisheries Society in association with State of the Salmon, Bethesda, MD. 478 p.

Korman, J., Ahrens, R.N.M., Higgins, P.S. and Walters, C.J. 2002. Effects of observer efficiency, arrival timing, and survey life on estimates of escapement of steelhead trout *(Oncorhynchus mykiss)* derived from mark-recapture experiments. Can. J. Fish. Aquat. Sci. 59: 1116-1131.

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

Schubert, N.D. 2007. Estimating the 1995 Fraser River sockeye salmon *(Oncorhynchus nerka)* escapement. Can. Tech. Rep. Fish. Aquat. Sci. 2737: ix + 71p.

Schubert, N.D. 2000. The 1994 Stellako River sockeye salmon *(Oncorhynchus nerka)* escapement: evaluation of pooled Petersen and stratified mark-recapture estimates of a known population. Can. Tech. Rep. Fish. Aquat. Sci. 2303: 56p.

Schubert, N.D. 1998. The 1994 Fraser River sockeye salmon *(Oncorhynchus nerka)* escapement. Can. Tech. Rep. Fish. Aquat. Sci. 2201: 62p.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, second edition. Griffin, London.

Shardlow, T., Hilborn, R. and Lightly, D 1987. Component analysis of instream escapement methods for Pacific salmon (Oncorhynchus spp.). Can. J. Fish. Aquat. Sci. 44: 1031-1037.

Trouton, N.D. 2004. An investigation into the factors influencing escapement estimation for chinook salmon *(Oncorhynchus tshawytscha)* on the Lower Shuswap River, British Columbia. Thesis submitted (M.Sc.)

Visser, R., Dauble, D.D. and Geist, D.R. 2002. Use of aerial photography to monitor fall chinook salmon spawning in the Columbia River. Transactions of the American Fisheries Society 131: 1173-1179.

APPENDICES

Appendix 1. Habitat type, distance and upstream UTM (Map Datum NAD 27 Canada) for Horsefly and Stellako river calibration reaches, 2007.

River System	Calibration Reach	Habitat Type	Reach distance (m)	Upstream UTM
Horsefly	1	2	116	10 U 633088 5795476
	2	1	325	10 U 631374 5794762
	3	4	212	10 U 630977 5794995
	4	3	302	10 U 630351 5794977
	5	1	176	10 U 629946 5794846
	6	4	163	10 U 629871 5794993
	7	3	272	10 U 629448 5795153
	8	3	252	10 U 628126 5794016
	9	2	231	10 U 610125 5798128
	10	1	200	10 U 608899 5799839
	11	4	99	10 U 609045 5800403
	12	2	160	10 U 609098 5804955
	13	3	233	10 U 607614 5811663
	14	3	360	10 U 607635 5812681
Stellako	1	4	836	10 U 369924 5986815
	2	3	290	10 U 371034 5987918
	3	4	299	10 U 371068 5988291
	4	3	231	10 U 373995 5989912
	5	3	279	10 U 373975 5990172
	6	3	138	10 U 374214 5990251
	7	3	225	10 U 374472 5990465

Appendix 2. Daily counts of sockeye through the Horsefly River Spawning Channel Diversion fence, 2007.

Count Period (dd/mm/yyyy)	Untagged Sockeye Upstream	Untagged Sockeye Downstream	Tagged Sockeye Upstream	Tagged Sockeye Downstream	Net Upstream (Tagged + Untagged) (U/S - D/S)
16/08/2007	0	0	0	0	0
17/08/2007	0	0	0	0	0
18/08/2007	0	0	0	0	0
19/08/2007	0	0	0	0	0
20/08/2007	0	0	0	0	0
21/08/2007	0	0	0	0	0
22/08/2007	0	0	0	0	0
23/08/2007	0	0	0	0	0
24/08/2007	220	0	2	0	222
25/08/2007	1,844	1	37	0	1,880
26/08/2007	2,590	1	27	0	2,616
27/08/2007	2,065	3	21	0	2,083
28/08/2007	2,972	1	26	0	2,997
29/08/2007	1,689	2	31	0	1,718
30/08/2007	1,910	5	36	1	1,940
31/08/2007	2,431	0	34	1	2,464
01/09/2007	1,696	0	20	0	1,716
02/09/2007	1,435	0	19	0	1,454
03/09/2007	2,977	3	17	0	2,991
04/09/2007	1,870	0	22	0	1,892
05/09/2007	903	0	41	0	944
06/09/2007	768	2	23	0	789
Total	25,370	18	356	2	25,706

Appendix 3. Horsefly DIDSON Daily Expanded and Cumulative Counts, 2007.

Date	Daily Expanded Count	Cumulative Count
13/08/07	24	24
14/08/07	24	48
15/08/07	15	63
16/08/07	5	68
17/08/07	17	85
18/08/07	11	95
19/08/07	54	149
20/08/07	75	224
21/08/07	144	368
22/08/07	564	932
23/08/07	2,348	3,280
24/08/07	1,539	4,819
25/08/07	4,511	9,329
26/08/07	6,974	16,303
27/08/07	3,857	20,159
28/08/07	4,377	24,536
29/08/07	2,514	27,050
30/08/07	2,760	29,810
31/08/07	1,389	31,199
01/09/07	2,823	34,022
02/09/07	5,159	39,181
03/09/07	2,708	41,888
04/09/07	2,379	44,267
05/09/07	876	45,143
06/09/07	516	45,659
07/09/07	836	46,494
08/09/07	1,838	48,332

continued

Appendix 3. Horsefly DIDSON Daily Expanded and Cumulative Counts, 2007 (cont'd).

Date	Daily Expanded Count	Cumulative Count
09/09/07	2,143	50,475
10/09/07	950	51,425
11/09/07	826	52,252
12/09/07	1,042	53,294
13/09/07	1,583	54,877
14/09/07	807	55,684
15/09/07	1,169	56,853
16/09/07	1,009	57,862
17/09/07	673	58,535
18/09/07	683	59,217
19/09/07	374	59,591
20/09/07	170	59,762
21/09/07	388	60,150
22/09/07	301	60,451
23/09/07	159	60,610
24/09/07	37	60,647
25/09/07	116	60,763
26/09/07	-42	60,721

Appendix 4. Horsefly River aerial counts (September 9 and 15) by mark-recapture reach and observer, 2007.

Reach	Sept 9th Flight (entire river)					Sept 15th Flight (below calibration fence)				
	Obs #1	Obs #2	Dead	Average	Total	Obs #1	Obs #2	Dead	Average	Total
1 and 2	299	265	0	282	282	-	-	-	-	-
3 and 4	4,277	5,040	250	4,659	4,909	-	-	-	-	-
5	3,990	2,940	200	3,465	3,665	-	-	-	-	-
6	2,460	1,926	150	2,193	2,343	-	-	-	-	-
7	174	161	30	168	198	-	-	-	-	-
8	110	120	10	115	125	-	-	-	-	-
9 and 10	1,273	1,480	30	1,377	1,407	-	-	-	-	-
11 (above fence)	790	940	150	865	1,015	-	-	-	-	-
11 (below fence)	2,465	2,605	300	2,535	2,835	1,660	1,980	400	1,820	2,220
12 and 13	594	710	150	652	802	539	534	200	537	737
14 and 16	4,381	4,770	250	4,576	4,826	3,750	3,730	400	3,740	4,140
Total Above Fence	13,373	12,872	820	13,123	13,943	-	-	-	-	-
Total Below Fence	7,440	8,085	700	7,763	8,463	5,949	6,244	1,000	6,097	7,097
Total	20,813	20,957	1,520	20,885	22,405	5,949	6,244	1,000	6,097	7,097

Appendix 5. Horsefly River aerial, ground and video counts by observer for calibration reaches, 2007.

Calibration Reach	Habitat Type	Aerial Counts					Ground Counts			Video Counts			
		Obs #1	Obs #2	Obs #3	Obs #4	Average	Obs #1	Obs #2	Average	Obs #1	Obs #2	Average	Rating
1	2	96	-	112	90	99	107	104	105	-	-	-	Poor
2	1	675	804	1,010	822	828	1,276	1,133	1,205	740	681	710	Moderate
3	4	400	334	274	269	319	357	369	363	216	155	185	Moderate
4	3	750	709	760	409	657	662	705	684	549	709	629	Good
5	1	580	662	635	465	586	857	793	825	560	541	550	Moderate
6	4	400	590	480	333	451	578	648	613	476	602	539	Good/Mod
7	3	740	838	840	417	709	1,030	956	993	887	880	884	Good
8	3	310	472	365	252	350	510	503	507	223	278	251	Good
9	2	320	289	252	226	272	241	397	319	285	253	269	Good/Mod
10	1	460	500	-	397	452	480	497	489	177	196	187	Good/Mod
11	4	295	195	-	267	252	202	253	228	259	252	255	Poor/Mod
12	2	110	127	-	110	116	172	118	145	58	17	38	Poor
13	3	430	360	-	411	400	430	488	459	238	294	266	Good
14	3	1,180	830	-	911	974	938	1,124	1,031	652	950	801	Good
Total		6,746	6,710	4,728	5,379	6,464	7,840	8,088	7,964	5,317	5,808	5,563	

Appendix 6. Stellako River aerial counts by mark-recapture reach and observer, September 29, 2007.

M/R Reach	Obs #1	Obs #2	Dead	Average	Total
1	770	680	0	725	725
2	4070	3280	0	3675	3675
3, 4	660	600	0	630	630
4	1700	1080	0	1390	1390
5	1360	1200	0	1280	1280
6 - Falls	40	30	0	35	35
Falls - Mouth	5650	5080	0	5365	5365
Total	14250	11950	0	13100	13100

Appendix 7. Stellako River aerial, ground and video counts by calibration reach, 2007.

Calibration Reach	Habitat Type	Aerial Counts			Ground Counts	Video Counts			
		Obs #1	Obs #2	Average	Average	Obs #1	Obs #2	Average	Rating
1	4	4,070	3,280	3,675	5,100	2,763	3,576	3,170	Moderate
2	3	1,700	1,080	1,390	2,055	995	972	984	Moderate
3	4	570	490	530	1,152	680	467	574	Moderate
4	3	1,080	960	1,020	840	725	803	764	Moderate
5	3	700	580	640	797	481	415	448	Poor
6	3	1,210	950	1,080	985	872	1,123	998	Moderate
7	3	1,810	1,740	1,775	1,560	1,477	1,485	1,481	Moderate
Total		11,140	9,080	10,110	12,489	7,993	8,841	8,417	

Appendix 8. Adams River (entire) aerial and ground counts by each area, 2007.

Area	Aerial Counts					Ground Counts
	Obs #1	Obs #2	Dead	Average	Total	Total
Adams Lake - Hwy Bridge	4,140	3,500	100	3,820	3,920	5,124
Hwy Bridge - Shuswap Lake	11,090	10,420	500	10,755	11,255	12,801
94 Channel	770	980	0	875	875	863
Total	16,000	14,900	600	15,450	16,050	18,788