Estimation of the 1995 Horsefly River System Sockeye Salmon *(Oncorhynchus nerka)* Escapement

R. Houtman and T.E. Cone

Fisheries and Oceans Canada
Science Branch, Pacific Region
100 Annacis Parkway, Unit 3
Delta, British Columbia
V3M 6A2

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R. Houtman and T.E. Cone

Fisheries and Oceans Canada

Science Branch, Pacific Region

100 Annacis Parkway, Unit 3

Delta, British Columbia

V3M 5P8

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In 1995, the Department of Fisheries and Oceans estimated the escapement of sockeye salmon (*Oncorhynchus nerka*) to the Horsefly River system. A mark-recapture study was conducted to estimate the escapement to the Horsefly River and the three tributaries that support sockeye salmon populations: Little Horsefly River, McKinley Creek and Moffat Creek. Sockeye were captured at one site in the lower Horsefly River; 1,349 were released with disk tags and secondary marks. The spawning grounds were surveyed through the period of spawning and die-off; 36,543 carcasses were recovered, of which 298 were marked. Analysis revealed a temporal application and recovery bias and a spatial application bias; however, because the 95% confidence intervals of the pooled Petersen estimates overlapped those of the stratified estimators, it was concluded that the pooled Petersen population estimates were not seriously biased. The mark-recapture estimate of the study area population is 73,632 males, 90,977 females and 1 jack. The remainder of the escapement, those sockeye which spawned in the Horsefly River spawning channel, were counted passing through an enumeration fence; 6,655 male and 9,608 females were counted. The estimated total escapement to the Horsefly River system, therefore, is 80,287 males, 100,585 females and 1 jack. Study design changes, including increased and improved allocation of sampling effort and improved resurvey procedures, are recommended.

RÉSUMÉ

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

En 1995, le ministère des Pêches et des Océans a estimé l'échappée de saumon rouge (*Oncorhynchus nerka*) dans le réseau de la rivière Horsefly. Une étude de marquage-recapture a été menée pour estimer l'échappée de la Horsefly et de ses trois affluents qui abritent des populations de saumon rouge : la Little Horsefly, le crique McKinley et le crique Moffat. Les saumons ont été capturés à une station du cours inférieur de la Horsefly; 1 349 spécimens ont été libérés après avoir été marqués avec des disques et des marques secondaires. Les frayères ont été surveillées pendant toute la période de fraye et de mortalité; 36 543 carcasses ont été récupérées, dont 298 étaient marquées. L'analyse a révélé un biais temporel de l'opération de marquage et de la récupération, et un biais spatial de la récupération; toutefois, étant donné que les intervalles de confiance de 95 % des résultats obtenus avec l'estimateur multiple de Petersen chevauchaient ceux des estimateurs stratifiés, il a été conclu que les estimations Petersen de la population n'étaient pas gravement biaisées. L'estimation de la population de la zone d'étude, d'après l'étude de marquage-recapture, est de 73 632 mâles, 90 977 femelles et 1 mâle précoce. Le reste de l'échappée, c'est-à-dire les saumons rouges qui frayaient dans la frayère artificielle de la Horsefly, a été dénombré à une barrière de comptage; on a compté 6 655 mâles et 9 608 femelles. On estime donc l'échappée totale dans le réseau de la Horsefly à 80 287 mâles, 100 585 femelles et 1 mâle précoce. Il est recommandé d'apporter des modifications au plan d'étude, notamment en accroissant et en répartissant mieux l'effort d'échantillonnage, et en améliorant les procédures.

INTRODUCTION

The Fraser River system supports the largest population of sockeye salmon (*Oncorhynchus nerka*) in the world (Northcote and Larkin 1989). Sockeye spawn in over 150 natal areas, ranging from small streams to large rivers and lakes, which are distributed throughout the accessible portion of the Fraser River system. The Department of Fisheries and Oceans estimates the stock-specific annual abundance of Fraser River sockeye spawners using a two-tiered system originally developed by the International Pacific Salmon Fisheries Commission. Stocks with forecasted escapements above 25,000 are assessed using enumeration fences or mark-recapture studies, while stocks with smaller escapements are assessed using visual techniques.

The Horsefly River system is located in the Quesnel River watershed (Fig. 1). The Horsefly River and three of its tributaries, Little Horsefly River, McKinley Creek and Moffat Creek, support spawning sockeye populations (Fig. 1). Sockeye diverted from the Horsefly River mainstem as they migrate past the outlet of the Horsefly River spawning channel (Fig. 2a) spawn in the channel. Sockeye arrive in the system in August, and spawning ends by early October. This report describes the estimation of the 1995 escapement of this stock aggregate.

Escapements to the Horsefly River system have been assessed and reported regularly since 1938. This population exhibits a quadrennial escapement cycle, with abundance increasing, from low values in 1941, consistently on all cycles (Appendix 1a). Escapement in the 1943-1991 off-cycle increased from under 100 in the 1950's to almost 40,000 in 1991 (Appendix 1a). Sockeye spawning in the Horsefly River spawning channel are counted as they pass through an enumeration fence into the spawning channel, by Salmonid Enhancement Program staff. In 1943-1991 cycle years before 1995, total escapements to the Horsefly River, Little Horsefly River, McKinley Creek and Moffat Creek have been below 25,000 (Appendix 1b-f) and therefore were enumerated visually. In 1995, the forecasted escapement to these areas was again appropriate for use of visual methods; however, in-season estimates of abundance of Horsefly River system sockeye migrating through the lower Fraser River (provided by the Pacific Salmon Commission) increased the estimate substantially, well above 25,000. A mark-recapture study, therefore, was quickly implemented to enumerate the escapement to the Horsefly River, Little Horsefly River, McKinley Creek and Moffat Creek. Cone (1999) described the enumeration of the 1994 Horsefly River system escapement, which also involved a mark-recapture study. The 1995 study was similar, but included modifications designed to reduce sample selectivity and to facilitate assessment of tag loss and the effects of sub-acute and acute stress.

This report describes the design, field methods and analysis of the study to estimate the escapement of sockeye salmon to the Horsefly River system, in 1995. Estimates of the sex-specific escapement and average spawning success are provided for the Horsefly River, Little Horsefly River, McKinley Creek and the spawning channel. Estimates of the adult age and length distributions and average fecundities, based on samples collected in the Horsefly River, are also provided. Mark-recapture biases are evaluated, including a comparison of escapement estimates calculated using alternative models. The report concludes with a discussion of the results and recommendations for the design of future studies.

STUDY AREA

Draining a watershed of 2,756 km^2 within the Cariboo Mountains, the Horsefly River (110 km) flows west-north-west and empties into Quesnel Lake (Fig. 1). Daily discharge (monitored above McKinley Creek) averages 19.4 m^{3}s^{-1} (1955-1990), with mean daily maxima (67 m^{3}s^{-1}) and minima (4 m^{3}s^{-1}) occurring in June and February, respectively (Environment Canada 1991).

The Horsefly River is accessible to sockeye upstream to an impassable falls approximately 62.6 km above the mouth. To facilitate the data aggregations required for bias testing, the river was divided into 13 areas (Fig. 2a and 2b). Areas were established based on three criteria: homogeneity of physical characteristics such as gradient, channel morphology and substrate type; the ability of the crews to access and survey an area in one day; and the existence of easily identifiable land marks to delineate the areas. The areas are described below. Past studies have distinguished the upper and lower Horsefly River, separated 0.5 km below the road bridge at km 37.7 (Fig. 2b); the boundary between Area 6 and 7 represents the conventional division between the upper and lower river.

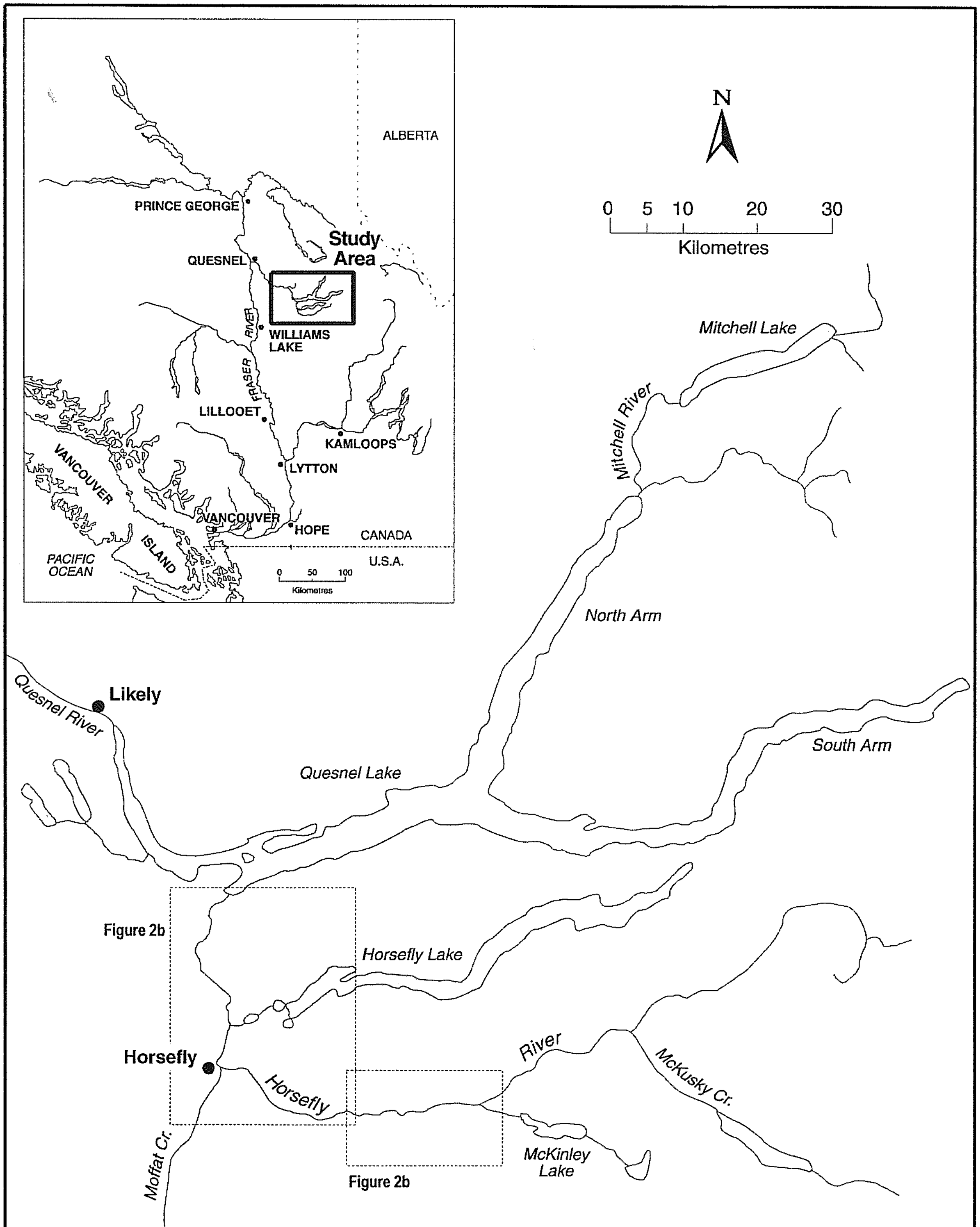

Figure 1. Horsefly River system study area location map

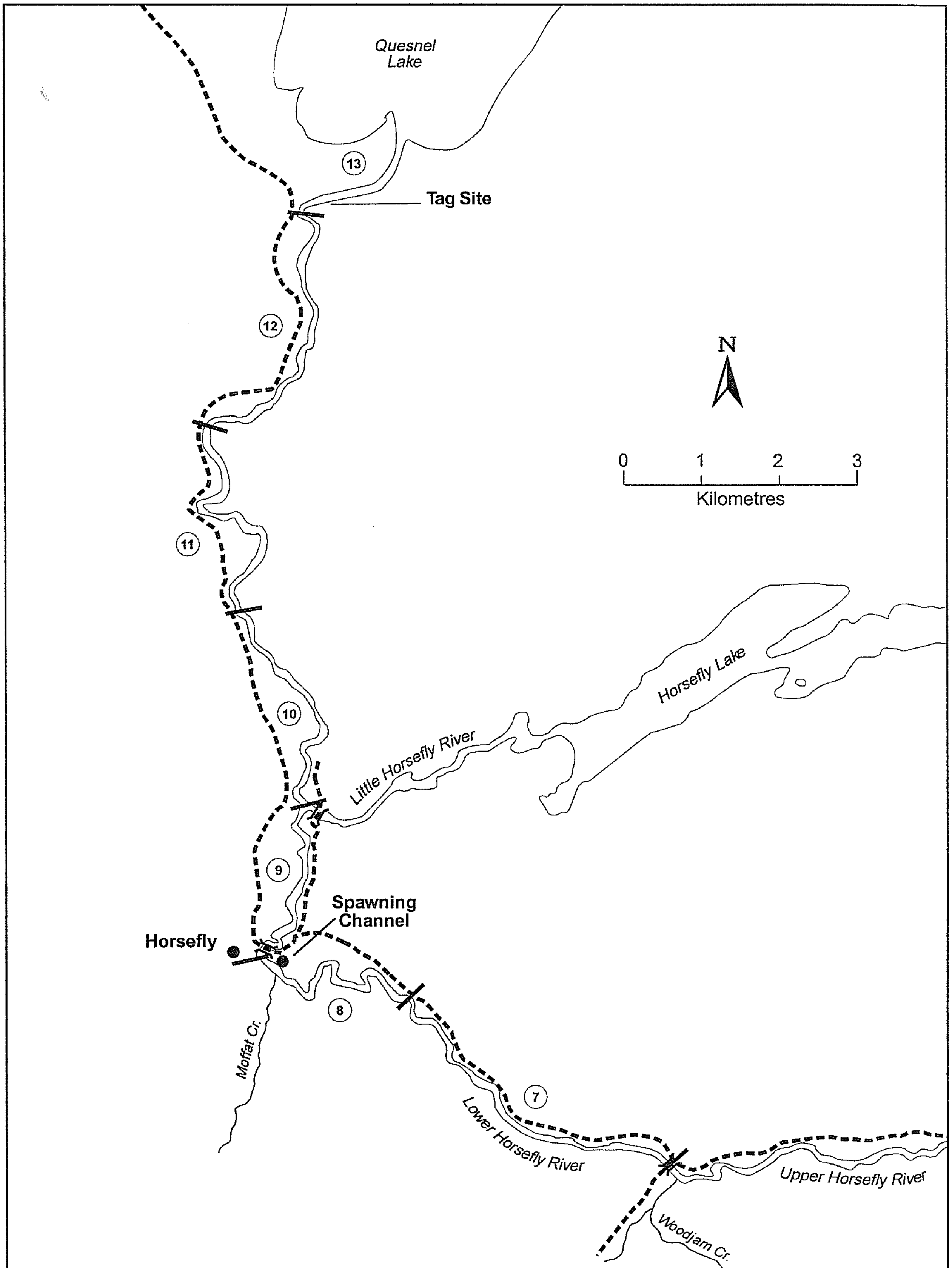

Figure 2a. Lower portion of the Horsefly River system and recovery areas.

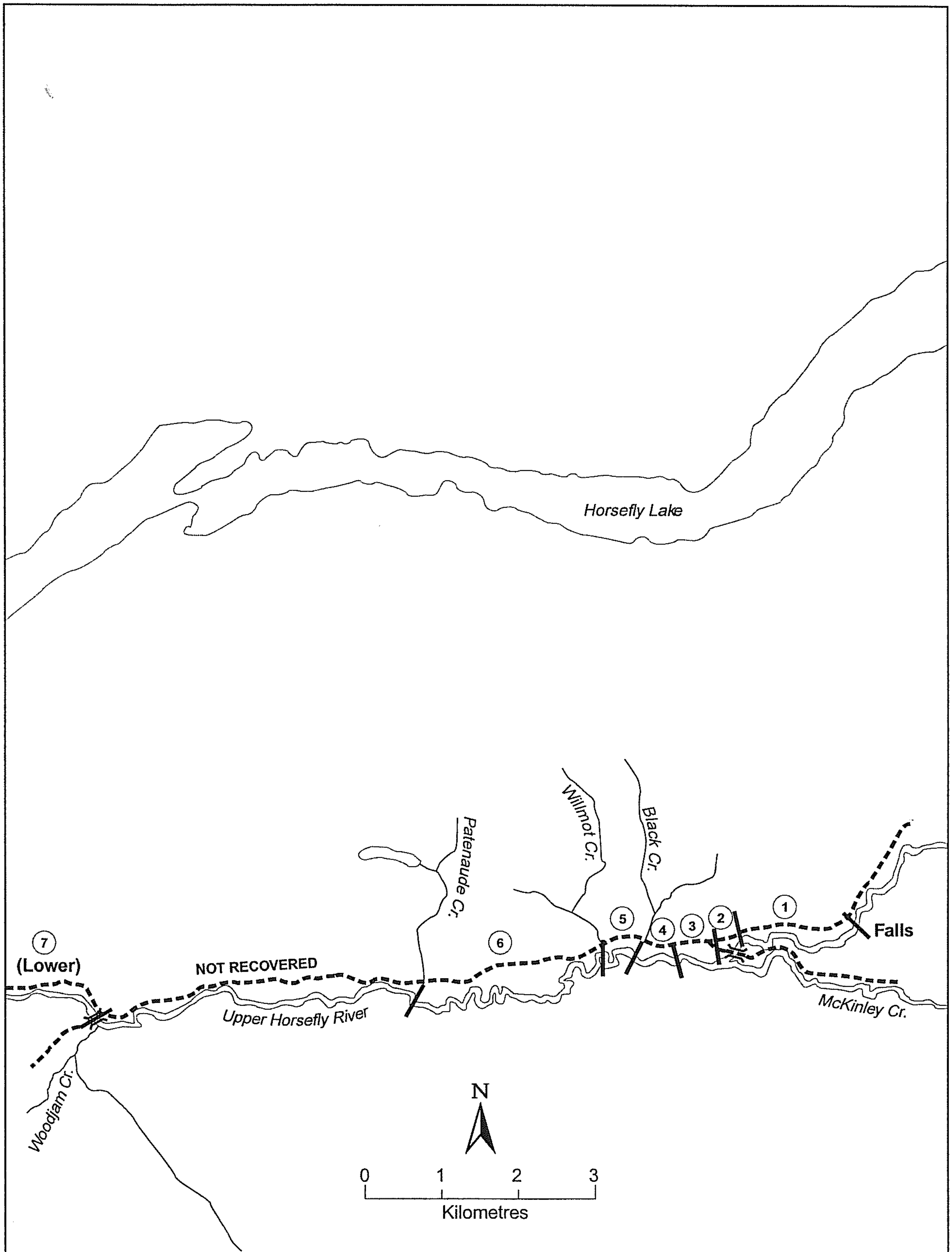

Figure 2b. Upper portion of the Horsefly River system and recovery areas

Areas 1 (3.3 km) and 2 (0.7 km), the uppermost areas surveyed in the Horsefly River, are characterized by riffles, pools and a cobble and gravel substrate. Area 1 extends from the falls downstream to a bridge; Area 2 extends from the bridge to the McKinley Creek confluence.

Areas 3 to 5 have a lower gradient, a more defined river channel and are characterized by pools, runs and side channels with sand and gravel substrate. Area 3 extends 1.5 km below the McKinley Creek confluence, while areas 4 (1.3 km) and 5 (1.3 km) extend to the confluences with Black and Willmot creeks, respectively.

In Area 6 (8.0 km), the river meanders through a broad flood plain and has primarily a mud, silt and sand substrate. The area ends at the confluence with Patenaude Creek. The remaining 9.3 km of the upper section of the Horsefly River was not surveyed, because no spawning occurs there and few carcasses accumulate there.

Area 7 (10.3 km) extends from the Woodjam Creek Bridge downstream to 4.0 km above the spawning channel outlet. The upstream end of the area is a wide, shallow channel with a substrate of large boulders and cobble. The gradient increases as the river transits a canyon midway through the area.

Area 8 (4.0 km) extends to the intake of the Horsefly River spawning channel. The river is channelized with banks of 3 to 6 m, gravel substrate and bordered on both sides by agricultural land. Moffat Creek joins in this area on the south bank just below the spawning channel intake.

Area 9 (5.4 km) extends to the confluence of the Little Horsefly River. The upstream end of the area has a moderate gradient with gravel substrate; in the lower end, the gradient decreases and the substrate is mud, silt and sand.

Area 10 (4.3 km) extends downstream to a rocky bar, which is accessible by road. In this area, the gradient is moderate and the channel braids frequently as it flows through a series of small steps in exposed bedrock.

Area 11 (6.7 km) extends downstream to the Squaw Flats recreation site. This area is similar to lower Area 10, with a canyon midway through the area. In the lower portion of this area, the gradient decreases and gravel substrate predominates.

Area 12 (5.0 km) extends downstream to the tagging site. The river gradient decreases and the channel is braided with a gravel substrate.

Area 13 (2.0 km) extends to Quesnel Lake. The river has a low gradient, and the substrate changes from gravel in the upper end of the area to mud, silt and sand through the middle and lower portions.

McKinley Creek drains an area of 450 km^2 (Fish Habitat Inventory and Information Program, 1991). Originating at Bosk Lake, it flows west for 59 km through McKinley Lake and into the Horsefly River. McKinley Creek has a mean annual discharge (measured just below McKinley Lake) of 5.11 m^3s^{-1} (1964-1986), with mean daily maxima (17 m^3s^{-1}) and minima (1.6 m^3s^{-1}) occurring in May and February, respectively (Environment Canada 1991). A temperature and flow control structure at the outlet of McKinley Lake moderates high water temperatures and low flows downstream, using cold water siphoned from deep in the lake. Some sockeye spawn in the section above McKinley Lake, upper McKinley Creek (45 km), in dominant and subdominant cycle-years (Appendix 1d); in the 1995 off-cycle, sockeye spawning was not expected and this section was not surveyed. The section below McKinley Lake (7.5 km; Fig. 2b), lower McKinley Creek, has a moderate gradient with cobble and gravel substrate in the upper portion and a low gradient with gravel substrate in the lower portion.

The Little Horsefly River (6.5 km) originates at the east end of Horsefly Lake and flows southeast to its confluence with the Horsefly River (Fig. 2a). A channel width of 10-20 m, an average depth of 0.5-1.0 m and a varied substrate of sand, mud and gravel characterize this river.

Sockeye also spawn in Moffat Creek (91.6 km; Fig. 2a) in dominant and subdominant cycle-years (Appendix 1f); in the 1995 off-cycle, sockeye spawning was not expected and this creek was not surveyed.The Horsefly River spawning channel (2 km, approximately) enters the Horsefly River 23.4 km upstream of Quesnel Lake (Fig. 2a). An enumeration fence near the channel outlet is closed after the channel is loaded with spawners.

FIELD METHODS

VISUAL SURVEYS

An observer stationed on the highway bridge at Likely counted sockeye migrating through the upper Quesnel River into Quesnel Lake (Fig. 1). Most days, four 15-min counts were made at 30-minute intervals, at 0800 h and again at 1600 h.

An observer in an inflatable boat counted live sockeye spawners visually; counts were made near the peak of spawning in Little Horsefly River and lower McKinley Creek.

TAG APPLICATION

Capture and tagging procedures were designed to tag at least 1% of the escapement, and to distribute those tags among adult males, females and jacks in a spatially and temporally representative manner. Sockeye were captured by beach seine at a tagging site in the Horsefly River 2 km upstream from Quesnel Lake (Fig. 2a). Because an independent estimate of daily abundance was unavailable, similar daily effort (typically between 5 and 8 sets per day) was applied throughout the run to achieve temporally proportional tag application. Tagging began when the project was implemented (recall the late implementation of the mark-recapture study based on in-season escapement estimates) and ended when low abundance indicated the immigration was virtually complete.

Sockeye were captured by a four-person crew using a 50 m x 7.6 cm-mesh x 100-mesh deep beach seine net. The net was set from a jet-powered boat in a downstream arc and withdrawn from the river to enclose an area of water along the riverbank. Captured fish were held in the net until removal for tagging. Previously tagged fish were identified upon recapture and immediately processed to avoid additional stress. The tag number was recorded and the tag checked; if damaged by recapture, it was replaced with a new tag. Other species and sockeye that were injured or showed advanced stages of maturation were released untagged.

Fish were tagged in a flexible plastic trough (12 x 20 x 100 cm) suspended in a wooden tray with a metre stick attached. In order to evaluate the susceptibility of this population to tagging-induced stress, standard and low stress tagging procedures were alternated every fish. Standard procedures entailed tagging the fish with the tray elevated from the water surface and releasing it by throwing it a short distance over the net's cork line. Low stress procedures entailed tagging the fish with the tray immersed in approximately 15 cm of water and releasing it by lowering a section of the cork line; at no time was the fish removed from the water. In addition, the following general fish handling guidelines were adopted in 1995 to reduce tagging-induced stress: crew activity within the net was minimized to reduce siltation; fish were removed from the water only when a tagger was ready and processed as quickly as possible; and, when removed from the water, the fish were cradled in two hands rather than dangled by the caudal peduncle.

The disk tags consisted of two red 15-mm diameter laminated cellulose acetate disks threaded through centrally punched holes onto a 77 mm long nickel pin. The pin was inserted with pliers through the musculature and pterygiophore bones approximately 12 mm below the anterior portion of the dorsal fin insertion. The disk tags, arranged with one on each side of the fish, were secured by twisting the pin into a double knot. One disk per pair was numbered with a unique code. Each tagged fish received a secondary mark to permit an assessment of tag loss. These consisted of one (males) or two (females) 7 mm diameter holes punched through the right operculum using a single hole punch. Care was taken to avoid gill tissue damage. Date and location of capture, disk tag number, nose-fork (NF) length (±0.5 cm), sex (fish with a NF length less than 50 cm were recorded as jacks), number of opercular holes punched, tagging method, and marks (troll, gill net and lamprey scars) were recorded for each fish released with a disk tag. Condition at release was recorded as 1 (swam away vigorously), 2 (swam away sluggishly) or 3 (required ventilation).

SPAWNING GROUND SURVEYS

Recovery Survey

Carcass recovery surveys were conducted on the Horsefly River (areas 1-13) by two-person crews; up to five crews were required at the peak of die-off. These surveys took 2 to 3 days to complete, and each survey began immediately upon completion of the previous one. Unfortunately, carcass recovery surveys did not begin until well after the beginning of die-off, and ended before the die-off was complete. Further, sections with low carcass abundance were not surveyed. Instead, surveyors moved by foot and inflatable boat between sections with relatively high carcass abundance. The portions of areas covered by this "bar-hopping" approach were similar, but not identical, between surveys. These aspects of the survey could have led to disproportionate recovery, both temporally (late start), and spatially (bar-hopping and inconsistency in surveyed portions of areas between surveys).

Carcasses were also recovered during the live counts of Little Horsefly River and lower McKinley Creek; in both areas, the entire shoreline was surveyed.

Crews were trained to recover carcasses independent of their tag status and, following recovery, to place a higher priority on the correct identification of tag and secondary mark status than on survey speed. All carcasses which were on shore or retrievable with a peough by wading into the river to knee depth were enumerated (except predator kills, which were excluded from the survey) and thrown on the bank above the high water mark. Carcass recoveries were recorded by date, area, sex, tag and secondary mark status, carcass condition (fresh, tainted or rotten) and female spawning success (0%, 50% or 100% spawned). If a disk tag was present, it was retrieved and the tag number was recorded before the carcass was processed.

Resurvey

Previously processed carcasses were resampled through the recovery period to identify disk tagged carcasses that had been erroneously classified as untagged. The resurvey, conducted by experienced technicians, recorded carcasses by date, area, sex and mark status. Cone (1999) identified deficiencies in the 1994 resurvey that were addressed by greater total survey effort and more frequent surveys.

On the initial survey, tags were removed from carcasses identified as disk tagged, but those carcasses were not excluded from the resurvey. The number of fish with only secondary marks which were misclassified as unmarked, therefore, could not be determined.

BIOLOGICAL SAMPLING

Biological samples were obtained following a protocol provided by the Pacific Salmon Commission. One hundred and twenty sockeye carcasses of each sex were sampled for postorbital-hypural plate (POH) and nose-hypural plate (standard) lengths (±0.5 cm), otoliths and scales (one from each preferred region, as defined by Clutter and Whitesel (1956)). Sixty carcasses were selected randomly from recoveries on both the upper and lower Horsefly River, on several days near peak die-off (based on the historic mean date). Any jacks were also to have been sampled for scales and lengths.

Near the end of arrival, 50 randomly selected females were killed at the tagging site. Each was sampled as above, and the egg skeins and loose eggs were removed, placed in a cotton bag and preserved in a 10% formaldehyde solution. The number of eggs in each sample was estimated as the product of the total skein weight (grams) and the number of eggs per gram in a weighed subsample of the skein, plus a count of the loose eggs.

ANALYTIC PROCEDURES

Analytic procedures are presented in three sections. The first section describes the procedures by which the data were evaluated and corrected for sex and tag identification error, emigration, tag loss, and acute stress effects. The second explains the procedure used to evaluate potential sampling biases. The results of this analysis were used to guide evaluations of bias in the resulting population estimates and the need to adopt stratified estimators. Finally, the third section describes the procedures used to calculate population estimates, and to evaluate alternative estimates.

DATA ADJUSTMENTS

Sex Identification Error

The application data were corrected for sex identification error by comparing the sexes recorded at release and carcass recovery. All errors are assumed to be made at application, because the development of sexually dimorphic traits was less advanced at application, recording errors were more likely to occur during the hectic tagging process and carcasses of ambiguous sex could be incised and examined internally.

The corrected total number of adult males (defined as males with NF $\geq$ 50 cm; hereafter, "males") tagged (M_m*) was estimated using an equation provided by Staley (1990). The corrected number of male sockeye tagged in a given application "stratum" was estimated by multiplying the fraction of all fish released as males that were released in that stratum by M_m*. The corrected number of adult females (hereafter, females) tagged in that stratum was estimated as the total number of adults actually released minus M_m*.

Emigration

Salmonid Enhancement Program ("SEP") staff diverted migrating sockeye into the spawning channel over a 1 or 2 day period. This process may have led to different mark incidence (proportion of fish with disk tags and/or secondary marks) for this population, compared to the bulk of the system, due to daily variability in mark incidence among migrants. SEP staff also recovered all carcasses from the channel. These recovery rates are much higher than those for the other areas in the system, where a large proportion of carcasses are unavailable to recovery crews. If the spawning channel were included in the mark-recapture study area, these differences would lead to a biased estimate. Channel recoveries, therefore, were not included in mark-recapture recovery data. Further, tagged fish recovered in the spawning channel were removed from the application sample used for all subsequent analyses.

Handling Stress

Tagging-induced stress can influence post-tagging behavior and the timing and probability of recovery. The data, therefore, were evaluated to determine whether specific tags should be excluded from the application sample. First, chi-square tests were used to test whether the proportion of tagged fish recovered was influenced by three potential stress factors: tagging method, release condition and the number of times tagged fish were recaptured in subsequent beach seine sets. When a test result was significant, the high stress group was excluded from subsequent analyses. (In this report, significant ($P<0.05$) and highly significant ($P<0.005$) test results are indicated with a single and double asterisk, respectively.) Second, fish recovered less than five days after release were excluded. While five days is an arbitrary criterion, unusually short times between application and recovery are typically associated with poor spawning success and assumed to result from tagging stress.

Tag Recognition Error

Resurvey data were used to correct the carcass recovery totals for tags missed by the initial survey. The number of missed tags was estimated, by sex, as the product of the tag incidence in the resurvey and the number of carcasses examined on the initial survey. For stratified population estimates, these recoveries were added to recovery strata in proportion to the fraction of total disk tagged carcasses recovered in each stratum.

Tag Loss

Because all fish released with a tag also received a permanent secondary mark, the rate of tag loss between application and carcass recovery could have been determined had survey crews examined untagged carcasses for secondary marks. Unfortunately, this was not done; thus, no estimate of tag loss is available for this study.

TESTS OF SAMPLING ASSUMPTIONS

Statistical tests were performed to assess whether application and recovery were proportional and whether complete mixing occurred (Seber 1982; p 434-9; Schwarz and Taylor 1998). The data were examined for temporal and fish sex biases at application and recovery, and spatial bias at application. Application bias (non-proportional application and incomplete mixing) was assessed by stratifying the recovery sample (not corrected for missed tags) and comparing the mark incidence among strata. Similarly, recovery bias (non-proportional recovery and incomplete mixing) was assessed by stratifying the application sample and comparing the proportion recovered among strata. The data used for the recovery bias tests are adjusted for sex identification error and handling stress, but not for tag loss (the application stratum of fish with only a secondary mark could not be determined). Comparisons were made using chi-square tests (Sokal and Rohlf 1981).

For temporal bias tests, the application and recovery samples were stratified into four (application) or five (recovery) periods of approximately equal duration, total effort (numbers of sets or recovery surveys) and total numbers of sockeye marked or recovered. These three stratifications were used to examine the sensitivity of the tests to period start and end dates. For spatial bias tests, the recovery sample was stratified into five recovery sections (areas 1-2 and McKinley Creek, 3-4, 5-6, 7-8 and 9-13).

The data were also examined for a size bias at recovery; application bias could not be assessed because unmarked carcasses were not measured. The cumulative NF length frequency distributions of recovered (not corrected for missed tags) and unrecovered portions of the application sample were compared using a Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981). For the male test, males smaller than 50 cm NF were included. A significant difference would indicate that the recovery sample was not random with respect to fish size.

Finally, spawning success of tagged and untagged female recoveries was compared. A three-dimensional chi-square test (Zar 1984) was used to test for interactions among tag status, recovery section (areas 1-8 vs. 9-13) and spawning success (incomplete - 0 or 50% - vs. complete). This test will indicate if spawning success depends on tag status and/or recovery section. Although an influence of tag status on spawning success could be due to sampling selectivity, tagging stress would most likely cause such an influence. For example, a study in coho salmon (*O. kisutch*) showed that spawning success was affected by electroshocking, a highly stressful capture technique (Schubert *et al.* 1994). Thus, this test is interpreted as indicating whether fish were stressed by tagging.

ESTIMATION OF SPAWNER POPULATION

Mark-Recapture

Horsefly River study area escapement was estimated using the simple or pooled Petersen estimator ("PPE"; Seber 1982) and two stratified estimators, the maximum likelihood Darroch estimator ("MLE"; Plante 1990; Arnason *et al.* 1996) and the Schaefer estimator (Seber 1982). The estimates were calculated using Stratified Population Analysis System software (Arnason *et al.* 1996), from mark-recapture data adjusted for sex and tag recognition errors and handling stress effects.

ML Darroch and Schaefer population estimates were calculated using two types of data stratifications: i) data stratified temporally at both application and recovery (hereafter, "time x time"), and ii) data stratified temporally at application and spatially at recovery ("time x space"). Temporally, the data were stratified into five application and recovery periods in which the number of tags applied or recovered were approximately equal. Spatially, the data were stratified into five recovery sections (the same as used for spatial application bias tests). Selected strata were then pooled when necessary to generate an estimate and satisfy assumptions of the MLE as assessed by Plante's goodness-of-fit test (Arnason *et al.* 1996). This selective pooling also permitted an evaluation of model sensitivity and stability. Only selective poolings that maintained s (number of application strata) $\geq t$ (number of recovery strata) were considered; this policy is appropriate if the population is closed (all fish vulnerable to tagging are vulnerable to recovery; Schwarz and Taylor 1998). Stratifications with $s < t$ are not valid unless the movement patterns, death and migration rates are the same among application strata and among tagged and untagged fish; this condition is less likely to have held in this study (see Discussion). For temporally stratified data, only temporally 'adjacent' strata were pooled, and the stratum with the smallest number of tags applied or recovered was generally pooled. For spatially stratified data, three stepwise poolings were done: i) areas 1-2 and McKinley Creek with areas 3-4, ii) areas 7-8 with areas 9-13, and iii) 1-4 and McKinley Creek with areas 5-6. Population estimates were calculated after each pooling step. When two or more stratifications led to MLE estimates, and passed Plante's goodness-of-fit test, the one with the most strata was accepted.

Sampling biases were addressed in two ways. First, population estimates were calculated for each sex because sex biases are common in mark-recapture studies. Second, spatial and temporal biases were evaluated by comparing the PPE and MLE estimates. The latter are considered most accurate, and therefore accepted, when the 95% confidence intervals of the two estimates did not overlap; otherwise, the PPE estimates are accepted because their precision is generally higher. Schaefer estimates were only calculated for comparison; they were not considered for use as the final population estimate because no precision estimates are available.

Area-Specific Population Estimates

The escapement to Little Horsefly River and McKinley Creek was estimated as the product of the maximum daily live count (peak live count) plus the cumulative recovery of all carcasses (males, females and jacks) up to and including the date of that count (cumulative dead count), and an expansion factor of 1.8 (Andrew and Webb MS 1987). The latter was based on historic comparisons of visual data with mark-recapture and enumeration fence data (Woodey 1984). For areas where the entire carcass sample was 10% or more of the area-specific escapement estimate, the sex ratio in the carcass sample was used to estimate the sex ratio of that escapement. For other areas, the ratio between male and female study area escapement estimates was used. The escapement to the Horsefly River was estimated by subtracting each of these estimates from the Horsefly River study area estimate. Note that the Horsefly River estimate includes the Moffat Creek population; however, the latter was certainly small (*i.e.*, <200) and probably zero (see below).

RESULTS

VISUAL SURVEYS

Bridge counts were made from August 21 to September 18, 1995 (Appendix 2). The average count, during this period, was 53. The largest average daily count, 213, occurred on August 28. The average count on August 21 was 100, suggesting that the immigration began several days earlier. Average counts dropped substantially between August 31 and September 2, and averaged 3 thereafter.

The Little Horsefly River was surveyed on September 10, 1995; no live sockeye were counted. McKinley Creek was surveyed on September 16, 1995; 46 live sockeye were counted. Moffat Creek was only examined cursorily, and no live sockeye were seen.

TAG APPLICATION

Sockeye were tagged between August 21 and September 8, 1995 (Appendix 3). A total of 1,483 sockeye adults and one jack were tagged. The sex of five (3.1%) recovered males and four recovered females (1.7%) were recorded incorrectly at the time of tagging. When corrected for this error, an estimated 648.6 males and 834.4 females were marked.

Two sets of fish were removed from the application sample before testing sampling assumptions. First, 55 males and 73 females recovered in the spawning channel were removed. Second, six females requiring ventilation upon release (condition 3) were removed because of the significantly different recovery rate for these fish (67.6%) relative to those not requiring ventilation (21.9%; Table 1). The proportion of tagged fish recovered in potential high-stress and corresponding low-stress groups did not differ significantly for application method or recapture status, for either sex, or by release code, for males (Table 1); therefore, fish in the high-stress groups were retained. Also, no fish were recovered less than five days after tag application; this likely reflected the extremely late start of recovery (see below). After removal of tagged fish recovered in the spawning channel and females requiring ventilation, an estimated 593.0 (43.8%) males and 756.0 females were marked (Table 2).

The mean NF length for males, females and jacks in the application sample was 65.7 cm, 62.2 cm and 31.5 cm, respectively; ageing samples (*i.e.*, otoliths or scales) were not obtained for any tagged fish. The incidence of net, lamprey and hook marks was 0.7%, 1.4% and 0.0% in males and 4.2%, 0.8% and 0.1% in females (Appendix 4); the single jack was not marked.

SPAWNING GROUND SURVEYS

Recovery Survey

A total of 14,416 male, 22,127 female and 0 jack sockeye carcasses were recovered using standard methods in the Horsefly River study area between September 2 and September 28, 1995 (Table 2; Appendix 5). Areas of the Horsefly River were surveyed an average of 7 times, resulting in 36,378 recoveries, 99.5% of the total. Most carcasses were recovered in areas 4 (16.5% of total recovery), 5 (15.6%), 7 (11.5%) and 8 (17.3%). Little Horsefly River and McKinley Creek were surveyed once, resulting in 0 and 165 recoveries, respectively (Appendix 5).

Of the total recovery, 104 (0.72%) males and 165 (0.75%) females were disk tagged (Table 2). Time between release and recovery averaged 15.6 days for males and 16.1 days for females, and was significantly longer among those tagged earlier in the study (Table 3; $p<0.005$, t-test). Average times between tagging and recovery differed significantly with recovery section ($p<0.05$, ANOVA), and were longest in the upper river and decreased downstream. Female spawning success averaged 97.3%, with lower success among the early spawners (Table 3); a comparison of the proportion of incomplete spawners (0 or 50% spawning success) in the early and late recoveries indicated that this difference was significant ($p<0.005$, chi-square). Spawning success also varied significantly by recovery section ($p<0.005$, chi-square), and was highest in areas 9-13 (98.7%) and lowest in areas 1-2 and McKinley Creek (96.3%).

Table 1. The influence of three potential stress factors on the proportion of tags recovered; test data and results for Horsefly River study area sockeye salmon, 1995. [a]

	Disk tags applied [b]			Disk tags recovered			Percent recovered		
Test of:	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Tag application method									
Standard	291.0	384.0	0	44	81	0	15.1%	21.1%	-
Low-stress	302.1	377.9	0	59	89	0	19.5%	23.5%	-
Release condition [c]									
1	562.7	711.3	0	102	155	0	18.1%	21.8%	-
2	12.1	29.9	0	0	7	0	0.0%	23.4%	-
3	8.1	5.9	0	0	4	0	0.0%	67.6%	-
Number of recaptures									
0	565.8	727.2	0	101	165	0	17.9%	22.7%	-
1 or more	27.3	34.7	0	2	5	0	7.3%	14.4%	-

Chi-square test results

	Male			Female		
Stress factor	$\chi^{2\,d}$	df	*P*	$\chi^{2\,d}$	df	*P*
Tag application method	1.71	1	0.19	0.53	1	0.46
Release condition						
Comparing 1, 2 and 3:	4.44	2	0.11 [e]	7.15	2	0.03 *
Comparing 1 vs 2:	-	-	-	0.00	1	1.00
Comparing 1+2 vs 3:	-	-	-	4.71	1	0.03 *
Recapture status	1.34	1	0.25	0.88	1	0.35

a. Excluding tagged sockeye recovered in the spawning channel.
b. Corrected for sex identification errors.
c. See text for description of release conditions.
d. χ^2 values are Yates corrected in all tests with 1 df.
e. Test result inaccurate due to small sample size in some cells.

Table 2. Sockeye tagged, total carcasses recovered and marked carcasses recovered, by sex, in the Horsefly River study area, 1995. [a]

			Marked sockeye carcasses recovered					
Sex	Disk tags applied	Total recovery	Both marks present [b]	2° mark only [b]	Resurvey adjustment	Total	Percent recovered	Mark incidence
Male	593.0	14,416	104	0	11.3	115.3	19.4%	0.8%
Female	756.0	22,127	165	0	18.1	183.1	24.2%	0.8%
Jack	1.0	0	0	0	0.0	0.0	-	-
Total	1,350.0	36,543	269	0	29.4	298.4	22.1%	0.8%

a. Values are based on the final application and recovery data sets, after exclusion of certain tagged and untagged fish for several reasons, and correction for sex identification errors- see text.
b. Survey crews did not examine untagged carcasses for secondary marks.

Table 3. Average elapsed time between tag application and recovery (for 'fresh' recoveries) and female spawning success, by recovery section, period and sex, for Horsefly River study area sockeye salmon, 1995.

			Mean time (days) between tag application and carcass recovery [a]				Female spawning success [a]	
Location	Section	Period [b]	Male	(n)	Female	(n)	%	(n)
Horsefly River	Area 1-2 & Mc. Cr.	Early	20.0	(1)	19.5	(13)	95.3%	(1,905)
		Late	18.0	(3)	16.4	(9)	98.0%	(997)
		Total	18.5	(4)	18.2	(22)	96.3%	(2,902)
	Area 3-4	Early	18.9	(18)	18.3	(26)	97.2%	(4,238)
		Late	13.1	(8)	11.4	(9)	99.7%	(806)
		Total	17.2	(26)	16.5	(35)	97.6%	(5,044)
	Area 5-6	Early	18.6	(10)	17.2	(25)	96.8%	(4,190)
		Late	12.0	(11)	14.8	(8)	99.4%	(1,046)
		Total	15.1	(21)	16.6	(33)	97.4%	(5,236)
	Area 7-8	Early	16.7	(15)	15.8	(27)	96.6%	(4,917)
		Late	13.0	(13)	13.0	(20)	98.7%	(1,114)
		Total	15.0	(28)	14.6	(47)	97.0%	(6,031)
	Area 9-13	Early	15.5	(15)	17.1	(17)	98.4%	(1,657)
		Late	13.6	(10)	13.6	(11)	99.1%	(1,257)
		Total	14.7	(25)	15.7	(28)	98.7%	(2,914)
	Total	Early	17.4	(59)	17.4	(108)	96.8%	(16,907)
		Late	13.2	(45)	13.7	(57)	99.0%	(5,220)
		Total	15.6	(104)	16.1	(165)	97.3%	(22,127)

a. Calculated using all tagged recoveries except those recovered in the spawning channel and those females which required ventilation upon release.

b. Time out to recovery: early= 21-Aug to 29-Aug releases. Female spawning success: early= 2-Sep to 14-Sep recoveries.

Resurvey

Each area, other than Area 13, was resurveyed an average of five times between September 6 and September 29, 1995; 7,651 males and 12,219 females were re-examined, of which 6 male and 10 female carcasses were disk tagged (Appendix 6). Area 13 was not resurveyed because this area was characterized low numbers of recoveries (Appendix 5) and dense riparian vegetation making it difficult to find carcasses on the resurvey. An estimated 11.3 (9.8%) and 18.1 (9.9%) disk tagged male and female carcasses, respectively, processed during the main survey were not correctly identified as tagged fish (Table 2). When corrected for this error, a total of 115.3 male and 183.1 female disk tags were recovered, a mark incidence of 0.80% and 0.83%, respec-

Table 4. Percent at age and mean POH length at age of Horsefly River study area sockeye carcasses sampled on the spawning grounds, 1995.

		Percent at age					POH length (cm) at age				
Recovery location	Sex	3_2	4_2	4_3	5_2	5_3	3_2	4_2	4_3	5_2	5_3
Horsefly River	Male	-	31.6%	-	68.4%	-	-	48.9	-	53.9	-
	Female	-	15.7%	-	84.3%	-	-	48.5	-	52.3	-
	Jack [a]	-	-	-	-	-	-	-	-	-	-

a. No jacks were recovered in 1995.

Table 5. Proportion of the Horsefly River study area sockeye recoveries that were marked with disk tags and/or secondary marks, by recovery period and sex, in 1995, for the three stratifications used.

Recovery period	Number of surveys	Marked carcasses recovered: Male	Female	Jack	Total Recovery: Male	Female	Jack	Mark incidence: Male	Female	Jack
Equal recovery periods										
02-Sep to 07-Sep	2	9	18	0	4,115	4,172	0	0.2%	0.4%	-
08-Sep to 12-Sep	1	45	80	0	5,644	8,716	0	0.8%	0.9%	-
13-Sep to 17-Sep	1	40	44	0	3,598	6,784	0	1.1%	0.6%	-
18-Sep to 22-Sep	1	6	20	0	745	1,707	0	0.8%	1.2%	-
23-Sep to 28-Sep	2	4	3	0	314	748	0	1.3%	0.4%	-
Similar recovery effort										
02-Sep to 08-Sep	2	22	29	0	4,602	4,993	0	0.5%	0.6%	-
09-Sep to 12-Sep	1	32	69	0	5,157	7,895	0	0.6%	0.9%	-
13-Sep to 16-Sep	1	35	34	0	2,830	5,164	0	1.2%	0.7%	-
17-Sep to 20-Sep	1	8	21	0	1,165	2,415	0	0.7%	0.9%	-
21-Sep to 28-Sep	2	7	12	0	662	1,660	0	1.1%	0.7%	-
Similar total number of recoveries										
02-Sep to 07-Sep	2	9	18	0	4,115	4,172	0	0.2%	0.4%	-
08-Sep to 10-Sep	1	32	50	0	3,476	5,148	0	0.9%	1.0%	-
11-Sep to 12-Sep	1	13	30	0	2,168	3,568	0	0.6%	0.8%	-
13-Sep to 15-Sep	1	31	28	0	2,567	4,745	0	1.2%	0.6%	-
16-Sep to 28-Sep	2	19	39	0	2,090	4,494	0	0.9%	0.9%	-

Chi-square test results

Stratification scheme	Males: χ^2	df	P	Females: χ^2	df	P
Equal recovery periods	24.04	4	0.00**	15.31	4	0.00**
Similar recovery effort	16.10	4	0.00**	4.63	4	0.33
Similar total number of recoveries	26.39	4	0.00**	12.00	4	0.02*

tively.

BIOLOGICAL SAMPLING

Fifty females were sampled for fecundities at the tag site, from September 3 to 5, 1995. Only 47 were aged; eight were age 4_2 and averaged 51.5 cm standard length (range 48.9 to 55.7 cm), and 39 were age 5_2 and averaged 58.0 cm standard length (range 51.6 to 61.4; Appendix 7). The average fecundities were 3,108 (range 2,673 to 3,658) for age 4_2 fish and 4,048 (range 2,505 to 4,939) for age 5_2 fish (Appendix 7).

All of the carcasses in the adult carcass sample were either age 4_2 or 5_2; 31.6% of males and 15.7% of females were age 4_2 (Table 4; Appendix 8). Age 4_2 males and females averaged 48.9 and 48.5 cm, POH length, respectively. On average, age 5_2 fish were 5.0 (males) and 3.8 (females) cm longer. No jacks were recovered in 1995.

SAMPLING ASSUMPTIONS

Mark incidence differed significantly among recovery periods in all three stratifications tested in males, and in two of the stratifications (equal periods and similar number of recoveries) in females (Table 5). Mark incidence in adult carcasses ranged from 0.2% to 1.2%. In all stratifications, the mark incidence was lowest in the first recovery period. Application period affected the

Table 6. Proportion of disk tagged sockeye recovered in the Horsefly River study area, by application period and sex, in 1995, for the three stratifications used.

Application period	Number of sets	Disk tags applied[a]			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Equal application periods										
21-Aug to 24-Aug	26	117.2	150.8	0	27	34	0	23.0%	22.5%	-
25-Aug to 29-Aug	39	225.3	290.7	0	32	74	0	14.2%	25.5%	-
30-Aug to 03-Sep	31	232.4	293.6	0	43	56	0	18.5%	19.1%	-
04-Sep to 08-Sep	20	18.2	20.8	0	2	1	0	11.0%	4.8%	-
Similar application effort										
21-Aug to 24-Aug	26	117.2	150.8	0	27	34	0	23.0%	22.5%	-
25-Aug to 28-Aug	31	148.5	207.5	0	26	62	0	17.5%	29.9%	-
29-Aug to 01-Sep	28	272.8	347.2	0	44	67	0	16.1%	19.3%	-
02-Sep to 08-Sep	31	54.6	50.4	0	7	2	0	12.8%	4.0%	-
Similar number of tags applied										
21-Aug to 24-Aug	26	117.2	150.8	0	27	34	0	23.0%	22.5%	-
25-Aug to 28-Aug	31	148.5	207.5	0	26	62	0	17.5%	29.9%	-
29-Aug to 30-Aug	16	153.6	185.4	0	24	33	0	15.6%	17.8%	-
31-Aug to 08-Sep	43	173.8	212.2	0	27	36	0	15.5%	17.0%	-

Chi-square test results

Stratification scheme	Males			Females		
	χ^2	df	*P*	χ^2	df	*P*
Equal application periods	4.87	3	0.18	7.13	3	0.07
Similar application effort	3.66	3	0.30	18.67	3	0.00 **
Similar number of tags applied	3.32	3	0.34	12.64	3	0.01 *

[a.] Corrected for sex identification error.

proportion of tags recovered only in two of the stratifications tested in females (similar effort and number of tags applied; Table 6). The proportion of tags recovered ranged from 4.0% to 29.9% and generally decreased with application period; although not significant, a similar pattern was shown in males.

Spatial bias was detected in the application sample in males (Table 7). Mark incidence in recovered carcasses ranged from 0.3% to 1.7%. Additional tests indicate that the high mark incidence in areas 9-13 differed significantly from that in the other sections, but that mark incidence did not differ significantly among the other sections (Table 7).

Mark incidence among male and female carcasses, 0.7% for both sexes, did not differ significantly (Table 8). Application, therefore, was not sex selective. The recovery rates of tagged males (17.5%) and females (21.8%) did not differ significantly at α=0.05 (Table 8); however, it seems appropriate to consider recovery biased (towards females), due to the low p-value for this chi-square test, 0.06.

The size distributions of recovered and unrecovered tagged fish did not differ significantly for either sex, indicating that the recovery sample was not size selective (Table 9).

Finally, the mean spawning success of marked and unmarked female recoveries was 99.7% and 97.3%, respectively. The 3-dimensional chi-square test indicated that the proportion of incomplete spawners, and recovery section, were independent of tag status, (p>0.05, chi-square). The conclusions of all tests of sampling assumptions are summarized in Table 10.

Table 7. Proportion of the Horsefly River study area sockeye recoveries that were marked with disk tags and/or secondary marks, by recovery section and sex, in 1995.

	Marked carcasses recovered			Total Recovery			Mark incidence		
Recovery section	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Area 1-2 & Mc. Cr. [a]	4	22	0	1,405	2,902	0	0.3%	0.8%	-
Area 3-4	26	35	0	3,495	5,044	0	0.7%	0.7%	-
Area 5-6	21	33	0	3,538	5,236	0	0.6%	0.6%	-
Area 7-8	28	47	0	4,485	6,031	0	0.6%	0.8%	-
Area 9-13	25	28	0	1,493	2,914	0	1.7%	1.0%	-

Chi-square test results

	Males			Females		
Test compares:	χ^2 [b]	df	P	χ^2	df	P
All (5) sections:	24.10	4	0.00 **	3.05	4	0.55
All but Area 9-13	3.51	3	0.32	-	-	-
Area 9-13 versus other sections pooled:	19.66	1	0.00 **	-	-	-

a. Mc. Cr.= McKinley Creek.

b. χ^2 values are Yates corrected in all tests with 1 df.

Table 8. Sex composition of Horsefly River study area sockeye in the application and recovery samples, 1995.

	Application sample, by recovery status			Recovery sample, by mark status		
Sex	Disk tags applied [a]	Disk tags recovered	Percent recovered	Total recovery	Marked recoveries	Mark incidence
Male	593.0	104	17.5%	14,416	104	0.7%
Female	756.0	165	21.8%	22,127	165	0.7%
χ^2 value [b]:	Recovery bias test:		3.57	Application bias test:		0.04
P (df=1):			0.06			0.84

a. Corrected for sex identification error.

b. χ^2 values are Yates corrected.

SPAWNING POPULATION ESTIMATES

Mark-Recapture

The 1995 Horsefly River study area sockeye escapement estimates, based on the pooled (Table 2) and stratified (Table 11 and 12) data, are presented in Table 13. The PPE estimates ± 95% confidence limits are 73,632 ± 11,901 (16.2%) adult males and 90,977 ± 11,354 (12.5%) adult females (excluding the females sampled for fecundities). The PPE estimate of the total escapement, produced by summing the sex-specific estimates, is 164,610 ± 16,449 (10.0%) adult sockeye. The age-specific estimates are based on the sex-specific age composition in the aged carcass sample (Table 4). The jack escapement estimate of one is based on the application sample since none were recovered (Table 2).

Selective pooling of strata (Tables 11 and 12) resulted in satisfaction of the MLE assumptions for both sexes with time x time stratification, but only for males with time x space stratification (Table 13). MLE and PPE estimates differed by -5.4% and 2.2% (time x time) and -27.6% and 12.0% (time x space), for males and females, respectively.

Although Schaefer estimates were produced at all stratification scales, the reported values are those produced at the same scale as the reported

Table 9. Proportion of disk tagged sockeye recovered in the Horsefly River study area, by sex and 3 cm increments of nose-fork length, 1995.

Nose-fork length (cm)	Disk tags applied [a]			Carcasses recovered with disk tags			Percent recovered		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
31 - 33.9	1.0	0.0	1.0	0	0	0	0.0%	-	0.0%
49 - 51.9	0.0	1.0	1.0	0	0	0	-	0.0%	0.0%
52 - 54.9	1.0	23.0	24.0	0	7	7	0.0%	30.4%	29.2%
55 - 57.9	12.1	70.9	83.0	3	18	21	24.7%	25.4%	25.3%
58 - 60.9	62.6	103.4	166.0	16	24	40	25.5%	23.2%	24.1%
61 - 63.9	89.9	305.1	395.0	12	61	73	13.3%	20.0%	18.5%
64 - 66.9	146.5	217.5	364.0	24	44	68	16.4%	20.2%	18.7%
67 - 69.9	219.2	33.8	253.0	35	11	46	16.0%	32.6%	18.2%
70 - 72.9	59.6	1.4	61.0	13	0	13	21.8%	0.0%	21.3%
73 - 75.9	2.0	0.0	2.0	1	0	1	49.5%	-	50.0%
Kolmogorov-Smirnov 2-sample test Dmax (continuous data; see text):							0.066	0.042	0.061
Kolmogorov-Smirnov 2-sample test Dcritical (α = 0.05):							0.147	0.120	0.093

[a] Corrected for sex identification error. Both jacks and adult males are included as males here.

Table 10. Bias profile for the 1995 Horsefly River study area sockeye escapement estimation study.

Bias type	Test of:	Between	Test result [a]
Application sample			
Temporal	Tagged: untagged recoveries	Equal recovery periods	Mid/late period bias: M, F
		Periods of similar rec. effort	Mid/late period bias: M, F
		Periods of similar total recoveries	Mid/late period bias: M, F
Spatial	Tagged: untagged recoveries	Five recovery sections	Lower reach bias in males
Fish sex	Tagged: untagged recoveries	Sexes	No bias
Stress	Tagged fish recovered less than 5 days after release:		None
	Recovered: unrecovered tags	Application methods	No bias
	Recovered: unrecovered tags	Release condition 1 vs 2+3 [b]	Condition 3 females excluded
	Recovered: unrecovered tags	0+1 vs 2 or more recaptures	No bias
	Tagged: untagged recoveries	0+50% vs 100% spawned and recovery section	No bias
Recovery sample			
Statistical	Minimum recovery of 5 tags:	-	No jack males recovered
Temporal	Recovered: unrecovered tags	Equal application periods	No bias
		Periods of similar application effort	Early/mid period bias in females
		Periods of similar applications	Early period bias in females
Fish sex	Recovered: unrecovered tags	Sexes	No bias
Fish size	Size-frequency distrib:	Recovered: unrecovered tags	No bias

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

[b] See text for description of release conditions.

Table 11. Tag application-recovery matrices, stratified temporally at both application and recovery, for the 1995 Horsefly River study area sockeye mark-recapture study. The finest scale stratifications (see text) are shown; bracketed strata were aggregated to produce an ML Darroch estimate and attempt to meet the assumptions of the ML Darroch model.

Male

Application period	Tags applied	[2-Sep to 7-Sep	8-Sep to 10-Sep]	[11-Sep to 12-Sep	13-Sep to 15-Sep]	16-Sep to 28-Sep	Total Recovered
		Recovery period					
21-Aug to 24-Aug	117.2	6.7	8.9	3.3	6.7	4.4	29.9
25-Aug to 28-Aug	148.5	2.2	11.1	4.4	5.5	5.5	28.8
29-Aug to 30-Aug	153.6	0.0	10.0	3.3	8.9	4.4	26.6
31-Aug to 08-Sep	173.8	1.1	5.5	3.3	13.3	6.7	29.9
Total tags:	593.0	10.0	35.5	14.4	34.4	21.1	115.3
Total recovered:		4,115	3,476	2,168	2,567	2,090	14,416

Female

Application period	Tags applied	[2-Sep to 7-Sep	8-Sep to 10-Sep]	[11-Sep to 12-Sep	13-Sep to 15-Sep	16-Sep to 28-Sep]	Total Recovered
		Recovery period					
21-Aug to 24-Aug	150.8	12.2	15.5	1.1	3.3	5.5	37.7
[25-Aug to 28-Aug	207.5	5.5	20.0	11.1	16.6	15.5	68.8
29-Aug to 30-Aug]	185.4	0.0	13.3	6.7	6.7	10.0	36.6
31-Aug to 08-Sep	212.2	2.2	6.7	14.4	4.4	12.2	40.0
Total tags:	756.0	20.0	55.5	33.3	31.1	43.3	183.1
Total recovered:		4,172	5,148	3,568	4,745	4,494	22,127

MLE estimate. All Schaefer estimates differ by less than 1.9% from the PPE estimates.

The sex-specific PPE estimates are accepted for the following reasons. First, the 95% confidence intervals of all four MLE estimates overlap those of the PPE estimates extensively, indicating that the discrepancies are small relative to the uncertainty in each estimate. Second, all stratifications which produced the four reported MLE estimates passed one of the two "complete mixing" tests which SPAS reports. These tests are equivalent to the temporal and spatial application and recovery bias tests reported earlier; however, their results may differ because they test the data as it is stratified to produce a particular MLE estimate. Arnason *et al.* (1996, p. 27) state that "if either test passes ... it should be safe to use the pooled Petersen estimate."

Area-Specific Population Estimates

The escapement estimates for each component area of the Horsefly River system are presented in Table 14. Also included are the estimates for the spawning channel (provided by the Salmonid Enhancement Program). The reported escapement of zero to Moffat Creek (Table 14), is a probable value based on casual observations made near the mouth of the Creek during recovery surveys of the Horsefly River shoreline. The estimated escapement to the system, including spawning channel recoveries, was 80,287 males, 100,585 females and 1 jack. An estimated 91.6% of males and 90.3% of females spawned in the Horsefly River. The spawning channel received the next largest escapement; 8.3% of males and 9.5% of females.

DISCUSSION

ASSUMPTIONS

The Petersen mark-recapture technique is based on the principle that, by tagging a random sample of fish, permitting them to redistribute through the population, and obtaining a second random sample of tagged and untagged individuals, the number of fish in the population can be estimated with known precision. The accuracy of

Table 12. Tag application-recovery matrices, stratified temporally at application and spatially at recovery, for the 1995 Horsefly River study area sockeye mark-recapture study. The finest scale stratifications (see text) are shown; bracketed strata were aggregated to produce an ML Darroch estimate and attempt to meet the assumptions of the ML Darroch model.

Male

Application period	Tags applied	Recovery section: [Above Area 3	Area 3-4]	[Area 5-6	Area 7-8	Area 9-13]	Total Recovered
21-Aug to 24-Aug	117.2	1.1	11.1	5.5	7.8	4.4	29.9
[25-Aug to 28-Aug	148.5	0.0	8.9	5.5	7.8	6.7	28.8
29-Aug to 30-Aug	153.6	3.3	3.3	7.8	4.4	7.8	26.6
31-Aug to 08-Sep]	173.8	0.0	5.5	4.4	11.1	8.9	29.9
Total tags:	593.0	4.4	28.8	23.3	31.0	27.7	115.3
Total recovered:		1,405	3,495	3,538	4,485	1,493	14,416

Female

Application period	Tags applied	Recovery section: [Above Area 3	Area 3-4	Area 5-6]	[Area 7-8	Area 9-13]	Total Recovered
21-Aug to 24-Aug	150.8	5.5	15.5	7.8	7.8	1.1	37.7
[25-Aug to 28-Aug	207.5	8.9	11.1	17.8	17.8	13.3	68.8
29-Aug to 30-Aug]	185.4	4.4	10.0	5.5	11.1	5.5	36.6
31-Aug to 08-Sep	212.2	5.5	2.2	5.5	15.5	11.1	40.0
Total tags:	756.0	24.4	38.8	36.6	52.2	31.1	183.1
Total recovered:		2,902	5,044	5,236	6,031	2,914	22,127

an escapement estimate depends on how well the study meets the assumptions underlying the technique. These assumptions have been described in various forms by Ricker (1975), Otis *et al.* (1978), Eames *et al.* (1981), Seber (1982) and Arnason *et al.* (1996) and are discussed below in the context of the current study.

Population Closure

In a closed population the number of animals does not change during the study. The population did change during this study, through immigration, die-off and emigration; however, such factors will not violate the closure assumption if all components of the population are vulnerable to either marking and/or carcass recovery, and death and emigration affect marked and unmarked fish equally (Arnason *et al.* 1996). The current study achieved the former condition spatially; all fish were vulnerable to marking, since the tagging site was downstream of virtually all spawning, and all areas known to support spawners were surveyed for carcasses. Temporally, however, marking may have started up to one week after sockeye first entered the river, and recovery probably began approximately one week after die-off began and ended a few days before die-off ended. Because the number of animals missed during these "tails" of immigration and recovery would have been relatively small, the influence of this violation on the population estimates is likely small.

Sockeye can become unavailable to recovery (emigrate from the study area) by several mechanisms, including carcass decomposition, predator activity and fishing, and flushing downstream. The former were likely unimportant to the current study because inter-survey periods averaged only three days, there was little predator activity and no fisheries in the study area. Further, it is unlikely that marked fish were disproportionately affected by these mechanisms. Conversely, a large number of carcasses probably flushed out of the system, and marked fish may have been more or less likely to flush out due to application selectivity and/or tagging stress. For example, both selectivity for fish which spawned in the lower areas of the Horsefly River, and impaired swimming ability due to tagging stress, could have caused marked

Table 13. Sockeye escapement estimates [a] and 95% confidence limits, by age and sex, for the Horsefly River study area, 1995. Asterisks indicate accepted estimates.

		Escapement at age						95% confidence limits on total	
Estimator	Sex	3_2	4_2	4_3	5_2	5_3	Total	Lower	Upper
Pooled	Male	0	23,252	0	50,380	0	73,632 *	61,731 *	85,533 *
Petersen	Female	0	11,525	0	62,107	0	90,977 *	79,623 *	102,331 *
	Total [b]	0	34,777	0	112,487	0	164,610 *	148,161 *	181,058 *
	Total [c]	-	-	-	-	-	164,766	148,397	181,134
	Jack	-	-	-	-	-	1 *	-	-
Application and recovery stratified temporally									
ML	Male [d,e]	-	-	-	-	-	61,829	39,965	83,694
Darroch	Female [d]	-	-	-	-	-	91,072	79,452	102,691
Schaeffer	Male [d]	-	-	-	-	-	73,564	-	-
	Female [d]	-	-	-	-	-	91,309	-	-
Application stratified temporally, recovery stratified spatially									
ML	Male [d, e]	-	-	-	-	-	66,484	46,346	86,623
Darroch	Female [d, e]	-	-	-	-	-	88,336	76,140	100,533
Schaeffer	Male [d]	-	-	-	-	-	73,956	-	-
	Female [d]	-	-	-	-	-	91,074	-	-

a. Does not include 50 females which were killed for fecundity samples.

b. Sum of male and female estimates. Confidence intervals calculated as in Schubert (1997).

c. Petersen estimate based on combined male and female data.

d. Stratifications used to produce estimates are indicated in Table 11 and 12.

e. Model assumptions are satisfied (passes Plante's goodness-of-fit test (Arnason et al. 1996)).

Table 14. Sockeye escapement estimates, by sex, for Horsefly River, Little Horsefly River, McKinley Creek, Moffat Creek and the Horsefly spawning channel, 1995.

			Adult escapement			
Area	Peak live count	Cumulative dead count	Male	Female	Total	Jack
Horsefly River [a]	n/a	n/a	73,519	90,710	164,230	1
Little Horsefly River	0	0	0	0	0	0
McKinley Creek	46	165	113	267	380	0
Moffat Creek [b]	0	0	0	0	0	0
Spawning channel [c]	n/a	n/a	6,655	9,608	16,263	0
System total [d]	n/a	n/a	80,287	100,585	180,873	1

a. Calculated as the difference between the mark-recapture estimate for the study area and all of the area-specific escapement estimates (not including the spawning channel).

b. Probable escapement based on casual observations in lower Moffat Creek.

c. Estimates provided by the Salmonid Enhancement Program; not included in mark-recapture study area.

d. Does not include 50 females killed for fecundity samples.

fish to flush out at higher rates than unmarked ones. In this study, care was taken to avoid application selectivity and tagging-induced stress. Based on the above, and our later evaluation of selectivity and stress, we conclude that the population closure assumption is reasonably valid for this study.

Correct Identification of Tag Status

If uncorrected, misidentification of carcasses with a disk tag and/or secondary mark as unmarked results in an overestimate of escapement. Surveyor inexperience, fatigue or assigning a higher priority to recovery speed than to thoroughness can all contribute to this error. In the current study, a resurvey of 54.8% of the recovered carcasses showed that 9.8% of the disk tags present on the initial survey had been misidentified as unmarked. This error rate is higher than contemporary studies (*e.g.*, Houtman and Schubert 2000; Houtman and Fanos 2000), and also than the 7.3% error rate in the previous Horsefly River system study, when many more (92,951) carcasses were recovered (Cone 1999). Thus, earlier recommendations for increased accuracy of identification of tag status during the initial recovery survey (Cone 1999) were not implemented. During future studies, survey crews must exercise greater care.

The estimated number of missed tags is likely reasonably accurate and more accurate than previous studies due to procedural changes implemented in 1995. The resurveys were more frequent and spatially more representative, and examined a larger proportion of the carcasses. The estimated number of missed tags is probably an overestimate, since predators could have carried some unrecovered carcasses above the high water mark; the magnitude of this error can not be estimated. In future studies, recovered carcasses should be chopped in two to allow previously recovered carcasses to be distinguished on the resurvey. Unfortunately, the only available method for incorporating the variance of the missed tag estimate into the population variance (Rajwani and Schwarz 1997) was not applicable to this study, because carcasses identified as tagged on the initial survey were included in the resurvey. The precision of the population estimates, therefore, is overestimated (*i.e.,* the 95% confidence intervals reported are too small). In future studies, carcasses identified on the recovery survey as marked should be excluded from the resurvey, so that the variance estimation procedures of Rajwani and Schwarz (1997) can be applied. This can be easily achieved either by making such carcasses identifiable (*e.g.*, by chopping them in three, with chops in front and behind the dorsal fin) or by throwing them far up the bank.

No Undetected Tag Loss

The undetected loss of disk tags between application and recovery would result in an underestimate of the proportion of the population with tags and an overestimate of escapement. Tag loss can result from poor tag application technique, tangling of the tag in the net after release, or the fighting which is common among males during spawning. In the current study, tag loss was to be assessed by applying an opercular punch as a permanent secondary mark. Unfortunately, survey crews did not examine untagged carcasses for opercular punches; therefore, no estimate of tag loss is available. Tag loss rates in other 1995 mark-recapture studies of Fraser River sockeye stocks range from 0.00% (Birkenhead River, Houtman *et al.* 2000; Seymour River, Houtman and Schubert 2000) to 0.25% (Adams River study area, Houtman and Fanos 2000). If the tag loss rate in the current study was actually 2.5%, the population estimate would only be 2.4% lower. In future studies, recovered carcasses must be examined for secondary marks and disk tagged and/or secondary marked fish must be excluded from the resurvey to allow the incidence of missed secondary marks to be determined. Further, alternate secondary marks should be evaluated and available for use should the accurate detection of opercular punches prove untenable.

Equal Catchability

Recovery probabilities across strata (hereafter, 'average' recovery probabilities) of marked and unmarked sockeye must be equal for the PPE estimate to be unbiased. For stratified models to be unbiased, average recovery probabilities of these two groups can differ, but recovery probabilities within strata must be equal (Arnason *et al.* 1996). Note that even when recovery probabilities are equal within each stratum, unequal average recovery probabilities can exist unless one or more of the following three conditions exist: i) proportional application, ii) proportional recovery, and iii) complete mixing. If recovery probabilities differ within strata, average recovery probabilities will rarely be equal.

Tagging-stress effects and selective application sampling can both influence where and when tagged carcasses become recoverable, potentially causing unequal recovery probabilities of tagged and untagged fish. Stress can influence the distance and duration of movements by impairing swimming ability and causing earlier death; application can favour fish with specific spawning ground distributions or spawning schedules. While the application bias tests should detect such differences, they do not indicate their cause. Application bias will not induce unequal recovery probabilities of marked and unmarked fish, however, if the recovery sample is unbiased or has an independent source of bias (Junge 1963; Seber 1982).

In the current study, tag application was designed to minimize tagging-stress (see above). Only 14 (1.0%) sockeye required ventilation and 42 (3.1%) sockeye swam away sluggishly upon release. Further, no tagged fish were recovered less than five days after release. These observations suggest that application was reasonably stress-free. As well, tagged fish were excluded from the analysis if there were indications that they were stressed by application. Six females that required ventilation at release were excluded, because the different (higher) recovery rate of this group may have been caused by a high stress level. These procedures, however, probably did not fully eliminate the influence of tagging-stress on tagged fish.

The sampling methods were also designed to minimize selectivity, through proportional application and recovery. To achieve application proportionality, fish were captured using a gear known to minimize selectivity, and a standardized daily tagging effort was applied throughout the study. Expending application effort evenly may not achieve proportional application, however, due to variability in: river conditions; the proportion of the fish which migrate at night; daily set times; the technique used during each set; and the daily size of the migration (large migrations may exceed the tagging capacity of the crew). Also, fish migrating at night (and other periods of the day in which application did not occur) may have differed, in behavior, sex ratio, size distribution or other aspects, leading to application selectivity for these attributes. Similarly, although the recovery survey effort was applied relatively equally (spatially and temporally) throughout the die-off, sample selectivity may have persisted for a variety of reasons, including variable river conditions.

Here, evidence is examined regarding the likelihood that recovery probabilities of tagged and untagged sockeye were equal (at either level). In this study, no data was collected to provide a direct test of this assumption at the within-stratum level. In future, consideration should be given to recovering carcasses from deep pools and other sites where substantial numbers of carcasses would be unavailable to normal recovery. Comparison of the tag incidence among such carcasses with that among standard recoveries provides evidence regarding whether recovery probabilities of tagged and untagged carcasses were the same within a limited (spatially and temporally) stratum (*e.g.* Houtman and Schubert 2000).

Spawning success was independent of tag status, suggesting that the behavior of tagged and untagged females was similar, increasing the likelihood that the two groups had similar recovery probabilities. This result also suggests that tagging procedures were relatively unstressful, since spawning success is known to be sensitive to stress in salmon (Schubert *et al.* 1994).

Examination of the application and recovery samples indicated several biases: i) a temporal application bias in both sexes, ii) a temporal recovery bias in females, and iii) a spatial application bias in males (Table 10). Thus, application and/or recovery was proportional with respect to sex and size in both sexes, time in males, and space in females, and these factors should not have produced unequal recovery probabilities.

Note, however, that nonsignificant results of bias tests ($p>0.05$) do not prove that no bias exists. For example, the power of some or all of the tests may be low, and the stratification used in a bias test may "hide" an actual bias. Separate estimates, therefore, were calculated for males and females. Further, PPE estimates were compared with estimates produced by stratified models with data stratified two ways (see above), to determine whether temporal and spatial biases influenced the estimates substantially.

In males, application was spatially biased; also, a spatial bias in recovery could not be tested for and thus could not be ruled out. In females, both application and recovery were biased temporally. Both the male and female PPE estimates, therefore, are potentially biased. The male and female MLE estimates, for both types of stratification, were all lower than the PPE estimates, suggesting that the PPE estimates, if biased, were positively biased. This bias direction is expected considering the nature of the temporal biases. In both sexes, mark incidence was lowest among early recoveries, and the proportion of tagged sockeye recovered was lowest for fish marked late. The average recovery probability of marked fish, therefore, would have been less than untagged fish, increasing the PPE estimate. Although the PPE estimates were accepted for both sexes, for the reasons discussed above, these estimates are probably slightly positively biased.

GENERAL DISCUSSION

It is important to consider possible causes for the temporal and spatial biases found in this study, in order to direct future study design modifications to avoid such biases. The temporal application bias, characterized mainly by low mark incidence among early recoveries, was a result of application beginning well after sockeye entered the Horsefly River. This late start was a consequence of the 'last-minute' decision to implement a mark recapture program in this area. This bias can be avoided by beginning the program earlier.

The temporal recovery bias, characterized by sockeye tagged late in application having the lowest proportion recovered, was probably caused by recovery ending several days before the end of die-off. In future studies, recovery should begin when the first carcasses are sighted, and continue until the end of die-off.

Finally, the spatial application bias involved relatively high mark incidence in the lower areas (9-13) of the Horsefly River. This pattern was present in both sexes, although the bias test was not significant for females. This pattern was also present in 1994, among males. Similar trends were present in several contemporary sockeye escapement studies of Fraser River stocks (*e.g.*, Houtman *et al.* 2000; Houtman and Schubert 2000). As in those studies, this bias was probably caused, in part, by higher vulnerability of lower area spawners to capture at the application site. If so, a small increase in the selectivity of tagging crews for "fresher" fish may reduce this bias in future studies. The late start to tagging probably also contributed to this bias, since sockeye entering the river early tended to spawn in the upper areas (Table 12). An earlier start of tagging, therefore, should also help reduce the spatial bias.

Marking stress may also have caused or contributed to the spatial pattern of tag incidence, if stressed sockeye do not swim as far. This possible mechanism can not be properly evaluated, due to the types of data available. Two weak sources of evidence, however, suggest that this mechanism was not too important. First, as discussed above, spawning success was not influenced by mark status, as it may have been if marked sockeye were stressed. Second, of the six females (removed from application) requiring ventilation upon release, of which four were recovered, one was recovered in Area 6, one in Area 7 and two in Area 8.

In this study, the recovery survey was poorly executed. Recovery began 12 days after tagging, too late to determine if fish that were tagged early in the program died soon after tagging (a sign of tagging stress). In future studies, the delay between the beginning of tagging and recovery should be less than five days. As well, surveyors failed to examine carcasses for secondary marks and misidentified tagged carcasses as untagged at a high rate. More careful training and supervision of surveyors will result in proper examination of carcasses and reduce the tag miss rate.

RECOMMENDATIONS

The 1995 study was implemented late, due to the delayed realization that the run size would justify a mark-recapture study. This study, therefore, was not executed as well as contemporary studies, nor were several of Cone's (1999) recommendations implemented. Future studies should incorporate those recommendations as well as the following:

1. The following changes should be considered to reduce temporal and spatial sampling biases:

- tagging should begin when sockeye first enter the river;
- recovery should begin immediately after tagging and continue until die-off is virtually complete;
- tagging crews should be slightly more selective for "fresher" fish, to reduce the spatial application bias toward lower area spawners.

2. Recovery of carcasses that would not be recovered in the normal surveys (because they are too deep) would allow testing of the assumption that tagged and untagged carcasses are equally likely to be recovered. In order to make this test reasonably representative, such pool recoveries should be made at three times in recovery (*e.g.*, several days before, on, and several days after, peak die-off) at sites in several of the more important recovery areas (*e.g.*, areas 4, 5 and 8). Such recoveries should be made by the most ap-

propriate means for each site; possible methods include carcass seining and gaffing from shore or tethered boat.

3. The following changes will improve the estimation of tag-status identification error rate:

- on the initial survey, all carcasses examined should be chopped in two, and only carcasses which have been chopped should be included in the resurvey. This procedure will ensure that the resurvey excludes unexamined carcasses deposited on the bank by predators or high water. When carcass abundance is high, chopping of 100% of carcasses may not be practicable due to surveyor fatigue and safety concerns. Resurveys in areas where some but not all recovered carcasses have been chopped should keep separate records for the two types of carcasses.
- to allow for incorporation of the uncertainty in the misidentification error rate into population estimates (Rajwani and Schwarz 1997), carcasses identified as disk tagged and/or secondary marked should be excluded from the resurvey, by chopping them in three (with chops in front and behind the dorsal fin). This change will also enable an estimation of the rate at which carcasses which had lost a disk tag but retained a secondary mark were misidentified as unmarked on the initial survey.

4. In this study, the rate at which disk tagged carcasses were misidentified as untagged was unacceptably high (9.8%). Thus, as recommended by Cone (1999), the importance of correct identification of tag status of recovered carcasses must be emphasized to survey crews.

5. The rate of sex-identification errors is estimated from the recovery sample (only a subsample of the application sample). The uncertainty in this estimate contributes to the uncertainty in the population estimates; currently, this contribution is unaccounted for. As recommended by Cone (1999) analytical methods should be developed to allow for the variance in these error rate estimates to be incorporated into the variance of the population estimates.

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APPENDICES

Appendix 1a. Sockeye jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Horsefly River system, 1938-1995.

	Escapement				Percent	
Year	Total	Jacks	Males	Females	spawning success	Effective females
1938	0	0	0	0	0.0%	0
1939	7	0	3	4	100.0%	4
1940	74	46	11	17	100.0%	17
1941	945	0	464	481	95.0%	457
1942	0	0	0	0	0.0%	0
1943	0	0	0	0	0.0%	0
1944	9	0	4	5	100.0%	5
1945	4,441	0	1,032	3,409	99.0%	3,374
1946	104	0	43	61	71.4%	44
1947	11	2	3	6	100.0%	6
1948	100	0	50	50	95.0%	48
1949	30,000	0	10,170	19,830	95.0%	18,839
1950	398	0	121	277	95.0%	264
1951	49	0	27	22	40.0%	9
1952	7,015	6,831	92	92	55.8%	51
1953	108,581	8	46,491	62,082	75.0%	46,530
1954	281	0	140	141	97.3%	137
1955	63	0	31	32	95.0%	30
1956	2,655	2,574	40	41	95.0%	39
1957	220,990	0	81,032	139,958	95.0%	131,250
1958	1,798	0	542	1,256	98.4%	1,236
1959	76	11	35	30	95.0%	29
1960	3,052	2,760	128	164	73.9%	123
1961	295,745	9	115,843	179,893	38.0%	68,043
1962	1,073	0	459	614	95.0%	564
1963	86	3	36	47	84.8%	40
1964	15,670	15,278	218	174	83.3%	159
1965	359,232	10	164,408	194,814	53.2%	103,661
1966	1,611	0	545	1,066	91.5%	975
1967	119	0	59	60	40.0%	24
1968	5,759	5,064	347	348	95.0%	331
1969	264,195	5	110,009	154,181	49.7%	73,903
1970	1,350	5	453	892	41.8%	373
1971	171	0	65	106	15.4%	16
1972	3,403	3,295	39	69	60.0%	44
1973	253,386	0	113,807	139,579	72.4%	101,233
1974	4,459	0	1,846	2,613	99.0%	2,587
1975	201	8	88	105	100.0%	105
1976	2,096	1,798	93	205	100.0%	205
1977	473,114	24	226,050	247,040	61.8%	147,409
1978	7,377	0	3,595	3,782	98.4%	3,721
1979	511	0	243	268	88.6%	238
1980	3,162	2,854	154	154	60.0%	98
1981	677,391	31	316,400	360,960	81.5%	293,379
1982	35,974	0	17,386	18,588	98.1%	18,136
1983	2,036	0	662	1,374	75.5%	1,038
1984	6,123	5,229	316	578	95.5%	539
1985	1,071,780	0	490,417	581,363	94.9%	570,702
1986	150,392	6	65,972	84,414	93.6%	78,539
1987	16,808	13	6,086	10,709	84.0%	9,001
1988	23,652	17,780	1,857	4,015	89.1%	3,519

Continued

Appendix 1a. Sockeye jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Horsefly River system, 1938-1995.

Year	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
Continued						
1989	1,614,400	0	788,915	825,485	96.2%	812,277
1990	439,485	0	201,200	238,285	98.5%	228,740
1991	38,569	0	17,040	21,529	100.0%	21,016
1992	8,901	3,039	2,816	3,046	100.0%	3,046
1993	1,865,806	258	733,493	1,132,055	99.4%	1,107,550
1994	523,575	17	229,883	293,675	99.0%	289,368
1995	180,873	1	80,287	100,585	97.3%	97,898

Appendix 1b. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Horsefly River, 1938-1995.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1938	-	-	0	0	0	0	0.0%	0
1939	-	-	7	0	3	4	100.0%	4
1940	Sep 01	Sep 08-Sep 14	74	46	11	17	100.0%	17
1941	Aug 15	Aug 25-Aug 30	918	0	451	467	95.0%	444
1942	-	-	0	0	0	0	0.0%	0
1943	-	-	0	0	0	0	0.0%	0
1944	-	-	5	0	2	3	100.0%	3
1945	Aug 14	Sep 07-Sep 08	4,441	0	1,032	3,409	99.0%	3,374
1946	Aug 15	Aug 30	104	0	43	61	71.4%	44
1947	-	-	11	2	3	6	100.0%	6
1948	-	-	100	0	50	50	95.0%	48
1949	Aug 08	Sep 01-Sep 05	30,000	0	10,170	19,830	95.0%	18,839
1950	Aug 23	Aug 25-Aug 27	385	0	115	270	95.0%	257
1951	Aug 20	Aug 26	49	0	27	22	40.0%	9
1952	Aug 12	Aug 26-Sep 03	7,013	6,829	92	92	55.8%	51
1953	Aug 04	Aug 27-Aug 29	105,440	8	45,146	60,286	75.0%	45,184
1954	Aug 23	Sep 02-Sep 05	274	0	137	137	97.3%	133
1955	Aug 21	Sep 05	63	0	31	32	95.0%	30
1956	Aug 18	Aug 31	2,556	2,482	37	37	95.0%	35
1957	Aug 05	Sep 02-Sep 05	214,254	0	78,540	135,714	95.0%	127,218
1958	Aug 15	Sep 07-Sep 10	1,784	0	535	1,249	98.4%	1,229
1959	-	-	49	0	24	25	95.0%	24
1960	Aug 19	[a]	3,029	2,748	123	158	73.9%	117
1961	Aug 5	Aug 28-Aug 31	277,305	9	108,394	168,902	38.0%	64,200
1962	Aug 23	Aug 30-Sep 04	1,001	0	430	571	95.0%	526
1963	Aug 12	Aug 25-Aug 29	86	3	36	47	84.8%	40
1964	Aug 25	Sep 10-Sep 12	15,315	15,061	162	92	83.3%	77
1965	Aug 06	Aug 29-Sep 03	359,232	10	164,408	194,814	53.2%	103,661
1966	Aug 15	Sep 03-Sep 06	1,607	0	543	1,064	91.5%	973
1967	Aug 14	Sep 01-Sep 05	119	0	59	60	40.0%	24
1968	Aug 20	Sep 03-Sep 08	5,686	4,996	345	345	95.0%	328
1969	Aug 07	Aug 27-Sep 01	236,219	5	98,846	137,368	49.7%	68,204
1970	Aug 24	Sep 04-Sep 07	1,350	5	453	892	41.8%	373
1971	-	Aug 30-Sep 01	171	0	65	106	15.4%	16
1972	Aug 20	Sep 05-Sep 10	2,859	2,769	33	57	60.0%	34
1973	Aug 14	Aug 29-Sep 02	238,278	0	107,793	130,485	72.4%	94,471
1974	-	Sep 06-Sep 10	4,459	0	1,846	2,613	99.0%	2,587
1975	-	[b]	101	4	44	53	100.0%	53
1976	Sep 07	Sep 15-Sep 20	1,279	1,233	14	32	100.0%	32
1977	Aug 09	Sep 01-Sep 08	431,920	22	207,675	224,223	61.8%	138,641
1978	Aug 20	Sep 04-Sep 10	7,287	0	3,552	3,735	98.4%	3,675
1979	-	Sep 12-Sep 15	511	0	243	268	88.6%	238
1980	-	Sep 10	2,815	2,541	137	137	60.0%	82
1981	Aug 11	Aug 24-Sep 05 [c]	661,614	31	309,213	352,370	81.5%	287,094
1982	-	-	30,317	0	14,839	15,478	98.1%	15,177
1983	-	Sep 04-Sep 08	1,998	0	650	1,348	75.5%	1,018
1984	-	Sep 04-Sep 08	5,606	4,782	291	533	95.5%	509
1985	Aug 10	[d]	988,710	0	453,695	535,015	94.9%	507,516
1986	-	[e]	144,757	6	63,500	81,251	93.6%	75,975
1987	-	[e]	16,745	13	6,064	10,668	84.0%	8,964
1988	Aug 11	[f]	19,775	14,247	1,696	3,832	89.1%	3,413

Continued

Appendix 1b. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Horsefly River, 1938-1995.

			Escapement				Percent	
Year	Arrival	Period of peak spawning	Total	Jacks	Males	Females	spawning success	Effective females
Continued								
1989	-	Sep 05-Sep 14 [g]	1,462,605	0	718,643	743,962	96.2%	731,903
1990	Aug 15	Sep 03-08	398,468	0	178,411	220,057	98.5%	216,790
1991	-	-	19,754	0	9,877	9,877	100.0%	9,877
1992	-	-	6,777	2,686	1,943	2,148	100.0%	2,148
1993	Aug 20	Sep 18-Sep 23	1,650,083	254	650,262	999,567	99.4%	993,519
1994	Aug 15-20	Sep 09-Sep 12	467,646	6	202,440	265,200	99.0%	262,551
1995	Aug 15-20	Sep 07-Sep 11	164,230	1	73,519	90,710	97.3%	88,280

[a] Two peaks: Sep 05-Sep 07 and Sep 14-Sep 18.
[b] Two peaks: Aug 30-Sep 02 and Sep 15-Sep 18.
[c] Estimate includes Lower McKinley Creek.
[d] Two peaks: Sep 06-Sep 10 and Sep 12-Sep 16.
[e] Two peaks: Sep 06-Sep 08 and Sep 08-Sep 12.
[f] Two peaks: Aug 30-Sep 03 and mid Sep.
[g] Estimate includes Little Horsefly River.

Appendix 1c. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in McKinley Creek, 1953-1995.[a]

Year	Arrival	Period of peak spawning	Escapement				Percent spawning success	Effective females
			Total	Jacks	Males	Females		
1953	-	-	3,141	0	1,345	1,796	75.0%	1,346
1954	-	-	0	0	0	0	0.0%	0
1955	-	-	0	0	0	0	0.0%	0
1956	-	-	94	92	1	1	100.0%	1
1957	Aug 05	Sep 02-Sep 05	6,698	0	2,478	4,220	95.0%	4,009
1958	-	-	0	0	0	0	0.0%	0
1959	-	-	0	0	0	0	0.0%	0
1960	-	-	0	0	0	0	0.0%	0
1961	Aug 05	Sep 03-Sep 06	18,400	0	7,432	10,968	35.0%	3,839
1962	-	-	0	0	0	0	0.0%	0
1963	-	-	0	0	0	0	0.0%	0
1964	-	-	0	0	0	0	0.0%	0
1965	-	-	0	0	0	0	0.0%	0
1966	-	-	0	0	0	0	0.0%	0
1967	-	-	0	0	0	0	0.0%	0
1968	-	-	0	0	0	0	0.0%	0
1969	-	Aug 25-Aug 30	19,512	0	7,785	11,727	33.9%	3,973
1970	-	-	0	0	0	0	0.0%	0
1971	-	-	0	0	0	0	0.0%	0
1972	-	Sep 12	526	508	6	12	85.7%	10
1973	-	Sep 01-Sep 07	10,942	0	4,356	6,586	74.4%	4,897
1974	-	-	0	0	0	0	0.0%	0
1975	-	-	100	4	44	52	100.0%	52
1976	-	Sep 15-Sep 20	783	533	78	172	100.0%	172
1977	-	-	33,064	2	14,771	18,291	38.4%	7,018
1978	-	Sep 01-Sep 03	85	0	41	44	98.4%	43
1979	-	-	0	0	0	0	0.0%	0
1980	-	-	0	0	0	0	0.0%	0
1981	-	[b]	0	0	0	0	0.0%	0
1982	-	Sep 03-Sep 07	5,578	0	2,511	3,067	95.1%	2,918
1983	-	Aug 25	38	0	12	26	75.5%	20
1984	-	Mid Sep	472	402	25	45	66.7%	30
1985	-	Sep 08-Sep 12	82,553	0	34,753	47,800	95.3%	45,567
1986	-	Sep 08-Sep 12	4,973	0	2,182	2,791	79.4%	2,217
1987	-	Sep 05-Sep 07	63	0	22	41	89.5%	37
1988	-	Sep 07-Sep 15	3,440	3,116	156	168	53.9%	91
1989	-	Sep 05-Sep 10	113,330	0	51,237	62,093	98.5%	61,180
1990	Aug 24	Sep 03-Sep 08	11,365	0	5,089	6,276	0.0%	0
1991	-	[b]	0	0	0	0	0.0%	0
1992	-	-	0	0	0	0	0.0%	0
1993	Aug 22	Sep 18-Sep 23	163,470	4	66,276	97,190	82.0%	79,627
1994	Aug 24	Sep 08-Sep 12	34,581	11	18,689	15,881	92.4%	14,347
1995	[c]	[c]	380	0	113	267	100.0%	267

[a] No surveys recorded prior to 1953.

[b] Estimate included in Horsefly River totals.

[c] The creek was only surveyed once.

Appendix 1d. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in Upper McKinley Creek, 1969-1995.[a]

Year	Arrival	Period of peak spawning	Escapement				Percent spawning success	Effective females
			Total	Jacks	Males	Females		
1969	-	Aug 25-Aug 30	8,424	0	3,361	5,063	33.9%	1,715
1970	-	-	0	0	0	0	0.0%	0
1971	-	-	0	0	0	0	0.0%	0
1972	-	-	0	0	0	0	0.0%	0
1973	-	Sep 01-Sep 07	4,162	0	1,656	2,506	74.4%	1,863
1974	-	-	0	0	0	0	0.0%	0
1975	-	-	0	0	0	0	0.0%	0
1976	-	Sep 15-Sep 20	2	0	1	1	100.0%	1
1977	-	-	8,024	0	3,549	4,475	38.4%	1,717
1978	-	Sep 05-Sep 07	5	0	2	3	100.0%	3
1979	-	-	0	0	0	0	0.0%	0
1980	-	Sep 15	347	313	17	17	91.7%	16
1981	-	Sep 01-Sep 07	15,775	0	7,186	8,589	73.2%	6,284
1982	-	Sep 03-Sep 07	79	0	36	43	95.1%	41
1983	-	-	0	0	0	0	0.0%	0
1984	-	-	0	0	0	0	0.0%	0
1985	-	Sep 03-Sep 07	14,999	0	5,980	9,019	96.4%	8,690
1986	-	Sep 03-Sep 07	662	0	290	372	93.4%	347
1987	-	-	0	0	0	0	0.0%	0
1988	-	Mid Sep	36	36	0	0	0.0%	0
1989	-	Sep 05-Sep 10	4,500	0	2,034	2,466	100.0%	2,466
1990	Aug 24	Sep 03-Sep 08	378	0	169	209	98.5%	206
1991	-	-	0	0	0	0	0.0%	0
1992	-	-	0	0	0	0	0.0%	0
1993	Late Aug	Sep 18-Sep 23	5,902	0	1,641	4,261	99.7%	4,248
1994	Aug 20	Sep 08-Sep 12	1,166	0	572	594	98.2%	583
1995 [b]	-	-	-	-	-	-	-	-

[a] No surveys recorded prior to 1969.

[b] No surveys conducted in 1995.

Appendix 1e. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Little Horsefly River, 1938-1995.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1938	-	-	0	0	0	0	0.0%	0
1939	-	-	0	0	0	0	0.0%	0
1940	-	-	0	0	0	0	0.0%	0
1941	-	Oct 05	27	0	13	14	95.0%	13
1942	-	-	0	0	0	0	0.0%	0
1943	-	-	0	0	0	0	0.0%	0
1944	-	-	4	0	2	2	100.0%	2
1945	-	-	0	0	0	0	0.0%	0
1946	-	-	0	0	0	0	0.0%	0
1947	-	-	0	0	0	0	0.0%	0
1948	-	-	0	0	0	0	0.0%	0
1949	-	-	0	0	0	0	0.0%	0
1950	Oct 01	-	13	0	6	7	100.0%	7
1951	-	-	0	0	0	0	0.0%	0
1952	-	-	2	2	0	0	0.0%	0
1953	-	-	0	0	0	0	0.0%	0
1954	Sep 21	Oct 08-Oct 12	7	0	3	4	100.0%	4
1955	-	-	0	0	0	0	0.0%	0
1956	Oct 01	Oct 06-Oct 10	5	0	2	3	100.0%	3
1957	-	-	38	0	14	24	95.0%	23
1958	-	Oct 15-Oct 20	14	0	7	7	100.0%	7
1959	Sep 15	Sep 25	27	11	11	5	100.0%	5
1960	Sep 21	[a]	23	12	5	6	100.0%	6
1961	-	-	40	0	17	23	16.7%	4
1962	Sep 15	Sep 28-Oct 03	72	0	29	43	87.5%	38
1963	-	-	0	0	0	0	0.0%	0
1964	-	-	355	217	56	82	100.0%	82
1965	-	-	0	0	0	0	0.0%	0
1966	Sep 25	-	4	0	2	2	100.0%	2
1967	-	-	0	0	0	0	0.0%	0
1968	-	Sep 20-Sep 25	73	68	2	3	100.0%	3
1969	Aug 07	Aug 27-Sep 01	40	0	17	23	49.7%	11
1970	-	-	0	0	0	0	0.0%	0
1971	-	-	0	0	0	0	0.0%	0
1972	-	-	18	18	0	0	0.0%	0
1973	-	-	4	0	2	2	100.0%	2
1974	-	-	0	0	0	0	0.0%	0
1975	-	-	0	0	0	0	0.0%	0
1976	-	-	32	32	0	0	0.0%	0
1977	-	Sep 12-Sep 16	106	0	55	51	63.8%	33
1978	-	-	0	0	0	0	0.0%	0
1979	-	-	0	0	0	0	0.0%	0
1980	-	-	0	0	0	0	0.0%	0
1981	-	-	2	0	1	1	100.0%	1
1982	-	-	0	0	0	0	0.0%	0
1983	-	-	0	0	0	0	0.0%	0
1984	-	-	45	45	0	0	0.0%	0
1985	-	-	17,030	0	7,806	9,224	96.8%	8,929
1986	-	-	0	0	0	0	0.0%	0
1987	-	-	0	0	0	0	0.0%	0
1988	-	Mid Sep	401	381	5	15	100.0%	15

Continued

Appendix 1e. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Little Horsefly River, 1938-1995.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
Continued								
1989	-	[b]	0	0	0	0	0.0%	0
1990	-	[b]	0	0	0	0	0.0%	0
1991	-	-	0	0	0	0	0.0%	0
1992	-	-	0	0	0	0	0.0%	0
1993	Mid Aug	Sep 18-Sep 23	21,361	0	7,038	14,323	99.7%	14,280
1994	Aug 15	Sep 08-Sep 12	216	0	115	101	100.0%	101
1995	[c]	[c]	0	0	0	0	-	0

[a] Two peaks: Sep 21-Sep 28 and Oct 08-Oct 16.

[b] Included in Horsefly River estimate.

[c] The creek was only surveyed once.

Appendix 1f. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in Moffat Creek, 1989-1995.[a]

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1989	-	Sep 08-Sep 14	10,665	0	5,579	5,086	99.5%	5,058
1990	-	-	0	0	0	0	0.0%	0
1991	-	-	0	0	0	0	0.0%	0
1992	-	-	0	0	0	0	0.0%	0
1993	Mid Aug	Sep 18-Sep 23	7,099	0	2,268	4,831	99.2%	4,793
1994	Aug 25	Sep 08-Sep 12	369	0	121	248	99.7%	247
1995 [b]	-	-	-	-	-	-	-	-

[a] No surveys recorded prior to 1989.

[b] No surveys conducted in 1995.

Appendix 1g. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females that spawned effectively in the Horsefly Channel, 1989-1995.[a]

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1989	-	-	23,300	0	11,422	11,878	98.3%	11,670
1990	-	Sep 03-Sep 08	29,274	0	17,531	11,743	100.0%	11,744
1991	-	-	18,815	0	7,163	11,652	95.6%	11,139
1992	-	-	2,124	353	873	898	100.0%	898
1993	-	-	17,891	0	6,008	11,883	93.3%	11,083
1994	-	-	19,597	0	7,946	11,651	99.0%	11,539
1995	-	-	16,263	0	6,655	9,608	97.3% [b]	9,351

[a] Channel not operated prior to 1989.

[b] Mean spawning success of carcasses sampled in the Horsefly River.

Appendix 2. The number of sockeye counted, by 15-minute period (start time of each period is shown) and date, from the bridge over the Quesnel River at Likely, B.C., in 1995.

	Morning counts				Afternoon counts				
Date	0800	0830	0900	0930	1600	1630	1700	1730	Mean
21-Aug	86	109	72	-	129	112	91	-	100
22-Aug	94	125	305	-	161	107	165	-	160
23-Aug	68	92	134	-	146	126	253	177	142
24-Aug	55	311	451	350	191	49	95	146	206
25-Aug	0	32	136	168	52	44	93	123	81
26-Aug	9	19	112	174	13	9	4	18	45 [a]
27-Aug	59	142	293	231	20	49	44	85	115
28-Aug	99	246	296	415	165	207	140	138	213
29-Aug	132	181	279	224	172	67	18	159	154
30-Aug	137	140	126	160	97	6	106	63	104
31-Aug	114	100	202	172	52	82	156	67	118
1-Sep	67	108	123	149	56	45	16	66	79
2-Sep	9	12	30	23	19	13	29	20	19
3-Sep	5	0	3	4	2	0	3	2	2
4-Sep	2	3	7	3	5	4	2	3	4
5-Sep	2	1	1	2	0	7	2	0	2
6-Sep	1	5	16	3	19	15	15	8	10
7-Sep	3	3	12	18	20	6	6	1	9
8-Sep	1	1	3	2	0	0	0	0	1
9-Sep	0	1	0	1	1	1	0	0	1
10-Sep	1	0	0	0	2	0	1	0	1
11-Sep	0	1	1	0	2	0	1	0	1
12-Sep	2	1	0	3	0	0	3	4	2
13-Sep	0	1	1	0	4	4	5	3	2
14-Sep	2	3	3	7	7	6	4	3	4
15-Sep	2	2	1	1	6	7	3	1	3
16-Sep	4	2	10	4	2	0	1	0	3
17-Sep	3	1	1	5	1	4	4	3	3
18-Sep	6	1	0	1	0	3	2	3	2
Mean	33	57	90	82	46	34	44	40	53

[a] Kayakers disrupted the sockeye migration for last two counts of the day.

Appendix 3. Number of sockeye salmon marked with disk tags and secondary marks, and the number of recaptures of previously tagged sockeye, by date and sex, in the Horsefly River, 1995. Values are not corrected for sex identification error.

Date	Sets made	Sockeye marked			Recaptures		
		Male	Female	Jack	Male	Female	Jack
21-Aug	5	11 [c]	9	0	0	0	0
22-Aug	7	15	25	0	0	0	0
23-Aug	7	24	33	0	0	0	0
24-Aug	7	66 [a, c]	85 [c]	1	3	0	0
25-Aug	8	58	92 [a, b, c]	0	1	7	0
26-Aug	8	40 [2a]	62 [b]	0	1	7	0
27-Aug	8	25 [a, c]	32 [4a, b]	0	1	0	0
28-Aug	7	24 [7a]	23 [6a]	0	0	0	0
29-Aug	8	76 [24a, c]	84 [38a, b, c]	0	6 [2a]	2 [a]	0
30-Aug	8	76 [a]	103 [2a, c]	0	5 [a]	4	0
31-Aug	8	105 [4a]	139 [2a, 2b, c]	0	6	9	0
1-Sep	4	13 [3a]	24 [2a]	0	2	1	0
2-Sep	6	25 [10a]	29 [12a]	0	2	4 [2a]	0
3-Sep	5	11	1 [a]	0	0	0	0
4-Sep	7	9 [2a]	6 [2a]	0	0	0	0
5-Sep	2	1	1 [a]	0	0	0	0
6-Sep	3	1	3	0	0	1	0
7-Sep	5	2	8 [a]	0	0	0	0
8-Sep	3	5	3 [a]	0	0	0	0
Total	116	587	762	1	27	35	0

[a.] Excluding fish recovered in spawning channel.

[b.] Excluding fish requiring ventilation upon release.

[c.] Sex at recovery was opposite that at application.

Numbers preceding notes indicate the number of sockeye to which the associated notes apply, in cases where notes apply to more than one fish.

Appendix 4a. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among adult male sockeye examined during tag application in the Horsefly River, 1995. Values are not corrected for sex identification errors.

Date	Number examined	Net marks Number	Net marks Percent	Lamprey marks Number	Lamprey marks Percent	Hook marks Number	Hook marks Percent	*F. columnaris* [a] Number	*F. columnaris* [a] Percent
21-Aug	11	0	0.0%	0	0.0%	0	0.0%	-	-
22-Aug	15	0	0.0%	0	0.0%	0	0.0%	-	-
23-Aug	24	0	0.0%	1	4.2%	0	0.0%	-	-
24-Aug	66	0	0.0%	3	4.5%	0	0.0%	-	-
25-Aug	58	1	1.7%	0	0.0%	0	0.0%	-	-
26-Aug	40	0	0.0%	0	0.0%	0	0.0%	-	-
27-Aug	25	0	0.0%	0	0.0%	0	0.0%	-	-
28-Aug	24	0	0.0%	3	12.5%	0	0.0%	-	-
29-Aug	76	0	0.0%	0	0.0%	0	0.0%	-	-
30-Aug	76	0	0.0%	0	0.0%	0	0.0%	-	-
31-Aug	105	0	0.0%	0	0.0%	0	0.0%	-	-
1-Sep	13	0	0.0%	0	0.0%	0	0.0%	-	-
2-Sep	25	2	8.0%	1	4.0%	0	0.0%	-	-
3-Sep	11	0	0.0%	0	0.0%	0	0.0%	-	-
4-Sep	9	0	0.0%	0	0.0%	0	0.0%	-	-
5-Sep	1	0	0.0%	0	0.0%	0	0.0%	-	-
6-Sep	1	0	0.0%	0	0.0%	0	0.0%	-	-
7-Sep	2	1	50.0%	0	0.0%	0	0.0%	-	-
8-Sep	5	0	0.0%	0	0.0%	0	0.0%	-	-
Total	587	4	0.7%	8	1.4%	0	0.0%	-	-

[a] *F. columnaris* incidence was not recorded in 1995.

Appendix 4b. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among female sockeye examined during tag application in the Horsefly River, 1995. Values are not corrected for sex identification errors.

Date	Number examined	Net marks		Lamprey marks		Hook marks		*F. columnaris* [a]	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
21-Aug	9	1	11.1%	1	11.1%	0	0.0%	-	-
22-Aug	25	1	4.0%	2	8.0%	0	0.0%	-	-
23-Aug	33	1	3.0%	0	0.0%	0	0.0%	-	-
24-Aug	85	2	2.4%	0	0.0%	1	1.2%	-	-
25-Aug	92	2	2.2%	0	0.0%	0	0.0%	-	-
26-Aug	62	2	3.2%	0	0.0%	0	0.0%	-	-
27-Aug	32	3	9.4%	0	0.0%	0	0.0%	-	-
28-Aug	23	1	4.3%	1	4.3%	0	0.0%	-	-
29-Aug	84	3	3.6%	0	0.0%	0	0.0%	-	-
30-Aug	103	3	2.9%	0	0.0%	0	0.0%	-	-
31-Aug	139	5	3.6%	0	0.0%	0	0.0%	-	-
1-Sep	24	1	4.2%	0	0.0%	0	0.0%	-	-
2-Sep	29	2	6.9%	0	0.0%	0	0.0%	-	-
3-Sep	1	0	0.0%	0	0.0%	0	0.0%	-	-
4-Sep	6	1	16.7%	0	0.0%	0	0.0%	-	-
5-Sep	1	0	0.0%	0	0.0%	0	0.0%	-	-
6-Sep	3	0	0.0%	1	33.3%	0	0.0%	-	-
7-Sep	8	4	50.0%	1	12.5%	0	0.0%	-	-
8-Sep	3	0	0.0%	0	0.0%	0	0.0%	-	-
Total	762	32	4.2%	6	0.8%	1	0.1%	-	-

[a] *F. columnaris* incidence was not recorded in 1995.

Appendix 5. Daily sockeye carcass recoveries, by recovery area, mark status[a] and sex, in the Horsefly River study area, 1995. No jacks were recovered.

Date	Area	Number of surveys	Disk tag present Male	Disk tag present Female	Disk tag present Total	Untagged Male	Untagged Female	Untagged Total	Total Male	Total Female	Total Total
2-Sep	1	-	0	0	0	38	47	85	38	47	85
	2	-	0	0	0	40	44	84	40	44	84
	3	-	0	0	0	74	72	146	74	72	146
	4	-	0	0	0	239	180	419	239	180	419
	5	-	0	0	0	40	22	62	40	22	62
3-Sep	7	-	0	0	0	112	67	179	112	67	179
	8	-	0	0	0	214	159	373	214	159	373
	9	-	0	0	0	0	0	0	0	0	0
5-Sep	1	-	0	0	0	236	327	563	236	327	563
	2	-	0	0	0	107	100	207	107	100	207
	4	-	0	1	1	463	470	933	463	471	934
	5	-	0	3	3	729	795	1,524	729	798	1,527
6-Sep	2	-	0	1	1	41	66	107	41	67	108
	3	-	1	2	3	90	108	198	91	110	201
	4	-	2	1	3	219	210	429	221	211	432
	6	-	0	0	0	163	153	316	163	153	316
7-Sep	7	-	2	4	6	705	652	1,357	707	656	1,363
	8	-	4	6	10	596	681	1,277	600	687	1,287
	9	-	0	0	0	0	1	1	0	1	1
8-Sep	10	-	0	3	3	30	40	70	30	43	73
	11	-	1	0	1	67	90	157	68	90	158
	12	-	10	7	17	323	629	952	333	636	969
	13	-	2	1	3	54	51	105	56	52	108
9-Sep	1	-	0	3	3	179	330	509	179	333	512
	2	-	1	2	3	138	292	430	139	294	433
10-Sep	2	-	0	0	0	38	54	92	38	54	92
	3	-	1	10	11	365	446	811	366	456	822
	4	-	7	9	16	838	1,284	2,122	845	1,293	2,138
	5	-	7	12	19	884	1,152	2,036	891	1,164	2,055
	6	-	3	3	6	528	730	1,258	531	733	1,264
	LHR[b]	-	0	0	0	0	0	0	0	0	0
11-Sep	7	-	5	11	16	655	1,165	1,820	660	1,176	1,836
	8	-	6	15	21	1,105	1,542	2,647	1,111	1,557	2,668
	9	-	0	0	0	48	88	136	48	88	136
12-Sep	10	-	0	0	0	36	49	85	36	49	85
	11	-	1	2	3	110	158	268	111	160	271
	12	-	1	2	3	152	449	601	153	451	604
	13	-	0	0	0	49	87	136	49	87	136
13-Sep	1	-	1	6	7	138	357	495	139	363	502
	2	-	0	0	0	92	276	368	92	276	368
	3	-	1	3	4	194	374	568	195	377	572
	4	-	8	4	12	537	1,064	1,601	545	1,068	1,613
	5	-	4	4	8	493	824	1,317	497	828	1,325
	6	-	5	4	9	244	488	732	249	492	741
14-Sep	7	-	0	2	2	217	381	598	217	383	600
	8	-	4	1	5	147	231	378	151	232	383

Continued

Appendix 5. Daily sockeye carcass recoveries, by recovery area, mark status[a] and sex, in the Horsefly River study area, 1995. No jacks were recovered.

Date	Area	Number of surveys	Disk tag present			Untagged			Total		
			Male	Female	Total	Male	Female	Total	Male	Female	Total
Continued											
15-Sep	8	-	6	4	10	410	513	923	416	517	933
	9	-	0	0	0	0	0	0	0	0	0
	10	-	0	0	0	17	24	41	17	24	41
	11	-	2	0	2	47	185	232	49	185	234
16-Sep	12	-	3	5	8	211	298	509	214	303	517
	Mc. Cr.[b]	-	1	1	2	48	115	163	49	116	165
17-Sep	1	-	0	2	2	46	188	234	46	190	236
	2	-	0	2	2	103	224	327	103	226	329
	3	-	2	1	3	224	373	597	226	374	600
	4	-	2	1	3	89	166	255	91	167	258
	5	-	1	3	4	130	308	438	131	311	442
	6	-	0	1	1	171	351	522	171	352	523
19-Sep	7	-	0	2	2	30	74	104	30	76	106
	8	-	1	2	3	188	326	514	189	328	517
	11	-	1	1	2	20	38	58	21	39	60
	12	-	0	1	1	16	36	52	16	37	53
20-Sep	9	-	1	3	4	40	142	182	41	145	186
	10	-	0	0	0	34	67	101	34	67	101
	13	-	0	2	2	66	101	167	66	103	169
21-Sep	1	-	0	2	2	32	83	115	32	85	117
	2	-	0	3	3	91	296	387	91	299	390
	3	-	0	1	1	48	106	154	48	107	155
	4	-	2	1	3	52	93	145	54	94	148
	5	-	0	0	0	88	204	292	88	204	292
	6	-	1	2	3	34	121	155	35	123	158
23-Sep	7	-	0	0	0	29	80	109	29	80	109
	8	-	0	0	0	39	80	119	39	80	119
	9	-	0	0	0	57	134	191	57	134	191
	10	-	1	0	1	16	22	38	17	22	39
24-Sep	11	-	2	1	3	32	70	102	34	71	105
	12	-	0	0	0	29	57	86	29	57	86
26-Sep	1	-	0	0	0	8	27	35	8	27	35
	2	-	1	0	1	26	54	80	27	54	81
	3	-	0	0	0	7	20	27	7	20	27
	4	-	0	1	1	30	43	73	30	44	74
	5	-	0	0	0	4	13	17	4	13	17
	6	-	0	1	1	9	42	51	9	43	52
28-Sep	7	-	0	0	0	1	11	12	1	11	12
	8	-	0	0	0	9	22	31	9	22	31
	9	-	0	0	0	4	15	19	4	15	19
	10	-	0	0	0	0	0	0	0	0	0
	11	-	0	0	0	3	26	29	3	26	29
	12	-	0	0	0	7	29	36	7	29	36

Continued

Appendix 5. Daily sockeye carcass recoveries, by recovery area, mark status[a] and sex, in the Horsefly River study area, 1995. No jacks were recovered.

Date	Area	Number of surveys	Disk tag present			Untagged			Total		
			Male	Female	Total	Male	Female	Total	Male	Female	Total
Continued											
Total	1	7	1	13	14	677	1,359	2,036	678	1,372	2,050
	2	9	2	8	10	676	1,406	2,082	678	1,414	2,092
	3	7	5	17	22	1,002	1,499	2,501	1,007	1,516	2,523
	4	8	21	18	39	2,467	3,510	5,977	2,488	3,528	6,016
	5	7	12	22	34	2,368	3,318	5,686	2,380	3,340	5,720
	6	6	9	11	20	1,149	1,885	3,034	1,158	1,896	3,054
	7	7	7	19	26	1,749	2,430	4,179	1,756	2,449	4,205
	8	8	21	28	49	2,708	3,554	6,262	2,729	3,582	6,311
	9	7	1	3	4	149	380	529	150	383	533
	10	6	1	3	4	133	202	335	134	205	339
	11	6	7	4	11	279	567	846	286	571	857
	12	6	14	15	29	738	1,498	2,236	752	1,513	2,265
	13	3	2	3	5	169	239	408	171	242	413
	LHR	1	0	0	0	0	0	0	0	0	0
	Mc. Cr.	1	1	1	2	48	115	163	49	116	165
	Total	-	104	165	269	14,312	21,962	36,274	14,416	22,127	36,543

[a] Recovery crews did not examine carcasses for secondary marks.

[b] LHR= Little Horsefly River; Mc. Cr.= McKinley Creek.

Appendix 6. Daily number of sockeye carcasses examined and disk tags recovered, by recovery area and sex, during the resurvey of the Horsefly River study area, 1995.

		Number of surveys	Disk tag present			Total examined			Disk tag incidence		
Date	Area		Male	Female	Total	Male	Female	Total	Male	Female	Total
6-Sep	1	-	0	0	0	14	14	28	0.00%	0.00%	0.00%
	2	-	0	0	0	65	102	167	0.00%	0.00%	0.00%
	3	-	0	0	0	32	37	69	0.00%	0.00%	0.00%
	4	-	0	0	0	527	537	1,064	0.00%	0.00%	0.00%
	5	-	0	1	1	575	554	1,129	0.00%	0.18%	0.09%
9-Sep	7	-	0	0	0	69	54	123	0.00%	0.00%	0.00%
	8	-	0	0	0	259	297	556	0.00%	0.00%	0.00%
	9	-	0	0	0	0	0	0	-	-	-
	10	-	0	0	0	18	14	32	0.00%	0.00%	0.00%
	11	-	0	0	0	43	73	116	0.00%	0.00%	0.00%
11-Sep	1	-	0	0	0	68	133	201	0.00%	0.00%	0.00%
	2	-	0	0	0	61	134	195	0.00%	0.00%	0.00%
	3	-	0	0	0	118	124	242	0.00%	0.00%	0.00%
	4	-	3	1	4	647	883	1,530	0.46%	0.11%	0.26%
	5	-	0	0	0	699	885	1,584	0.00%	0.00%	0.00%
	6	-	1	0	1	653	814	1,467	0.15%	0.00%	0.07%
12-Sep	7	-	0	0	0	123	189	312	0.00%	0.00%	0.00%
	8	-	0	1	1	675	1,034	1,709	0.00%	0.10%	0.06%
	9	-	0	0	0	9	22	31	0.00%	0.00%	0.00%
13-Sep	11	-	0	0	0	80	91	171	0.00%	0.00%	0.00%
	12	-	0	1	1	252	261	513	0.00%	0.38%	0.19%
14-Sep	1	-	0	0	0	97	314	411	0.00%	0.00%	0.00%
	2	-	0	0	0	119	328	447	0.00%	0.00%	0.00%
	3	-	0	0	0	189	359	548	0.00%	0.00%	0.00%
	4	-	0	2	2	346	656	1,002	0.00%	0.30%	0.20%
	5	-	0	0	0	306	453	759	0.00%	0.00%	0.00%
	6	-	0	2	2	148	238	386	0.00%	0.84%	0.52%
16-Sep	7	-	0	0	0	25	18	43	0.00%	0.00%	0.00%
	8	-	0	0	0	115	132	247	0.00%	0.00%	0.00%
	9	-	0	0	0	0	0	0	-	-	-
	11	-	0	0	0	45	146	191	0.00%	0.00%	0.00%
18-Sep	1	-	0	1	1	52	310	362	0.00%	0.32%	0.28%
	2	-	0	0	0	82	281	363	0.00%	0.00%	0.00%
	3	-	1	0	1	19	77	96	5.26%	0.00%	1.04%
	4	-	0	0	0	177	282	459	0.00%	0.00%	0.00%
	5	-	0	0	0	122	179	301	0.00%	0.00%	0.00%
	6	-	1	0	1	164	196	360	0.61%	0.00%	0.28%
20-Sep	7	-	0	0	0	84	220	304	0.00%	0.00%	0.00%
	11	-	0	0	0	17	25	42	0.00%	0.00%	0.00%
	12	-	0	0	0	38	84	122	0.00%	0.00%	0.00%
22-Sep	1	-	0	0	0	4	31	35	0.00%	0.00%	0.00%
	2	-	0	0	0	56	250	306	0.00%	0.00%	0.00%
	3	-	0	0	0	14	28	42	0.00%	0.00%	0.00%
	4	-	0	0	0	82	113	195	0.00%	0.00%	0.00%
	5	-	0	0	0	118	548	666	0.00%	0.00%	0.00%
	6	-	0	0	0	59	180	239	0.00%	0.00%	0.00%

Continued

Appendix 6. Daily number of sockeye carcasses examined and disk tags recovered, by recovery area and sex, during the resurvey of the Horsefly River study area, 1995.

Date	Area	Number of surveys	Disk tag present			Total examined			Disk tag incidence		
			Male	Female	Total	Male	Female	Total	Male	Female	Total
Continued											
25-Sep	7	-	0	0	0	7	44	51	0.00%	0.00%	0.00%
	8	-	0	0	0	18	42	60	0.00%	0.00%	0.00%
	9	-	0	0	0	32	79	111	0.00%	0.00%	0.00%
	10	-	0	0	0	2	9	11	0.00%	0.00%	0.00%
	11	-	0	0	0	13	31	44	0.00%	0.00%	0.00%
	12	-	0	1	1	11	36	47	0.00%	2.78%	2.13%
27-Sep	1	-	0	0	0	3	14	17	0.00%	0.00%	0.00%
	2	-	0	0	0	15	31	46	0.00%	0.00%	0.00%
	3	-	0	0	0	4	6	10	0.00%	0.00%	0.00%
	4	-	0	0	0	12	15	27	0.00%	0.00%	0.00%
	5	-	0	0	0	0	14	14	-	0.00%	0.00%
	6	-	0	0	0	1	21	22	0.00%	0.00%	0.00%
29-Sep	7	-	0	0	0	3	15	18	0.00%	0.00%	0.00%
	8	-	0	0	0	6	22	28	0.00%	0.00%	0.00%
	9	-	0	0	0	9	32	41	0.00%	0.00%	0.00%
	10	-	0	0	0	23	38	61	0.00%	0.00%	0.00%
	11	-	0	0	0	18	48	66	0.00%	0.00%	0.00%
	12	-	0	0	0	9	22	31	0.00%	0.00%	0.00%
Totals	1	6	0	1	1	238	816	1,054	0.00%	0.12%	0.09%
	2	6	0	0	0	398	1,126	1,524	0.00%	0.00%	0.00%
	3	6	1	0	1	376	631	1,007	0.27%	0.00%	0.10%
	4	6	3	3	6	1,791	2,486	4,277	0.17%	0.12%	0.14%
	5	6	0	1	1	1,820	2,633	4,453	0.00%	0.04%	0.02%
	6	5	2	2	4	1,025	1,449	2,474	0.20%	0.14%	0.16%
	7	6	0	0	0	311	540	851	0.00%	0.00%	0.00%
	8	5	0	1	1	1,073	1,527	2,600	0.00%	0.07%	0.04%
	9	5	0	0	0	50	133	183	0.00%	0.00%	0.00%
	10	3	0	0	0	43	61	104	0.00%	0.00%	0.00%
	11	6	0	0	0	216	414	630	0.00%	0.00%	0.00%
	12	4	0	2	2	310	403	713	0.00%	0.50%	0.28%
	Total	64	6	10	16	7,651	12,219	19,870	0.08%	0.08%	0.00%

Appendix 7. Fecundity sampling results and analytic details for sockeye salmon captured in the Horsefly River, 1995.

Age	Standard length (cm) [a]	Skein weight (g)	Skein sub-sample Weight (g)	Skein sub-sample Egg count	Estimated fecundity	Actual fecundity	Loose eggs	Adjusted fecundity
4_2	48.9	201.8	103.2	1,367	2,673		0	2,673
4_2	49.1	278.8	104.2	1,138	3,045		0	3,045
4_2	49.7	297.9	145.3	1,345	2,758	2,757	0	2,757
4_2	50.8	220.2	108.2	1,451	2,953	2,975	62	3,037
4_2	51.2	285.1	103.2	1,122	3,100		10	3,110
4_2	52.0	265.9	104.4	1,184	3,016		8	3,024
4_2	54.7	346.2	118.3	1,250	3,658		0	3,658
4_2	55.7	356.6	194.1	1,938	3,560	3,558	0	3,558
5_2	51.6	217.8	102.2	1,173	2,500		5	2,505
5_2	53.5	328.3	113.4	1,362	3,943		10	3,953
5_2	53.5	318.5	108.7	1,163	3,408		24	3,432
5_2	54.4	341.5	116.2	1,223	3,594		10	3,604
5_2	54.7	318.1	108.4	1,192	3,498		54	3,552
5_2	55.1	333.9	114.1	1,371	4,012		6	4,018
5_2	55.3	457.1	155.7	1,392	4,087		0	4,087
5_2	55.6	323.4	166.9	1,798	3,484	3,471	10	3,481
5_2	56.4	420.7	143.6	1,160	3,398		2	3,400
5_2	56.5	415.8	143.1	1,405	4,082		0	4,082
5_2	57.1	331.4	113.8	1,451	4,225		0	4,225
5_2	57.2	397.2	135.5	1,383	4,054		10	4,064
5_2	57.2	378.7	198.4	2,172	4,146	4,175	6	4,181
5_2	57.2	428.5	145.9	1,360	3,994		2	3,996
5_2	57.5	456.3	155.2	1,484	4,363		0	4,363
5_2	57.6	464.6	159.3	1,543	4,500		10	4,510
5_2	57.6	415.0	142.0	1,358	3,969		10	3,979
5_2	57.6	444.4	152.1	1,671	4,882		0	4,882
5_2	57.7	326.3	110.9	1,261	3,710		0	3,710
5_2	57.9	339.5	116.3	1,089	3,179		10	3,189
5_2	58.5	370.3	126.6	1,264	3,697		13	3,710
5_2	58.6	369.1	126.0	1,474	4,318		10	4,328
5_2	58.9	452.9	250.4	2,338	4,229	4,194	10	4,204
5_2	59.0	384.9	184.0	1,895	3,964	3,935	2	3,937
5_2	59.0	362.8	155.4	1,700	3,969		0	3,969
5_2	59.5	468.6	250.0	2,347	4,399	4,415	524	4,939
5_2	59.9	444.8	151.2	1,378	4,054		0	4,054
5_2	59.9	418.4	144.5	1,528	4,424		0	4,424
5_2	59.9	517.2	175.9	1,497	4,402		8	4,410
5_2	60.0	329.5	111.1	1,498	4,443		10	4,453
5_2	60.1	391.4	134.2	1,288	3,757		0	3,757
5_2	60.3	415.6	204.4	2,068	4,205	4,145	0	4,145
5_2	60.5	430.3	146.0	1,394	4,108		0	4,108
5_2	60.5	458.8	155.8	1,525	4,491		0	4,491
5_2	60.5	432.2	147.7	1,343	3,930		10	3,940
5_2	60.6	497.4	169.6	1,516	4,446		1	4,447
5_2	61.1	424.4	145.1	1,463	4,279		0	4,279
5_2	61.2	557.4	187.3	1,579	4,699		0	4,699
5_2	61.4	435.7	198.2	1,984	4,361	4,345	5	4,350

Continued

Appendix 7. Fecundity sampling results and analytic details for sockeye salmon captured in the Horsefly River, 1995.

Age	Standard length (cm) [a]	Skein weight (g)	Skein sub-sample Weight (g)	Skein sub-sample Egg count	Estimated fecundity	Actual fecundity	Loose eggs	Adjusted fecundity
Continued								
n/r	58.2	440.0	149.9	1,670	4,902		6	4,908
n/r	58.7	373.9	127.3	1,318	3,871		0	3,871
n/r	59.4	359.8	123.0	1,128	3,300		10	3,310
Means								
4_2 (n=8)	51.5	281.6	122.6	1,349	3,095	3,097	10	3,108
5_2 (n=39)	58.0	400.5	150.4	1,515	4,031	4,097	20	4,048

[a] Not adjusted for shrinkage which occurs in carcass recoveries.

Appendix 8. Proportion at age and mean length (Standard and POH) at age, by sex, section and sample period, from the sockeye carcasses recovered on the Horsefly River, 1995.

						Standard length (cm)		POH length (cm)	
Sex	Section [a]	Sampling date	Age	Sample size	Percent	Mean	Standard deviation	Mean	Standard deviation
Male	Upper River	10-Sep	4_2	14	24.6%	56.7	2.3	49.1	2.1
			5_2	43	75.4%	61.4	10.0	53.3	8.6
			Unaged	3	-	65.1	1.1	56.2	0.6
	Lower River	12-Sep	4_2	4	20.0%	54.5	3.0	47.1	2.8
			5_2	16	80.0%	63.2	1.8	54.6	1.5
			Unaged	1	-	57.4	-	49.5	-
		14-Sep	4_2	18	48.6%	54.9	2.1	49.0	1.8
			5_2	19	51.4%	61.5	2.1	54.8	1.8
			Unaged	2	-	60.1	0.6	53.9	0.6
		Total	4_2	36	31.6%	55.6	2.4	48.9	2.1
			5_2	78	68.4%	61.8	7.5	53.9	6.5
			Unaged	6	-	62.1	3.5	54.3	2.7
Female	Upper River	10-Sep	4_2	3	5.3%	55.2	0.6	49.3	0.8
			5_2	54	94.7%	57.8	8.3	51.6	7.4
			Unaged	3	-	58.3	1.6	52.5	1.4
	Lower River	12-Sep	4_2	2	7.4%	55.2	1.7	49.7	2.0
			5_2	25	92.6%	59.9	1.6	53.3	1.5
			Unaged	2	-	56.7	0.9	51.1	0.6
		14-Sep	4_2	13	41.9%	52.2	1.4	48.1	1.3
			5_2	18	58.1%	57.7	1.7	53.3	1.6
		Total	4_2	18	15.7%	53.0	1.9	48.5	1.4
			5_2	97	84.3%	58.3	6.3	52.3	5.6
			Unaged	5	-	57.6	1.5	51.9	1.2

[a] Upper River: Areas 1-6