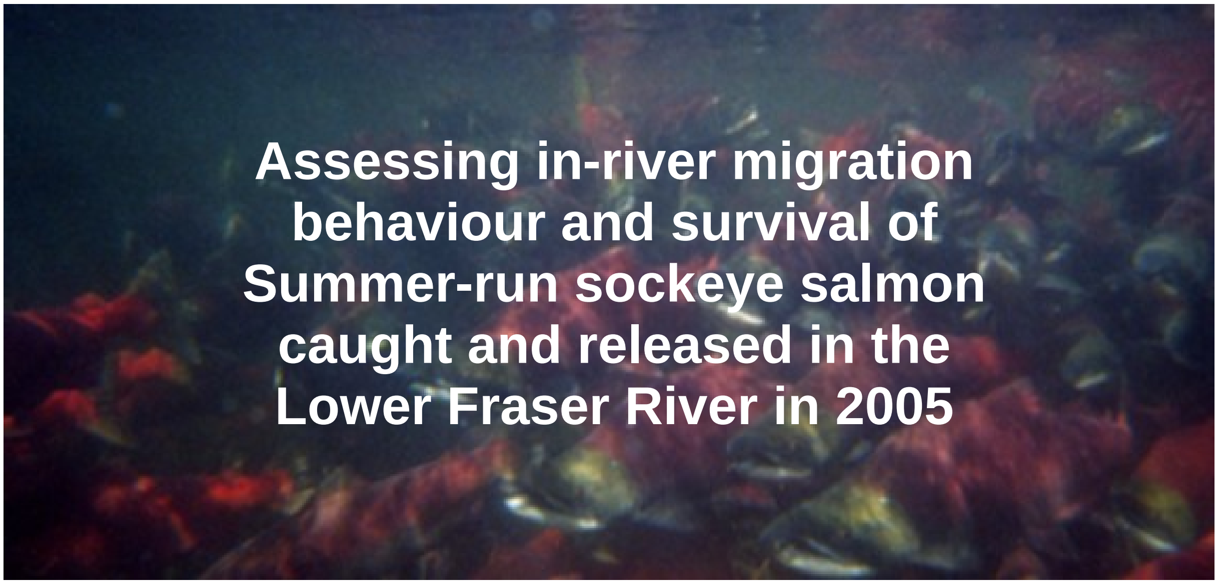

Assessing in-river migration behaviour and survival of Summer-run sockeye salmon caught and released in the Lower Fraser River in 2005

Prepared for:

Pacific Salmon Commission
600-1155 Robson Street
Vancouver, BC, Canada
V6E 1B5

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EA1756

Assessing in-river migration behaviour and survival of Summer-run sockeye salmon caught and released in the Lower Fraser River in 2005

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EXECUTIVE SUMMARY

In recent years, there has been a large discrepancy between the estimates of abundance derived from the Mission hydroacoustic surveys, and those made on the spawning grounds. This study was designed to do two things: (1) assess the feasibility of catching, tagging and releasing large numbers of sockeye salmon (*Oncorhynchus nerka*) from a location not far downstream of the Mission hydroacoustic site; and (2) to track the salmon throughout the Fraser river and into spawning tributaries in order to determine the extent and location of en-route losses, and to attribute losses to natural vs. fishery-related causes.

Using tangle nets, 411 sockeye were collected, tagged and released without difficulty from a site about 10 km downstream of Mission. Sample sizes could easily be doubled in future years without much increase in cost. Further increases in sample size might require additional crew or additional work days per week.

A total of 403 (98.1%) sockeye were detected at least once after release. In total, 392 of the radio-tagged fish (95.1%) were known to pass the Mission site. The focus or the study was Summer-run stocks which represented 316 (76.9%) of the sockeye tagged. A total of 303 Summer-run sockeye were detected at or above Mission and we estimated that 50 of these fish were caught in fisheries, based on daily harvest rates for each fishery upstream of Mission. Excluding the estimated fishery removals and tagging related losses, 222 of the radio-tagged Summer-run sockeye were classified as potential spawners and 154 (69.5%) of these were tracked to the vicinity of a spawning area for Summer-run stocks.

Median movement rates of Summer-run sockeye (31.5 km/d) were significantly faster than those for Late-run fish (21.3 km/d). Summer-run sockeye increased their migration speed as they traveled up the River. Migration speeds varied among Summer-run stocks. Stellako and Stuart stocks were slowest, whereas Horsefly and Quesnel stocks traveled fastest.

Assuming that the PSC estimates for the number of Summer-run sockeye passing Mission (4.3 M) and caught above Mission (434,380) are correct, we estimate that 2.7 M Summer-run would have reached the vicinity of the spawning grounds in 2006. This is somewhat larger than the DFO estimate derived from spawning ground surveys (2.365 M). However, our estimate is sensitive to the assumption regarding the survival rate for the 774,500 Summer-run sockeye that were estimated to have passed Mission after the tagging period. Subtracting the estimated catch and spawning ground escapement from the PSC Mission estimate suggests that the total en-route loss for Summer-run sockeye in 2006 was 1,149,000. Assuming that the distribution of the 67 sockeye classified as en-route losses are representative of the untagged sockeye, 77.6% of the en-route losses occurred between Sawmill Creek and the Cottonwood confluence and 22.4% were fish that migrated upstream of Sawmill Creek and subsequently dropped back below Sawmill Creek. In three years of radio-tagging and tracking Summer-run sockeye (2002, 2003 and 2005), similar proportions of the Summer-run sockeye that passed Mission (11.4%, 8.6% and 10.7%, respectively) were last detected between Thompson and Chilcotin. In future years, mobile survey effort in this section of the mainstem should be increased in order to more precisely determine the nature of these consistent losses.

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INTRODUCTION

The management of the Fraser River sockeye salmon (*Oncorhynchus nerka*) stocks is complex. There are more than 30 separate Fraser sockeye populations that spawn in more than 150 terminal streams throughout the watershed (Roos 1991). The adult sockeye, which return to the Fraser from late June into October, are managed as four separate run-timing groups: Early Stuart, Early Summer, Summer and Late runs (Pacific Salmon Commission 1989). Each run-timing group includes several genetically distinct stocks (Beacham et al. 2004), and the weaker stocks are afforded protections at the expense of lost fishing opportunities on the more abundant stocks. Decisions to open and close fisheries are based on a combination of pre-season and in-season estimates of run-timing, stock composition and abundance. Pre-season forecasts are based on the size of return in the brood year, estimates of spawning success, fry-to-smolt survival, and historic spawner-recruit relationships. In-season abundance estimates result from test-fishing in near-shore marine waters, gillnetting in the lower Fraser, and hydroacoustic monitoring at Mission (Woodey 1987). Post-season, estimates of escapement on the spawning grounds provide a measure of the success of the management measures to meet spawning escapement goals.

Successful management of such a complex species requires reasonably accurate data. The accuracy of post-season spawner abundance estimates affects predictions of future-year abundances (the future "pre-season" forecasts). The abundances measured in-season are used to determine whether spawner abundance goals have been met, and whether fisheries should be opened or closed (Woodey 1987). The Mission abundance estimates are especially important since they measure escapement through all marine fisheries, and through the bulk of the Lower Fraser in-river fisheries. However, in 2005, in-season estimates from the Mission program overestimated sockeye passage. The Mission hydroacoustic program estimates the daily passage of all salmon species migrating upstream. The total salmon estimated from acoustics is then partitioned into species (and into stocks) based on the species (and stock) composition of the test-fishing sets that occur adjacent to the site. In 2005, there was substantially more overlap in the upstream migrations of pink (*Oncorhynchus gorbuscha*) and sockeye salmon because the Summer-run fish entered the river later than usual, and the pink salmon have been migrating upstream early in recent years. Because most test fishing drifts occurred near the main river channel, pink salmon (which seem to prefer shallower water than sockeye) proportions were underestimated, and the abundance of sockeye that passed Mission was overestimated. In an attempt to correct for this bias, post-season estimates of sockeye passage were computed using species composition proportions obtained from marine area purse seine test fisheries.

Escapement goals are set to allow a certain proportion of fish to avoid marine and in-river fisheries. In most years, the vast majority (80-99%) of fish that successfully avoid capture survive the remainder of their migration to their natal stream where they spawn and die (Cooke et al. 2004). The remaining fish succumb to one of the many challenges that are faced by migrating salmon, including osmoregulation, starvation and predation. However, there have been years in which some Fraser River stocks showed above-average pre-spawning mortality rates. In the 1960's, the International Pacific Salmon Fisheries Commission (IPSFC) reported that 47-62% of the Horsefly River stock died in freshwater before spawning (Roos 1991). Wood (1965) documented a pre-spawn mortality rate of 90% for the Chilko run in 1963. More recently, spawning ground surveys in 2004 could only account for 6%, 9% and 20% of the Mission in-season hydroacoustic estimate (less catches that occurred upstream of Mission) for Early Stuart, Early Summer-run and Summer-run stocks, respectively (Williams 2005). Several potential causes for this discrepancy include: biases in the hydroacoustic and spawning ground estimates, in-river mortalities due to environmental factors (e.g., elevated water temperatures, river flow, parasite levels), unaccounted for in-river harvests, or a combination of these factors.

There is a high priority need to determine whether the recent discrepancies between the Mission and spawning ground estimates are due to biases in estimation or due to en-route losses. If the discrepancies are primarily due to en-route losses, it is critical to determine whether these losses are likely the result of in-river fisheries or non-fishery related factors (e.g., elevated water temperature, river flow, parasites, etc.). One of the goals of this project was to identify the magnitude, timing and location of in-river losses, and attribute them both to fisheries and non-fishery related causes.

Radio-telemetry was identified as a method to help meet the first goal of the project. In order to assess losses between Mission and the spawning sites, it was necessary to tag and release sockeye immediately downstream of the Mission hydroacoustic site. However, since no tagging projects had yet attempted to capture large numbers of fish in this location, a second goal of this project was to assess the feasibility of catching adequate numbers of sockeye in this location.

The specific goals of this project were five-fold:

1) to identify sites and capture methods required to radio-tag sockeye downstream of Mission and assess the in-river survival of these fish from Mission to their respective spawning area;
2) to focus the capture, tagging and tracking efforts on Summer-run sockeye and specifically the Quesnel River stock;
3) to produce estimates of in-river survival from Mission to spawning areas, assess the magnitude of losses in known fishing areas, and identify en-route losses that are likely not related to fisheries;
4) to provide data on migration speed and behaviour, which can be combined with data from 2002 and 2003 to make comparisons among the different river flows and water temperatures observed during the migration period; and
5) to assess post-release survival rates for adult sockeye caught and released in sport fisheries along the lower Fraser River.

MATERIALS AND METHODS

Study area

The main study area extended from the Mission hydroacoustic site (rkm 79) to the upper reaches of the Fraser River (Figure 1). Radio telemetry receivers were deployed along the Fraser mainstem, and at major tributary confluences. The sockeye were captured, tagged and released about 10 km downstream of Mission (at rkm 69) or about 1 km upstream of Crescent Island. A receiver was deployed at the downstream end of Crescent Island to detect any tagged fish that drop-back downriver after being tagged. A pair of receivers was deployed at Mission to detect time at which the tagged fish moved upstream through the hydroacoustic site and into the study area. Since the focus of the study was Summer-run sockeye, receivers were also deployed in major Summer-run spawning areas, including the Quesnel and Nechako river systems.

Study design

The basic components of the radio-telemetry study proposed were:

1. testing fishing methods and locations such that a large number of sockeye could be captured, tagged and released immediately downstream of Mission;
2. timing tagging efforts to target Summer-run stocks;
3. fixed-station tracking at strategic locations along the Fraser River;
4. fixed-station and mobile tracking of Summer-run stocks in the Quesnel and Nechako river drainages.

Prior to the main tagging period, the areas downstream of Mission were explored for potentially productive sockeye fishing sites. The potential gear types being considered were angling, beach seining, and tangle netting. However, early in the study period, the beach seining crew were forced to drop out of the study as a result of some politics involved with the splitting of the Sto:lo First Nation into two parts. Anglers looked for sandy bars near shallow water, and tangle-netters looked for areas of adequate flow that were free from potential snarls. The tagging crew looked for beaches near the potential capture sites as bases for the tagging operations.

The initial goal for tagging operations was to apply tags to the Summer-run stocks in proportion to the run. That is, a few tags would be applied early in the run (late-July to early August), most tags would be applied during the peak of the run (mid to late-August), and a few more tags would be applied late in the run (early September; Table 1; Figure 2). The exact tagging periods and tag allocations were expected to change slightly in-season based on actual run timing and relative abundance of the Summer-run stocks.

The fixed-station tracking involved the deployment of antennas and receivers at strategic locations along the Fraser River to provide data on study-area entry times, in-river movement patterns, and spawning destinations. The mobile tracking in the Harrison, Seton, Quesnel and along the Fraser River between the Seton and Chilcotin junctions were conducted to determine the fate of the fish last detected at fixed-station receivers adjacent to these areas.

Radio-transmitters

The radio transmitters used during this study were model MCFT-3A micro coded fish transmitters manufactured by Lotek Wireless, Inc. of Newmarket, Ontario, Canada. They were 16 mm in diameter, 46 mm long, and had a 460-mm-long antenna. The transmitters were powered by 3 V batteries, with an expected life of 761 d. The transmitters were programmed to stop transmitting after 154 d to minimize interference with other studies. Tags transmitted on four different frequencies (320, 360, 440 and 600 kHz) within the 150 MHz band. Within each frequency, three different pulse intervals (4.5, 5.0, and 5.5 s) were used to reduce the incidence of signal collisions when several transmitters were present at the same location at the same time.

Tracking systems

Radio-tagged sockeye were monitored using fixed stations and mobile tracking. Both monitoring systems used SRX400 or SRX400A radio receivers manufactured by Lotek Wireless, Inc., and 3-element or 4-element Yagi antennas manufactured by Maxrad, Inc., Hanover Park, Illinois or Grant Systems Engineering Inc., of King City, Ontario.

Fixed stations

Nineteen fixed stations similar to those described by English et al. (2004) were established along the Fraser River and within major tributaries (Figure 1) to monitor tagged fish movements towards and into spawning areas. Specific locations were chosen to monitor the arrival of fish into the study area, the to document departures from the mainstem of the Fraser River into spawning tributaries, and to bracket areas where mortality might arrive from natural sources or from fisheries. The first two fixed stations upstream of the tagging site were located near the Mission hydroacoustic site. Because the entry time of radio-tagged fish into the study area was of importance to the study, we maximized radio-coverage at the Mission site by deploying two receivers, positioned 0.73 km apart and on opposite sides of the river. Details of the fixed station locations are given in Appendix Report A.

Each fixed station consisted of two or three antennas (see Appendix Table A1), antenna switching hardware, a receiver, a 12 V battery, an enclosure to protect the equipment, and a solar panel to charge to battery. Antennas were placed more than 10 m above the water level, either in a tree or on an aluminum mast. Antennas were aimed to detect fish that were present downstream of the station, up a tributary (if present), and upstream of the station. The sequence of detections on each antenna permitted the determination of the direction of the fish's movements.

The detection range of each fixed station was tested in the upstream and downstream direction of the mainstem, and up the tributary. Ranges were tested by drifting a radio tag, at 2 m depth, at one-half and three-fourths of the channel width. In each case, adjustments were made to the antenna position and signal gain to ensure that tags were detectable across most of the river channel, and that there was good separation among antennas in the areas covered. At Mission, the antennas at the two fixed stations were aimed in different directions so that noise from radios and equipment would not affect all antennas at the same time.

Plots of the daily detections of radio-tagged fish and noise levels recorded by each receiver (Appendix Figure A1) were used to assess the effect of signal collisions and environmental noise on the detectability of radio-tagged fish, and to identify any gaps in the monitoring period. Details of receiver performance are provided in Appendix Table A2.

Mobile tracking

Mobile tracking was conducted to confirm the final locations and fate of radio-tagged sockeye, particularly in and near spawning areas. Mobile tracking included some areas that were not monitored by fixed stations, such as Mitchell River (Figure 1). Three modes of transport were used for mobile tracking: foot, boat, and helicopter (Bell 206). During foot surveys, a hand-held 3-element Maxrad or a folding antenna (AF Antronics, Inc., Urbana, Illinois) was used to detect radio-tagged fish. During boat and helicopter surveys, a 3-element Maxrad antenna was mounted on a wooden mast or support. The mast was mounted or held vertically in the boat, and was mounted horizontally on the skids of the helicopter. All radio-tagged fish detected during mobile surveys were assigned to specific stream reaches that were routinely surveyed for escapement by Fisheries and Oceans Canada. Mobile survey data, methods, effort, and numbers detected are provided in Appendix B.

Fish capture procedures

Angling

The goal was to use local anglers to capture sockeye in the areas downstream of Mission. Anglers looked for sandy bars from which to fish, and concluded that the fishing locations in the areas between Mission and Crescent Island were not good enough to produce the numbers of sockeye required for a large-scale radio-tagging study.

Tangle netting

An area along the south bank of the river about 1 km upstream of Crescent Island (adjacent to Glenlyon Provincial Park) was chosen for sampling (Figure 1), as it was relatively free of snags, had a good downstream current, and was near a beach site that was appropriate for the tagging setup. The site had adequate catch rates during preliminary tests.

Fish were captured using a 8.9 cm (3.5 inch) mesh drift gillnet measuring 60 m long and about 3.3 m (37 meshes) deep. The small mesh size ensured that the sockeye were not gilled, but were instead tangled in the loose-hanging mesh. A large float was attached to one end of the net, and the other end was kept in the small craft from which the net was deployed. When about three fish had hit the net (evident from movement of the buoys attached along the float line of the net), it was hauled back into the boat. Typically, only about one third of the net was deployed by the time this many fish were caught. On average, the boat drifted about 300 m per drift. When fishing was slow, about half the net would be deployed, and the boat could drift as much as 600 m downstream before the net was hauled back into the boat.

Captured fish were gently removed from the tangle net, and sockeye without significant scale loss or seal-injuries were placed in 190 L totes. The totes were filled with river water at the time of fish capture, and supplied with oxygen using a battery-operated aquarium air-stone kit. Other fish were returned to the river live, as quickly as possible. If four or more fish were caught in the first drift, these were brought back to shore for tagging. If less than four sockeye were caught on the first drift, another drift was performed before bringing the catch of both drifts back to shore. Two totes were kept on board the boat, and no more than 5 fish were put either tote.

Captured fish were transferred to a 750 L holding tank, located onshore adjacent to a semi-permanent tagging setup. The holding tank had continuously circulating river water pumped with a 4500 L/h bilge pump (powered by a 12 V RV battery), such that the entire tank was refreshed every 10 minutes. The intake for the bilge pump was floated about 2 m offshore to minimize the amount of silt entrained, though the water was never entirely free of silt. Fish that quickly righted themselves in the tank were selected for tagging.

Fish tagging procedures

Fish selected for tagging were placed in a V-shaped tagging trough filled with a constant supply of fresh river water (using a second bilge pump). Fish were measured (nose-fork length), and those greater than 40 cm and that appeared to be in good condition had a tissue sample taken from the adipose fin (for DNA analysis), a scale was taken (for ageing), and the radio tag was orally inserted into the stomach of the fish using a plastic tag applicator.

A subset of the fish also underwent a physiological sampling process. From these fish, blood was taken below the anal fin using a 3 ml vacutainer with a 2 cm long 21 gauge needle, a piece of gill tissue was removed using blunt-nose scissors, and a dorso-anterior reading of the percent body lipid was taken on the left side of the fish using the fat probe meter. All fish were released from the beach immediately after tagging.

Tagging periods were chosen prior to the season to span the duration of the Summer-run sockeye migration, but were modified by in-season stock composition (from DNA analyses; Beacham et al. 2004) and abundance indices. For example, the planned tagging start date was delayed to protect the Early-Summer stocks, which arrived several weeks later than usual. And since the Summer-run was also late, the tag allocations were re-calculated several times in-season, while managers tried to calculate when the peak of the run would arrive. Fish were tagged three days a week for six weeks, from 2 Aug to 8 Sept (Table 1).

Effects of physiological-sampling on survival

The effects of physiological sampling on the survival of sockeye was examined by comparing the proportion of physiologically-sampled fish that survived to the Thompson junction to that for sockeye which were not sampled. A two-way logistic regression was performed, where the dependent variable (survival = yes / no) was modeled as a function of tagging period (I to VI) and sampling type (no physio vs. complete physio). If the interaction term was statistically significant, then the effect of physiological sampling would be tested within each period, otherwise simple main effects would be examined.

Telemetry data management

Data from fixed stations were downloaded at regular intervals, which depended on the number of fish passing the location and the accessibility of the station. Remote stations were downloaded every 7 d, and readily accessible sites were downloaded every 2-3 d during periods when large numbers of radio-tagged fish were passing. After downloading, and before erasing the internal memory in the receiver, a diagnostic program was run on the download file to ensure that all data had been transferred, the file was readable, and the receiver and antennas had been operating properly.

The downloaded data were processed and analyzed using LGL's custom database software, "*Telemetry Manager*". *Telemetry Manager* facilitates data organization, record validation, and analysis through the systematic application of user-defined criteria. Raw data were archived so that the temporal or spatial resolution, or noise filtering criteria could be changed by the user at any time without altering the raw data. An important aspect of radio-telemetry is the removal of false records in receiver files, for example, those that arise from electronic noise. In this study, the following criteria were set for records to be considered valid: 1) power levels had to be greater than 50 (on a 1 to 232 scale); 2) detections had to be paired within a single zone, and recorded within 20 minutes of each other (single records, or records separated by more than 20 minutes were rejected); 3) detections had to be recorded at zones that were geographically located between the locations of previous and subsequent valid detections. Once false records were removed, *Telemetry Manager* created a compressed database of sequential detections for each fish. Each record included the tag number, zone number (antenna number, fixed station number, or a general location), the first and last time and date for sequential detections in a specific zone, and the maximum power for all detections in that interval. The compressed database was used to determine when each fish entered the study area, residence times at each fixed-station or spawning area, rates of movement between detection sites, and sites of last detection.

Fishery recovery estimates

Fisheries and Oceans Canada (DFO) provided estimates of in-river catches in First Nations and recreation fisheries. The Pacific Salmon Commission (PSC) compiled the catch estimates from DFO, and estimated stock-specific escapement past Mission on a daily basis (J. Gable, PSC, pers. comm.). These data were used to estimate daily harvest rates and the expected number of tag removed by fisheries.

Harvests were divided up into four fisheries: (1) Mission to Harrison; (2) Harrison to Hope; (3) Hope to Sawmill; and (4) upstream of Sawmill. In the data provided by DFO, catches upstream of Sawmill Creek were divided into sub-areas, but for the purpose of this analysis, these sub-areas were combined and treated as a single fishery. Daily harvest rates were calculated for each fishery as the proportion of fish that passed into the fishery on a given day that were subsequently caught. Median travel times, measured in previous years (English et al. 2004), showed that sockeye take about 1 day to travel through each of the first three fisheries, whereas 7 days were required to pass through the major fisheries upstream of Sawmill.

Because of uncertainty regarding daily escapement and daily catch estimates for Summer-run sockeye, daily harvest rates (HR_{fd}) for the first three fisheries were calculated using a three-day running average of catch, divided by a three-day running average of escapement:

$$HR_{fd} = \sum_{i=-1}^{1} C_{fd+i} \Big/ \sum_{i=-1}^{1} E_{fd+i} \qquad \text{where } f \in \{1,2,3\} \qquad \text{(Eqn 1)}$$

where E_{fd+i} is the escapement into fishery f on day $d+i$, and C_{fd+i} is the total catch in fishery f on day $d+i$. Daily fishery-specific catch estimates were supplied by the PSC. Daily estimates of stock-specific escapement past Mission (also supplied by the PSC) were used as E_d for the first fishery, and the survivors of a given fishery became the escapement for the subsequent one:

$$E_{fd} = E_{f-1d} - C_{f-1d} \qquad \text{(Eqn 2)}$$

Harvest rate calculation for the fishery above Sawmill was more complex, as fish were exposed to fishing pressure for seven days (whereas for the first three fisheries, the fish were exposed for one day). On any given day, the sum of seven daily escapements would be available to be caught in the fishery, and the survival of an escapement cohort entering the fishery on day *d* would be:

$$S_d = 1 - \left(C_d \Big/ \sum_{j=0}^{6} E_{d-j}\right) \qquad \text{(Eqn 3)}$$

The harvest rate for a cohort entering the "above Sawmill" fishery on day *d* would be:

$$HR_{fd} = 1 - \prod_{j=0}^{6} S_{d+j} \qquad \text{where } f = 4. \qquad \text{(Eqn 4)}$$

The total catch of the radio-tagged fish that entered into fishery *f* on day *d* was estimated using the formula:

$$RC_{fd} = \sum_{d=1}^{D} RE_{fd} HR_{fd} \qquad \text{(Eqn 5)}$$

where HR_{fd} was the fishery-specific harvest rate for day *d*, and RE_{fd} was the number of radio-tagged fish that entered into the fishery on day *d* (known from the tracking data).

The tag reporting rate was not calculated on a daily basis, since estimates would be too noisy. Since radio-tagging occurred for three contiguous days each week, it made sense to pool data into weeklong blocks. Each block, called "Mission Passage Periods", corresponded to the week during which fish from a given tagging period traveled past Mission. The tag reporting rate (*TR*) for Mission passage period *p* was calculated as:

$$TR_p = \sum_{p=one}^{six} RR_p \Big/ \sum_{p=one}^{six} RC_p \qquad \text{(Eqn 6)}$$

where RR_p was the number of radio-tagged fish from period *p* that was caught and reported by river fishers upstream of Mission, and where RC_p (the estimated total number of radio tagged fish that was caught by fishers upstream of Mission) was calculated from:

$$RC_p = \sum_{f=1}^{4} \sum_{d=(7(p-1))+1}^{(7(p-1))+6} RC_{fd} \qquad \text{where } p \in \{1..6\}. \qquad \text{(Eqn 7)}$$

Stock assignment

During this study, information was obtained on stock movement through various fisheries, and the location and time of pre-spawn mortality. The spawning destination of each fish (termed 'stock of origin') was required to determine stock-specific movement rates. Tagged fish detected in spawning areas were assigned to that river (i.e., stock). Radio-tagged fish caught in various fisheries, and those that died before reaching the spawning areas, were assigned to a stock group based on a DNA analysis of their tissue sample (as per Beacham et al. 2004).

In-river movements

Travel times for each individual fish were calculated based on the time required to pass between the various fixed-station receivers along the river. Travel time between two receivers was calculated as the time between the first detection at the downstream receiver and that at the upstream receiver. Migration rates were calculated by dividing the distance (in km) between receivers by the travel time.

Median travel times and migration rates were compared among run-timing groups and among stocks of Summer-run sockeye using the Kruskal-Wallis test. For within-individual comparisons (e.g., to test if migration rates change as the fish travel upriver), parametric matched pair statistics were used, as the distribution of differences between the paired observations tended to be normally distributed.

Receiver detection efficiency estimation

Detection efficiencies for each fixed-station receiver site were estimated by dividing the total number of unique radio-tagged fish detected at the site by the total number of unique radio-tagged fish known to have passed. The total number known to have passed included all those fish detected at that site, or at any site located farther upstream.

Survival estimation

Survival rates from Mission to the spawning grounds were computed for each Mission Passage Period, and was computed separately each Summer-run stock. Fixed-station and mobile tracking data were used to determine the fate for each radio-tagged sockeye that moved upstream past Mission. Chilko fish were classified as surviving to a spawning area if they were tracked into the Chilcotin. Horsefly and Quesnel fish were classified as spawners if they were tracked past the Quesnel receiver at Likely. Nechako and Stuart fish were classified as spawners if they were tracked past the Nechako-Stuart junction. Estimates of survival (S_v) and the standard deviation were computed using the equations:

$$S_v = \frac{O_v}{E_v - C_v} \qquad \text{(Eqn 8)}$$

$$\sigma(S_v) = \sqrt{\frac{S_v(1-S_v)}{E_v - C_v - 1}} \qquad \text{(Eqn 9)}$$

where E_v is the number of fish in group v that were detected at Mission, C_v is the number of fish in group v that were caught upstream of Mission, and O_v is the number of fish in group v that survived to a spawning area. The groups denoted by v could defined in any way, but in this report, survival was examined by (1) stock; (2) by Mission Passage Period; and (3) by stock *and* Mission Passage Period. Equation 9 is the formula for proportions based on high sampling fractions (Cochran 1977).

RESULTS

Capture methods

Anglers associated with the Fraser Valley Salmon Society (FVSS, a local sport-fishing group) concluded that the fishing locations in the areas between Mission and Crescent Island were not good enough to produce the numbers of sockeye required for a large-scale radio-tagging study (Frank Kwak, FVSS, pers. comm.).

Tangle netting was a successful method of fish capture. Drifts started less than 50 m from shore, and slowly drifted towards the central parts of the channel with time. Catch rates were higher in shallow water near shore, but so was pink salmon bycatch. When the net drifted more than about 100 m offshore, catch rates declined but the ratio of sockeye to pink salmon was higher. No fish were caught in the centre of the channel (pers. obs.).

Since very large catches would have been counterproductive to the goal of minimizing stress to each individual fish (and since seal kleptoparasitism was quite frequent when catch rates were low), the fishing crew started to haul the net back into the boat as soon as they noticed a fish hitting the net. Typically, only about one third of the net was deployed by this time. Average soak times ranged from 4.9 to 7.4 minutes.

Target numbers for the six tagging periods were 40, 60, 62, 90, 90 and 69 radio-tagged sockeye (Table 1). These targets were achieved in 30, 91, 39, 42, 24, and 23 sets, respectively. Catch rates ranged from 7.1 to 52.7 sockeye per hour of soak (Figure 3), which translated to work days ranging from 3.3 to 7.7 hours in duration (Figure 3). Duration of work days was based on the time the first net went in the water to the time the last net came out, plus one hour for tagging the last batch of fish.

Tag releases

In all, 411 fish were radio-tagged, including 113 that were physiologically sampled (Table 1). Of the 113 fish, 100 fish were fully sampled physiologically, and the remaining 13 were going to be further sampled (the fish was poked with the vacutainer needle), but blood could not be extracted within 30 sec, and the rest of physiological sampling was aborted. Processing time (from the time the fish was placed in the tagging trough to the time it was released into the river) was 37 seconds for the simple procedure, and 1.37 min for the physiologically sampled fish. On average, the time from capture to release was 11 minutes (maximum 40 minutes).

The majority (76.9%) of sockeye that were tagged were identified as Summer-run, though the proportion varied over time. The proportion of Summer-run was just under 60% during the first two tagging periods, but was greater than 80% thereafter (Figure 4). The proportion of Early-Stuart sockeye in the sample declined with time, but that of Early-summer and Late-run sockeye did not vary notably.

The stock composition of Summer-run sockeye that were radio-tagged during each of the tagging periods is shown in Figure 5. The Chilko stock made up a consistently large proportion of the tagged fish, whereas the Nechako stock never accounted for many. The proportion of Quesnel fish increased consistently over time, and increased to over 14% for the last two tagging periods. Conversely, the proportion of Stuart fish declined consistently over time, ranging from 30% during tagging period I, down to 4% in the last two periods. The proportions of Horsefly fish increased over time, peaked at 48% during tagging period V, and declined afterwards. Conversely, the proportions of Stellako fish peaked at 31% during tagging period II, and declined consistently thereafter.

Tracking histories and Fixed-station detection efficiencies

A total of 403 (98.1%) sockeye were detected at least once after release. Of these, 50 fish dropped back downriver after being tagged, and were first detected at the fixed station on Crescent Island. One dropback fish was caught downstream of Mission, and recovered from New Westminster Quay, and 9 were never detected again. The remaining 40 drop-back fish returned upriver and eventually passed the Mission fixed station.

In total, 392 of the radio-tagged fish (95.4%) were known to pass the Mission site (Table 2), although 16 were not detected upon passage. One was first detected in the Harrison River system, and the other 15 were first detected at the Rosedale Bridge. Individual travel times from release to Rosedale were was used to interpolate Mission passage times for these 15 fish.

Detection efficiencies in 2005 (Table 2) were similar to those estimated in previous years (English et al. 2004). All fixed stations had detection efficiencies greater than 85%, and only two were less than 90% efficient. The Hell's Gate site, which had been problematic in previous years (English et al. 2004), operated at 99.6% efficiency in 2005. Daily detections of radio-tagged fish and corresponding receiver noise levels recorded by each fixed-station receiver are given in Appendix Figure A1.

The zone of last detection of the radio-tagged sockeye are shown in Table 3. In all, 180 (46% of the fish that passed Mission) were tracked to the vicinity of spawning areas, including 9 to spawning areas for Early summer stocks, 154 for Summer-run and 17 for Late-run stocks. Of the fish that passed Mission, 170 (43%) were last tracked on the Fraser mainstem, including 105 between Mission and Sawmill Creek, 51 between Sawmill Creek and the Chilcotin confluence (29 at the Seton junction), and 15 upstream of the Chilcotin confluence. No monitoring stations were deployed within the Harrison watershed in 2006, so the 32 sockeye last tracked at the Mission site (Table 3) could include some Harrison watershed spawners not detected during the two mobile surveys conducted in this watershed.

DNA stock assignments and straying

Prior to the arrival of radio-tagged sockeye in known stock areas, DNA micro-satellite analyses provided estimates of stock origins for 409 of the 411 radio-tagged sockeye. Radio-tracking provided additional insight to the stock-classifications. In total, 190 radio-tagged sockeye were tracked upstream of the Thompson confluence, either as the fish passed fixed-station receivers, or by mobile tracking. Final stock assignments for these 190 sockeye were used to assess the classification accuracy of the *a priori* DNA analysis.

The radio-tracking data indicated the DNA analysis assigned radio-tagged fish to the correct run-timing group 95.2% of the time (Table 4). Summer-run stock groups provided the largest sample (n = 154), and 98.0% of the DNA stock assignments for these fish were correct.

Effects of physiological-sampling

The survival of sockeye (measured at the Thompson junction) varied depending on the week during which they were tagged (Figure 6). Since the two-way logistic regression showed no statistically significant interaction term (χ^2_5 = 6.9; P = 0.23), it was eliminated from the model, and the model was re-run. Examination of the main effects revealed significant effects of tagging period (χ^2_5 = 26.4; P = 0.0001), but no statistically significant effects of sampling (χ^2_1 = 2.2; P = 0.13). Consequently, subsequent analyses of migration and survival patterns were conducted using all radio-tagged fish, without distinguishing those that were physiologically-sampled from those that were not.

In-river migration rates

Radio-tagged sockeye exhibited median travel times that were similar across release groups (Figure 7). Movement rates of Summer-run sockeye between Mission and the Thompson Junction (median = 31.5 km/d) were significantly faster than those for Late-run fish (median = 21.3 km/d; χ^2_2 = 19.2; $P < 0.0001$; Figure 8).

In general (Table 5), and particularly for Summer-run stocks, sockeye increased their migration speed as they traveled up the River (Figure 9). Matched pair t-tests showed that individual Summer-run sockeye passed through the Mission-Thompson reach (median 31.5 km/d) significant slower than through the Thompson-Chilcotin reach (median 38.9 km/d; t_{116} = 14.5; $P < 0.0001$). Similarly, travel through the Thompson-Chilcotin reach was significantly slower than through the Chilcotin-Quesnel reach (median 51.5 km/d; t_{116} = 20.4; $P < 0.0001$; Figure 9).

Migration speeds varied among Summer-run stocks. There was a general trend for stocks with farthest destinations to travel the most slowly (Figure 9). Stellako and Stuart stocks were slowest, whereas Horsefly and Quesnel stocks traveled fastest. Travel time differences among stocks were statistically significant in all reaches ($\chi^2_{3 or 4}$ = 32.8 to 48.7; *P* < 0.0001). However it should be noted that Quesnel and Horsefly fish had significantly longer fork lengths than other Summer-run stocks ($F_{4,311}$ = 16.1; *P* < 0.0001), and there was a significant negative relationship between length and travel time ($F_{1,210}$ = 14.9; *P* = 0.0002). Note also that migration rates appeared to be faster for fish that entered the river later (Figure 10).

Fishery recoveries

Fishery recoveries were calculated from tag returns, and expanded for an estimated tag return rate. In 2005, it was estimated that about 34.5 of the radio-tagged Summer-run sockeye should have been harvested in First Nation fisheries in the areas between Mission and Sawmill Creek, and a further 15.4 tags should have been harvested upstream of Sawmill Creek (Appendix C). In all, 16 and 13 tags were actually returned from these respective fisheries (see Appendix Table B2). The period-specific return rate varied widely among Mission Passage periods, but was 46% for the Mission to Sawmill fisheries and 84% for fisheries above Sawmill Creek.

Survival Estimates

Survival rates for sockeye migrating from Mission to their respective spawning areas were derived by dividing the number of fish last detected in the vicinity of a spawning area by the number of tagged fish that remained after tagging related losses and estimated fishery removals (Tables 6-8). The zones of last detection were shown by run-timing group in Table 6, but survival rates were not calculated because the study was not designed to measure survival to spawning for groups other than Summer-run. For other run-timing groups, sample sizes were low, and monitoring efforts in the spawning areas for these stocks were incomplete due to focus on the Summer-run group.

Table 7 shows the zone of last detection for each Summer-run fish, and survival by Mission Passage Period. Period-specific survival rates were lowest during the first period (32.2%), and increased for the next four periods from 58.3% to 78,5%, and declined somewhat to 70.2% during period 6 (Figure 11). The survival rates in Table 7 were calculated from the last detection data through several steps. Firstly, not all fish that passed Mission were expected to be available for spawning, since some were removed by fisheries and there were likely some tagging related losses. Comparison of the reach-specific survival rates for fish that dropped back to Crescent Island after tagging with those that did not drop back after tagging suggested that tagging-related effects were largely restricted to reaches downstream of Hope. The reach-specific survival rate the drop back fish were 20% lower than the non-drop back group in the first two reaches above Mission but similar for both groups in the reaches above Hope (Figure 12). An upper bound on the extent of tagging-related losses below Sawmill was estimated to be 10.4% of the Summer-run sockeye that past Mission, ranging from 4.6% to 35.4% depending on the passage period (Appendix C3). These are upper bounds because they represent to difference between the expected numbers of tags passing Sawmill (i.e., those that passed Mission, less fishery removals = 268.5) and those that actually passed the monitoring station at Sawmill Creek (237). This level of tagging related loss was consistent with that observed in other adult sockeye tagging studies where tags are applied in the lower river reaches above tidal influence

(Alexander and Bocking 2003). Next, these estimated tagging-related losses were subtracted from the total number of fish that passed Mission, and the difference was called the "Effective tags". Third, fishery removals were calculated (separately upstream and downstream of Sawmill) by applying daily harvest rate estimates to the daily accounting of the number of tags entering each fishing area (Table 9 and Appendix C). Fourth, the differences between the effective tags and the estimated number of fishery removals were the numbers of radio-tagged sockeye that were available to spawn from each Mission Passage Period. Finally, the survival rates were the proportion of available spawners that were last detected in stock-specific spawning areas. Note that our estimate of the number of Chilko fish that escaped fisheries in the lower Chilcotin River was the number of Chilko sockeye last detected at the Chilcotin junction (43) less an estimated 1 additional tag removed by Chilcotin fisheries (based on our estimated tag reporting rate of 84% for fisheries above Sawmill Creek). Note also that one radio-tagged Summer-run sockeye was recovered from a sockeye that spawned in Williams Lake Creek, and was therefore also included as a successful spawner. Analysis of a DNA sample from this individual suggested that it was a Late-Stuart fish, tagged during the last release period.

Survival was estimated for each Summer-run stock (Table 8). Survival of the Horsefly stock (85.5%) was significantly higher than that of the Chilko stock (66.0%) or of the combined Stellako / Stuart stocks (50.0%; see non-overlapping confidence limits in Figure 13). Survival of the Quesnel stock (79.2%) was significantly higher than that of the combined Stellako / Stuart stocks.

The overall survival estimate for Summer-run sockeye (69.5%; Table 7) indicates that 30.5% of the radio-tagged sockeye (approximately 67 fish) that escaped river fisheries did not complete their migration to spawning areas. Details on the last detection locations for these fish are provided below.

Fate of Radio-tagged Sockeye

A total of 81 Summer-run sockeye were last detected between Mission and Sawmill Creek, including 16 tags returned by fishers and 65 tags last detected by fixed station receivers. We estimate that 31.5 of these fish were tagging related mortalities, 34.5 were fishery removals and 15 were sockeye that dropped back after being detected at or above Sawmill Creek. Information on last detection dates and migration behaviour for these fish is useful for assessing the potential causes of mortality. Daily estimates of the sockeye catch were plotted together with the last detection time for these radio-tagged sockeye. Figure 14 shows that most of the 16 tag returns were reported on dates when fisheries occurred between Mission and Sawmill Creek. Figure 14 also shows that 28 fish dropped back, including the 15 fish that dropped back from locations at or above Sawmill Creek. Since most tagging-related mortalities occurred prior to the fish arriving at Sawmill Creek (see Figure 12), the 13 lower-river drop back fish were potentially tagging-related mortalities; and conversely, the 15 upper-river drop back fish would be classified as en-route losses (i.e., natural mortality, net drop outs, or other non-fishery related causes). The last detections dates for the remainder of the sockeye (37) in coincide with the timing of fisheries between Mission and Sawmill (Figure 15). If the assumptions that tagging-related mortality was 10% and that catch estimates for fisheries between Mission and Sawmill Creek are correct, then half of these 37 fish would be fishery removals and the remainder would be tagging related mortalities.

Of the 67 tags that we estimate were en-route losses after accounting for tagging-related effects and fishery removals, 15 were the fish that dropped back to sites below Sawmill Creek and 52 were last detected on the Fraser mainstem between Hells Gate and the Cottonwood confluence (24 last detected at the Seton confluence).

DISCUSSION

Capture Methods

Tangle nets will be a useful tool for sockeye collection, even if future studies require greatly increased sample sizes relative to those in 2005. Catch rates were good, and tagging quotas were met in just a few hours. Assuming similar catch rates in future years, the number of tagged fish could easily be doubled either by fishing for twice as long (9.3 h per day) on each tagging day, by fishing 6 days a week, by hiring a second fishing crew, or some combination of these. Increasing fishing time within a day would be most effective, given the technicians are paid by the day. Since days were short in 2005, and since 9.3 hour work-days are not unusual during the field season, it would be feasible to substantially increase daily tagging numbers without increasing crew costs. Note that catch rates were especially low and seal predation was especially high during tagging period II, hence more (and longer) sets were required to catch the weekly quota. On these days, it took full days (average 7.7 h of fishing) to get the required numbers of fish. However, catch rates in other tagging periods were very good, thus if future catch quotas are allowed to be somewhat dynamic, poor fishing days will be balanced by good ones.

Angling was not used as capture method in 2005. One of the goals of this study (goal #1) was to identify capture methods that could be used to radio-tag sockeye downstream of Mission. Angling was one method that was proposed. Anglers associated with the Fraser Valley Salmon Society concluded that the fishing locations in the areas between Mission and Crescent Island were not good enough to produce the numbers of sockeye required for a large-scale radio-tagging study. Since no tags were applied to sockeye caught by angling, it was not possible to assess post-release survival rates for adult sockeye caught and released in sport fisheries along the lower Fraser River (which was goal #5).

Run-timing and Mission Estimates

The run-timing of Summer-run stocks was more than two weeks late, relative to historical timing. In 2005, peak sockeye passage at Mission occurred on 30 August. In 2003, median passage occurred on 15 August (English et al. 2004). Historically (1974-2002), the median Mission passage date for the Chilko stock was 13 August (PSC, unpublished data).

In 2005, in-season estimates from the Mission program overestimated sockeye passage. For the most part this is due to the fact that the Mission hydroacoustic program produced estimates of the combined the daily passage of all salmon species migrating upstream. The total salmon estimate is then partitioned into species (and into stocks) based on the species (and stock) composition of the test-fishing sets that occur adjacent to the site. These species composition estimates tend to overestimate the number of sockeye passing the Mission hydroacoustic site because test fishing drifts do not effectively sample the near-shore areas where pink salmon are more common. This bias was important in 2005 when there was substantially more overlap in the upstream migrations of pink salmon and Summer-run sockeye than in previous years. Bias in species composition estimates have been a concern in all pink salmon years. However, when the sockeye and pink salmon have more "normal" run-timing, only the latter part of the Late-run sockeye stocks passes Mission concurrently with pink salmon. The species composition bias is negligible on even years when pink salmon are absent from the Fraser River.

In an attempt to address the bias associated with the in-season estimation procedure, sockeye to pink salmon catch ratios from the marine purse seine test fisheries were applied to the daily estimates of salmon escapement at Mission to estimate the number of sockeye that passed Mission. These purse seine test fisheries operated on both approach routes and are believed to catch pink and sockeye salmon in proportion to their relative abundance. The species composition estimates from this latter method were used to generate post-season estimates of daily sockeye passage past Mission, and these post-season estimates have been used in this report.

Migration speeds

Migration speeds of the Summer-run sockeye were similar to those of previous years. In 2005, Summer-run sockeye took a median 14.0 days to travel from Mission to the Quesnel junction, or 38.8 km/d. English et al. (2004) reported similar migration speeds for 80 Summer-run sockeye in 2002 (43 km/d) and for 47 Summer-run sockeye in 2003 (40 km/d). Moreover, mean migration speeds of 41.5 km/d were computed for the same reach using historical data from the period 1993-2001 (English et al. 2004). Despite the similarities in median values, a Kruskal-Wallis rank order test (non-parametric equivalent to the ANOVA) showed that Summer-run migration rates in 2002 were significantly faster than in 2005 (χ_2^2 = 26.4; $P < 0.0001$).

Migration speeds varied among Summer-run stocks. There was a general trend for stocks with farthest destinations to travel the most slowly (Figure 9), but also to be smaller-bodied (and hence have slower swim speeds). It also appeared to be the case that migration rates were faster for fish that entered the river later (Figure 10). Since Horsefly and Quesnel stocks were larger and passed Mission later than other Summer-run stocks (Figure 5), run-timing and fish-size effects could explain the differences among stocks in migration rate.

Summer-run sockeye traveled faster than Late-run stocks. In 2005, Late-run stocks moved between Mission and the Thompson Junction at a leisurely 21.3 km/d (n=9). Similar results were observed in 2002 and in 2003. In 2002, median travel rates for Late-run sockeye ranged from 17-21 km/d between Mission and the Thompson Junction, and from 16-23 km/d farther upstream (English et al. 2003). In 2002, Late-run median migration rates were reported to be between 17 and 24 km/d (English et al. 2004). Quality historical migration speed data were not available for Late-run stocks. However, 2005 estimates comport with results of a 1940's tagging study, which reported movements of 27 km/d between Hell’s Gate and the Adams River (Killick 1955).

Extrapolation of Tagging Results to Whole Summer-run

PSC’s post-season estimates of the number of Summer-run sockeye that passed Mission each day were combined with estimates of daily catch for fisheries above Mission and period-specific survival estimates (derived from the tag tracking results) to estimate both the total number of Summer-run sockeye that survived to spawning areas and the extent of en-route losses. Eight periods were defined for these analyses: six periods associated with the upstream migration of the six tag release groups and two periods outside the tagging period (one before and one after). The PSC estimates indicated that the tagging periods encompassed 81%

(3,515,844 fish) of the Summer-run sockeye migration past Mission, and 97.6% of the total fishing activity (corresponding to 424,100 captured Summer-run sockeye) above Mission. The majority of the remaining escapement past Mission occurred after that last tagging period. The number of Summer-run sockeye that escaped the fisheries above Mission in each period was estimated by subtracting the period-specific catch from the Mission abundance estimate for that period. The period-specific survival estimates (Table 8) were applied to estimate that 2.2 M Summer-run sockeye should have survived to the spawning areas from the 3.5 M that passed Mission during the tagging periods (Table 10). Assuming the survival rates for sockeye migrating before and after the tagging period were 32.2% and 70.2%, respectively (i.e., equal to those for the adjacent tagging periods), the total escapement to spawning areas for Summer-run sockeye would be 2.7 M (with 95% confidence bounds of 2.3 and 3.2 M). These confidence bounds are based solely on the precision of the survival estimates and would be much larger if the uncertainties associated with daily catch and Mission escapement estimates were included. The DFO estimate derived from spawning ground surveys (2.365 M) is smaller than our estimate, but within the confidence bounds. Note that our total escapement estimate is sensitive to the assumption regarding the survival rate used for the 774,500 Summer-run sockeye that were estimated to have passed Mission after the tagging period. Given the very late return of Summer-run stocks in 2005, the survival rate for those that passed Mission after 8 September was likely less than the value that was assumed (i.e., 70.2%, or the survival rate of the sixth Mission passage period). Lastly, an estimate of the total en-route loss (1,149,000) was computed by subtracting the estimated catch and spawning ground escapement from the PSC Mission estimate. The confidence bounds for the en-route loss estimate, calculated using the upper and lower bounds of the spawning estimates, were 700,476 and 1,597,528 (Table 10). It should be noted that our estimate of en-route losses could include some Summer-run fish that spawned in streams a long distance from their natal stream. For example, the DNA analysis for the three radio-tagged fish that were last tracked in the Bridge River system suggested that these fish originated in the Chilko, Quesnel and Stuart systems, respectively. Lacking evidence that these fish spawned, we classified these fish as en-route losses. However, one radio-tag was recovered from a Late-Stuart sockeye that spawned in Williams Lake Creek. This fish was classified as a successful spawner.

The above extrapolations of the radio-telemetry results to the totals for Summer-run sockeye are heavily dependent on the accuracy of Mission escapement estimates for each of the Mission passage periods. Lower estimates for Summer-run sockeye passing Mission would increase the estimated harvest rate on the tagged fish and reduce our estimates of the total escapement to spawning areas and total en-route loss.

We also examined the sensitivity of our estimates to unsanctioned catch taken in fisheries below Sawmill Creek. Our current estimates are based on the assumption that all non-fishing losses downstream of Sawmill were likely due to the effects of tagging. Therefore, any increase in the harvest rate below Sawmill would cause tags to be shifted from the "tagging-related loss" category to the "fishery removal" category, and there would be no change in the estimates of spawning numbers or en-route loss. On the other hand, any increase in the harvest rate for fisheries above Sawmill Creek would result in an equivalent reduction in our estimate of en-route loss.

Our assessment of the location of en-route losses is independent of the Mission escapement estimates. The 2005 radio-telemetry data indicate that the majority of en-route losses occurred above Sawmill Creek. Assuming that the distribution of the 67 sockeye classified as en-route losses are representative of the untagged sockeye, 77.6% of the en-route losses occurred between Sawmill Creek and the Cottonwood confluence and 22.4% were fish that migrated upstream of Sawmill Creek and subsequently dropped back downstream.

Detailed migration histories for the 154 Summer-run sockeye tracked to the vicinity of a spawning area were compared to the 29 fish last detected at either the Thompson or Seton confluences to assess the nature of these en-route losses (Figure 16). It can be seen from this figure that 79% of the Summer-run sockeye that disappeared between Thompson and Chilcotin were migrating at speeds typical of successful migrants. The majority of the fish that disappeared were not fish that were slowing down for lack of energy, or other reasons. These data suggest that something other than fish health has affected their migration in this river reach. There is a fishway on the Fraser above the Seton confluence, which, combined with other factors such as flow, water temperature and/or local fisheries, could be acting as a significant migratory barrier. There are significant fisheries conducted near the Seton site (near Lillooet), and it is possible that these fisheries may be having a larger impact on Summer-run sockeye migration than what is indicated by the reported catch. While the fate of these fish is unknown, a mobile flight conducted on 6 Dec detected seven of these tags on the Fraser mainstem upstream of Lillooet. Six of these fish had travel times that were similar to those observed for fish that migrated successfully to spawning areas. This is direct evidence that some Summer-run sockeye that appeared to be migrating at “normal” rates to Seton, died upstream the Seton junction and their tags remained in the river. The most likely explanations for these observations is that these fish were mortally injured/stressed during a capture attempt or fish was removed by a fishery and the tag was discarded along with the entrails back into the Fraser River. More frequent and rigorous mobile surveys, using GPS to precisely locate the tags, would be required to associate these losses with a specific fishery.

In three years of radio-tagging and tracking Summer-run sockeye (2002, 2003 and 2005), similar proportions of the Summer-run sockeye that passed Mission (11.4%, 8.6% and 10.7%, respectively) were last detected between Thompson and Chilcotin (see English et al. 2003, 2004). In future years, mobile survey effort in this section of the mainstem should be increased in order to more precisely determine the nature of these consistent losses.

The migration rates of the 154 Summer-run sockeye tracked to spawning areas were also compared to those of 10 fish last detected at the Quesnel junction, and 4 fish last detected at the Cottonwood junction (Figure 17). All Summer-run sockeye that were last detected at the Quesnel junction were migrating at speeds typical of successful migrants. These data suggest that something other than fish health has affected their migration after this point. None of these fish were subsequently detected during mobile surveys. On the other hand, three of the four Summer-run sockeye that were last detected in the Cottonwood-Nechako reach were slow migrants. These data suggest that the most likely explanation for these fish not reaching a spawning area was non-fishery related factors (e.g. poor health or in sufficient energy reserves).

ACKNOWLEDGMENTS

We thank Keri Benner, Al Cass, Mike Chamberlain, Sue Grant, Brian Riddell and Timber Whitehouse of Fisheries and Oceans Canada; Mike Lapointe of the Pacific Salmon Commission for their guidance in planning and conducting this study. We are very grateful to the Public Utility District #2 of Grant County for providing 11 of the fixed-station receivers that formed the backbone of this study. We thank BC Hydro, UBC, Nicola First Nation and Grant County PUD for providing additional receivers and the BC Ministry of Environment, specifically Cory Williamson, for including our tag frequencies on the receivers that they deployed in the upper Fraser and for providing us with the data files from these receivers.

Staff from LGL Limited assisted with various phases of the project: Dorothy Baker, Anita Blakely, Jim Ferguson, Marion McIntosh, Cezary Sliwinski, Troy Ganzeveld, CEJ Mussell and Jack Mussell. Kim Hruska (of the University of British Columbia) and her technicians performed the physiological sampling, and helped with tangle netting and tagging data recording. Sue Grant at DFO (Anasis Island) provided some equipment.

We thank the following land owners who provided us areas for receiver deployment and antenna setup: BC Frozen Foods in Mission, Pacific Salmon Commission, Ed Reid, and Don Petrula.

Frank Kwak and Jim Rissling of the Fraser Valley Salmon Society assisted with the angling portions of this study. Lindsey Wilson constructed the tangle nets.

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TABLES

Table 1. Summary of the 2005 radio tag releases by date and tagging period. Some fish were sampled for physiological data (see text).

Tagging		Physiological Sampling			Total
Period	Date	None	Partial	Complete	Release
I	2 Aug	10	0	0	10
I	3 Aug	2	3	15	20
I	4 Aug	10	0	0	10
II	9 Aug	20	0	0	20
II	10 Aug	20	0	0	20
II	11 Aug	1	4	15	20
III	16 Aug	8	2	15	25
III	17 Aug	25	0	0	25
III	18 Aug	12	0	0	12
IV	23 Aug	30	0	0	30
IV	24 Aug	30	0	0	30
IV	25 Aug	8	2	20	30
V	30 Aug	30	0	0	30
V	31 Aug	9	1	20	30
V	1 Sep	30	0	0	30
VI	6 Sep	23	0	0	23
VI	7 Sep	23	0	0	23
VI	8 Sep	7	1	15	23
Total		298	13	100	411

Table 2. Numbers of radio-tagged sockeye that passed and that were detected passing the fixed-station receiver sites, 2005. The detection efficiency (the detected/passed quotient) of each receiver is also shown. Since no detection sited are located upstream of terminal zones, detection efficiency cannot be computed.

Fixed-station Site	Passed	Detected	Detection Efficiency
Mission Bridge	392	376	95.9%
Rosedale Bridge	354	323	91.2%
Hope	327	326	99.7%
Fraser-Sawmill Junction	284	282	99.3%
Hell's gate	268	267	99.6%
Fraser-Thompson Junction	248	243	98.0%
Thompson-Nicola Junction	9	9	100.0%
Thompson-North Thompson Junction	2	2	terminal
Fraser-Seton Junction	228	203	89.0%
Fraser-Chilcotin Junction	190	189	99.5%
Fraser-Quesnel Junction	132	132	100%
Quesnel at Likely	82	82	100%
Quesnel-Horsefly Junction	54	54	terminal
Fraser-Cottonwood Junction	38	36	94.7%
Fraser-Nechako Junction	33	29	87.9%
Nechako-Stuart Junction	30	30	terminal
Fraser, above Willow Junction	3	3	terminal

Table 3. Zone of last detection of radio-tagged sockeye, by stock. For each stock, fish are considered to have escaped to a spawning ground if they were last detected at one of the zones that are shaded in the table. Numbers in stock names correspond to run-timing groups. For the purposes of this table, Birkenhead fish are included in the Late-run timing group.

	Stocks																			Run-timing Groups			
Last Detection Zone	1-Stuart	2-Bowron	2-Chilko	2-Fennell	2-Gates	2-Nadina	2-Thompson	3-Chilko	3-Horsefly	3-Quesnel	3-Stellako	3-Stuart	4-Adams	4-Chilliwack	4-Harrison	4-Shuswap	4-Thompson	4-Weaver	5-Birkenhead	Early Stuart	Early Summer	Summer-run	Late-run
Release Site	2					1		3	1			1								2	1	5	0
Crescent Island						1		1	1		3	4			5	1				0	1	9	6
Mission	3				1	3		5	4		5	1	1	1	3	1		3	1	3	4	15	10
Harrison Confluence															5			4	1	0	0	0	10
Rosedale Bridge	4				2	3		5	8	1	2	6	1							4	5	22	1
Hope	2		2	4	1			4	4	2	4	7	1		1					2	7	21	2
Sawmill Creek Confluence				1				1	2		1	3								0	1	7	0
Hell's Gate								1	1	1	1		1							0	0	4	1
Thompson Confluence	1	1	1		1	1		3				2	1							1	4	5	1
Thompson / Nicola							1						5				1			0	1	0	6
Thompson / N. Thompson							1						1							0	1	0	1
Seton Confluence	1		2		3			12	7	2		3	2							1	5	24	2
Chilcotin Confluence				1				43	3	1		1								0	1	48	0
Williams Lake												1								0	0	1	0
Quesnel Confluence									5	5										0	0	10	0
Quesnel at Likely									6	22										0	0	28	0
Horsefly									54											0	0	54	0
Cottonwood Confluence		1									3	1								0	1	4	0
Nechako / Stuart						1					17	12								0	1	29	0
Upstream of Willow Confluence		3																		0	3	0	0
Fisheries																							
FN Below Mission								1												0	0	1	0
FN Mission to Sawmill							1	4	2	1	3	4								0	1	14	0
FN Above Sawmill (not Chilcotin)					2		3	4		2		2								0	5	8	0
FN Chilcotin								5												0	0	5	0
Sport Fishery										1		1								0	0	2	0
Totals																							
Total Below Mission	2	0	0	0	0	2	0	5	2	0	3	5	0	0	5	1	0	0	0	2	2	15	6
Total at or Above Mission	11	5	5	6	10	8	6	87	96	38	36	44	13	1	9	1	1	7	2	11	40	301	34
Fates																							
Above Mission Fisheries	0	0	0	0	2	0	4	13	2	4	3	7	0	0	0	0	0	0	0	0	6	29	0
Escapement to Spawning Grounds	0	3	0	0	3	1	2	43	60	22	17	12	6	na	5	0	1	4	1	0	9	154	17
Other Fate	13	2	5	6	5	9	0	36	36	12	19	30	7	1	9	2	0	3	1	13	27	133	23

na - no survey effort at Chilliwack spawning ground.

Table 4. DNA classification accuracy for Fraser sockeye run-timing groups assessed using radio-telemetry data.

	Final Stock Assignment			
DNA Assignment	Early Summer	Summer	Late-run	% correct
Early Summer	20	1	0	95.2%
Summer	2	148	4	96.1%
Late-run	0	2	12	85.7%
Overall	90.9%	98.0%	75.0%	95.2%

Table 5. Travel times and speeds for radio-tagged sockeye released above Crescent Island and detected in the Fraser Basin, 2005.

River Reach	Median Travel Time (d)	Travel Speed (km/d)	Sample Size (n)
Release - Crescent Isl.	0.19	-5.25	56
Release - Mission	0.65	15.30	376
Mission - Rosedale	1.41	31.13	307
Mission - Hope	2.49	32.07	312
Mission - Sawmill Cr.	3.62	31.51	271
Mission - Hell's Gate	4.18	30.12	256
Mission - Thompson Junction	5.81	31.15	232
Thompson Junction - Seton R. Junct.	1.67	34.05	198
Thompson Junction - Chilcotin R. Junct.	5.27	38.88	185
Thompson Junction - Quesnel R. Junct.	8.27	43.88	129

Table 6. Zone of last detection of sockeye, by run-timing group.

	Run-timing Group				
Last Detection Zone	Early Stuart	Early Summer	Summer-run	Late-run	Total
Release Site	2	1	5	0	8
Crescent Island	0	1	9	6	16
Mission	3	4	15	10	32
Harrison Confluence	0	0	0	10	10
Rosedale Bridge	4	5	22	1	32
Hope	2	7	21	2	32
Sawmill Creek Confluence	0	1	7	0	8
Hell's Gate	0	0	4	1	5
Thompson Confluence	1	4	5	1	11
Thompson / Nicola	0	1	0	6	7
Thompson / N. Thompson	0	1	0	1	2
Seton Confluence	1	5	24	2	32
Chilcotin Confluence	0	1	48	0	49
Williams Lake	0	0	1	0	1
Quesnel Confluence	0	0	10	0	10
Quesnel at Likely	0	0	28	0	28
Horsefly	0	0	54	0	54
Cottonwood Confluence	0	1	4	0	5
Nechako / Stuart	0	1	29	0	30
Upstream of Willow Confluence	0	3	0	0	3
FN Fishery - Below Mission	0	0	1	0	1
FN Fishery - Mission-Sawmill	0	1	14	0	15
FN Fishery - above Sawmill (not Chilcotin)	0	5	8	0	13
FN Fishery - Chilcotin	0	0	5	0	5
Sport Fishery	0	0	2	0	2
Total tagged	13	42	316	40	411

Table 7. Survival of Summer-run sockeye, after accounting for fishery removals, by Mission Passage period. The dates on which radio-tagged sockeye passed Mission were grouped into six weeklong "Mission passage periods".

	Mission Passage Period						
Last Detection Zone	one	two	three	four	five	six	Total
Crescent Island	0	1	0	0	1	0	2
Mission	2	3	3	2	2	3	15
Rosedale Bridge	1	1	5	4	7	4	22
Hope	1	5	5	7	0	3	21
Sawmill Creek Confluence	0	0	3	3	0	1	7
Hell's Gate	1	1	1	0	1	0	4
Thompson Confluence	1	0	2	0	1	1	5
Seton Confluence	3	4	5	5	2	5	24
Chilcotin Confluence	0	3	6	10	18	11	48
Williams Lake	0	0	0	0	0	1	1
Quesnel Confluence	0	1	0	2	3	4	10
Quesnel at Likely	0	0	1	9	8	10	28
Horsefly	0	2	4	14	24	10	54
Cottonwood Confluence	0	0	0	0	2	2	4
Nechako / Stuart	3	6	6	10	2	2	29
FN Fishery - Mission-Sawmill	4	3	4	2	1	0	14
FN Fishery - above Sawmill (not Chilcotin)	2	1	2	2	1	0	8
FN Fishery - Chilcotin	1	0	1	2	1	0	5
Sport Fishery	0	0	0	0	2	0	2
Totals							
Fish that Passed Mission	19.0	31.0	48.0	72.0	76.0	57.0	303.0
├Tagging related losses	6.0	5.7	1.5	4.0	7.8	6.5	31.5
└Effective tags	13.0	25.3	46.5	68.0	68.2	50.5	271.5
Estimated Fishery Removals							
Below Sawmill Creek *	2.0	4.3	14.5	8.0	4.2	1.5	34.5
Above Sawmill Creek *	1.7	2.1	6.7	2.8	1.6	0.6	15.5
Total Estimated Removals	3.7	6.5	21.2	10.8	5.7	2.1	50.0
Estimated Harvest rate	19.3%	20.8%	44.1%	15.1%	7.5%	3.7%	16.5%
Survival Estimation							
Remainder After Fishery	9.3	18.9	25.3	57.2	62.4	48.4	221.5
Survived to Spawning Area	3.0	11.0	16.0	41.0	49.0	34.0	154.0
Survival Rate	32.2%	58.3%	63.3%	71.7%	78.5%	70.2%	69.5%
Standard Error	11.0%	9.0%	7.0%	5.3%	4.7%	6.1%	2.6%

* Derived by applying daily river-reach-specific harvest rates to the escapement of tags into each reach.

Table 8. Stock-specific survival of Summer-run sockeye, after accounting for fishery removals, by Mission passage period .

	Mission Passage Period						
	one	two	three	four	five	six	Total
Parameters							
Tagging related loss rate	31.7%	18.3%	3.2%	5.5%	10.3%	11.3%	10.4%
Harvest Rate	19.3%	20.8%	44.1%	15.1%	7.5%	3.7%	16.5%
Chilko Stocks							
Tags past Mission	6.0	6.0	17.0	17.0	21.0	20.0	87.0
Tagging related losses	1.9	1.1	0.5	0.9	2.2	2.3	9.1
Estimated Fishery Removals	1.2	1.2	7.5	2.6	1.6	0.7	14.4
Remainder after fishery	2.9	3.7	9.0	13.5	17.3	17.0	63.6
Survived to spawning areas	0.0	3.0	5.0	8.0	15.0	11.0	42.0
Survival rate	0.0%	82.2%	55.9%	59.2%	86.9%	64.7%	66.0%
Standard error	0.0%	17.1%	12.4%	12.3%	7.5%	11.0%	5.1%
Horsefly							
Tags past Mission	3.0	4.0	9.0	24.0	37.0	19.0	96.0
Tagging related losses	1.0	0.7	0.3	1.3	3.8	2.2	10.0
Estimated Fishery Removals	0.6	0.8	4.0	3.6	2.8	0.7	15.8
Remainder after fishery	1.5	2.4	4.7	19.1	30.4	16.1	70.2
Survived to spawning areas	0.0	2.0	4.0	17.0	25.0	12.0	60.0
Survival rate	0.0%	82.2%	84.4%	89.2%	82.2%	74.4%	85.5%
Standard error	0.0%	22.1%	12.8%	6.5%	6.4%	10.3%	3.6%
Quesnel							
Tags past Mission	1.0	2.0	3.0	9.0	11.0	12.0	38.0
Tagging related losses	0.3	0.4	0.1	0.5	1.1	1.4	4.0
Estimated Fishery Removals	0.2	0.4	1.3	1.4	0.8	0.4	6.3
Remainder after fishery	0.5	1.2	1.6	7.1	9.0	10.2	27.8
Survived to spawning areas	0.0	0.0	1.0	6.0	7.0	8.0	22.0
Survival rate	0.0%	0.0%	63.3%	83.9%	77.5%	78.4%	79.2%
Standard error	0.0%	0.0%	34.1%	13.0%	13.2%	12.4%	6.7%
Stellako & Stuart							
Tags past Mission	9.0	19.0	19.0	22.0	7.0	6.0	82.0
Tagging related losses	2.9	3.5	0.6	1.2	0.7	0.7	8.5
Estimated Fishery Removals	1.7	4.0	8.4	3.3	0.5	0.2	13.5
Remainder after fishery	4.4	11.6	10.0	17.5	5.8	5.1	60.0
Survived to spawning areas	3.0	6.0	6.0	10.0	2.0	3.0	30.0
Survival rate	68.0%	51.9%	60.0%	57.2%	34.8%	58.8%	50.0%
Standard error	16.5%	11.8%	11.5%	10.8%	19.4%	22.0%	5.6%

Table 9. Reported and estimated fishery harvest during the study period, by Mission Passage Period. Estimates of the tags caught in fisheries were derived using daily harvest rate estimates for each fishery (see Appendix C).

	Expansion Factors			Mission-Sawmill Fishery			Above Sawmill			Reported Catch			Catch (based on HR Est.)		
Tagging Period	Mission Abundance	Effective Tags per Period	Fish per Tag	Tags Returned	Est. Tags Caught	Return Rate	Tags Returned	Est. Tags Caught	Return Rate	Mission to Sawmill	Above Sawmill	Total	Mission to Sawmill	Above Sawmill	Total
One	157,497	13.0	12,143	4.0	2.0	203.0%	3.0	1.7	177.5%	14,161	14,544	28,705	15,103	20,474	35,577
Two	206,063	25.3	8,140	3.0	4.3	69.5%	1.0	2.1	46.8%	24,706	20,516	45,222	24,997	20,838	45,836
Three	146,936	46.5	3,163	4.0	14.5	27.7%	3.0	6.7	44.6%	39,674	26,807	66,481	40,940	20,916	61,856
Four	1,375,649	68.0	20,221	2.0	8.0	24.9%	4.0	2.8	142.5%	107,251	34,564	141,816	103,789	40,999	144,789
Five	1,150,507	68.2	16,878	3.0	4.2	72.0%	2.0	1.6	128.0%	77,568	30,720	108,288	74,091	25,333	99,424
Six	479,193	50.5	9,481	0.0	1.5	0.0%	0.0	0.6	0.0%	19,719	13,869	33,588	18,343	5,751	24,095
Sub-total	3,515,844	271.5	12,951	16.0	34.5	46.4%	13.0	15.5	83.8%	283,079	141,021	424,100	277,264	134,312	411,576
Outside Tagging Period															
Before	49,346									4,358	997	5,354	4,761	3,818	8,579
After	774,500									0	4,925	4,925	0	6,859	6,859
Sub-total	823,846									4,358	5,922	10,280	4,761	10,677	15,438
Total	4,339,690									287,437	146,943	434,380	282,025	144,989	427,013

Table 10. Summer-run sockeye harvests by period and extrapolation of radio-telemetry results to estimate Summer-run spawning numbers and en-route losses for fish that past Mission both during and outside the tagging period. Survival rates for fish that past Mission before and after the tagging period were assumed to be equal to those for period one and six, respectively.

	Pre-	Mission Passage Periods						Post-		% during
	tagging	one	two	three	four	five	six	tagging	Total	Tagging
Mission Abundance	49,346	157,497	206,063	146,936	1,375,649	1,150,507	479,193	774,500	4,339,690	81.0%
Effective tags at Mission	na	13.0	25.3	46.5	68.0	68.2	50.5	na	271.5	100.0%
Fish per Tag	na	12,143	8,140	3,163	20,221	16,878	9,481	na	15,985	
Reported catch	5,354	28,705	45,222	66,481	141,816	108,288	33,588	4,925	434,380	97.6%
Remaining after catch	43,992	128,791	160,841	80,455	1,233,834	1,042,219	445,604	769,574	3,905,310	79.2%
Percent Harvest	10.9%	18.2%	21.9%	45.2%	10.3%	9.4%	7.0%	0.6%		
Percent Surv after Harvest	32.2%	32.2%	58.3%	63.3%	71.7%	78.5%	70.2%	70.2%	70.6%	
Total estimates										
Harvest	5,354	28,705	45,222	66,481	141,816	108,288	33,588	4,925	434,380	97.6%
Spawning	14,175	41,500	93,792	50,929	884,498	817,925	312,973	540,516	2,756,308	79.9%
En-route Losses	29,817	87,292	67,049	29,525	349,336	224,294	132,631	229,058	1,149,002	77.5%
Spawning Confidence bounds (based on binomial error around survival estimate)										
Lower bound	4,678	13,694	65,414	39,843	755,198	720,988	259,610	448,356	2,307,782	
Upper bound	23,673	69,305	122,169	62,016	1,013,797	914,862	366,336	632,675	3,204,834	
En-route Loss Confidence bounds (based on lower and upper spawning bounds)										
Lower bound	20,319	59,486	38,672	18,439	220,037	127,357	79,268	136,899	700,476	
Upper bound	39,314	115,097	95,427	40,611	478,636	321,232	185,994	321,218	1,597,528	

FIGURES

Figure 1. Location of release sites, fixed-station sites, mobile tracking areas and tag recovery areas for the 2005 sockeye radio-telemetry study.

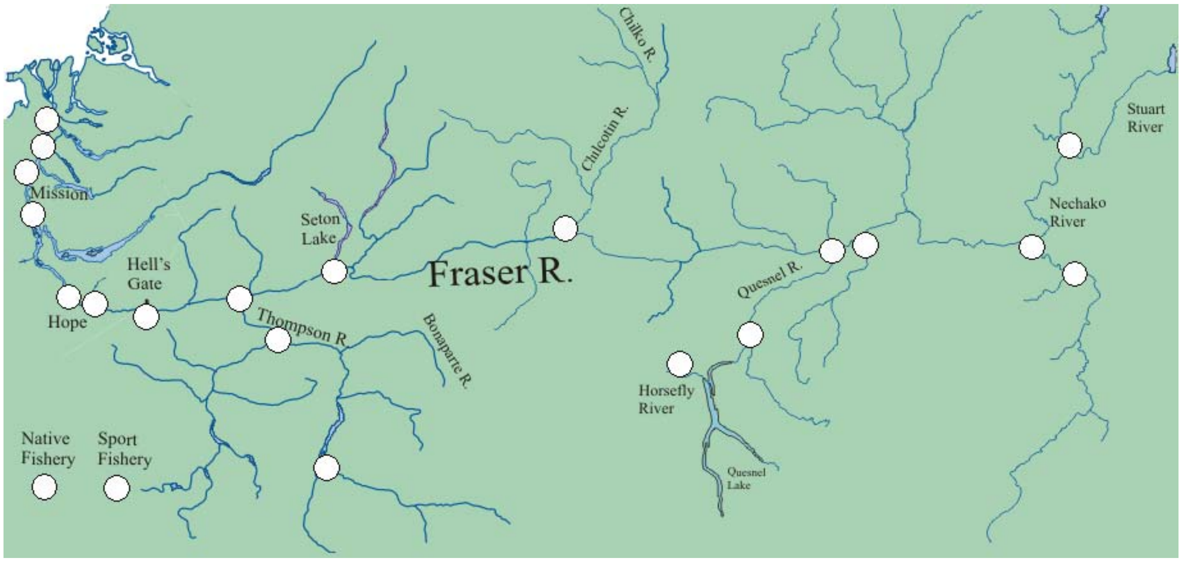


Figure 2. Pre-season run-timing curves for Fraser sockeye stock groups based on average historical timing and the 2005 abundance forecasts. Tag days are shown as black squares.

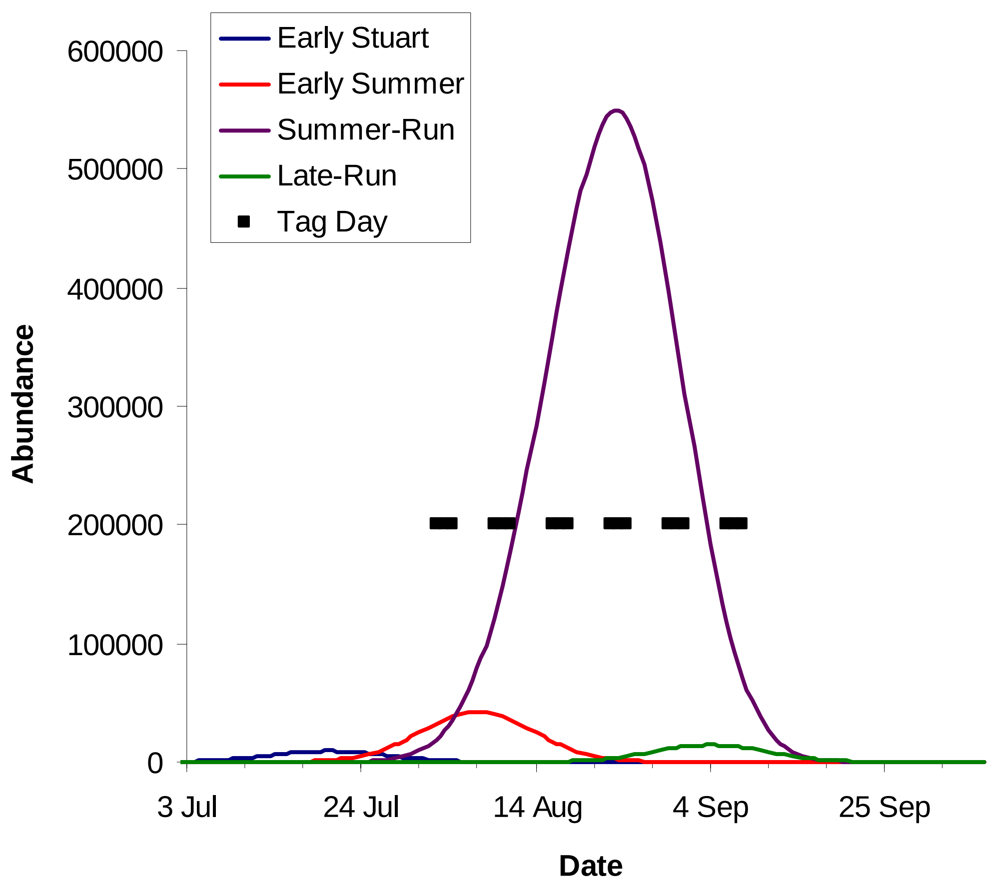


Figure 3. Performance of tangle nets for sockeye fishing near Crescent Island in 2005. Average soak times (in minutes) are plotted on the left vertical axis, and all other metrics are plotted on the right vertical axis. Number of fishing sets and total sockeye catch are summed within each three-day tagging period. Soak times are averaged. Catch per hour is weighted.

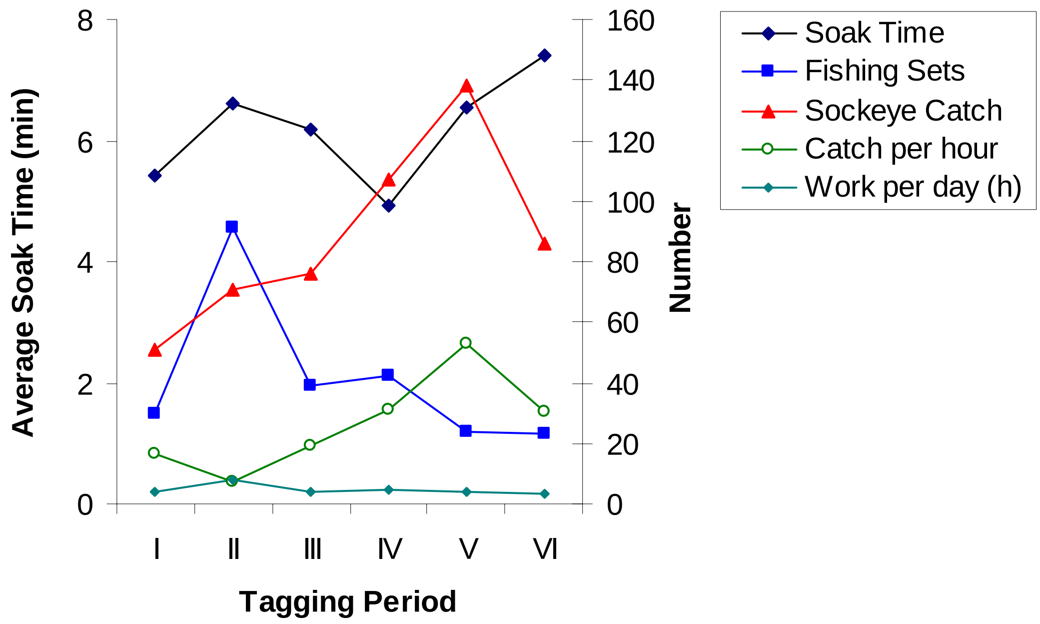


Figure 4. Daily abundance of sockeye passing Mission (black line, as estimated from hydroacoustic sampling) and the number sockeye from each run-timing group that was radio-tagged during the 6 tagging periods at Crescent Island in 2005.

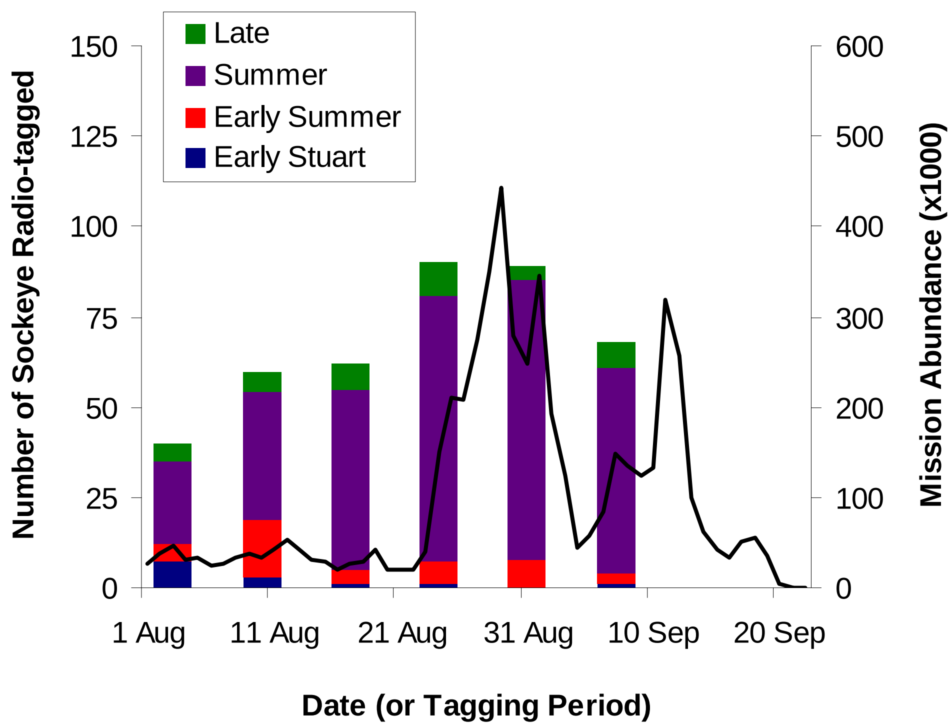


Figure 5. **Number and proportion of Summer-run sockeye that was radio-tagged during the 6tagging periods at Crescent Island in 2005.**

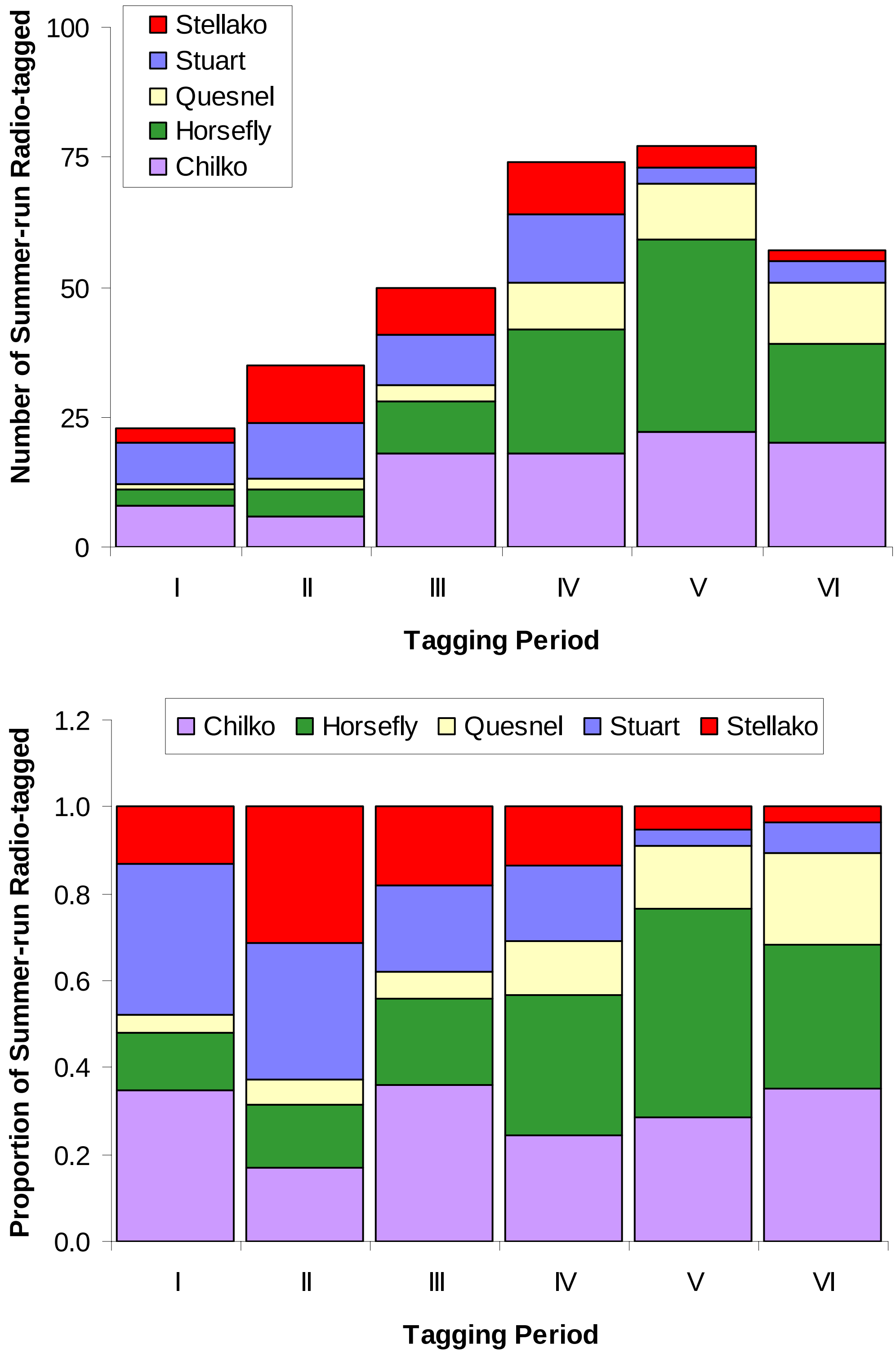


Figure 6. Effect of physiological sampling on the migratory abilities of sockeye tagged during six tagging periods in 2005. Sockeye were radio-tagged near Crescent Island from 2 Aug to 8 Sept, 2005. In addition to being radio-tagged, some fish underwent additional physiological procedures.

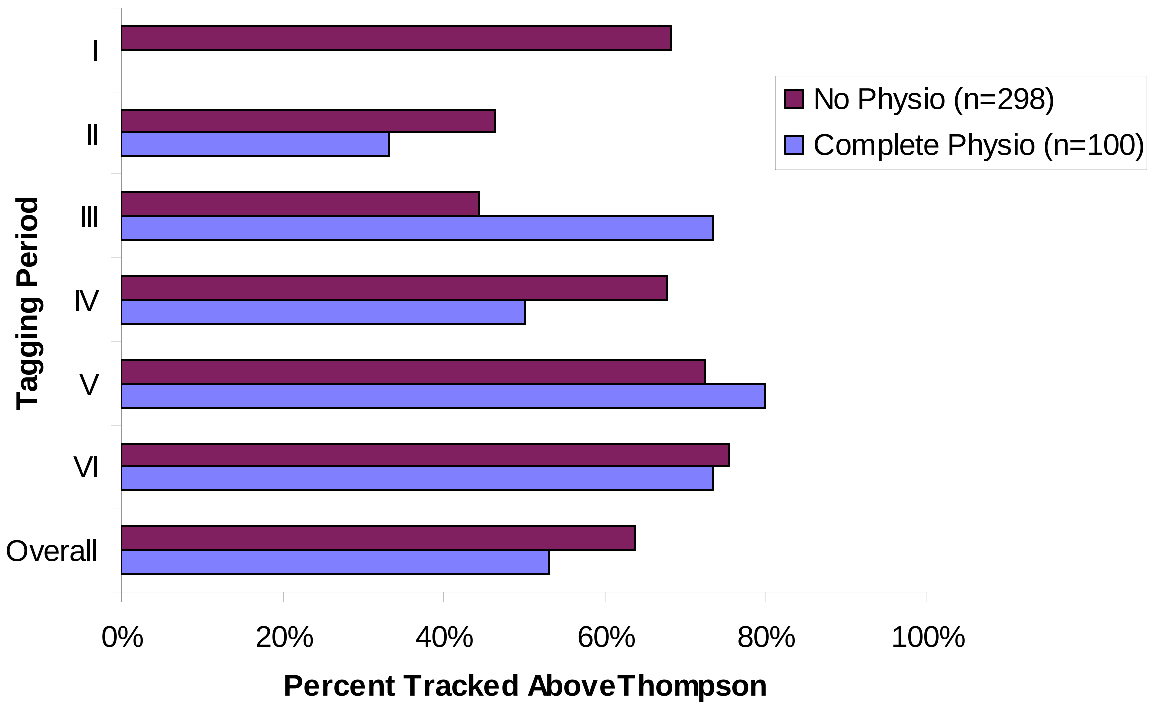


Figure 7. Travel times from Mission to several Fraser River destinations for radio-tagged Summer-run sockeye tagged during six separate tagging periods in 2005.

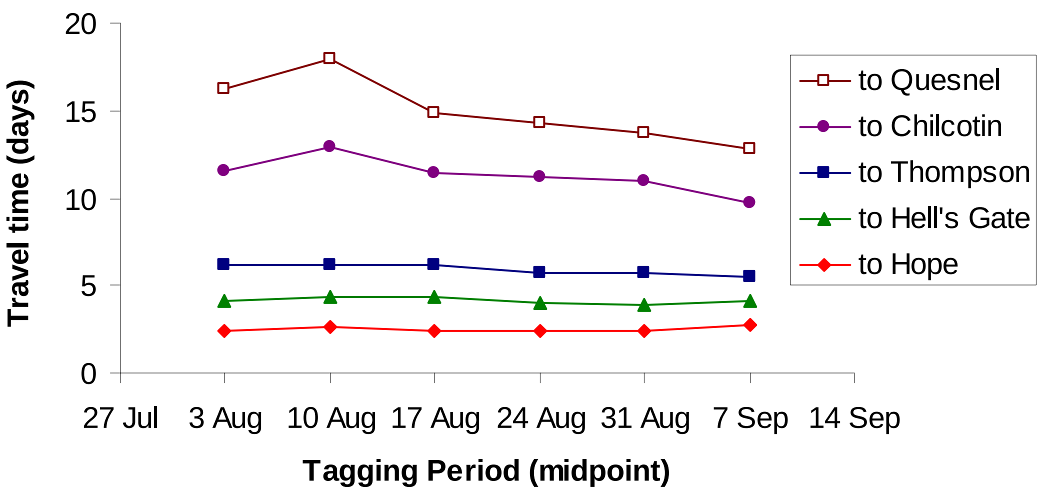


Figure 8. **Migration speeds from Mission to several Fraser River destinations for radio-tagged sockeye of several different run-timing groups tagged in 2005. Error bars typically represent 95% confidence in the median value (generated using the method recommended in Zar, 1984), but for Early-summer stocks upstream of Thompson, sample sizes were low (n=6) and the bars show the complete range of observed values. Note that statistical comparisons (see text) were done using non-parametric Kruskal Wallis tests, and that overlapping error bars do not preclude statistical significance.**

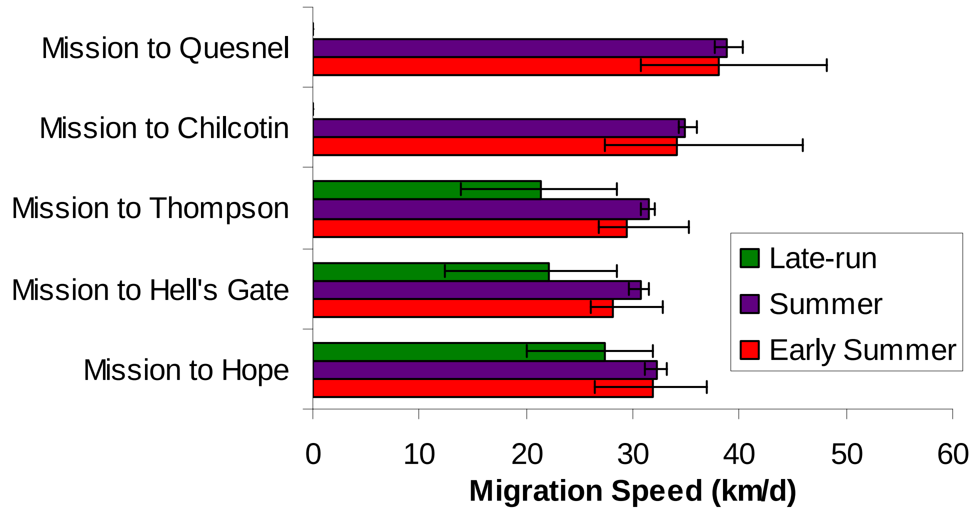


Figure 9. **Migration speeds within several major Fraser River reaches for radio-tagged Summer-run sockeye, by stock. Error bars typically represent 95% confidence in the median value (generated using the method recommended in Zar, 1984), but for Stuart stocks upstream of Thompson, sample sizes were low (n=6) and the bars show the complete range of observed values. Note that statistical comparisons (see text) were done using non-parametric Kruskal Wallis tests, and that overlapping error bars do not preclude statistical significance.**

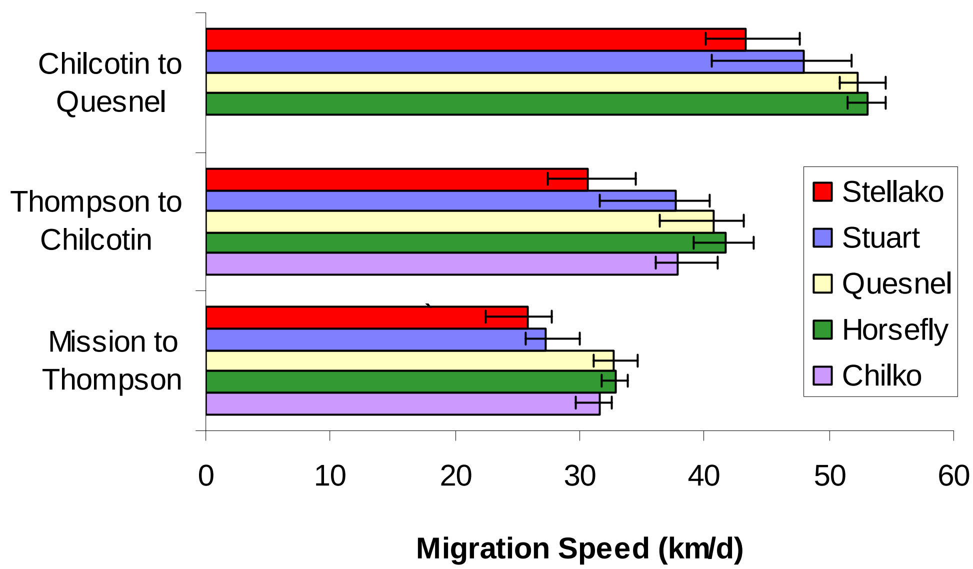


Figure 10. Migration speeds within several major Fraser River reaches for radio-tagged Summer-run sockeye, by stock and by tagging period. Sample sizes are too low to generate meaningful error bars or to test for statistical significance.

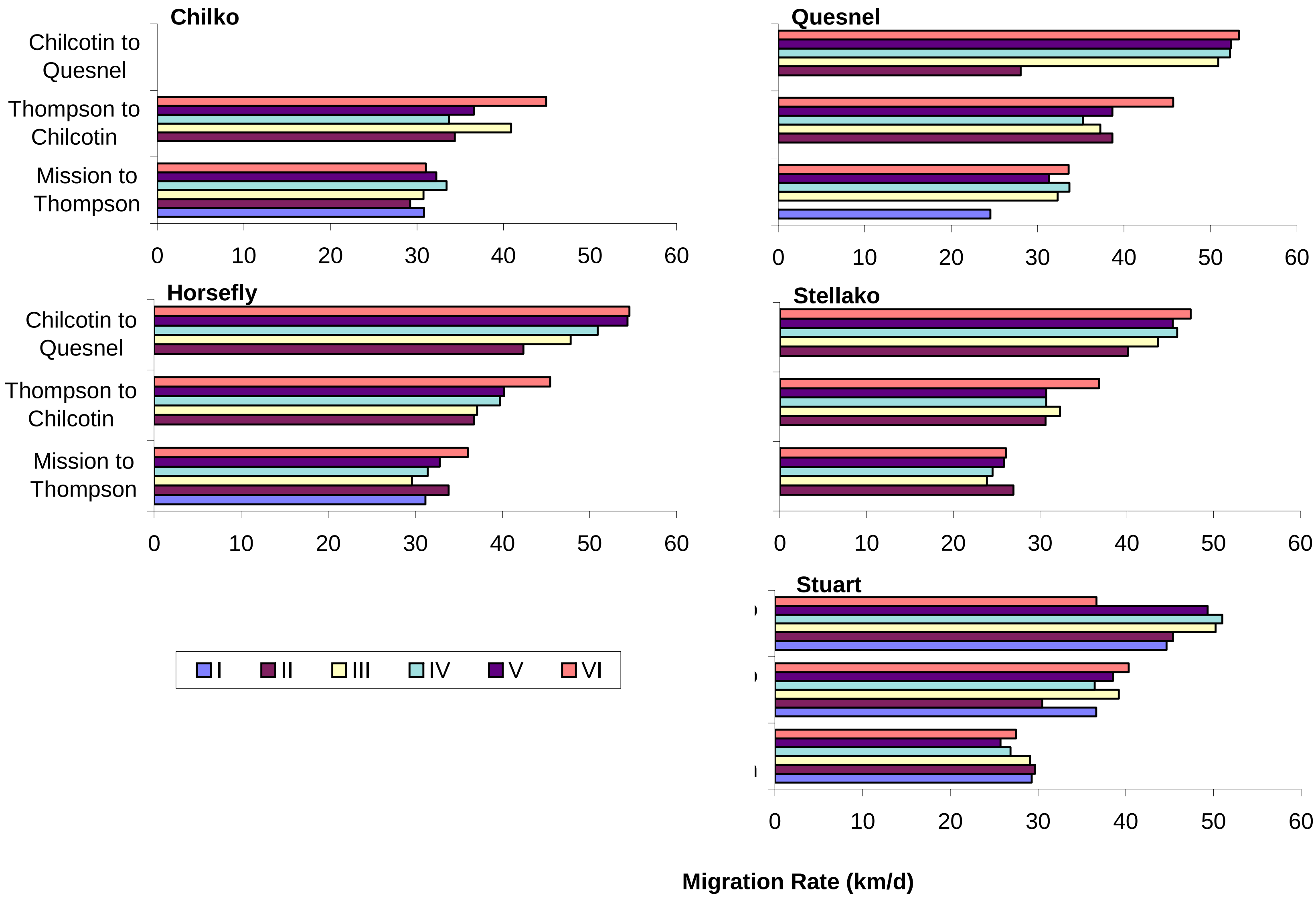


Figure 11. Summer-run survival rates by tagging period. Survival estimates are the proportion of fish that are tracked to spawning areas (after accounting for fishery removals). Error bars represent 95% confidence where standard errors follow the binomial distribution.

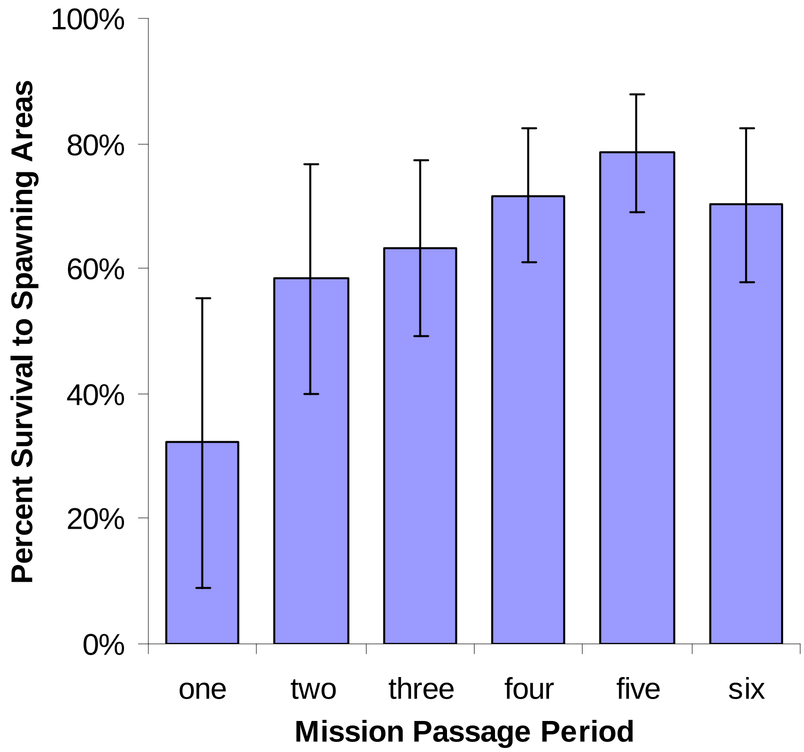


Figure 12. Reach-specific survival rates for fish that dropped back to Crescent Island after tagging versus those that were first detected at Mission. Drop-back fish subsequently re-ascended past Mission. Reach-specific survival rates were calculated as the proportion of fish passing the downstream reach boundary that subsequently passed the upstream reach boundary.

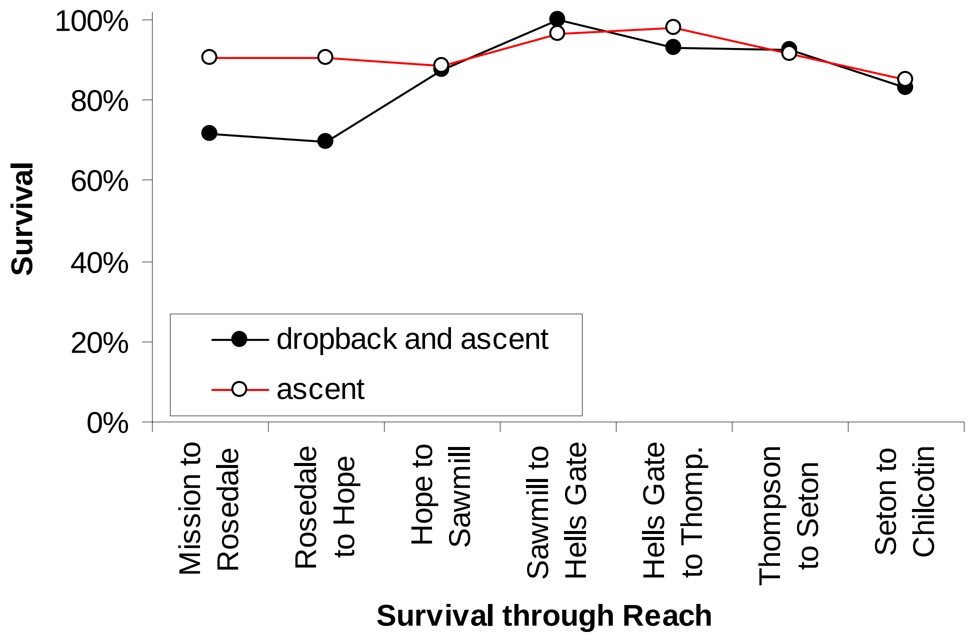


Figure 13. Stock-specific survival rates for Summer-run sockeye. Survival estimates are the proportion of fish that are tracked to spawning areas (after accounting for fishery removals). Error bars represent 95% confidence where standard errors follow the binomial distribution.

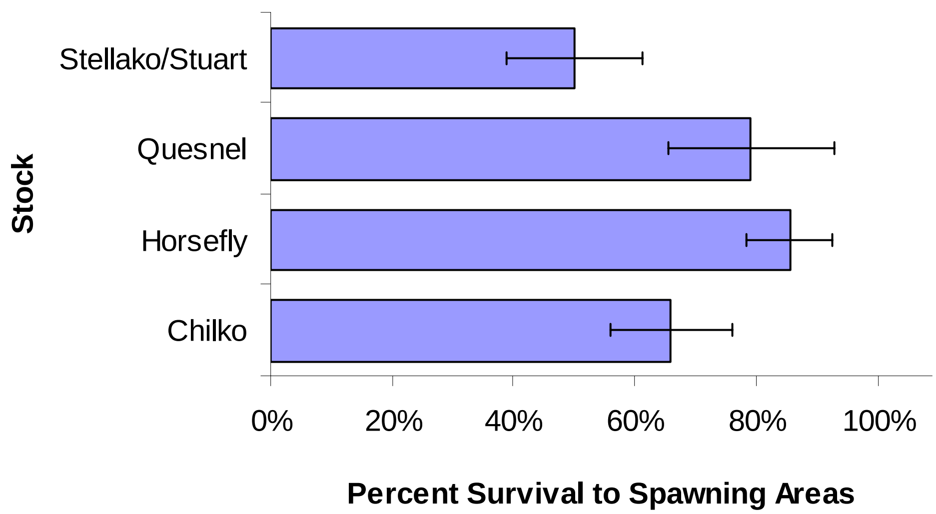


Figure 14. **Date of last detection of Summer-run sockeye that were lost en-route to spawning grounds (downstream of Sawmill). Sockeye that were known fishery recoveries, those that dropped back downstream are shown separately from those that were last detected between Mission and Sawmill. Also shown: fishery sockeye catch between Mission and Sawmill.**

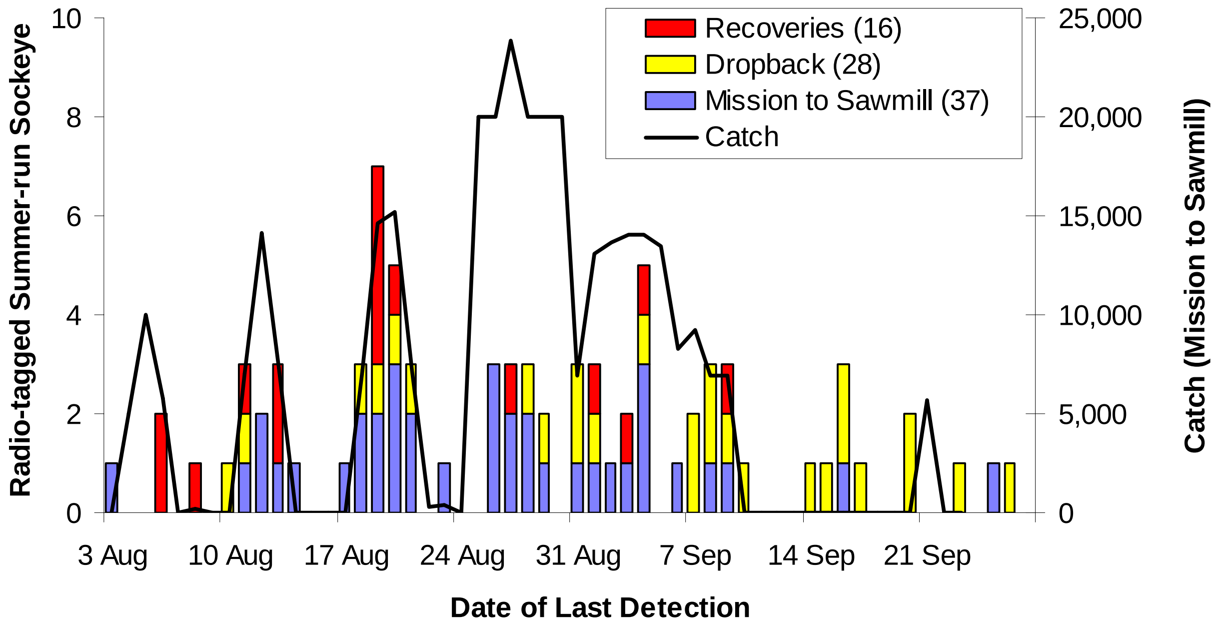


Figure 15. **Date of last detection of Summer-run sockeye that were last detected in the main fishing areas (i.e., between Mission and Sawmill), and the fishery catch of sockeye between Mission and Sawmill.**

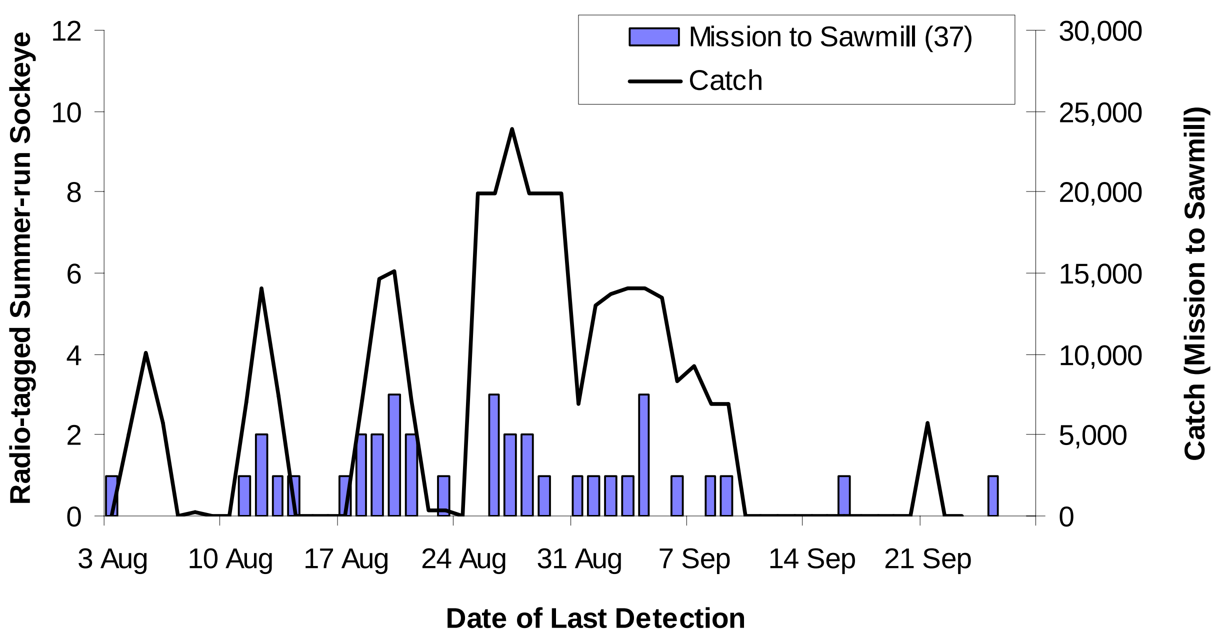


Figure 16. **Travel times for 29 Summer-run sockeye last detected at the Thompson or Seton detection zones. The shaded area delimits the 95th percentile travel times for 154 sockeye that successfully migrated to stock-specific spawning areas; and the central line shows the median. Of the fish that vanished in the Thompson/Seton area, 79% (open squares) were moving upriver at the same rate as their surviving counterparts.**

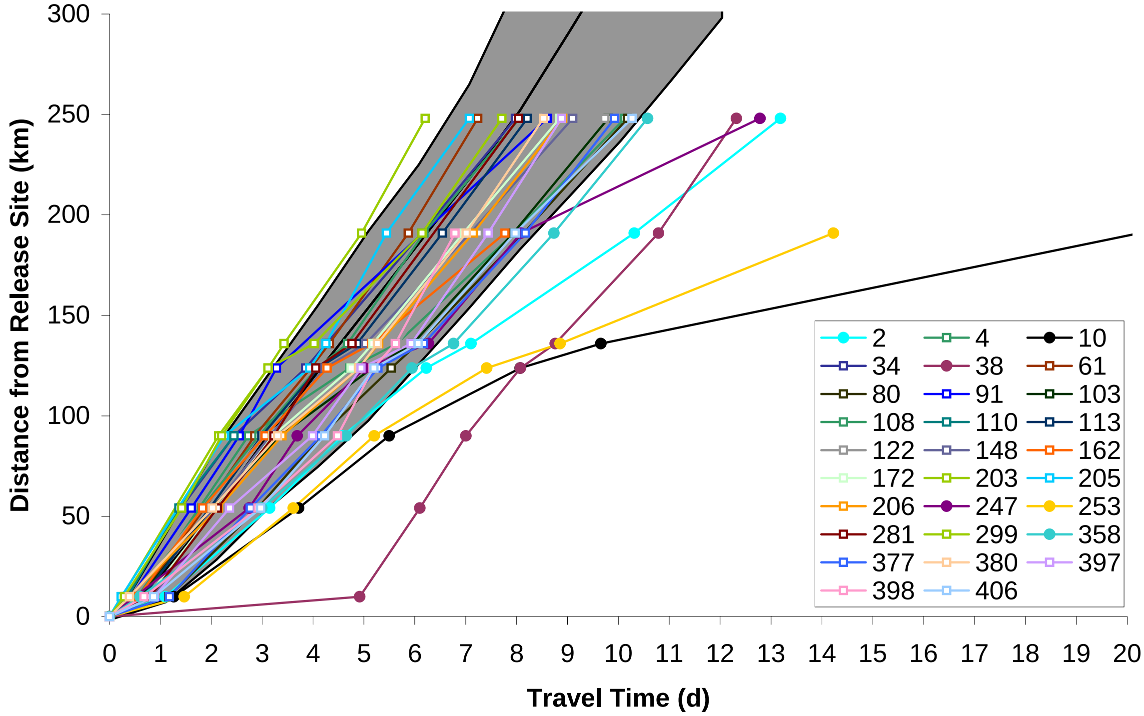
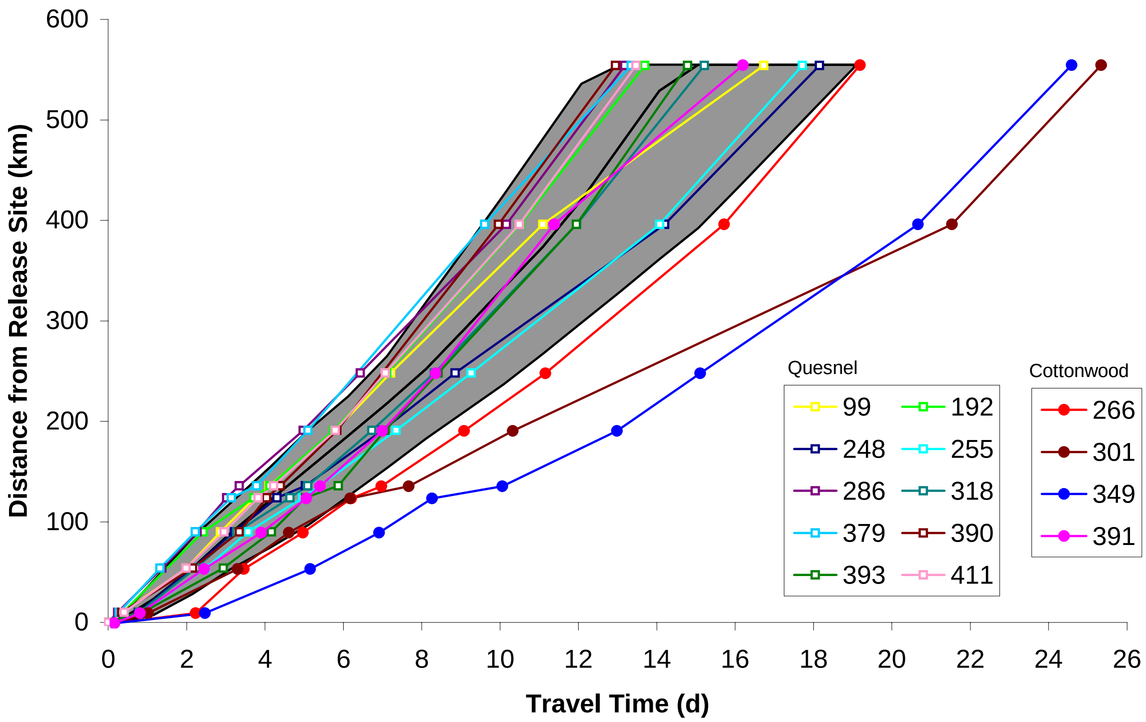


Figure 17. Travel times for 10 Summer-run sockeye last detected at the Quesnel (open squares) and 4 last at Cottonwood (closed circles) detection zones. The shaded area delimits the 95th percentile travel times for 154 sockeye that successfully migrated to stock-specific spawning areas; and the central line shows the median. Three of the four fish that were last detected at the Cottonwood junction traveled unusually slowly.



APPENDICIES

APPENDIX A

Fixed station Receiver Locations and Performance

APPENDIX REPORT A

Description of fixed station sites

Nineteen fixed station receivers were set-up at 18 sites in 2005 to monitor radio-tagged sockeye moving up the Fraser River (Figure 1; Appendix Table A1). With the exception of the Horsefly River and Agassiz bridge sites, all fixed stations along the Fraser River were tested and operational before radio-tagged sockeye were released.

Fixed stations usually had two to three directional antennas (usually "Yagi" models) secured to a tree stem or to an aluminum pole >10 m above ground, a peripheral unit to switch between antennas, a Lotek model SRX_400 receiver, a 12 V deep cycle battery to power it, a waterproof metal enclosure to house the receiver, and a co axial cable joining the antennas to the switcher unit. Several stations had solar panels and a voltage regulator to keep the batteries charged. Three sites (Mission South; Quesnel at Likely; and Hell's Gate) were powered by an AC source. Koski et al. (1996) described the operations of the antenna-switching units and the antenna orientations used to determine presence and movement of radio-tagged fish. Maintenance of the receiver sites included checking the 12 V battery power levels, and downloading data from the receiver using a portable laptop computer.

Differentiation of directionality was tested when the stations were set up. Following the basic setup procedure (antennas raised, cables connected to the receiver, etc.), an active radio tag was attached to a weighted rope, and lowered to a depth of 5-10 m in the river. Signal reception and signal strength of the radio tags were tested at different positions and depths. Typically, testing was conducted in the center channel from a position starting 500-700 m upstream of the station to a point approximately 500-700 m downstream of the station. Gain settings (described below) refer to the power of the antenna, the higher the gain the farther away a tag could be detected. Optimal gains were those that maximized detection distance while preventing background noise from interfering with tag detection.

Receiver stations along the mainstem of the Fraser River (not at a tributary junction) had two antennas to detect signals from upstream and downstream locations. Stations at the confluence of a tributary had three antennas to distinguish between signals emanating from the mainstem (up and downstream) and from within the tributary. Station setup and antenna position were identical in the stations used in 2002 and 2003 (English et al. 2003, 2004) unless otherwise noted.

Driving directions, receiver settings and operational details.

Crescent Island: The Crescent island receiver site was located directly across from the Fraser-Stave confluence (rkm 66), approximately 3 km downstream from the release site . To access the site, travel by boat approximately 13 km downstream from the Mission launch. The site was located in a large cottonwood tree at the downstream end of the island. Four antennas were mounted 20 m up the tree, and scanned upstream and downstream on either side of the island. The site was tested by drifting the tag at 2 m depth from 500 m upstream of the station to 500 m downstream of the station. The test involved three transects including ¼, ½, and ¾ of the channel widths. Results indicated that at a gain of 85, the tag was easily detected on all transects. There was some sporadic coding of noise from industry located on the North bank.

Mission North: Traveling west on the highway from Mission to Harrison, take the first driveway to the right downstream of the Tourist Information Booth. This leads to the BC Frozen Foods parking lot and factory. Park at the end of the lot closest to the road, and head up the trail crossing the railway track down to the river bank. The receiver was located upstream of the pathway. Two antennas were mounted 20 m above the water in a large cottonwood tree. The first antenna scanned downstream, and the other upstream.

This site was tested by placing at 2 m depth, and drifting from 500 m upstream of the station to 500 m downstream of the station. The test involved three transects including ¼, ½, and ¾ of the channel widths. Results indicated that at a gain of 75, the tag was easily detected on all transects. This station was located directly in front of frequent train traffic and occasional boat traffic, which was an issue of concern. Before this study, a noise analysis of background interference was done at this station, and it was determined that 75 was the optimal gain.

Mission South: Traveling north on the Mission Abbotsford Highway, turn right on Harris Road, just before the Mission Bridge. Then left on Bell Road, then left on Page Road, and right on Sim Road. Head down to Kelleher Road and turn left. The test fishery site is at the end of this road on the left, and the cottonwood tree is straight in front of you. Setup consisted of two antennas mounted about 10 m above water. One antenna scanned downstream, and the other scanned upstream. The battery charger at this station was powered from the AC voltage source at the acoustic site.

This station was tested in the same manner as Mission North, with similar results in that the tag was detected easily at ¼, ½, and ¾ of the channel widths at a 2 m depth. Background noise from boat traffic was a slight concern at this site, but this station was able to operate efficiently at a relatively high gain (75) throughout the study with no major problems.

Rosedale Bridge: Traveling north on Hwy #9 (Agassiz Highway), take the first right after crossing the Rosedale – Agassiz Bridge. The road winds underneath the bridge, park just beyond the intersection with the overhead bridge. Two antennas were mounted about 13 m above water. The first scanned downstream, and the second scanned upstream.

This station was tested in a similar manner to the Mission sites. The tag was placed at 2 m depth and drifted at ½ and ¾ of the channel width on the Fraser mainstem. Results indicated adequate detections and good separation between Fraser and Harrison antennas. Detections of fish traveling near the south bank may have been difficult due to the great distance from the antennas (2 km). Background noise from motors of fishing boats may have also made detection of tags difficult, and may have compromised the efficiency of the station slightly.

Hope: From Chilliwack, head east on Highway 1. Take exit 165, turn left over the highway and proceed east on Frontage Road past the Husky Station. Continue to the next intersection with Highway 1. Valley Helicopters is on the left. Turn left just past Valley Helicopters and continue on across the railroad tracks. At the fork, turn right. The access road to the station site is a small dirt/gravel trail between the trees just before the first building on the right. Follow the trail out to the bank above the river. There were two antennas mounted about 20 m above water in a spruce tree. The first antenna scanned downstream, and the second scanned upstream.

This station was tested by placing the tag at 2 m depth, and drifting from 500 m upstream of the station to 500 m downstream of the station. Results indicated strong detections and good separation between the downstream and upstream antennas. There were no background noise issues at this site, and the receiver performed efficiently at a gain of 75, throughout the study.

Sawmill Creek: From Yale, head north for approximately 6 km and park on the first pull out on the right after crossing over the Sawmill Creek Bridge. There is a small path leading down to the train tracks, cross over the tracks and follow a wide trail for 100 m upstream. Two antennas were mounted approximately 5 m up a large spruce tree, which was situated on a cliff, 30 m above the water.

This site was not tested due to remote and difficult access. Given the optimal height of the antennas and narrowness of the channel, the station performed very efficiently. There was some noise generated by passing trains that may have hampered detection efficiency slightly.

Hell's Gate: Take the Tramway down to the lower tourist area. There are two sets of antennas at this site. The downstream array, which monitored downstream of Hell's Gate consisted of two antennas on a cliff about 25 m above water, directly under the walkway of the north bank. The antennas from the lower area were amplified, and the coax cable was linked to the upper site. To get to the upper site, you need several keys to get to the receiver, take the boardwalk to the left, go right through the locked gate at the north end of the suspension bridge and follow the road to the building the farthest upstream and along the river. The receiver is in an old garage on a table at the back. There were two antennas, combined on a 5 m conduit, positioned about 25 m above water, upstream of the garage used to monitor the upstream passage at Hell's Gate.

Testing of this site was performed by lowering a tag from the start of the left bank fishway to a depth of 2 m, which placed the tag slightly upstream of the downstream antennas. Results of the testing of the downstream array indicated good detection. To test the upstream array, a tag was placed at a 2 m depth off the edge of the upstream portion of the left bank fish ladder. The upstream array also showed good detection of the tag. There was also good separation between antenna detections, as the tag was detected very weakly by the downstream antenna and strongly by the upstream antenna when the tag was placed upstream and vice versa.

Fraser-Thompson Confluence: Once in Lytton, head north towards Lilloett across the Thompson. About 2 km down that road, take the ferry to cross the Fraser. Then travel up the road and take the first main road to the left. Head south down the Fraser for about 2 km until you are across from the mouth of the Thompson River. The station is on your left, about 100 m from the road. The 3 antennas were visible from the road, mounted about 10 m up a large spruce tree. The tree was on a steep bank, on the far side of the meadow, about 20 m above water. The first antenna scanned downstream, the second scanned the Thompson River, and the third scanned upstream. The GPS coordinates for this site are (50.23202° N; 121.58930° W).

To test this site we placed the tag at a depth of 2 m about 100 m upstream in the Thompson mainstem and 200 m upstream from the confluence in the Fraser mainstem. The antennas were re-oriented in 2005 to improve tag position detection between the Fraser and Thompson systems. Results showed good separation between antennas with stronger detection for the Thompson antenna when the tag was placed in the Thompson mainstem and weaker detection for the Thompson antenna when placed upstream in the Fraser mainstem. The same was true for the Fraser upstream antenna, the signal was much weaker when placed in the Thompson compared to the Fraser placement. The downstream Fraser antenna recorded the tag as well, but the signal was weaker than for the Thompson and upstream Fraser antenna for both placements. There were no apparent noise problems at this station and the receiver worked efficiently at a gain of 75.

Thompson-Nicola Confluence: Travel north from Spence's Bridge until you reach a pullout on the right about 1 km out of town. Directly across the river is the mouth of the Nicola River, and the train bridge. Park inside the pullout and look over the bank. There were three antennas mounted about 6 m up a cottonwood tree on the cliff about 20 m above water. The first antenna scanned the downstream section of the Thompson River, the second scanned the Nicola River, and the third scanned the upstream section of Thompson.

Because this station was implemented when tagged fish were already traveling through the system, the testing involved visual observation of fish passing the station and adjustment of gain to maximize detection. It was not necessary to have clear distinction between the Thompson and Nicola antennas, since the main objective was to determine if tagged fish passed the station. Because of high background noise levels, the gain had to be lowered to 60 to detect tags efficiently. At this gain, visual inspection suggested that all antennas were coding tags effectively.

Thompson-North Thompson Confluence: From Highway 1 east in Kamloops, take the Columbia Street exit and turn onto Summit Drive. Follow this road down the hill, then take the exit for the north shore, and turn right onto Tranquille Road, which turns into 8th Street. Turn right on Westsyde, then right onto Walkem, and at the end of the road park beside the last house on the left. Walk through the gate on the side of the house. The antennas were mounted about 10 m up a large cottonwood tree in the back yard, with a box mounted on the back of the fence. The first antenna scanned the confluence of the North Thompson, and the second scanned upstream in the North Thompson.

Testing of this station involved walking the tag along the bank approximately 200 m downstream and 50 m upstream and placing at a depth of 2 m. Results indicated good detections on both antennas. This station was initially problematic because of the proximity to the train tracks generated a lot of noise on channel 1. To overcome this noise problem and still be able to code tags on channel 1, the gain had to be lowered to 63. A tag test using a channel 1 tag revealed that the tag was only masked occasionally by background noise on this channel. Despite this small problem, this station operated very efficiently.

Fraser-Seton Confluence: Take the road into Lillooet and turn left instead of turning right into town. Take the first left after crossing a single lane bridge. There is a white house on the left that has a fence around the property. The landowner would prefer that you park there and walk down to the station rather than going through the gate, which is just after the bridge. The station was located at the confluence of the Seton on the south side of the Fraser River. To prevent the horses from chewing on the cable, the box and solar panel were mounted about 8 ft off the ground in a tree. Three antennas were mounted approximately 10 m a large cottonwood tree. Antenna one scanned downstream on the Fraser, antenna two scanned upstream in the Seton, and antenna three scanned upstream in the Fraser River.

Testing of this station involved walking the tag along the bank approximately 200 m downstream and 50 m upstream and placing at a depth of 2 m. All three antennas tested well with good power levels and good separation between antennas.

Fraser-Chilcotin Confluence: From Williams Lake, head west on Highway 20 (toward Alexis Creek, Bella Coola). Cross the Fraser River ("Sheep Creek Bridge"), drive past the Toosey IR, and turn left (south) on the "Big Creek - 2000 Road". There are signs to the Junction Wildlife Area. Drive south past the entrance to Junction, proceed down the switchbacks, and cross the

Chilcotin River (this is "Farwell Canyon"). Proceed up the hill on the south side of the canyon. Turn left at 27 ¾ km, the road is narrow with several shallow mud puddles. Stay left on this road at all major intersections, and stay on the well used path. It is the lowest elevation road paralleling the south side of the Chilcotin River on the main ridge. There are other roads above this one with similar directions, but this is the only one that goes to the Fraser River. Travel on this road for 14 km until you reach a T-junction. Turn left through the gate onto Ward Ranch. Keep left, and go downhill. The road is rough, and there is one place where a spring cuts across the road, and the banks are yellow-gold. You will reach a grassy flat with an old log cabin on the left. Drive past the cabin 200 m and turn left (downhill). This area is about 2 km from the river. Park in the wide area on the right side of a curve about half way down. Walk down to the flat in front of the Chilcotin-Fraser confluence. The station was in the last line of trees downstream of the Chilcotin. The station box was on one tree, and the solar panel was to the right. Three antennas were mounted in a large spruce tree, about 20 m above water. The first antenna scanned the downstream section of the Fraser mainstem, the second scanned the Chilcotin River, and the third scanned the upstream section of the Fraser.

Testing involved placement of the tag in 1 m of water about 200 m downstream on the Fraser mainstem and 200 m upstream in the Chilcotin mainstem (further access was not possible). Tag detections were good for the downstream Fraser antenna, weak for the Chilcotin antenna and weak for the upstream Fraser antenna when the tag was placed downstream in the Fraser mainstem. Similarly, detections for the Chilcotin antenna were strong, while the Fraser antennas were weak when the tag was placed in the Chilcotin mainstem, which was expected. Since there was no background noise at this station, this station could be operated at a very high gain (80), and the system ran very efficiently.

Fraser-Quesnel Confluence: Head north on the main highway into Quesnel. When coming down a hill before crossing the Quesnel River, take the exit to the McDonalds, and travel south on Johnston Avenue. Travel through the roundabout, turn right on Carrie Street, and cross the railroad tracks. The station is on the right in the third big cottonwood tree. Three antennas were mounted about 10 m up a large cottonwood tree, some 15 m above water. The first antenna scanned the downstream section of the Fraser River mainstem, the second scanned the Quesnel River, and the third scanned upstream in the Fraser.

Testing involved placement of the tag at a 2 m depth about 100 m upstream, downstream and in front of the station. Results indicated good tag detection for all antennas with the expected separation related to tag position. This station was also very quiet and ran efficiently at a gain of 75 for all antennas with no problems from background noise.

Quesnel at Likely: From Horsefly River town site, travel approximately 55 km northwest on the main paved Horsefly – Likely road. Approximately 2 km before reaching Likely, there is a turn off to the left for the UNBC research facility. Follow the dirt road down for 1 km to the hatchery facility. Two antennas were mounted (2m ht) in a small spruce tree located at the downstream edge of the property. The first antenna scanned downstream in the Quesnel River and the second scanned upstream.

To test this site, a tag was placed at a 1 m depth, 20 m upstream and downstream of the site. Results indicated good detection on both antennas with the expected separation between antennas.

Horsefly River: From Horsefly River town site, travel approximately 30 km north on the Horsefly – Likely crossover road. There is a small road to the right with a wooden gate on it. From here, follow the path through the meadow to the river and the station was set up approximately 500 m downstream on the observation tower. Two antennas were mounted on the metal tower about 6 m above water. The first antenna scanned downstream in the Horsefly River and the second scanned upstream.

To test this site, a tag was placed at a 1 m depth, 100 m upstream and downstream of the site. Results indicated good detection on both antennas with the expected separation between antennas. There were some problems at this site with the data banks loading up when fish were in proximity of the tower, this was corrected by lowering the gain on the receiver.

Fraser-Nechako Confluence: This site was located at the mouth of the Nechako River at the Spruce City Wildlife Hatchery in Prince George. Three antennas were mounted approximately 5 m above the water to a large aluminum pole on the side of the building. The first antenna scanned downstream in the Fraser River, the second scanned upstream in the Nechako River, and the third antenna scanned upstream in the Fraser River. The receiver was powered by 110 volt power supply from the building.

To test this site, a tag was placed in the air up and downstream of the site. Results indicated good detection on all antennas with the expected separation between antennas.

Nechako-Stuart Confluence: This site was located at the confluence of the Nechako and Stuart Rivers and was accessed by boat from the Finmore boat launch, west of Prince George. The first antenna was mounted approximately 10 m above water on a bench in a mature spruce tree and scanned downstream in the Nechako River. Antenna two and three were mounted 15 m above waters edge to an aluminum pole, antenna two scanned upstream in the Stuart River and antenna three scanned upstream in the Nechako River.

This site was tested by placing the tag in air and drifting downstream in the boat. Results indicated good detection on all antennas with the expected separation between antennas.

Fraser-Cottonwood Confluence: This site was located at the confluence of the Cottonwood and Fraser rivers. The site was accessed by road from the town of Quesnel. Three antennas were mounted in standard configuration, with one scanning up the Cottonwood, one scanning up the Fraser, and one scanning down the Fraser.

Fraser River Upstream of the Willow River: This site was located along the Fraser, upstream from its confluence with Willow River. The site was accessed by road from the town of Prince George. Three antennas were mounted in standard configuration, with one scanning up the Willow, one scanning up the Fraser, and one scanning down the Fraser.

Appendix Table A1. Orientation of each antenna at each fixed station receiver site, 2005.

Fixed Station Receiver Site	Antenna	Antenna Orientation
Crescent Island	1	downstream Right Channel
Crescent Island	2	upstream Right Channel
Crescent Island	3	downstream Left Channel
Crescent Island	4	upstream Left Channel
Mission	1	upstream North Bank
Mission	2	downstream North Bank
Mission	3	upstream South Bank
Mission	4	downstream South Bank
Rosedale Bridge	1	upstream Fraser
Rosedale Bridge	2	downstream Fraser
Hope	1	upstream Fraser
Hope	2	downstream Fraser
Sawmill Creek Confluence	1	upstream Fraser
Sawmill Creek Confluence	2	downstream Fraser
Hell's Gate	1	upstream Fraser
Hell's Gate	2	downstream Fraser
Thompson Confluence	1	upstream Fraser
Thompson Confluence	2	downstream Fraser
Thompson Confluence	3	upstream Thompson
Thompson-Nicola Confluence	1	upstream Thompson
Thompson-Nicola Confluence	2	downstream Thompson
Thompson-Nicola Confluence	3	upstream Nicola
Thompson-N. Thompson Confl.	1	upstream Thompson
Thompson-N. Thompson Confl.	2	downstream Thompson
Thompson-N. Thompson Confl.	3	upstream North Thompson

continued to right…

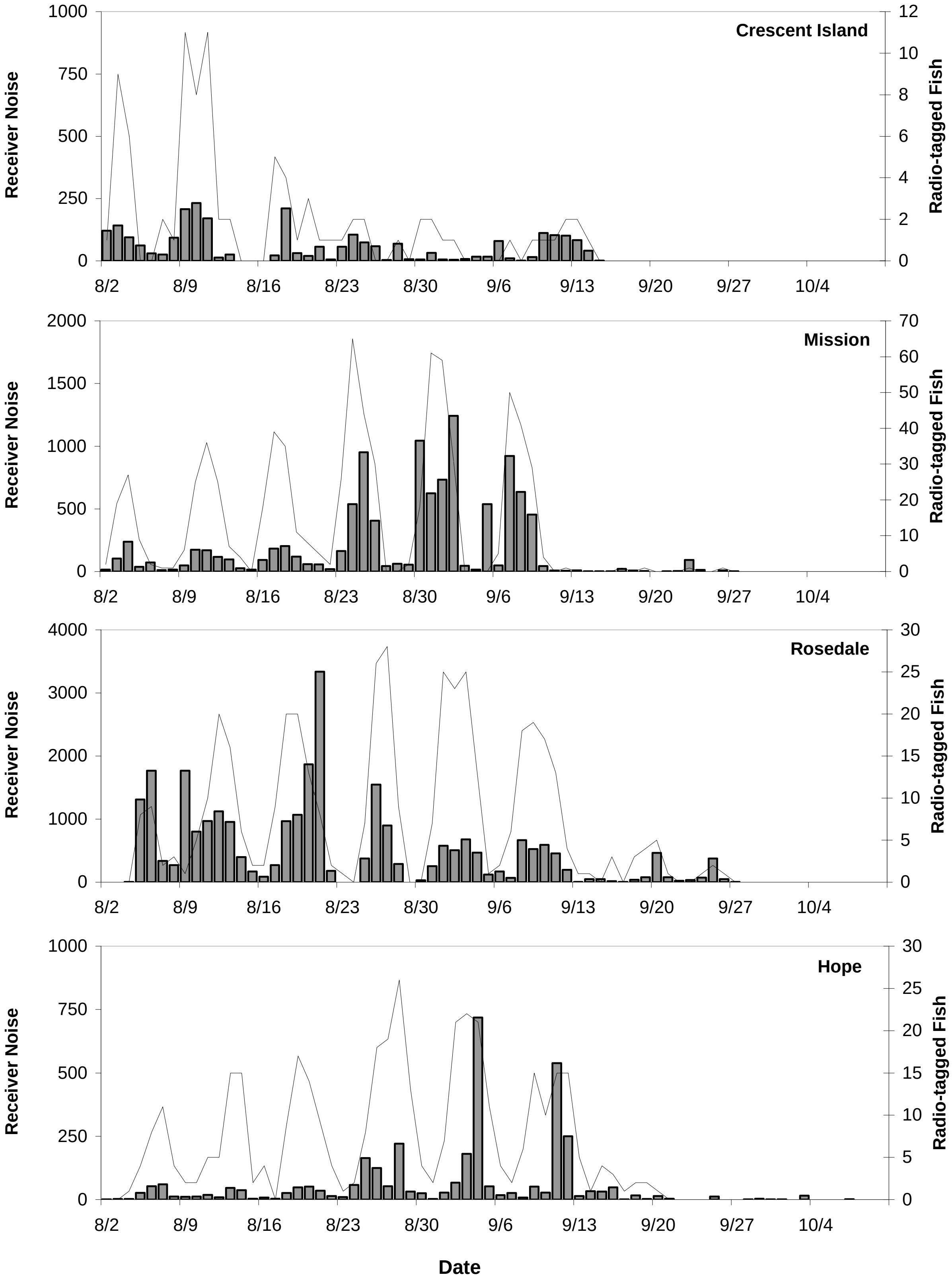
Fixed Station Receiver Site	Antenna	Antenna Orientation
Seton Confluence	1	upstream Fraser
Seton Confluence	2	downstream Fraser
Seton Confluence	3	upstream Seton
Chilcotin Confluence	1	upstream Fraser
Chilcotin Confluence	2	downstream Fraser
Chilcotin Confluence	3	upstream Chilcotin
Quesnel Confluence	1	upstream Fraser
Quesnel Confluence	2	downstream Fraser
Quesnel Confluence	3	upstream Quesnel
Quesnel R. at Likely	1	upstream Quesnel
Quesnel R. at Likely	2	downstream Quesnel
Horsefly R.	1	upstream Horsefly
Horsefly R.	2	downstream Horsefly
Fraser R - Cottonwood Confl.	1	upstream Fraser
Fraser R - Cottonwood Confl.	2	downstream Fraser
Fraser R - Cottonwood Confl.	3	upstream Cottonwood
Nechako Confluence	1	upstream Fraser
Nechako Confluence	2	downstream Fraser
Nechako Confluence	3	upstream Nechako
Nechako-Stuart Confluence	1	upstream Nechako
Nechako-Stuart Confluence	2	downstream Nechako
Nechako-Stuart Confluence	3	upstream Stuart
Upstream of the Willow River	1	upstream Fraser
Upstream of the Willow River	2	downstream Fraser
Upstream of the Willow River	3	upstream Willow

Appendix Table A2. Fixed station monitoring efficiency (percent operational) by week for all sites monitored between 2 Aug and 15 Nov, 2005.

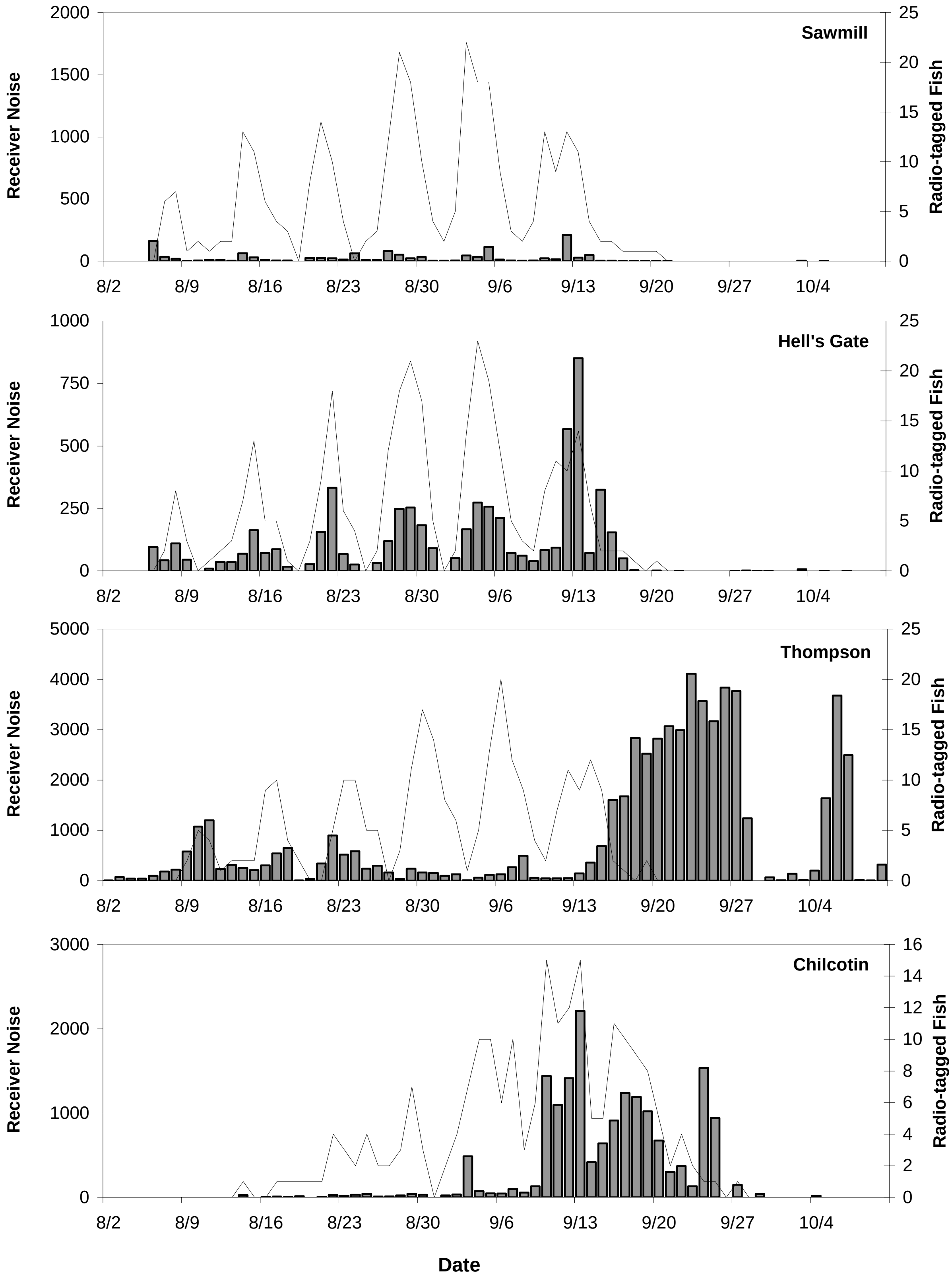
	Fixed Station Receiver Site									
Week End Date	Crescent Island	Mission North	Mission South	Rosedale	Hope	Sawmill Creek	Hell's Gate	Thompson Confl.	Chilcotin Confl.	Quesnel Confl.
9 Aug	99%	100%	100%	100%	100%	83%	100%	99%	100%	100%
16 Aug	71%	100%	100%	100%	100%	100%	100%	100%	100%	100%
23 Aug	71%	100%	100%	100%	100%	100%	100%	81%	100%	100%
30 Aug	100%	100%	100%	40%	100%	100%	100%	99%	100%	100%
6 Sep	100%	100%	100%	90%	100%	100%	100%	100%	100%	100%
13 Sep	100%	100%	100%	100%	100%	100%	100%	100%	100%	98%
20 Sep	100%		100%	100%	100%	100%	100%	100%	100%	100%
27 Sep			99%	100%	100%	100%	100%	100%	100%	99%
4 Oct			100%	100%	100%	100%	100%	77%	100%	100%
11 Oct					100%	100%	100%	100%	100%	100%
18 Oct								100%	100%	100%
25 Oct									100%	
Overall	**91%**	**100%**	**100%**	**91%**	**100%**	**98%**	**100%**	**96%**	**100%**	**100%**

	Fixed Station Receiver Site								
Week End Date	Quesnel at Likely	Quesnel - Horsefly Confl.	Seton Confl.	Thompson - Nicola Confl.	Thompson - N. Thomp. Confl.	Nechako Confl.	Nechako - Stuart Confl.	Cottonwood Confl.	Fraser upstream of Willow
9 Aug	100%		100%				100%		
16 Aug	100%		100%	100%		100%	100%		
23 Aug	100%	100%	100%	100%		100%	100%	100%	
30 Aug	100%	100%	100%	100%		100%	100%	98%	100%
6 Sep	100%	100%	100%	100%		100%	100%	100%	100%
13 Sep	100%	99%	100%	100%	100%	100%	100%	100%	100%
20 Sep	100%	100%	50%	100%	100%	92%	100%	100%	100%
27 Sep	100%	100%	100%	100%	100%	100%	100%	100%	100%
4 Oct	100%	100%	100%	100%	100%	100%	100%	100%	100%
11 Oct		100%	100%	100%	100%	100%	100%	100%	82%
18 Oct			100%	100%		100%	100%	100%	33%
25 Oct						100%	100%		
1 Nov						100%	100%		
8 Nov						100%	100%		
15 Nov						100%			
Overall	**100%**	**100%**	**95%**	**100%**	**100%**	**99%**	**100%**	**100%**	**88%**

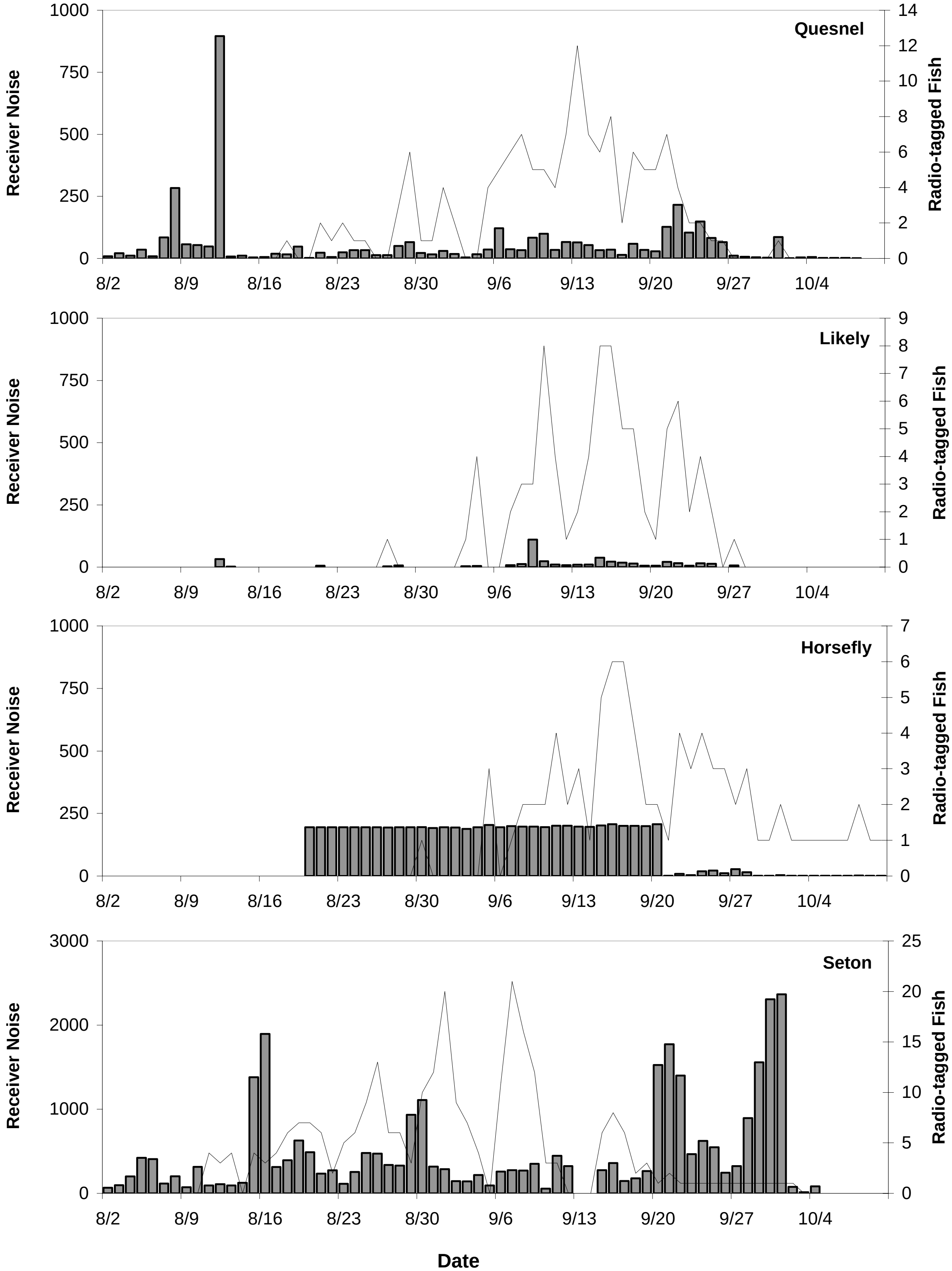
Appendix Figure A1. **Receiver noise/collisions (bars) and total number of fish detected (line) by day from 2 August-10 October, 2005.**



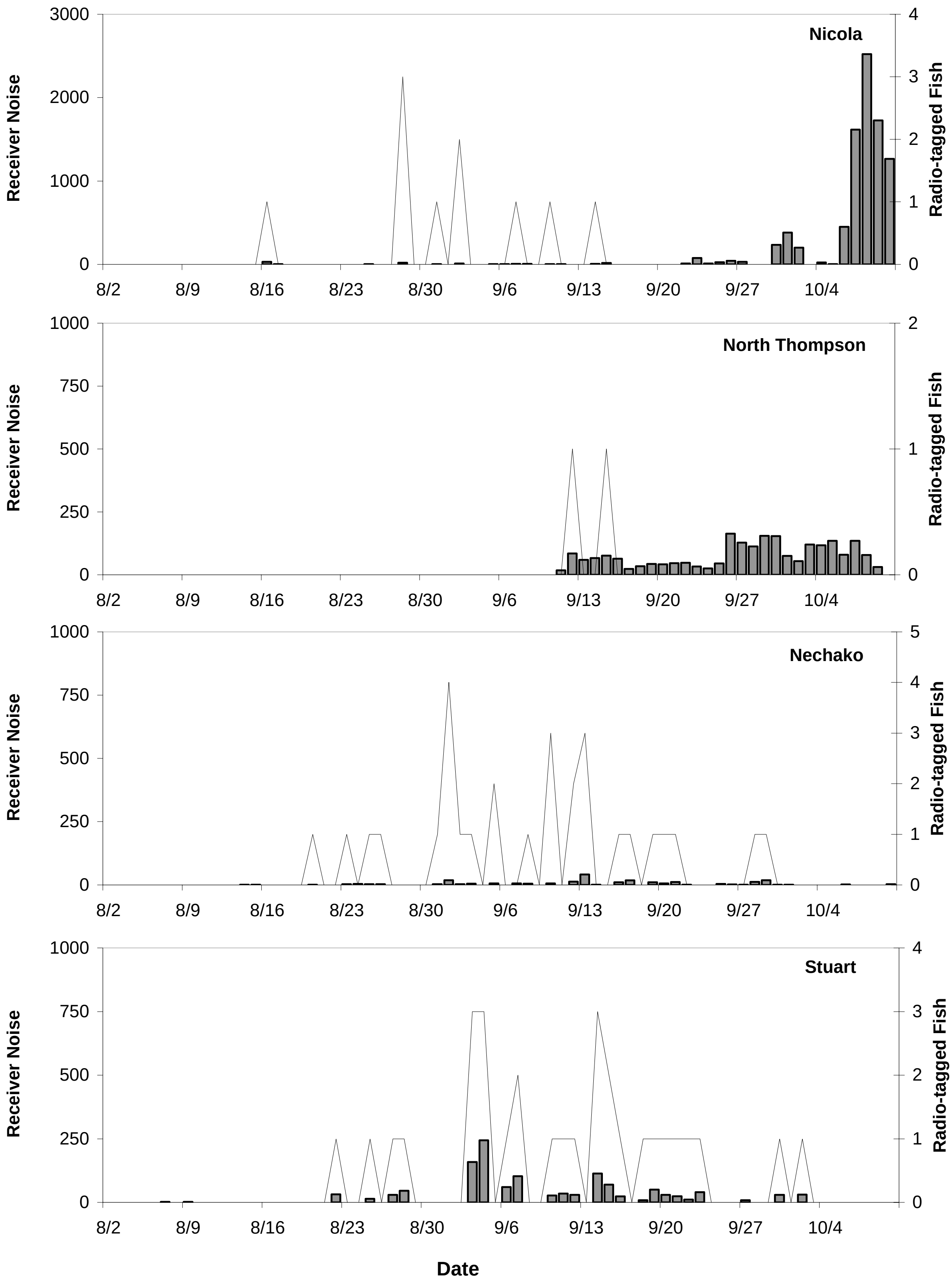
Appendix Figure A1 continued.



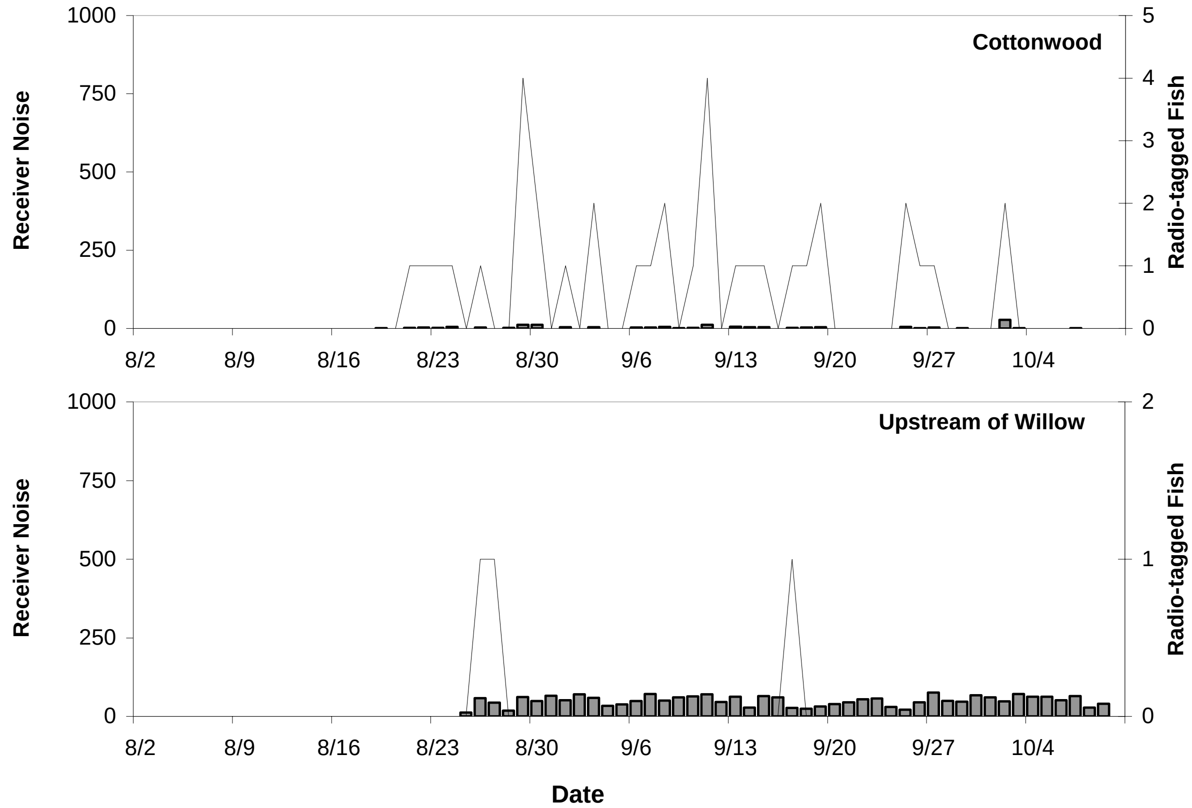
Appendix Figure A1 continued.



Appendix Figure A1 continued.



Appendix Figure A1 continued.



APPENDIX B

Mobile Detections, Spawning ground Recoveries, and Fishery Returns

Appendix Table B1. **Dates and locations of mobile tracking surveys conducted up until 31 December, 2005. Code 'ns' indicates that no survey was conducted in the zone/period stratum.**

Date	Weaver Creek	Harrison River	Birkenhead River	Fraser Mainstem	Chilko Watershed	Quesnel Watershed
21-Sep	ns	ns	ns	aerial	ns	ns
21-Oct	ns	ns	ns	ns	aerial	aerial
Oct-Nov	ns	ns	ns	ns	boat and aerial	boat and aerial
3-Nov	ns	ns	ns	ns	aerial	ns
11-Nov	aerial	aerial	aerial	aerial	ns	ns
6-Dec	ns	ns	ns	aerial	ns	ns

Appendix Table B2. Tags recovered from fisheries, and reported before 31 December, 2005.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Capture Method	Zone	Recovery Location
8	I	Summer-run	8 Aug	gillnet	Mission to Sawmill	near Siwash Creek
9	I	Summer-run	6 Aug	gillnet	Mission to Sawmill	near Strawberry Island
19	I	Summer-run	6 Aug	gillnet	Mission to Sawmill	Legacy Bridge- 10-15 miles past Chilliwack
21	I	Summer-run	19 Aug	gillnet	Mission to Sawmill	Island 22, Chilliwack
29	I	Summer-run	12 Aug	gillnet	Above Sawmill	mouth of Bridge River
32	I	Summer-run	18 Aug	dip net	Above Sawmill	Farewell Canyon - Chilcoltin River - 45 minutes West of Williams Lake
39	I	Summer-run	12 Aug	gillnet	Above Sawmill	mouth of Bridge River
43	II	Summer-run	13 Aug	gillnet	Mission to Sawmill	under Agassiz Bridge
49	II	Summer-run	11 Aug	drift net	Mission to Sawmill	near Sumas, BC
55	II	Summer-run	13 Aug	gillnet	Below Mission	New Westminister Quay Note - location is downstream of Mission
69	II	Summer-run	24 Aug	dip net	Above Sawmill	Fraser R. at Williams Lake
79	II	Summer-run	13 Aug	gillnet	Mission to Sawmill	near Strawberry Island
106	III	Summer-run	31 Aug	dip net	Above Sawmill	Chilcoltin River at Siwash
120	III	Summer-run	19 Aug	gillnet	Mission to Sawmill	near Strawberry Island
121	III	Summer-run	24 Aug	gillnet	Above Sawmill	Bridge River
124	III	Summer-run	19 Aug	gillnet	Mission to Sawmill	near Strawberry Island
130	III	Summer-run	20 Aug	gillnet	Mission to Sawmill	18 Km above Hope
157	III	Summer-run	23 Aug	gillnet	Above Sawmill	Boston Bar
158	III	Summer-run	19 Aug	gillnet	Mission to Sawmill	under Agassiz Bridge
160	III	Early Summer	23 Aug	gillnet	Above Sawmill	Boston Bar (5 km south)

… continued

Appendix Table B2 continued.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Capture Method	Zone	Recovery Location
166	IV	Summer-run	9 Sep	?	Mission to Sawmill	Seabird Island - above Agassiz - found dead on beach
174	IV	Summer-run	11 Sep	dip net	Above Sawmill	Bridge River conflu
180	IV	Early Summer	28 Aug	gillnet	Above Sawmill	Jackass Mtn. Fraser River 10 minutes east of Boston Bar
187	IV	Summer-run	4 Sep	dip net	Above Sawmill	Soda Creek
215	VI	Summer-run	14 Sep	dip net	Above Sawmill	Siwash Bridge near Chilko River
226	IV	Summer-run	27 Aug	gillnet	Mission to Sawmill	Squay Reserve by Chilliwack Mtn
246	IV	Summer-run	6 Sep	dip net	Above Sawmill	Farewell Canyon - Chilcoltin River - 45 minutes West of Williams Lake
249	IV	Early Summer	31 Aug	?	Mission to Sawmill	1mile south of Rosedale Br
270	V	Summer-run	13 Sep	?	Above Sawmill	Farewell Canyon - Chilcoltin River - 45 minutes West of Williams Lake
284	V	Early Summer	8 Sep	dip net	Above Sawmill	Thompson R. - 7 miles N of Lytton
287	V	Summer-run	1 Sep	drift net	Mission to Sawmill	Fraser River at Chilliwack
300	V	Summer-run	3 Sep	angling	Mission to Sawmill	Jesperson Rd Chilliwack
309	V	Summer-run	7 Sep	dip net	Above Sawmill	17.6 kms south of Spences Bridge on Thompson R.
314	V	Early Summer	8 Sep	dip net	Above Sawmill	Siska - below Lytton
327	V	Summer-run	4 Sep	angling	Mission to Sawmill	Herrling Island (15 minutes drive before Hope on Hwy 1)
378	VI	Early Summer	14 Sep	dip net	Above Sawmill	North of Lytton on Thompson River

Appendix Table B3. Tags tracked in spawning grounds or recovered from spawning ground surveys, and reported before 31 December, 2005.

Tag No.	Sampling Period	Recovery Date	Last detection zone	Recovery Location
7	I	24 Sep	Nechako at Stuart	Nadina
14	I	14 Nov	Rosedale	Harrison, Kilby Boat Launch
20	I	14 Nov	Rosedale	Harrison, Native Village
23	I	14 Nov	Mission	Harrison, Native Village
37	I	6 Oct	Nechako at Stuart	Tachie
44	II	21 Oct	Chilcotin Junc.	Chilko
72	II	20 Sep	Horsefly	Horsefly
82	II	10 Nov	Crescent	Weaver
100	II	5 Oct	Nechako at Stuart	Stellako
119	III	21 Oct	Chilcotin Junc.	Chilko
134	III	20 Oct	Horsefly	Quesnel
145	III	13 Sep	Horsefly	Horsefly
152	III	29 Sep	Chilcotin Junc.	Chilko
154	III	14 Nov	Mission	Harrison, Kilby Boat Launch
159	III	5 Oct	Nechako at Stuart	Stellako
177	IV	21 Oct	Chilcotin Junc.	Chilko
185	IV	21 Oct	Chilcotin Junc.	Chilko
191	IV	30 Sep	Nechako at Stuart	Stellako
212	IV	21 Oct	Quesnel	Mitchell, Quesnel
213	IV	14 Nov	Mission	Weaver
260	V	4 Oct	Horsefly	Horsefly
271	V	21 Oct	Quesnel	Mitchell, Quesnel
272	V	3 Nov	Chilcotin Junc.	Chilko
276	V	21 Oct	Chilcotin Junc.	Chilko
280	V	21 Oct	Quesnel	Wasko, Quesnel

… continued

Appendix Table B3. continued.

Tag No.	Sampling Period	Recovery Date	Last detection zone	Recovery Location
288	V	20 Oct	Horsefly	Quesnel system
295	V	4 Oct	Horsefly	Horsefly
296	V	21 Oct	Chilcotin Junc.	Chilko
297	V	14 Nov	Mission	Birkenhead
303	V	21 Oct	Chilcotin Junc.	Chilko
312	V	20 Oct	Quesnel	Quesnel
319	V	21 Oct	Chilcotin Junc.	Chilko
321	V	14 Nov	Mission	Weaver, Morris Slough
324	V	20 Oct	Horsefly	Quesnel system
325	V	26 Sep	Horsefly	Horsefly
330	V	14 Nov	Mission	Harrison
331	V	-	Horsefly	Horsefly
338	V	21 Oct	Chilcotin Junc.	Chilko
341	V	21 Oct	Chilcotin Junc.	Chilko
342	V	20 Oct	Quesnel	Mitchell, Quesnel
344	VI	-	Chilcotin Junc.	Williams Lake Creek
346	VI	-	Horsefly	Horsefly
348	VI	21 Oct	Chilcotin Junc.	Chilko
356	VI	21 Oct	Chilcotin Junc.	Chilko
359	VI	3 Nov	Chilcotin Junc.	Chilko
361	VI	14 Nov	Rosedale	Harrison, Native Village
364	VI	21 Oct	Chilcotin Junc.	Chilko
384	VI	18 Oct	Chilcotin Junc.	Chilko
388	VI	21 Oct	Chilcotin Junc.	Chilko
399	VI	20 Oct	Quesnel	Mitchell, Quesnel
402	VI	21 Oct	Chilcotin Junc.	Chilko
404	VI	21 Oct	Chilcotin Junc.	Chilko
407	VI	21 Oct	Quesnel	Mitchell, Quesnel

APPENDIX C

Daily Escapement and Harvest in Four In-River Fisheries

Appendix Table C1. The daily escapement into four in-river fisheries, daily catch in each fishery, and daily harvest rates. Data for F2, F3 and F4 are offset by one, two and three days so that data for each cohort lines up with its Mission Passage Date. Harvest rates for F1 to F3 wee calculated by dividing the running average catch by the running average escapement. That for F4 is more complex as fish were exposed to the fishery for longer than one day (see text). F1 = Mission to Harrison; F2 = Harrison to Hope; F3 = Hope to Sawmill; and F4 = upstream of Sawmill.

	Mission	Number entering fishery				Fishery Harvest						Harvest Rate			
						FN Catch				Sport	Total				
	Date	F1	F2	F3	F4	F1	F2	F3	F4	F2	Catch	F1	F2	F3	F4
	20 Jul	335	335	335	335	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	21 Jul	259	259	259	259	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	22 Jul	171	171	171	171	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	23 Jul	280	280	280	280	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	24 Jul	263	263	263	263	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	25 Jul	232	232	232	232	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	26 Jul	91	91	91	91	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	27 Jul	84	84	84	84	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
	28 Jul	8539	8539	8539	8530	0	0	9	0	0	9	0.0%	2.6%	0.2%	5.1%
	29 Jul	9105	9105	8637	8619	0	467	18	22	0	507	0.9%	5.7%	4.7%	6.3%
	30 Jul	9388	9150	8093	6925	238	1056	1168	7	0	2470	3.1%	8.1%	5.0%	8.5%
	31 Jul	8089	7505	6936	6936	584	569	0	7	0	1160	3.6%	5.6%	4.3%	10.4%
	1 Aug	12511	12264	12264	12264	248	0	0	960	0	1208	2.1%	1.5%	5.1%	12.5%
Passage Period One	2 Aug	18889	18889	18889	16946	0	0	1943	960	0	2903	0.4%	1.4%	10.0%	12.6%
	3 Aug	26507	26507	25717	21961	0	790	3756	960	0	5506	0.7%	3.8%	12.0%	13.5%
	4 Aug	20454	19966	18303	16425	489	1663	1878	1169	0	5199	2.4%	5.5%	8.3%	14.9%
	5 Aug	26655	25409	23882	23882	1246	1528	0	2568	0	5341	3.6%	5.0%	3.4%	16.1%
	6 Aug	19317	18628	18628	18448	689	0	180	2568	0	3437	2.9%	2.4%	0.3%	15.2%
	7 Aug	20521	20521	20521	20521	0	0	0	3037	0	3037	1.1%	0.0%	0.3%	14.3%
	8 Aug	25153	25153	25153	25153	0	0	0	3283	0	3283	0.0%	0.0%	4.4%	13.3%
Passage Period Two	9 Aug	24964	24964	24964	21884	0	0	3080	3893	0	6973	0.0%	2.4%	12.4%	12.3%
	10 Aug	21987	21987	20276	14609	0	1711	5667	3941	0	11319	1.6%	7.0%	16.4%	11.2%
	11 Aug	30394	29184	25567	22701	1210	3617	2866	3982	0	11674	4.2%	7.6%	9.7%	10.0%
	12 Aug	47273	44291	42386	42386	2982	1905	0	2141	0	7028	5.2%	5.1%	2.8%	8.8%
	13 Aug	35608	33939	33939	33939	1668	0	0	2165	0	3834	4.5%	1.9%	0.0%	10.9%
	14 Aug	20535	20535	20535	20535	0	0	0	2165	0	2165	2.0%	0.0%	0.0%	13.4%
	15 Aug	25302	25302	25302	25302	0	0	0	2228	0	2228	0.0%	0.0%	6.1%	15.9%
Passage Period Three	16 Aug	16404	16404	16404	12612	0	0	3792	2411	0	6203	0.0%	2.4%	18.3%	18.8%
	17 Aug	20005	20005	18542	11300	0	1463	7241	2390	0	11094	1.8%	8.5%	33.3%	21.2%
	18 Aug	24227	23119	19517	12415	1108	3602	7102	2322	0	14134	4.2%	11.0%	25.4%	21.9%
	19 Aug	38069	35758	32122	28651	2310	3637	3471	5073	0	14491	7.7%	12.1%	16.5%	21.9%
	20 Aug	16811	14122	12563	12563	2689	1558	0	4976	0	9223	8.6%	8.4%	5.8%	19.9%
	21 Aug	16145	15020	14748	14748	1124	273	0	4720	0	6117	7.9%	4.8%	0.0%	17.2%
	22 Aug	15275	15275	14972	14972	0	303	0	4915	0	5218	1.8%	0.9%	16.5%	14.2%
Passage Period Four	23 Aug	32072	32072	32072	21866	0	0	10207	5089	0	15296	0.0%	2.9%	11.7%	10.4%
	24 Aug	131029	131029	126204	116202	0	4825	10002	5028	0	19855	0.8%	2.9%	9.7%	6.6%
	25 Aug	161033	158599	153943	143999	2434	4655	9945	5028	0	22062	1.0%	4.1%	7.5%	4.8%
	26 Aug	128096	126145	118778	108618	1952	7366	10161	4867	0	24345	1.4%	3.3%	6.0%	3.7%
	27 Aug	232109	229429	224355	214552	2680	5073	9803	4839	0	22395	1.1%	2.7%	4.6%	2.8%
	28 Aug	297092	294413	289339	280361	2680	5073	8978	4944	0	21675	0.9%	1.6%	2.5%	2.3%
	29 Aug	394218	391405	386530	382801	2813	4875	3729	4770	0	16187	0.9%	1.3%	1.8%	2.0%
Passage Period Five	30 Aug	236624	233942	231925	228196	2682	2017	3729	4368	0	12797	0.7%	1.7%	1.3%	2.0%
	31 Aug	222783	222109	214278	210695	674	2107	3583	5199	5724	17287	0.5%	2.4%	1.4%	2.2%
	1 Sep	315736	315046	306564	302989	689	2713	3575	5199	5769	17945	0.3%	3.5%	1.6%	2.4%
	2 Sep	181010	180302	171784	168049	709	2725	3735	3900	5793	16862	0.4%	4.2%	1.9%	2.8%
	3 Sep	109508	108509	100064	96299	999	2701	3765	3891	5744	17100	0.8%	7.6%	2.9%	2.7%
	4 Sep	39666	38667	30809	29649	999	2115	1160	4066	5743	14082	1.5%	11.7%	3.6%	2.6%
	5 Sep	45180	44290	38213	37063	890	765	1150	4098	5311	12215	1.3%	13.8%	6.7%	2.4%
Passage Period Six	6 Sep	68537	68465	61520	55028	72	1471	6492	4115	5474	17624	0.5%	5.9%	6.6%	2.1%
	7 Sep	106777	106571	106571	100566	206	0	6005	4080	0	10290	0.1%	2.5%	4.7%	1.8%
	8 Sep	99856	99856	99856	99856	0	0	0	4080	0	4080	0.1%	0.0%	2.0%	1.4%
	9 Sep	92292	92292	92292	92292	0	0	0	785	0	785	0.0%	0.0%	0.0%	0.8%
	10 Sep	111731	111731	111731	111731	0	0	0	809	0	809	0.0%	0.0%	0.0%	0.6%
	11 Sep	268474	268474	268474	268474	0	0	0	775	0	775	0.0%	0.0%	0.0%	0.5%
	12 Sep	210943	210943	210943	210943	0	0	0	795	0	795	0.0%	0.0%	0.0%	0.4%
	13 Sep	77437	77437	77437	77437	0	0	0	820	0	820	0.0%	0.0%	0.0%	0.4%
	14 Sep	50248	50248	50248	50248	0	0	0	849	0	849	0.0%	0.0%	0.0%	0.4%
	15 Sep	34420	34420	34420	34420	0	0	0	849	0	849	0.0%	0.0%	0.0%	0.3%
	16 Sep	26879	26879	26879	26879	0	0	0	156	0	156	0.0%	0.0%	0.0%	3.7%
	17 Sep	36023	36023	36023	36023	0	0	0	169	0	169	0.0%	0.0%	0.0%	3.7%
	18 Sep	39072	39072	39072	39072	0	0	0	176	0	176	0.0%	0.0%	0.0%	4.0%
	19 Sep	27412	27412	27412	27412	0	0	0	176	0	176	0.0%	0.0%	0.0%	4.4%
	20 Sep	3590	3590	3590	3590	0	0	0	160	0	160	0.0%	0.0%	0.0%	4.9%

Appendix Table C2. **The daily movement of radio-tagged sockeye into four in-river fisheries, daily harvest rates, and predicted number of tags being harvested. Data for F2, F3 and F4 are offset by one, two and three days so that data for each cohort lines up with its Mission Passage Date. F1 = Mission to Harrison; F2 = Harrison to Hope; F3 = Hope to Sawmill; and F4 = upstream of Sawmill.**

	Mission	Tags entering fishery				Harvest Rate				Estimated tag removals			
	Date	F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
Passage Period One	2 Aug	1				0.4%	1.4%	10.0%	12.6%	0.0	0.0	0.0	0.0
	3 Aug	6	2	2		0.7%	3.8%	12.0%	13.5%	0.0	0.1	0.2	0.0
	4 Aug	9	7	5	4	2.4%	5.5%	8.3%	14.9%	0.2	0.4	0.4	0.6
	5 Aug	2	6	6	5	3.6%	5.0%	3.4%	16.1%	0.1	0.3	0.2	0.8
	6 Aug			1		2.9%	2.4%	0.3%	15.2%	0.0	0.0	0.0	0.0
	7 Aug	1	2	1	2	1.1%	0.0%	0.3%	14.3%	0.0	0.0	0.0	0.3
	8 Aug		1			0.0%	0.0%	4.4%	13.3%	0.0	0.0	0.0	0.0
Passage Period Two	9 Aug	2	1	2	1	0.0%	2.4%	12.4%	12.3%	0.0	0.0	0.2	0.1
	10 Aug	6	2	1		1.6%	7.0%	16.4%	11.2%	0.1	0.1	0.2	0.0
	11 Aug	14	11	10	8	4.2%	7.6%	9.7%	10.0%	0.6	0.8	1.0	0.8
	12 Aug	6	10	10	7	5.2%	5.1%	2.8%	8.8%	0.3	0.5	0.3	0.6
	13 Aug	2	2	1	3	4.5%	1.9%	0.0%	10.9%	0.1	0.0	0.0	0.3
	14 Aug	1	1	1	2	2.0%	0.0%	0.0%	13.4%	0.0	0.0	0.0	0.3
	15 Aug					0.0%	0.0%	6.1%	15.9%	0.0	0.0	0.0	0.0
Passage Period Three	16 Aug	11	7	8		0.0%	2.4%	18.3%	18.8%	0.0	0.2	1.5	0.0
	17 Aug	16	13	12	7	1.8%	8.5%	33.3%	21.2%	0.3	1.1	4.0	1.5
	18 Aug	16	13	10	13	4.2%	11.0%	25.4%	21.9%	0.7	1.4	2.5	2.8
	19 Aug	3	7	6	6	7.7%	12.1%	16.5%	21.9%	0.2	0.8	1.0	1.3
	20 Aug	2	4	3	4	8.6%	8.4%	5.8%	19.9%	0.2	0.3	0.2	0.8
	21 Aug		1	1		7.9%	4.8%	0.0%	17.2%	0.0	0.0	0.0	0.0
	22 Aug				2	1.8%	0.9%	16.5%	14.2%	0.0	0.0	0.0	0.3
Passage Period Four	23 Aug	12	5	6	3	0.0%	2.9%	11.7%	10.4%	0.0	0.1	0.7	0.3
	24 Aug	30	22	17	11	0.8%	2.9%	9.7%	6.6%	0.2	0.6	1.6	0.7
	25 Aug	13	19	16	18	1.0%	4.1%	7.5%	4.8%	0.1	0.8	1.2	0.9
	26 Aug	17	18	20	16	1.4%	3.3%	6.0%	3.7%	0.2	0.6	1.2	0.6
	27 Aug		5	8	9	1.1%	2.7%	4.6%	2.8%	0.0	0.1	0.4	0.3
	28 Aug			1	2	0.9%	1.6%	2.5%	2.3%	0.0	0.0	0.0	0.0
	29 Aug				1	0.9%	1.3%	1.8%	2.0%	0.0	0.0	0.0	0.0
Passage Period Five	30 Aug	8	5	4	4	0.7%	1.7%	1.3%	2.0%	0.1	0.1	0.1	0.1
	31 Aug	29	21	19	19	0.5%	2.4%	1.4%	2.2%	0.2	0.5	0.3	0.4
	1 Sep	25	19	19	15	0.3%	3.5%	1.6%	2.4%	0.1	0.7	0.3	0.4
	2 Sep	14	21	16	17	0.4%	4.2%	1.9%	2.8%	0.1	0.9	0.3	0.5
	3 Sep		7	7	8	0.8%	7.6%	2.9%	2.7%	0.0	0.5	0.2	0.2
	4 Sep			1	1	1.5%	11.7%	3.6%	2.6%	0.0	0.0	0.0	0.0
	5 Sep					1.3%	13.8%	6.7%	2.4%	0.0	0.0	0.0	0.0
Passage Period Six	6 Sep	3	2	3	4	0.5%	5.9%	6.6%	2.1%	0.0	0.1	0.2	0.1
	7 Sep	24	15	14	13	0.1%	2.5%	4.7%	1.8%	0.0	0.4	0.7	0.2
	8 Sep	17	13	7	7	0.1%	0.0%	2.0%	1.4%	0.0	0.0	0.1	0.1
	9 Sep	13	15	15	15	0.0%	0.0%	0.0%	0.8%	0.0	0.0	0.0	0.1
	10 Sep		8	13	10	0.0%	0.0%	0.0%	0.6%	0.0	0.0	0.0	0.1

Appendix Table C3. **Tag loss (additional en-route losses) between Mission and Sawmill for Summer-run stocks, by Mission Passage Period.**

Mission Passage Period	Tags Past Mission	Estim. Tag harvest	Harvest Rate	Tags After Harvest	Tags Past Sawmill	Difference (tag loss)	Additional En-route Losses
one	19	2.0	10.4%	17.0	11	6.0	35.4%
two	31	4.3	13.9%	26.7	21	5.7	21.3%
three	48	14.5	30.1%	33.5	32	1.5	4.6%
four	72	8.0	11.2%	64.0	60	4.0	6.2%
five	76	4.2	5.5%	71.8	64	7.8	10.9%
six	57	1.5	2.7%	55.5	49	6.5	11.6%
Total	303	34.5	11.4%	268.5	237	31.5	