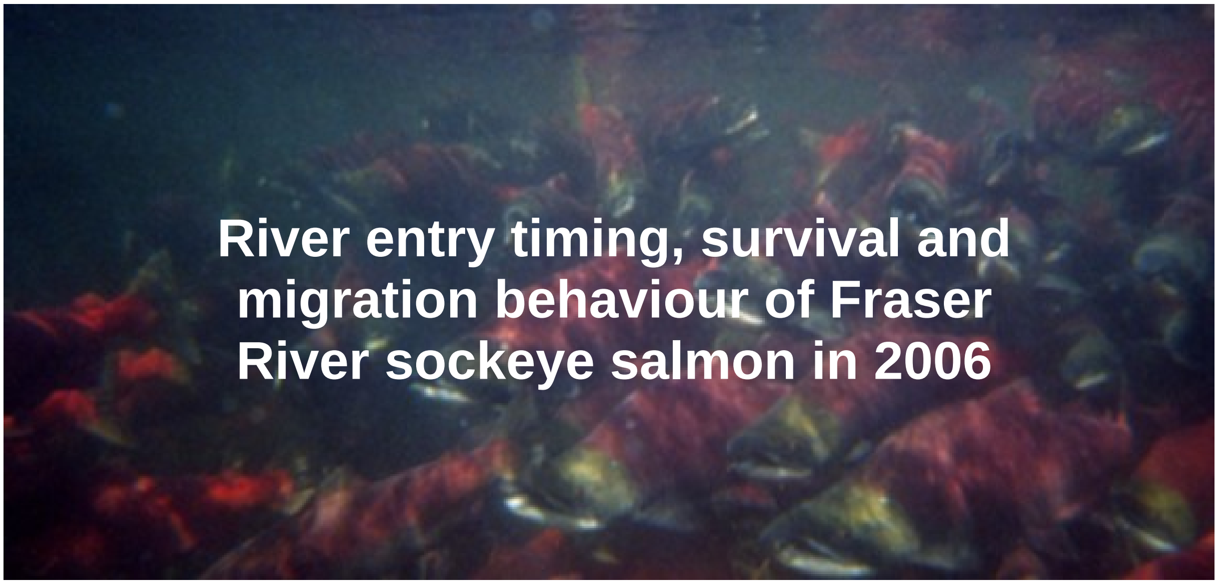

River entry timing, survival and migration behaviour of Fraser River sockeye salmon in 2006

Prepared for:

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

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Dave Robichaud and Karl K. English[1]

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Vancouver, BC, Canada
V6E 1B5

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[1] LGL Limited Environmental Research Associates, 9768 Second Street, Sidney, BC V8L 3Y8

EXECUTIVE SUMMARY

In recent years, large numbers of Late-run Fraser River sockeye salmon have died in fresh water before reaching their spawning grounds. Early river entry has been associated with increased levels of pre-spawn mortality for this stock. In 2006, a large scale study was conducted to evaluate three alternative explanations for early migration behaviour: 1) the “stay with the school” hypothesis; 2) the maturation hypothesis; and 3) the osmoregulation hypothesis. This report describes the results pertaining to the “stay with the school” hypothesis.

Using purse seines in marine waters 660 sockeye were captured, radio-tagged and released over three August tagging intervals in Juan de Fuca and Johnstone straits. To evaluate the “stay with the school” hypothesis required variance in the ratio of Late-run to Early-summer/Summer-run sockeye among the three marine tagging intervals. In 2006, these ratios were: 0.5, 2.2, and 6.5. An additional 378 sockeye were radio-tagged over seven approximately weekly tagging periods near Glenlyon Park, at river km 69.

Twenty-four fixed station receivers were established along the Fraser River and within major tributaries to monitor tagged fish movements towards and into spawning areas. The telemetric tracking data were used to determine river-entry times, assess in-river migration rates, and confirm spawning destinations. A total of 572 (55%) radio-tagged sockeye were known to pass the Mission hydro-acoustic site, and enter into the study’s tracking area. Of these, 252 (44%) were tracked to the vicinity of spawning areas, 89 (16%) were harvested in fisheries upstream of Mission, and the remaining 231 (40%) fish were either tagging related or en-route losses. The highest rates of en-route loss for Summer-run occurred between Bridge River and Chilcotin. For Early-Summer and Late-run sockeye, the highest rates of en-route loss occurred between Spence’s Bridge and Kamloops Lake.

Late run sockeye delayed river entry (relative to Summer-run sockeye) for periods ranging from 4-14 days. Late-run sockeye tagged later in the study showed increasingly shorter holding periods. The portion of radio-tagged Late-run sockeye that entered the Fraser River without delay also decreased with time (79%, 37%, and 3% for the first, second and third marine release groups, respectively.

Survival rates (after harvest) varied among run-timing groups (67.2%, 51.9%, 67.1%, and 72.0% for Early Stuart, Early-Summer, Summer-run and Late-run sockeye, respectively). As in prior years, Late-run sockeye in-river survival rates increased over the course of the study period. Survival was near zero for late-run fish that passed Mission during the first two passage periods in August. For the remaining Mission passage periods, late-run survival rates fell between the survival curves fit to the 2002 and 2003 data.

Movement rates between Mission and the Thompson Junction were significantly faster for Early Stuart (median = 36.7 km/d), Early Summer (median = 28.1 km/d) and Summer-run sockeye (median = 29.5 km/d) than those for Late-run fish (median = 22.8 km/d). Within the Thompson River, migration rates for Early Summer sockeye (median = 25.3) were significantly faster than those for Late-run .

In this study, the correlations between Summer-run abundance, river-entry timing, and Late-run survival support the “stay with the school” hypothesis. A more detailed analysis of all three alternative explanations for early migration behaviour will be provided in a subsequent report.

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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). The first three run-timing groups usually migrate rapidly through coastal fisheries in July-August and enter the river with little or no delay in the ocean or estuary. In contrast, Late-run stocks typically arrive on the coast from late July to early September, migrating through coastal fisheries about two weeks later than Summer-run stocks. 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.

The ability of managers to meet spawner escapement goals has been hampered when sockeye salmon experience unexpectedly high pre-spawning mortality rates or there are major discrepancies between the sockeye abundance estimates in the lower Fraser River and the spawning ground estimates. 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. Pre-spawn mortality in 2000 and 2001 was estimated at >90% for Weaver Creek sockeye (Mike Lapointe, PSC, pers. comm.). It has been hypothesized that the high pre-spawning mortality observed for Late-run sockeye in freshwater was due to: 1) stress related to the non-adaptive early river entry behaviour; 2) longer freshwater residence times before spawning, during which a myxosporan parasite, *Parvicapsula minibicornis*, contracted upon river entry, induces additional mortality via renal failure before spawning occurs (St-Hilaire et al. 2002); and 3) exposure of fish to higher freshwater temperatures, which promote the development of the parasite (S. Jones, DFO, pers. comm.). Large scale radio-telemetry studies conducted in 2002 and 2003 found very low survival rates between Mission and the spawning areas for Late-run sockeye that enter before the middle of August, moderate survival rates for Late-run sockeye entering in late August and early September, and consistently high survival for those that enter the Fraser River after mid-September (English et al. 2005).

Unexpectedly low numbers of spawning sockeye salmon were observed in 2004 when spawning ground surveys 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). In 2005, sockeye tagged near Mission were tracked throughout the Fraser watershed to determine the magnitude and location of en-route losses for summer-run sockeye stocks (Robichaud and English 2006). One of the goals of this project was to determine the magnitude, timing and location of in-river losses for each run timing component of Fraser sockeye. The other major focus for the 2006 study was to evaluate alternative hypotheses for the mechanisms that determine the degree of early entry migration behaviour for Late-run sockeye stocks. This report represents one part of an interdisciplinary, multi-investigator research program designed to investigate three alternative explanations for early migration behaviour of Late-run sockeye: 1) the "stay with the school" hypothesis; 2) the maturation hypothesis; and 3) the osmoregulation hypothesis. In the following sections, a brief description of the basis for each hypothesis is provided, however we only report on results pertaining to the "stay with the school" hypothesis.

Potential causes of early entry-timing of Late-run sockeye

"Stay with the school" hypothesis

Recent analyses made on historical abundance and timing data (1978-2003) has suggested that the proportion of Late-runs that are entering the river early positively correlates with the abundance of co-migrating Summer-runs (English et al. 2005). It is possible that the early entry behaviour of Late-run sockeye may result from these fish following large summer runs as they enter the Fraser River with little or no delay in the SOG. Large-scale telemetry studies conducted in 2002 and 2003 have confirmed during periods of relatively low summer-run abundance (e.g., after mid-August in 2002) only 10% of tagged late-run sockeye migrated upriver early compared to 60-77% for periods with higher summer-run abundance (e.g., early August 2002, and all release periods in 2003; English et al. 2005). In 2006, a coastal telemetry study was conducted (as in 2002 and 2003) where large numbers of fish across all timing segments of Late-run fish, and co-migrating Summer-runs, are tagged immediately prior to reaching the SOG. Unlike past years, physiological biopsy will be performed on all fish and ensure that all coastal migrating timing segments of the Late-run are sampled and tagged. If the SWTS hypothesis is true, one would expect a large portion of the Late-run sockeye, those that migrate though coastal waters when summer-run stocks are numerically dominant, to enter the Fraser River with little or no delay. Conversely, late-run stocks will delay longer off the mouth of the Fraser River when Late-run stocks are the numerically dominant group. For SWTS to be the sole cause of early entrance, one would expect no differences in either the maturation or osmoregulatory status of tagged fish that entered early compared to those that entered at expected normal times.

Recent modeling, based on our 2003 telemetry and physiology data, suggests that rapid proliferation of thermal-mediated diseases could be responsible for high migration mortality in early entering Late-runs (Wagner et al. 2005; Hinch and Cooke 2005). The effects of river entry time, fish physiology, and migratory temperature on freshwater migration rates, locales of mortality, and migration success were examined in addition to the assessment of the SWTS hypothesis. Migratory thermal information was obtained from data loggers placed at strategic locales. Further, archival thermal loggers were attached to each transmitter such that the complete migration temperature history could be determined for those fish where tags are recovered.

Maturation hypothesis

Using telemetry combined with non-invasive biopsy (Cooke et al. 2005), researchers have found that Late-run fish which display their historically typical 'SOG holding behaviour' for > 2 weeks have high rates of river migration success (> 80%), and are characterized in the ocean as having relatively high gross somatic energy levels and are not mature (e.g., have relatively low levels of reproductive hormones). Those that do not hold in the SOG have low migration success (< 20%), and in the ocean have low somatic energy and show advanced maturation (e.g., have relatively high levels of reproductive hormones; Cooke et al. submitted). Gene array analyses have also revealed advanced senescence and reproductive signals in early entry fish sampled at Whonnock. Low somatic energy and advanced maturation could be the characteristics responsible for initiating early entry into freshwater because of advanced biological clocks and limited time or energy available to reach spawning areas. The underlying physiological differences between Late-run fish that hold or don't hold in SOG are already evident in fish examined prior to reaching the SOG (i.e., at JS; Cooke et al. submitted). Thus, testing this hypothesis involves examination and physiological interventions of fish at a locale earlier in their migration than JS. Recent sampling indicates that the QCI is an appropriate locale as feeding and energy accrual have not yet ceased and Late-run fish can be readily captured (Hinch et al. 2005). Experiments, with appropriate control groups, were conducted to alter the maturation rates at the QCI of individual migrating fish using implants of gonadotropin-releasing hormone (GnRH) to accelerate maturation (Fukaya et al. 1998) and by using GnRH inhibitors to decrease maturation rates. These experiments included 4 release groups (control, sham, accelerated maturity treatment and inhibited maturity treatment) with 50 sockeye per group. Sockeye were implanted with acoustic transmitters, physiologically biopsied, and their migration timing and fate assessed (see Hinch et al. in prep.). If advanced maturation causes early migration, then fish with GnRH implants would be expected to enter the Fraser River much earlier than those with GnRH inhibitors. Biopsy telemetry has shown that Late-runs which die during upriver migration are ones that spend the least amount of time in the SOG and hence are exposed for the longest periods of time to high river temperatures and freshwater diseases (Wagner et al. 2005). Fish with GnRH implants are also expected to exhibit the highest rates of migration mortality because they should spend the least amount of time in the SOG.

Osmoregulation hypothesis

Researchers have identified a negative correlation between levels of early in-river migration and salinity in the upper layer of the southern SOG (based on the "Brackish Layer Model" developed by R. Thomson, DFO). Fish which are more developed reproductively (see hypothesis 2) are hypothesized to be more susceptible to freshwater 'cues' that are now more available in the SOG during coastal migration than they were 10 years ago (R. Thomson, Unpublished Data). Exposure to these cues may accelerate the initiation of the osmoregulatory system and lead to more rapid entry into the Fraser River. Physiological assessments of early migrants indicates that some have activated their osmoregulatory systems by the time they reach the SOG whereas others haven't (Shrimpton et al. 2005; Cooke et al. submitted). Testing this hypothesis involved experimental physiological interventions of fish as they pass through the SOG. Sockeye were captured, moved to the West Vancouver Laboratory, exposed to salinity and maturation treatments for 1-2 weeks. The five treatments were proposed for 2006: high salinity, freshwater, present salinity @ SOG (i.e., control salinity), GnRH X control salinity, GnRH X freshwater), inserted with transmitters, physiologically biopsied, released and tracked to assess migration timing and fate (telemetry details below). Only Late-run stocks, as determined through analysis of DNA samples, were tagged and subjected to these laboratory treatment, therefore, sample size has been set at 30 fish per treatment (150 fish in total). The study also included two control groups (50 fish per group of unknown stock origin). The control fish were caught, tagged and released in SOG on the same days as the experimental releases. Therefore, the total release target for these experiments was 250 sockeye. Environmental data collected from SOG using towed CTDs (building on a 3-yr database), and depth data from transmitters, was collected to help discern associations with salinity patterns. If osmoregulatory issues are the primary cause of the early river entry, freshwater exposed fish should migrate in-river fastest. If it is the more mature fish that are affected by freshwater, then the maturation advanced fish exposed to freshwater will migrate in-river the fastest. As stated for hypothesis 2, whichever group has earliest river-entry timing (whether it is freshwater exposed treatment or maturation advanced fish exposed to freshwater treatment) is predicted to show the greatest in-river migration mortality.

Project goals

The specific goals of this project were three-fold:

1. Estimate the delay of Late-run sockeye in Georgia Strait for three parts of the late-run timing component, especially in relation to the Stay with the School hypothesis;
2. Estimate the in-river mortality and spawning success of Late-run stocks by river entry timing component; and
3. Assess the in-river survival of Early Stuart, Early Summer, Summer-run and Late-run fish from Mission to their respective spawning areas, assess the magnitude of losses in known fishing areas, and identify en-route losses that are likely not related to fisheries.

MATERIALS AND METHODS

Study area

The main study area extended from the Johnstone and Juan de Fuca straits, to the upper reaches of the Fraser River (Figure 1). Tracking effort was focused on areas upstream of the Mission hydroacoustic site. Sockeye were captured, tagged and released at two marine (Juan de Fuca and Johnstone straits) and one in-river (Glenlyon Park – about 10 km downstream of Mission) locations. A fixed-station receiver was deployed about 1 km downstream of the in-river tagging site - at the downstream end of Crescent Island (rkm 68) – to detect any tagged fish that drop-back downriver after being tagged.

Fixed-station receivers were deployed at 24 sites along the Fraser mainstem, at major tributary confluences, and within major sockeye tributaries (Figure 1). Tracking began at the lowest downstream fixed-station location, at Crescent Island. 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.

Study design

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

1. in-river tagging of all sockeye run-timing groups;
2. marine tagging of Late-run sockeye in three intervals (representing the first, middle and last parts of the Late-run sockeye run) in sufficient quantities such that 50-60 fish from each tagging interval would be available for detection in the Fraser River;
3. marine tagging of Summer-run sockeye that co-migrate with the Late-run sockeye;

4. fixed-station tracking at strategic locations along the Fraser River;
5. fixed-station and mobile tracking in spawning tributaries of all sockeye run-timing groups.

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, Mitchell, Little River, Adams, Seymour, Shuswap Lake, Lower Shuswap, and along the Thompson River around Kamloops Lake 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 six different frequencies (320, 360, 440, 460, 600 and 800 kHz) within the 150 MHz band using the Lotek 2000 codeset. 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, SRX400A, or SRX600 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. The newer model receiver, the SRX600, has larger memory capacity, and apparently higher tag detectability. One became available to us during the course of this study, and it was deployed at Mission South starting 16 Aug (an SRX400 had been in operation at the site until that time).

Fixed stations

Twenty-four 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, to document departures from the mainstem of the Fraser River into spawning tributaries, and to bracket areas where mortality might result from natural sources or from fisheries. The Mission fixed-station site was the point of entry into the part of the river where tracking efforts were being concentrated. Because the entry time of radio-tagged fish into the tracking 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 to four 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. Directional 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. At most fixed-station receiver sites, the antenna adjustments and detection range tests were performed in 2005 (as part of a previous study; see Robichaud and English 2006), the antennas were not removed after the 2005 study, and were used again in 2006.

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, Scotch Creek, Seymour River and Eagle River. Three modes of transport were used for mobile tracking: foot, truck, boat, and plane. 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 truck, boat and aerial surveys, a 3-element Maxrad antenna was mounted on a wooden mast or support. The mast was mounted or held vertically for boat and truck surveys. For aerial surveys, the mast was mounted horizontally on the skids of the plane. 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

Marine

Marine tagging occurred in three intervals. The first interval started in Juan de Fuca Strait from 6-10 Aug, and was moved to Johnstone Strait, were it continued until 12 Aug. Initial predictions were that the bulk of the Late-run sockeye would approach the River from the southern passage, and hence be passing through the Juan de Fuca Strait. However, DNA samples taken during the initial tagging interval showed that a lower than expected proportion of the fish were from Late-run stocks. As a result, starting 11 Aug, the tagging operations were moved to Johnstone Strait for the duration of the study period. The second and third intervals, which occurred entirely in Johnstone Strait, occurred from 16-19 Aug, and from 24-27 August, respectively (Table 1).

Marine tagging operations took place on board a commercial purse-seiner, which was contracted for the purposes of collecting sockeye for tagging. During each tagging interval, several sets were made each day. For each set, the purse-seine net was retrieved and pulled alongside the boat. After securing the net, 20-30 sockeye were selected based on their body shape (not thin) and size (55-65 cm nose-fork length) to increase the probability of selecting Late-run Fraser stocks (English et al. 2003; S. Latham, PSC, pers. comm.). The fish were transferred to one of two totes (726 L and 239 L capacities) using a long hand-held dipnet. Fish for tagging were first selected from the smaller tote, then from the larger tote. Fish that quickly righted themselves in the tank were selected for tagging.

In-river

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 worked for a similar study conducted in 2005. The site was relatively free of snags, had a good downstream current, and was near a beach site that was appropriate for the tagging setup. The goal was to tag three days a week, but avoidance of First Nation and commercial fishery openings forced a more sporadic schedule. In-river tagging days were organized into seven tagging intervals, starting 9 July and ending 1 Sept (Table 1).

Fish were captured using a 8.9 cm (3.5 inch) mesh drift gillnet measuring 30 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), or when the boat neared the end of the drift, the net was hauled back into the boat. If fishing was good, the boat drifted about 300 m per drift. When fishing was slow, the boat could drift as much as 600 m downstream before the net was hauled back into the boat. During the last tagging interval, when it was suspected that fish were passing below the net, two nets were strung together top-to-bottom to create a single net about 6.6 m deep.

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 short 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 in either tote. Water in the totes was kept fresh and cool, by using buckets to frequently exchange the tote water with fresh river water.

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, with a constant supply of clean water being pumped into the trough in the vicinity of the fish's head. Fish were measured (nose-fork length), and for those greater than 40 cm and that appeared to be in good condition, a blood sample was taken from 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. In addition, a tissue sample was taken from the adipose fin (for DNA analysis), three scales were taken (for ageing), a Floy tag was inserted into the dorsal musculature adjacent to the dorsal fin, and a radio tag was orally inserted into the stomach of the fish using a plastic tag applicator.

The fish tagged in marine water were subject to additional physiological sampling. A muscle core (5 mm diameter by 5 mm deep) was taken from the side of each fish (two cores were taken from about 10% of the fish), and an additional 10 scales were removed for genome analysis.

At the in-river tagging site, all fish were released from the beach immediately after tagging. In the marine areas, some fish (n=61) were held for extended periods after tagging because another fishing set was underway, and to release the fish would result in their immediate recapture. Initially, the protocol was for all marine-tagged fish to be released immediately after tagging. However, many of the released fish gasped at the surface, rather than do what all fish in prior studies had done: swim quickly away (pers. obs.). Thus, after 184 fish, it was decided to hold fish prior to release. The remaining 415 sockeye were held after tagging in a tank with circulating seawater until they were able to right themselves.

Effects of handling time on survival

The effects of handling time on the survival of sockeye were examined by using a two-way logistic regression, where the dependent variable (survival = yes / no) was modeled as a function of handling time (in minutes). In-river and marine tag groups were treated separately given the obvious difference in probability of in-river detection. Survival to the Thompson Junction was the metric of survival for fish tagged in-river, whereas that for marine-tagged fish was survival to Mission. For the in-river tagging site, "release group" was included as a categorical variable (levels were the 7 weeks) in the logistic model. Because several different holding strategies existed for the first marine release group (and not for subsequent release groups), the three marine release groups were analyzed separately. "Holding type" was included as a categorical variable (levels were "held to recover", "held while fishing" and "released immediately") in the logistic model for the first marine release group.

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. Most 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. Some remote stations in low noise environments, with few fish expected to pass, were download once per month. For most downloads, a diagnostic program was run before erasing the internal memory in the receiver, 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 30 (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; 4) detections requiring unrealistic travel times were removed. 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.

Receiver detection efficiencies

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.

Stock assignment

All radio-tagged fish tracked to known spawning destinations were assigned to a stock based on the location and timing of detection. 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). Together, these data were required to determine stock-specific movement rates. Since tissue samples were analyzed for all fish, including those tracked to spawning destinations, the accuracy of the DNA-based stock assignments could be assessed.

River entry timing

Mission Passage Timing was used as a surrogate for River Entry Timing. River Entry Timing was determined for all radio-tagged fish that passed Mission, whether or not they were detected when moving past the Mission site. For those fish that were detected, the first detection at the Mission fixed-station receivers was used as the Mission Passage Timing. For those that were not detected passing Mission, but *were* detected farther upstream, Mission Passage Timing was interpolated from the timing of detections at adjacent fixed-station sites (and assuming a constant swim speed).

Delay behaviour of Late-run sockeye

The amount of time that Late-run sockeye held in Georgia Strait before entering the Fraser River is not precisely known because radio-tagged fish cannot be tracked in brackish and saline waters at the river mouth. An index of holding (or delay) periods was calculated as the difference between Summer-run and Late-run fish in travel time between marine release sites and Mission. As in 2002 and 2003 (English et al. 2003; 2004), Late-run fish were divided into two groups: those that entered the Fraser River *with* the Summer-run fish (termed "early-entry" group), and those that entered *after* the Summer-run fish ("late-entry" group).

Delay periods for Late-run sockeye were calculated for each marine tagging period as the difference in travel times (release to Mission) between early and late entry fish. It is assumed that: (i) Summer-run and early-entry Late-run fish migrate through marine waters and enter the Fraser River with negligible delays; (ii) the effect of capture and handling on the behaviour of radio-tagged fish was similar for all tagged fish; and (iii) differences in travel times between the early-entry and late-entry groups of Late-run fish indicate holding periods in Georgia Strait.

In-river movements

Travel times (and travel speeds) for each individual fish were calculated based on the timing between detections at 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 using the Kruskal-Wallis test.

Tag recovery estimates for fisheries downstream of Mission

The number of radio tags that were caught in marine water and in the Fraser River downstream of Mission (*c*) was estimated from daily harvest rates of freshwater fisheries downstream of Mission (*HR_term*) and of marine fisheries (*HR_JDF*, *HR_JS*), and the daily number of radio-tagged sockeye from Juan de Fuca and Johnstone Strait that passed the Mission detection site (e_JDF_d, e_JS_d):

$$c = \left[\sum_d \left(\frac{\left(\frac{e\_JDF_d}{1 - HR\_term_d} \right)}{1 - HR\_JDF_d} - e\_JDF_d \right) \right] + \left[\sum_d \left(\frac{\left(\frac{e\_JS_d}{1 - HR\_term_d} \right)}{1 - HR\_JS_d} - e\_JS_d \right) \right]$$

The daily number of tags that passed the Mission detection site (e_JDF_d, e_JS_d) was known mainly from telemetric detection data. However, some fish passed Mission without being detected; for these individuals, the date of Mission Passage was interpolated from detections at adjacent arrays. The daily harvest rates of fisheries downstream of Mission were calculated from three-day averages of daily escapement and daily catch as:

$$HR\_term_d = \sum_{i=-1}^{1} C\_term_{d+i} \Big/ \sum_{i=-1}^{1} \left(E_{d+i} + C\_term_{d+i} \right) \qquad \text{where } i \in \{-1, 0, +1\}$$

$$HR\_JDF_d = \sum_{i=-1}^{1} C\_JDF_{d+i} \Big/ \sum_{i=-1}^{1} \left(C\_JDF_{d+i} + \left(E_{d+i} \cdot (1 - DR_{d+i}) \right) \right) \qquad \text{where } i \in \{-1, 0, +1\}$$

$$HR\_JS_d = \sum_{i=-1}^{1} C\_JS_{d+i} \Big/ \sum_{i=-1}^{1} \left(C\_JS_{d+i} + \left(E_{d+i} \cdot DR_{d+i} \right) \right) \qquad \text{where } i \in \{-1, 0, +1\}$$

where C_term_d is the daily catch in Area 29 and in the Fraser River downstream of Mission; C_JDF_d is the daily catch in US fisheries and in Area 20; C_JS_d is the daily catch in Areas 13-

16; E_d is the daily Mission escapement; and DR_d is the daily Johnstone Strait diversion rate, lagged by 8 days to account for travel times to Mission.

Returns of marine-applied tags were solicited in a manner identical to that for river-tagged fish (see above).

Tag recovery estimates for river fisheries

The number of tags expected to be caught in fisheries above Mission (*ABFR*) was the product of fishery harvest rates (HR_{fd}) and the number of tags known to be in the vicinity of active fisheries (T_{fd}), summed over the *f* fisheries and the *d* days of the study period.

$$ABFR = \sum_f \sum_d \left(HR_{fd} \cdot T_{fd} \right)$$

Harvest data, specifically in-river catches in First Nations and recreation fisheries, were provided by Fisheries and Oceans Canada (DFO). 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. 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.). Daily harvest rates (HR_{fd}) were estimated for each of the first three fisheries, using running three-day averages of catch and escapement:

$$HR_{fd} = \sum_{i=-1}^{1} C_{fd+i} \Big/ \sum_{i=-1}^{1} E_{fd+i} \qquad \text{where } i \in \{-1, 0, +1\} \text{ and } f \in \{1, 2, 3\}$$

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 estimates of stock-specific escapement past Mission were used as E_d for the first fishery, and the survivors of a given fishery became the escapement for the subsequent one:

$$E_{fd} = E_{f-1d} - C_{f-1d}$$

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:

$$S_d = 1 - (C_d \Big/ \sum_{j=0}^{6} E_{d-j})$$

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

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

Since there were radio-tracking fixed station receivers at the boundaries of each of the four fisheries, the daily number of radio-tagged fish that entered each fishery (T_{fd}) was known. Assuming that fish were exposed to each of the three lower fisheries for one day, and the uppermost fishery for seven days (based on median travel times, measured in previous years; English et al. 2004), and using a three-day running average for HR, it was possible to estimate the daily number of tagged fish that should have been caught, (i.e., *ABFR*, the expected number of tags removed).

Tag returns (*ABTR*) were solicited through flyers and meetings with user groups. All radio-tagged fish were marked near their dorsal fin with a blue spaghetti tag, in order to increase the probability that the fish be scrutinized, and the radio tag be noticed. A toll-free number and a mailing address were included on the label of the radio tags. Fishers that called the toll-free number were given directions on how to arrange for a courier to pick up the tag from their home, free of charge to the fisher. Moreover, each time a fisher returned a radio tag to LGL (along with the date and location of capture), they were entered into a draw for $1000. For each tag returned, a letter was mailed to the fisher describing where and when the fish had been tagged, and where it had been tracked to date.

The tag reporting rate was not calculated on a daily basis, since estimates would be too noisy. Data were pooled into 10 approximately week-long blocks. Each block, called "Mission Passage Periods", corresponded to the week during which fish traveled past Mission. The tag reporting rate (*RR*) for Mission passage period *p* was calculated as:

$$RR_p = \sum_f \sum_d ABTR_{fd} \bigg/ \sum_f \sum_d ABFR_{fd}$$

where *d* includes all days in Mission Passage Period *p*.

Escapements (and hence harvest rates), and expected fishery returns were calculated separately for each run-timing group.

Tagging-related loss

Not all fish respond equally to the effects of capture, handling and tagging. After tagging, some fish may immediately resume normal migratory behaviour, while others may spend some time to recover. For example, tagging in-river sometimes results in fish dropping back downstream after release, most of which subsequently resume upstream movements. Tagging-related effects for marine releases could not be assessed, but the majority, if not all of the effects would likely be manifest by the time the fish were first detected at Mission.

The extent of the in-river tagging effects was measured by comparing reach-specific survival rates of fish tagged in-river to those tagged in marine areas. River tagging effects were expected to be relatively large at first, then taper off to the point where reach-specific survival was equal for river and marine-tagged fish. Any fish lost before that point may be associated with tagging effects, whereas those lost upstream of that point would almost certainly not be tagging-related.

Analysis was limited to Late-run sockeye that passed Mission during Periods 5-7 (13 August to 2 September). Sample sizes for other run-timing groups were inadequate (<20). Analysis was limited to Passage Periods 5-7 since no marine-tagged fish passed Mission during Periods 1-4, and no river-tagged fish passed Mission during Periods 8-10.

Terminal detection zones

Each radio-tagged fish was assigned a terminal detection zone based on its farthest upriver movement into the river or tributary in which it was last detected. For example, a fish that entered the Adams, but which subsequently drifted out and was last detected in Little Shuswap Lake would have the Adams as its terminal zone.

Survival estimation

Survival rates from Mission to the spawning areas were computed for each Mission Passage Period, and were computed separately each run-timing group. Fixed-station and mobile tracking data were used to determine the fate for each radio-tagged sockeye that moved upstream past Mission. Fish were assumed to have survived to spawning areas if their terminal detections were at fixed stations (or during mobile tracks) adjacent to their stock-specific spawning locations.

Survival rates were derived by dividing the number of fish detected in spawning terminal areas by the number of tagged fish that remained after tagging related losses and estimated fishery removals:

$$S_v = \frac{O_v}{E_v - C_v - L_v}$$

$$\sigma(S_v) = \sqrt{\frac{S_v(1 - S_v)}{E_v - C_v - L_v - 1}}$$

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, L_v is the number of fish in group v that were lost due to tagging related effects, and O_v is the number of fish in group v that had a stock-specific spawning location as their terminal zone of detection. The groups denoted by v could defined in any way, but in this report, survival was examined by: (1) run-timing group; and (2) by run-timing group *and* Mission Passage Period. The standard deviation equation is the formula for proportions based on high sampling fractions (Cochran 1977).

Mission Escapement

In 2006, spawning ground surveys indicated that the Mission escapement estimates that derived from hydroacoustic data had significantly underestimated the number of sockeye that passed Mission. In May 2007, a series of reconstruction analyses were performed by the PSC to derive a new set of daily Mission abundance estimates for each run-timing group. These analyses were based on the final spawning ground escapement estimates (derived from DFO spawning ground surveys) and weekly estimates of sockeye survival from Mission to the spawning areas (derived from the radio-telemetry data). Details on the data and assumptions used in these analyses are presented in Appendix C.

The radio-telemetry data were used for two components in the Mission reconstruction analyses: 1) tracking data were used to estimate total survival from Mission to spawning areas; and 2) detailed data from fixed-stations, mobile surveys and dead pitch surveys were used to estimate the number of pre-spawn mortalities outside the major spawning areas for Late-run Shuswap Lake sockeye stocks. The telemetry data provided a reliable estimate of the number of radio-tagged Late-run sockeye that successfully migrated from Mission to the Little River monitoring site. DFO escapement surveys provided estimates of the escapement of Late-run sockeye to the Lower Shuswap River, Lower Adams River, Little River and several other tributary spawning areas within the Shuswap Lake system. The number of pre-spawn mortalities outside these spawning tributaries is difficult to estimate and was believed to be substantial in 2006. In previous years, pre-spawn mortality rate could have been inferred from telemetry data by estimating the proportion of fish detected at Little River that subsequently entered the major spawning areas (assuming pre-spawn mortality for those that did not). In 2006, poor detection efficiencies prevented a direct and reliable estimate of the number of radio-tagged sockeye that entered the Adams River. Instead, the number of radio-tagged sockeye that entered the Adams River was estimated from the station's detection efficiency. Appendix D provides details on these analyses and the resulting estimates for the number of radio-tagged sockeye that likely entered the Adams River and the number of pre-spawn mortalities outside the major spawning areas.

Effect of river entry timing on survival of Late-run sockeye

In 2002 and 2003, procedures developed by Schnute and Richards (1990) were used to fit a family of six curves to data describing the relationship between survival of Late-run sockeye and their river entry date. Similar likelihood estimates were derived for each of the six curve shapes. The two curves with the best fit included one sigmoid curve and one cut-off curve (English et al. 2003), with no statistical difference between the two curves. Sigmoid curves are "S" shaped curves where survival rates asymptote towards 0% and 100% and remain between these values over the entire range of possible river entry dates. Cut-off curves are curves with an X-intercept that defines the date when survival is estimated to be nil for all fish that enter the river on or before that date.

A similar curve-fitting analysis was performed using the 2006 survival estimates for the Late-run sockeye that passed Mission during seven passage periods between 1 August and 30 September 2006.

RESULTS

Tag releases and stock compositions

In the marine environment, a total of 660 sockeye were radio tagged. Of these, 236 were tagged in Juan de Fuca Strait, and 424 were tagged in Johnstone Strait (Table 1). The proportion of Late-run sockeye in the tagging sample increased consistently over time for marine tagging (Figure 2). During the first sampling session, in Juan de Fuca Strait, 27.9% of the sockeye were Late-run. A few days later in Johnstone Strait, the proportion was 58.1%. During the second and third weeks in Johnstone Strait, Late-run sockeye made up 67.9% and 84.7% of the tagged fish, respectively (Figure 2). The ratio of Late-run to Early-summer + Summer-run sockeye ("LR:ES/SR") in the three marine tagging intervals were: 0.5, 2.2, and 6.5.

In river, a total of 378 sockeye were caught, tagged and released over a seven week period from 9 July until 1 September (Table 1). During the first tagging week, the majority (78.9%) of the tagged fish were part of the Early Stuart run-timing group (Figure 2). This proportion dropped off to 14.3% by the second week of tagging, during which 50.0% of the tagged fish were Early Summer, and 35.7% were Summer-run. The first Late-run sockeye were tagged during the third week, totaling 15.7% of the fish tagged. During the last four tagging weeks, relative proportions of Early Summer, Summer and Late-run sockeye were fairly consistent (Figure 2).

Fixed-station detection efficiencies

Detection efficiencies in 2006 (Table 2) were similar to those estimated in previous years (English et al. 2004, Robichaud and English 2006). Most fixed stations had detection efficiencies greater than 90% efficient. The receivers that performed least efficiently were at the Fraser-Nechako junction (57.7%), and the Fraser-Harrison confluence (67.3%). The Fraser-Nechako junction, one of the later stations to be set-up, missed the radio-tagged fish that passed prior to the installation date. The Fraser-Harrison confluence was set up to detect fish migrating up the Harrison River and typically misses a portion of the fish migrating past this site on the Fraser River.

Detection efficiencies at Mission (79.0%) were lower than in 2005, most likely due to issues associated with the use of a new type of receiver (an SRX600) which logged unacceptable levels of noise, and recorded unprecedented numbers of bogus detections throughout its operational duration (it was installed 16 Aug). Noise levels for the Mission Zone increased significantly from 384 to 6978 hits per day (an 18-fold increase) starting 16 Aug (t_{105} = -10.0; P < 0.0001; Appendix Figure A1). Weekly detection efficiencies at the Mission site were significantly higher when the SRX400 was in place (91%) than when the SRX600 was in use (69%, t_5 = 6.4; P = 0.0014; Figure 3), and was more similar to detection efficiencies for that site in previous years (English et al. 2004, Robichaud and English 2006). Lotek has been contacted, and questions regarding the receiver configuration and sensitivity are being explored. One possible noise source was the presence of a satellite uplink on the nearby acoustic tag detection array. This uplink was present from 8 April until December, thus if it was the cause of noise, it appears to have only adversely affected the SRX600 receiver.

For the 120 fish that passed the Mission site undetected, we estimated the Mission passage time by interpolating between detections upstream and downstream of Mission, assuming a constant travel speed.

Fishery recoveries

Of the 660 sockeye radio-tagged in marine waters, 80 were estimated to have been caught in marine and Fraser River fisheries below Mission (Table 3). Of these, 66 (82.9%) were returned to LGL (41 from marine fisheries, and 25 from freshwater fisheries downstream of Mission). The below Mission harvest rate for the radio-tagged sockeye released in Juan de Fuca Strait and Johnstone Strait were 36.2% and 20.3%, respectively.

Of the 572 radio tagged sockeye detected at or above Mission (234 from marine releases and 338 from in river releases), 89 were estimated to have been removed in fisheries upstream of Mission (61 in First Nation Fisheries and 28 in recreational fisheries; Table 3). The tag return rate for these First Nation fisheries was 63% (38 of 61 returned).

Catch estimates for the recreational fisheries above Mission (calculated from the revised Mission abundance estimates) suggest a removal rate of only 12.5 radio-tags. However, 28 radio-tags were returned by anglers. This return rate, obviously biased high, likely resulted from a combination of two potential causes: an effective rewards program, and an underestimate in fishery catches. Prior to the 2006 tagging period, a $1000 lottery for tag returns was advertised along with information about the tagging program to over 400 lower Fraser anglers through the

Fraser Valley Salmon Society. These early communications were combined with in-season follow-ups. Together, these could have resulted in angler reporting rates approaching 100%. It is also likely that the number of sockeye caught by anglers was substantially larger than the 134,000 harvest estimate because more experienced anglers can readily catch more than the daily sockeye bag limit. The lottery may have encouraged anglers to remove radio-tags from their fish prior to release or the selective retention of tagged fish.

Table 4 shows the temporal and spatial variability in tag return rates for each of the run-timing groups. For Early Stuart, the data was too sparse to assess return rates. For all the other run timing groups, data were sufficient to identify two consistent patterns. The seasonal return rates for fisheries between Mission and Sawmill was higher for Early Summer stocks (83.0%) than for Summer-run and Late-run stocks (56.3% and 68.3%, respectively). While these estimates for the Mission to Sawmill fisheries look reasonable, there were several weeks when the return rates exceeded 100%. This was likely the result of the small number of tags recovered each week or deficiencies in the daily harvest rate estimates. In contrast, the number of tags returned from First Nation fisheries above Sawmill was consistently and, in some cases, substantially higher than the estimated number of tags caught in these fisheries. These results suggest that either these fisheries are selective for tagged fish or the reported harvest was less than the actual harvest in these fisheries.

Tracking histories

Of the 660 fish tagged in marine waters, 80 (12.1%) were estimated to have been caught in marine and Fraser River fisheries below Mission; and 343 (52%) were detected by one or more fixed station receivers within the Fraser watershed (234 passed Mission and 3 passed Crescent Island, but never made it to Mission; Table 3). The remaining 343 (52%) of the marine tags were never caught or detected after release. The portion of marine-applied tags that were accounted for was lowest for the first release period (30%-43%) and higher for the later two releases (43%-58%).

Of the 378 fish tagged in-river, two sockeye were removed by a fishery before being detected anywhere, and 21 (6%) sockeye were never caught or detected after release. Of the remaining 355 sockeye, 85 fish dropped downriver after being tagged, and were first detected at the fixed station on Crescent Island. Of these drop-back fish, 17 were never detected again, and the remaining 68 (80%) returned upriver and eventually passed the Mission fixed station. In all, 338 of the sockeye tagged in-river passed Mission and entered into the main study area. The portion of in river releases that were accounted for ranged from 92% to 100%, and averaged 94% over all releases (Table 3).

Of the 572 radio-tagged sockeye that passed Mission, 252 (44%) were tracked to the vicinity of spawning areas. Fisheries were estimated to harvest 89 (16%) of the fish that passed Mission. The remaining 231 (40%) fish were either tagging related losses or en-route losses between Mission and their spawning locations. Estimates for tagging related losses and the distribution of en-route losses are provided below.

Tagging-related loss

Comparison of the reach-specific survival rates between release locations suggested that tagging-related effects were largely restricted to reaches downstream of Sawmill (Figure 4). The reach-specific survival rate of river-tagged fish was 8% lower than marine-tagged fish in the first reach above Mission, but survival differences were less different farther upriver. For the reach between Sawmill and Hell's Gate, no effects of tagging could be detected.

The extent of tagging-related losses below Sawmill ranged from 11% to 22% of the sockeye that passed Mission, depending on the run-timing group (Table 5). These values represent the difference between the expected numbers of tags passing Sawmill, and those that actually passed the monitoring station at Sawmill Creek. That is, the tag loss rates may be lower if any of the losses between Mission and Sawmill result from factors other that tagging. On the other hand, if harvest rate is overestimated (due to an underestimate of fish passing Mission), then tag loss rates may be higher than those reported here. For example, the negative tag loss rates for Late-run sockeye in earlier versions of Table 5 were consistent with the later finding that the in-season estimates from the Mission hydroacoustic system were only 46% of the final post-season estimate.

Effects of handing time on survival

In the marine areas, 184 of the radio-tagged fish were released immediately after tagging. Other fish (n=61) were held for extended periods after tagging because another fishing set was underway, and to release the fish would result in their immediate recapture. The remaining 415 sockeye were held after tagging in a tank with circulating seawater and released immediately after they were able to right themselves (and the next set was complete). The total handling time (from the time a fish was put in the V-shaped trough to release) for these 415 fish ranged from 1:58 to 14 minutes (median 4 minutes; 88% of fish were held < 5 minutes; Figure 5). For the 184 fish released immediately after tagging, the total handling time ranged from 1:27 to 3:38 minutes (median 2:03 minutes; Figure 5).

Because several different holding strategies existed for the first marine release group, the three marine release groups were analyzed separately. "Holding type" (levels were "held to recover", "held while fishing" and "released immediately") was included as a categorical variable in the logistic model for the first marine release group. This logistic regression showed no statistically significant interaction term (χ^2_2 = 4.5; P = 0.10), thus it was eliminated from the model, and the model was re-run. Examination of the main effects showed no statistically significant effects of holding type (χ^2_2 = 3.4; P = 0.18; Figure 6) or of handling time (χ^2_1 = 2.7; P = 0.13). For the second marine tagging session, the logistic regression showed no statistically significant effects of handling time (χ^2_1 = 0.6; P = 0.44). For the third marine tagging session, there were three (of the 177) that were held for 24 to 30 minutes while fishing; all of which survived to Mission. Once these three fish were excluded from the model for the third marine sampling week, there was a significant negative effect of handling time (χ^2_1 = 5.2; P = 0.02; Figure 7).

At the in-river tagging site, all fish were released from the beach immediately after tagging. The total handling time ranged from 1:02 to 3:15 minutes (median 1:30 minutes; Figure 8). A logistic regression was run to determine the effect of handling-time on survival of fish tagged in-river. At first, a fully-factorial two-way logistic regression was run, but since the "tagging period X handling time" interaction term was not statistically significant (χ^2_6 = 2.9; P = 0.82), it was eliminated from the model. The reduced model revealed significant effects of tagging period (χ_6^2 = 14.7; P = 0.02; Figure 5), but no statistically significant effects of handling time (χ_1^2 = 1.9; P = 0.17).

DNA stock assignments and straying

Prior to the arrival of radio-tagged sockeye in known stock areas, DNA microsatellite analyses provided estimates of stock origins for all but 2 of the radio-tagged sockeye (2 samples were lost). Radio-tracking allowed the assessment of the accuracy of the DNA-based stock-classifications. In total, 269 radio-tagged sockeye with DNA-based stock assignments were tracked as far as, or were captured from spawning destinations or their tributaries[1]. The radio-tracking data indicated the DNA analysis assigned radio-tagged fish to the correct run-timing group 94.8% of the time (Table 6). Late-run stock groups provided the largest sample, and 95.7% of the DNA stock assignments for these fish were consistent with the tracking data for this group. These DNA stock assignments were combined with the detailed tracking results to determine the final distribution for each stock.

Mission escapement

The adjusted run-timing and abundance of sockeye that passed the Mission hydroacoustic site is shown in Figure 9. The timing of radio-tagged fish passing Mission (Figure 10 and Figure 11) approximately followed that of sockeye escapement, but the latest part of the run (fish that passed Mission after 9 Sept) was under represented by radio-tags.

Some fish held in the Strait of Georgia before entering the river, hence the daily stock composition at Mission was not expected to precisely follow that for the tagging sessions. The proportion of tagged fish that were part of the Late-run timing groups was 0% for the first two passage periods, ranged from 15% to 36% for Periods 3-5, from 47% to 56% for Periods 6-7, and from 92% to 100% for the last three periods (Figure 12).

The majority of the Late-run sockeye in 2006 (60.9%) were categorized as being part of the Lower Adams stock (Figure 13). Shuswap and Little River stocks were the next most abundant (19.8%, and 11.7%, respectively). The other Late-run stocks made up only 7.7% of the total number of Late-run sockeye tagged.

River-entry timing

Mission Passage Timing was used as a surrogate for River Entry Timing. Median travel times to Mission were significantly longer for fish released at Juan de Fuca than for those released in Johnstone Strait. For Early-summer and Summer-run sockeye tagged during the first tag-period, median travel time from Juan de Fuca to Mission was 8.7 days, whereas that from Johnstone Strait was 6.7 days (χ_1^2 = 7.3; P = 0.007). Similarly, Late-run sockeye tagged during the first tag-period took more time to travel from Juan de Fuca to Mission (13.9 days) than those

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[1] The number, 269 includes fish that reached a spawning area, but which subsequently either drifted downstream (n=21), or were removed in a fishery (n=4). Although not considered "spawners", these fish were considered a part of the spawning stock for the purposes of the DNA accuracy analyses. To note, there was one fish (an Early Stuart) that reached a spawning destination, but for which no DNA clip was taken. From these data, the total number of fish that ended in spawning areas could be calculated as 245 (269 - 21 - 4 + 1). Two of the 245 fish were classified as Birkenhead fish, hence do not appear in Table 9.

released in the Johnstone Strait (9.0 days; χ_1^2 = 12.2; *P* = 0.001). Subsequent comparisons of migratory timing among release groups use adjusted travel times for Juan de Fuca fish, where the adjustment was the run-timing-group-specific median difference in first-release-group travel times between release sites (2.0 days for Early-summer and Summer-run, and 4.8 days for Late-run).

Median travel times of Early-summer and Summer-run sockeye from Johnstone Strait to Mission were very similar among release groups (Figure 14). During the first, second and third tagging intervals, median travel times were 6.7, 6.9 and 6.7 days, respectively (χ_2^2 = 1.2; *P* = 0.6). Conversely, there were significant differences in median travel times among release groups for Late-run sockeye (Figure 14). Late-run sockeye released in Johnstone Strait during the first tagging interval (11-12 Aug) had significantly faster travel times (9.0 days) than those released during the second and third release groups (12.0 and 12.1 days, respectively; χ_2^2 = 13.6; *P* = 0.001). This difference in travel time is interpreted as a difference in river-entry timing, and hence in the amount of time spent holding in marine water before entering the Fraser River.

Additional differences between the Summer-run and Late-run stocks are revealed by the distribution of travel times from the release sites to Mission for each of the three release groups (Figure 14). Most of the Late-run fish in the first release group that entered the Fraser River passed Mission within 12 days of release (82%). Four fish from the first release group took more than 3 weeks to reach Mission. The travel times for the second release group were bimodal, with 63% of the tagged fish entering Fraser River in less than 12 days. The travel times for Late-run fish in the third release group were unimodal again, with most (97%) of this group passing Mission after the Summer-run.

Early-summer and Summer-run sockeye moved steadily and consistently between the release sites and Mission throughout the season (Figure 15). The daily abundance estimates for Early-summer and Summer-run sockeye obtained from the Mission hydroacoustic site were consistent with patterns observed for the radio-tagged fish. For Late-run stocks, river entry timing was different than the release timing (Figure 16). The first Late-run fish from marine releases passed the Mission site in mid-August and all of the tagged fish in this group were released during the first tagging period. The next pulse of Late-run fish that passed Mission in late-August included tagged fish primarily from the second tagging period. The peak entry period for Late-run fish was 4-8 September when 33% of the Late-run escapement passed Mission. This latter part of the run contained tagged fish from the second and third release periods but primarily from the third release. The daily migration of tagged Late-run sockeye at Mission tracked the total escapement of Late-run sockeye estimated from the Mission hydroacoustic system and DNA stock composition estimates from test fisheries (Figure 16).

Delay behaviour of Late-run sockeye

For the first two marine tagging periods, most Summer-run sockeye migrated past Mission within 12 days of release. As a result, Late-run sockeye released during the first two marine tagging periods that took less than 12 days to reach Mission were termed "early entry," whereas those that passed Mission more than 12 days after release were termed "late entry" fish.

All Summer-run sockeye released during the third marine tagging period migrated past Mission within 9 days (Figure 14). Hence, Late-run sockeye released during the third marine tagging period that took less than 9 days to reach Mission were termed "early entry," and those that passed Mission more than 9 days after release were termed "late entry" fish.

Delay periods for late-entry fish ranged from 4-14 days, with later release groups showing increasingly shorter holding periods (Table 7). The portion of late-run sockeye in each release group that entered the Fraser River without delay was relatively high for the 1st release group (79%) and decreased as the season progressed (37% for the 2nd and 3% for the 3rd release group).

In-river migration rates

Movement rates between Mission and the Thompson Junction were significantly faster for Early Stuart (median = 36.7 km/d), Early Summer (median = 28.1 km/d) and Summer-run sockeye (median = 29.5 km/d) than those for Late-run fish (median = 22.8 km/d; χ_3^2 = 39.1; $P <$ 0.0001; Table 8: Figure 17) significant differences were observed between the migration rates for Early Stuart, Early Summer and Summer-run sockeye for reaches between Mission and the Thompson Junction.

Within the Thompson River, migration rates for Early Summer sockeye (median = 25.3) were significantly faster than those for Late-run stocks (median = 15.6 km/d; χ_1^2 = 35.4; $P <$ 0.0001; Table 8; Figure 17).

Survival Estimates

Survival rates for sockeye migrating from Mission to their respective spawning areas were derived by dividing the number of fish with last detections in the vicinity of a spawning area by the number of tagged fish that remained after tagging related losses and estimated fishery removals. The last detection zones were shown by stock and run-timing group in Table 9. Fish were assumed to have survived to their spawning areas if their last detections were at fixed stations (or during mobile tracks) adjacent to the spawning tributaries (see shaded areas in Table 9).

Survival rates (after harvest) varied among run-timing groups (Table 10). Survival of Early Summer sockeye (51.9%) was significantly lower than that for Late-run fish (72.0%; Z = -3.7; *P* = 0.0014; Figure 17). Survival estimates for Early Stuart and Summer-run sockeye were 67.2% and 67.1%, respectively. No other pair-wise differences between run-timing groups were statistically significant. The confidence bounds around the Early Stuart estimates were large due to limited sample size (n = 17). Because of the temporal variability in fishery openings, harvesting effort was not spread evenly among the run-timing groups, hence the Mission-to-spawning survival rates varied more widely than after-harvest survival rates (Figure 18).

Late-run survival to Mission (after harvest) varied among marine release groups (Figure 19). Survival of the first Johnstone Strait release group (25.3%) was significantly lower than that of the second (45.3%) and third (54.4%) Johnstone Strait release groups (Z = -2.4 and -3.5, respectively; $P \leq 0.016$). Survival differences between the second and third release groups were not statistically significant (Z =-1.5; *P* = 0.13).

Fate of radio-tagged sockeye

The fates of radio-tagged sockeye last detected downstream of Sawmill are shown in Figure 20. When recoveries and dropbacks are excluded, the pattern of last detections coincides for the most part with the temporal pattern of harvest. As such, many of the missing fish could easily have been fishery removals.

The fates of radio-tagged sockeye are shown by last detection location and by run timing group in Figure 21. The highest rates of en-route loss were observed in two places. First, there was a relatively high rate of en-route loss for Summer-run fish that passed Bridge River (i.e., relatively few of these fish subsequently survived to pass the Chilcotin Site). In 2007, an additional receiver will be deployed between Bridge River and Chilcotin in order to further resolve the location (and hence nature) of these en-route losses. Second, there were relatively high rates of en-route loss for Early-Summer and Late-run sockeye that passed Spence's Bridge (and never arrived at the receiver site at the top of Kamloops Lake). Pre-spawn morality rates in the Thompson drainage in 2006 were unexpectedly high, with large numbers of un-spawned fish being found on the banks of area lakes and rivers (Keri Benner, pers. com.). The cause of the mortality has not been identified, but may have been temperature related. Figure 22 shows the temporal pattern in survival of fish passing Spence's Bridge. Temporal trends in thermal data show that temperatures were 1-2 degrees higher than normal during the early parts of the run, when mortality rates were highest. Figure 23 shows an example of a thermal profile experienced by a successful fish. The temperature logger, which was glued to the gastrically inserted radio tag, was collected from a fish on the Scotch Creek spawning ground.

River entry timing versus survival of late-run sockeye

As in prior years, Late-run sockeye in-river survival rates increased over the course of the study period (Figure 24). For late-run fish that passed Mission during the first two passage periods in August, survival was near zero. For the remaining passage periods in August, late-run survival rates fell between the survival curves fit to the 2002 and 2003 data (Figure 24). Late-run survival rates for Mission passage Periods in September fell on the 2002 survival curve.

All of the 2006 survival estimates were likely biased high. In previous years, fish that passed Little River in late September that were detected near the mouth of the Adams River but that did not migrate upstream of the receiver, were not classified as survivors to a spawning area. In 2006, all fish detected at Little River were classified as surviving to a spawning area (see Appendix D for details). Nevertheless, it is known that many of the fish that reached Little River, especially early in the season, were pre-spawn mortalities (see Appendix D). Moreover, DFO field survey personnel staff observed higher levels of pre-spawn mortality later in the spawning period than in previous years (Keri Benner, DFO Kamloops, pers. comm.). Therefore, the true survival rates for 2006 probably lie closer to the 2003 curve than the 2002 curve.

DISCUSSION

River entry timing

The river entry timing for Summer-run sockeye was consistent with historical timing (Appendix Figure E1). The adjusted Mission escapement estimates for 2006 indicated that 50% of the Summer-run fish had passed Mission by 17 August. This date was only slightly later than the historical (1974-2002) median date for the Chilko stock(13 August), a Summer-run stock for which robust historical data exist.

The median Mission timing for 2006 Late-run stocks deviated considerably from historical trends. In 2006, the median dates for Adams and Weaver stocks (5 and 7 September, respectively) were earlier than observed in the previous dominant cycle year (12 and 16 September in 2002), and substantially earlier than the historical median dates (Appendix Figure E1). Prior to 1995, the median Mission timing date was 24 September for Adams-Shuswap Late-run stocks, and 4 October for the Weaver Creek stock. From 1995-2003, the run timing for Weaver sockeye varied considerably (range 13 August - 16 September), with some median dates that were earlier than any other year on record (Appendix Figure E1). In 2000, the Late-run Weaver stock passed Mission at about the same time as the Summer-run Chilko stock, and managers estimated that >90% of the Weaver stock died prior to spawning (Jim Gable, PSC, pers. comm.). The timing of the Adams River stock (data available only for dominant and sub-dominant cycle years[1]) appears to have followed that of the Weaver stock, even after 1995.

Delay behaviour

In 2006, the Late-run sockeye showed reduced river-entry delaying behaviour relative to historical trends. Annual estimates of the median travel time from Juan de Fuca to Mission for Late-run sockeye have historically been derived by comparing the median migration dates through the Juan de Fuca Strait and that for the Mission hydroacoustic site. From 1974 to 1994, the median of these annual travel time estimates for Shuswap and Weaver Creek stocks were 38 d and 50 d, respectively. From 1995-02 travel time estimates for dominant and sub-dominant Shuswap sockeye were fairly consistent (26-30 d) while estimates for Weaver sockeye were more variable (7-36 d). In 2003, travel time estimates were reduced to 13 d and 16 d for Shuswap and Weaver, respectively. Similarly, the median Area 20 and Mission passage dates in 2006 were separated by 13 and 15 days for Adams and Weaver stocks, respectively.

Radio-telemetry data have shown that delay behaviour can vary substantially among individual fish and among timing components. For example, some of the Late-run sockeye tagged in early August 2006 took less than 6 days to migrate from marine tagging locations to Mission. These fish must have entered the river with little or no delay. Nevertheless, other fish tagged during the same period took greater than 20 days to cover this distance.

Radio- telemetry data have also provided evidence that there is complexity in the delay behaviour of Late-run sockeye that cannot be described by simply comparing median dates for the run passing Area 13 (and Area 20) to that at the Mission hydroacoustic site. The portion of the late-run sockeye that exhibited delay behaviour increased with arrival date in all three study years (2002, 2003 and 2006). In each year, the portion of the radio-tagged fish that delayed prior to river entry was lowest for the first marine release group (37%, 23% and 21% for 2002, 2003 and 2006, respectively), and was higher for subsequent release groups. These early-entry Late-run fish may have been responding to the abundance of Summer-run sockeye in the straits. In fact, their tracking data of early entry Late-run fish showed movements that were similar to co-migrating Summer-run sockeye, suggesting that they may have schooling with Summer-run stocks. There may be other factors contributing to the observed complexity in delay behaviour. For example, a large pulse of fish moved past Mission around 7 September, possibly responding to some physical cues (e.g., tidal cycle) that may have stimulated river-entry. This pulse of fish contained fish from multiple release groups (Figure 16), thus average delay times for the later release groups were reduced relative to earlier release groups. That is, fish that arrived in the

[1] The abundance of the Adams River stock fluctuates with a persistent 4-year cycle (dominant, sub-dominant, low, low).

strait a few days before the large ingress would have shorter delay periods compared to fish that had milled in the strait for several weeks before being induced by the physical cues to enter the river.

A preliminary assessment of the SWTS hypothesis is provided in a subsequent section. A thorough evaluation of the SWTS hypothesis and potential factors that could influence the peak river entry timing for late-run stocks in September will be included in the final report prepared by the interdisciplinary Late-run sockeye research team.

In-river migration rates

The migration speeds for Summer-run sockeye between Mission and Quesnel (median = 35 km/d) in 2006 were slightly slower than those estimated from the 2002-2005 radio-telemetry data. The median migration speeds for the radio-tagged Summer-run sockeye detected at the Mission and Quesnel Junction monitoring sites were 43 km/d, 40 km/d and 44 km/d in 2002, 2003 and 2005, respectively. Historical data on travel times from the PSC hydroacoustic site at Mission and daily counts of the escapement into Quesnel Lake were used to compute the average annual in-river migration rate for Summer-run stocks. Comparison of the 50% passage dates at Mission and Likely (near the outlet of Quesnel Lake) produced annual travel times of 14-19 d (mean 15.8 d) for the available data for 1993-2001. This is equivalent to a migration speed of 41.5 km/d and 13.2 d between Mission and the Quesnel Junction.

The migration speeds for Late-run sockeye between the Thompson Junction and Little River (16 km/d) in 2006 were slower than those estimated from the 2002 and 2003 radio-telemetry data (22 km/d). Historical estimates for Late-run stocks migrating to the Shuswap Lake watershed are very limited, but some fishery managers observed that Late-run sockeye tend to migrate slower than Summer-run sockeye. Estimates from tagging studies in the 1940's showed a travel rate between Hell's Gate and the Adams River of 27 km/d (Killick 1955).

In each telemetry study year, the migration rates for Summer-run fish were faster than those for Late-run fish through the same section of river. In 2002, migration speed between Mission and the Thompson Junction was 38 km/d for Summer-run fish compared to 20km/d for Late-run sockeye. In 2003, comparable migration rates were 35 km/d for Summer-run fish versus 21 km/d for Late-run fish. In 2006, summer-run stocks were slower through this reach (29 km/d) but still faster than Late-run stocks (23 km/d).

Survival in marine waters

The vast majority of the radio tags accounted for were detected at fixed-station sites or removed by fisheries in the lower Fraser River. As such, the portion of each release group that was accounted for can be used as an indicator of survival in coastal marine waters. These survival rates account for capture, handling and tagging effects as well as natural mortality. The bright orange cinch tags applied to all radio-tagged sockeye in 2002 were not applied in 2003 or 2006 to ensure that the radio-tagged fish were not more visible to predators than untagged sockeye. This, combined with higher abundance during the 1st release period, could explain the higher marine survival for these releases in 2003 (46%) and 2006 (40%) than those released during the 1st release period in 2002 (35%). However, marine survival rates for the 2nd and 3rd release periods in 2006 (50% and 58%), while higher than the 1st period, were lower than the rates estimated for similar periods in 2002 (74-75%) and 2003 (66-68%). It was hypothesized in 2002 that the differences between the estimates for each release period may be induced by the relative changes in total sockeye abundance. While the observed differences in marine survival within years is likely related to changes in sockeye abundance and fishing intensity, differences between years are more likely the results of other factors including: the addition of physiological sampling in 2003 and 2006, changes to release procedures, and variability in fish condition.

In 2003, physiological samples (blood, gill tissue and two fat probe readings) were obtained from 77% of the radio-tagged sockeye. In 2006, an increased emphasis on physiological sampling and the addition of gene array analysis resulted in the above samples plus a muscle core sample and 10 additional scales being obtained from all marine-tagged fish. Comparisons of survival rates for radio-tagged fish with and without physiological sampling in 2003 and 2005, were unable to detect a significant difference in the survival rate between these two groups, but overall survival of fish that were physio-sampled was 5-6% lower than those not sampled during the same release period (English et al. 2004; Robichaud and English 2006).

Another change in the marine tagging procedures in 2006 was a reduction in the post-tagging holding interval prior to release. In 2002 and 2003, radio-tagged sockeye were generally held for 20-30 minutes after tagging so they could be release along with untagged sockeye from the next seine set. The 2006 study design called for the "immediate" release of all tagged fish because of the higher survival (81%) observed for 178 acoustic tagged sockeye release without holding during the 2nd and 3rd release periods in 2003 (English et al. 2004). Concerns regarding the recapture of tagged fish in the next seine set resulted in variability in the holding times for marine releases in 2006. Statistical comparisons between the survival rates for fish with different handling times indicated a significant negative effect of handling time for some groups. This result is consistent with the 2003 observation of 14% higher post-release survival for acoustic tagged fish where handling time was less than 3 minutes. Other studies have also documented higher relative survival for radio-tagged fish released immediately after tagging than for those held or transported in recovery tanks (Alexander et al. 1996).

A detailed assessment of the effect of variability in fish condition on post-release survival will be included along with the other physiological sampling results in a companion report prepared by others members of the interdisciplinary Late-run sockeye study team.

Survival from Mission to spawning areas for Late-run stocks

As observed in 2002 and 2003, the radio-tagged Late-run sockeye that passed Mission in August had a much lower probability of survival to their spawning areas than those that passed Mission in September. These results are consistent with the 2000 and 2001 observations of higher pre-spawn mortality when a large portion of the Late-run sockeye entered the Fraser River in August.

English et al. (2003) suggested that changes in environmental factors could affect spawning timing and/or the development of the mortality agent, thus shifting the survival-vs.-entry-date curve to the left or right. It was hypothesized that higher water temperatures could increase the rate of development of the mortality agent (such as a parasite) thus decreasing survival (i.e., shifting the curve to the right). Fraser River water temperature data were obtained for the period when Late-run sockeye were migrating upstream in 2002, 2003 and 2006 (i.e., 10 August through 30 September). These data showed that average water temperatures measured in 2003 on the Fraser River near Hope and on the Thompson River near Chase were only slightly higher than those measured in 2002 for the same Late-run migration period. Daily temperature data from a monitoring site near Ashcroft in 2006 combined with individual sockeye temperature log data strongly indicated that accumulated temperature units (ATUs) played a significant role in determining survival to spawning areas and spawning success in 2006. Other research has shown that water temperature is a key determinant of survival for Late-run sockeye infected with *Parvicapsula* (Simon Jones, DFO, pers. comm.). In 2006, DFO increased the number of temperature monitoring stations within the Fraser Watershed. This combined with the ibutton and tracking data for recovered radio-tagged fish provided a unique opportunity to assess the effect of river and lake temperatures on migration rates and spawning success. A detailed assessment of the relationship between water temperatures, migration timing and spawning success will be included in separate report prepared by members of the interdisciplinary Late-run study team.

The radio-telemetry data collected in 2002, 2003 and 2006 confirm that river entry time is related to subsequent in-river survival of Late-run sockeye. While further investigations may be desirable to increase our confidence in this relation and to explain observed variability in survival between stocks (e.g., Shuswap versus Weaver), the available observations should be considered when formulating fishery management plans. The survival curves derived from the 2002 and 2003 studies were used in 2006 to provide in-season predictions of en-route mortality for Late-run sockeye. PSC in-season estimates of abundance for Early-summer, Summer-run and Late-run stocks were used in the SWTS Model to project Mission passage timing for Late-run stocks. These were combined with the survival rate predictions from the 2003 survival curve to estimate en-route mortality several times during the 2006 fishing season (Aug. 1, 22, 26, Sep. 1 and 29). The en-route mortality estimates computed on these dates were 27%, 21%, 29%, 29% and 32%. The PSC in-season run size estimates for the combined Early-summer and Summer-runs varied from 3 to 8 million while the Late-run estimates varied from 5 to 10 million fish. Our best estimate of survival for Late-run sockeye from Mission to spawning areas, excluding fishery removals, is 72.0%. This estimate is consistent with a 28% pre-spawn mortality estimate and very close to the in-season predictions made on Aug. 26 and Sep. 1 (prior to the PSC decreasing the project run size for Late-run stocks).

Evaluation of the Stay with the School hypothesis

To evaluate the stay with the school hypothesis required variance in the ratio of Late-run to Early-summer/Summer-run sockeye among the three marine tagging intervals. For this study, the proportion of Late-run sockeye increased steadily over time, and Late-run : (Early Summer + Summer-run) ratios (“LR:ES/SR”) for the three marine tagging intervals were: 0.5, 2.2, and 6.5. The increasing trend holds when Juan de Fuca samples were ignored (ratios would be 1.4, 2.2, and 6.5).

Given variability in the LR:ES/SR ratio, it was possible to test the hypothesis that Late-run sockeye would have earlier river-entry timing during periods of elevated Early-summer and Summer-run abundance. Late-run sockeye released in Johnstone Strait during the first tagging interval had significantly faster median travel times to Mission (9.0 days) than those released during the second and third groups (12.0 and 12.1 days). It appeared that Late-run fish released during periods of high Early-summer and Summer-run abundance held in marine water for less time than those that were released during periods when Late-run sockeye were more dominant in the Strait.

The median travel time for the second release group was the mid-point between those fish that entered the Fraser with little or no delay and those that entered during the peak upstream migration period for Late-run sockeye associated with the full moon and high tides in early September. The median time for the third release group reflected the time between the third tagging period and the peak migration days in early September. In 2002, the peak migration period for Late-run sockeye was 10 d later than that observed in 2006 and the median travel time from release to Mission for the third release group was 23 days in 2002 versus 12 days in 2006.

Survival estimates and en-route losses

Sockeye tracking data from 2006 identified a number of locations where significant numbers of tagged fish were either removed by fisheries or were en-route mortalities due to natural causes or fishery related factors. Harvest data, tag returns and tracking data indicated that the majority of fishery related removals or mortalities occurred in the lower Fraser below Sawmill Creek or in the fisheries near Lillooet. The most important location for en-route mortalities for Early-summer and Late-run stocks was between Spence’s Bridge and Kamloops while the largest en-route losses for Summer-run stocks occurred between Bridge River Rapids and the Chilcotin-Fraser junction. The en-route mortalities for Early-summer stocks migrating through the lower Thompson River were fairly evenly distributed throughout the run. All the radio-tagged sockeye from these Early-summer stocks migrated past the Spence’s Bridge monitoring site prior to 12 September, during periods with above normal temperatures (18-19.5 ^{o}C). For Late-run stocks destined for spawning areas in the Thompson drainage, the en-route mortality rates were highest for those fish that passed Spence’s Bridge during this high temperature period; and mortality rates dropped substantially for the later portion of the Late-run, which migrated through the Lower Thompson River in mid-September, after the temperatures declined to more normal levels (15.5-16.5 ^{o}C; Figure 22).

Detailed migration histories for the 123 Late-run sockeye tracked to the vicinity of a spawning area (Little River station) were compared to 43 Late-run sockeye last detected at the Spence’s Bridge station (Figure 25). Similarly, the tracking data for the 29 Early-summer sockeye tracked passed the Little River site were compared to the 16 fish last detected at Spence’s Bridge (Figure 26). It can be seen from these figures that all of the Late-run sockeye and most of the Early-summer sockeye last detected at Spence’s Bridge were migrating at speeds typical of successful migrants. These data suggest that something other than the health of the tagged fish prior to entering the Thompson system affected their migration success. Given the above normal water temperatures measured during the period when most of the mortalities occurred, high water temperature may have been the primary cause of these en-route losses.

In 2006, a fixed-station receiver was installed for the first time at the top end of the Bridge River Rapids fishway. In prior years, considerable en-route loss had occurred between the Seton and Chilton junctions with the Fraser. The new receiver was installed to help resolve the location and hence cause of the losses in this reach. That is, it would determine whether the losses occurred upstream or downstream of the Bridge River Rapids. Of the 135 sockeye that passed the Seton station in 2006, 100 survived to pass Chilcotin. Of the 35 that did not pass Chilcotin, 25 were last detected at Bridge River, and 10 were last detected at Seton. Since three fish passed Seton before the Bridge River site was deployed, the total number of fish last detected at Bridge River could have been as high as 28 (20.7% of the fish that passed Seton).

Of the 125 fish that passed the Bridge River station, 8 fish (6.4%) dropped back downstream (3 to Thompson junction, 4 to Seton and 1 re-ascended and was last detected at the Bridge River station). In addition to these drop back fish, 13 (10.4%) were last detected at the

Bridge River station. It is possible that some of the fish last detected at the Bridge River station could include fish that dropped back down, but not far enough to be detected at Seton.

In four years of radio-tagging and tracking Summer-run sockeye (2002, 2003, 2005, and 2006), similar proportions of the Summer-run sockeye that passed Mission (11.4%, 8.6%, 10.7%, and 10%, respectively) were last detected between Thompson and Chilcotin (see English et al. 2003; 2004; and Robichaud and English 2006). Given the uncertainties regarding the fate of the fish last seen in the Lillooet area, it is recommended that a site be identified between Bridge River and the Chilcotin to deploy another station to further narrow down the location of losses for this section of the river.

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TABLES

Table 1. Summary of the 2006 radio tag releases by date, tagging period and tag site.

	Marine Tagging Periods					In-River Tagging Periods								
	JDF	Johnstone St.												Grand
Date	MA1	MA1	MA2	MA3	Total	IR1	IR2	IR3	IR4	IR5	IR6	IR7	Total	Total
9 Jul						1							1	1
14 Jul						9							9	9
15 Jul						3							3	3
16 Jul						6							6	6
23 Jul							1						1	1
24 Jul							11						11	11
25 Jul							3						3	3
1 Aug								30					30	30
2 Aug								30					30	30
3 Aug								25					25	25
6 Aug	41				41									41
7 Aug	52				52									52
8 Aug	60				60				36				36	96
9 Aug	56				56				16				16	72
10 Aug	27				27				54				54	81
11 Aug		40			40									40
12 Aug		22			22									22
14 Aug										25			25	25
15 Aug										38			38	38
16 Aug			46		46					3			3	49
17 Aug			49		49									49
18 Aug			34		34									34
19 Aug			56		56									56
20 Aug											4		4	4
21 Aug											9		9	9
22 Aug											8		8	8
24 Aug				45	45									45
25 Aug				47	47									47
26 Aug				44	44									44
27 Aug				41	41									41
30 Aug												6	6	6
31 Aug												43	43	43
1 Sep												17	17	17
Total	236	62	185	177	660	19	15	85	106	66	21	66	378	1038

Table 2. **Numbers of radio-tagged sockeye that passed and that were detected passing the fixed-station receiver sites, 2006. The detection efficiency (the detected/passed quotient) of each receiver is also shown. No terminal zones are included as detection efficiencies for these sites cannot be computed (there are no upstream detection zones).**

Fixed-station Site	Passed	Detected	Detection Efficiency
Mission Bridge	572	452	79.0%
Harrison-Fraser Confluence	548	369	67.3%
Rosedale	510	437	85.7%
Hope	461	444	96.3%
Sawmill	413	412	99.8%
Hells Gate	395	386	97.7%
Thompson-Fraser Confluence	378	369	97.6%
Spence's Br	225	225	100%
Kamloops Lake	159	146	91.8%
Little River	156	156	100%
Seton-Fraser Confluence	133	133	100%
Bridge River	124	97	78.2%
Chilcotin-Fraser Confluence	100	90	90.0%
Quesnel-Fraser Confluence	49	48	98.0%
Nechako-Fraser Confluence	26	15	57.7%

Table 3. Summary of reported and estimated fishery recoveries, tags detected within the Fraser watershed and the percent of the tags applied accounted for from each marine and in-river tagging period, 2006.

	Marine Tagging Periods					In-River Tagging Periods								
	JDF	Johnstone St.				Glenlyon								Grand
	MA1	MA1	MA2	MA3	Total	IR1	IR2	IR3	IR4	IR5	IR6	IR7	Total	Total
Tags applied	236	62	185	177	660	19	15	85	106	66	21	66	378	1038
Reported fishery recoveries below Mission														
Marine														
Canada	7	1	10	2	20									20
US	20		1		21									21
Fraser River Below Mission														
First Nations Fishery	7	1	11	1	20				1	3		1	5	25
Commercial Fishery	4		1		5									5
Sub-total	38	2	23	3	66				1	3		1	5	71
Estimated fishery recoveries below Mission														
Marine + Fraser below Mission	36	8	25	11	80									80
Detections at or above Mission	64	11	68	91	234	16	14	76	98	52	20	62	338	572
Detections Crescent Is	2			1	3	3	1	8	5				17	80
Tags accounted for [3]	101	19	92	103	317	19	15	84	102	51	20	61	355	652
% of tags applied accounted for	43%	30%	50%	58%	48%	100%	100%	99%	96%	77%	95%	92%	94%	63%
Reported fishery recoveries above Mission														
First Nations Fishery	4	1	1	2	8		2	11	11	2		4	30	38
Recreational Fishery	2	1	3		6			4	5	6	1	6	22	28
Sub-total	6	2	4	2	14		2	15	16	8	1	10	52	66
Estimated fishery recoveries above Mission														
First Nations Fishery	7.4	1.4	6.7	2.4	18.0	0.1	3.6	12.4	13.9	6.1	2.7	4.0	42.8	60.8
Recreational Fishery[1]	2.0	1.0	3.0	0.0	6.0	0.0	0.0	4.0	5.0	6.0	1.0	6.0	22.0	28.0
Sub-total	9.4	2.4	9.7	2.4	24.0	0.1	3.6	16.4	18.9	12.1	3.7	10.0	64.8	88.8
Harvest Rate above Mission[2]	15%	22%	14%	3%	10%	1%	26%	22%	19%	23%	19%	16%	19%	16%

[1] Recoveries in recreational fisheries were not expanded because the number of reported tag recoveries was higher than would be estimated for the reported recreational catch.

[2] Estimated fishery recoveries above Mission divided by detections at or above Mission.

[3] Five fish passed Mission, and then dropped back and were caught in fisheries downstream of Mission. These fish are not counted twice.

Table 4. Tag returns, expected tag returns, and tag return rates by Mission Passage Period, and by run-timing group, for radio-tagged sockeye, 2006.

Early Stuart

	Mission-Sawmill Fishery			Above Sawmill		
Passage Period	Tags Returned	Est. Tags Caught	Return Rate	Tags Returned	Est. Tags Caught	Return Rate
1	0.0	0.0	0.0%	0.0	0.1	0.0%
2	1.0	0.7	134.3%	0.0	0.0	
3	0.0	0.1	0.0%	0.0	0.0	0.0%
4	0.0	0.1	0.0%	0.0	0.0	0.0%
5	0.0	0.0		0.0	0.0	
6	0.0	0.0		0.0	0.0	
7	0.0	0.0		0.0	0.0	
8	0.0	0.0		0.0	0.0	
9	0.0	0.0		0.0	0.0	
10	0.0	0.0		0.0	0.0	
Total	1.0	1.0	103.8%	0.0	0.2	0.0%

Summer-run

	Mission-Sawmill Fishery			Above Sawmill		
Passage Period	Tags Returned	Est. Tags Caught	Return Rate	Tags Returned	Est. Tags Caught	Return Rate
1	0.0	0.0		0.0	0.0	
2	0.0	1.1	0.0%	0.0	0.0	
3	4.0	4.0	100.2%	4.0	2.0	203.3%
4	1.0	4.2	23.9%	1.0	1.1	89.9%
5	3.0	6.2	48.1%	3.0	2.4	125.3%
6	0.0	1.6	0.0%	1.0	0.7	135.2%
7	4.0	4.0	99.3%	2.0	0.5	372.3%
8	0.0	0.2	0.0%	0.0	0.1	0.0%
9	0.0	0.0		0.0	0.0	
10	0.0	0.0		0.0	0.0	
Total	12.0	21.3	56.3%	11.0	6.8	161.1%

Early Summer

	Mission-Sawmill Fishery			Above Sawmill		
Passage Period	Tags Returned	Est. Tags Caught	Return Rate	Tags Returned	Est. Tags Caught	Return Rate
1	0.0	0.0	0.0%	0.0	0.0	0.0%
2	0.0	1.6	0.0%	0.0	0.1	0.0%
3	4.0	3.8	104.1%	1.0	0.6	160.6%
4	4.0	3.8	105.4%	3.0	0.6	516.5%
5	4.0	4.8	82.6%	1.0	0.7	149.9%
6	2.0	2.6	76.2%	1.0	0.3	316.6%
7	2.0	2.5	81.1%	1.0	0.3	309.3%
8	0.0	0.1	0.0%	0.0	0.0	
9	0.0	0.0		0.0	0.0	
10	0.0	0.0		0.0	0.0	
Total	16.0	19.3	83.0%	7.0	2.6	267.8%

Late-run

	Mission-Sawmill Fishery			Above Sawmill		
Passage Period	Tags Returned	Est. Tags Caught	Return Rate	Tags Returned	Est. Tags Caught	Return Rate
1	0.0	0.0		0.0	0.0	
2	0.0	0.0		0.0	0.0	
3	1.0	0.7	135.8%	1.0	0.3	286.8%
4	5.0	4.2	119.0%	2.0	0.6	348.9%
5	1.0	2.3	44.0%	1.0	0.7	146.0%
6	2.0	5.3	38.0%	1.0	1.5	68.6%
7	3.0	3.9	76.0%	0.0	1.1	0.0%
8	0.0	1.1	0.0%	1.0	0.7	149.8%
9	0.0	0.0		0.0	0.1	0.0%
10	0.0	0.0		0.0	0.0	0.0%
Total	12.0	17.6	68.3%	6.0	5.0	120.7%

Table 5. Tagging-related en-route loss (i.e., tag loss and tagging effects) between Mission and Sawmill, by run-timing group and Mission Passage Period, 2006.

Early Stuart

Passage Period	Tags Passing Mission	Est. Catch of Tags	Pooled HR for Miss-Saw	Tags at Sawmill Pred.	Tags at Sawmill Obs.	Tags at Sawmill (tag loss) Diff.	Tagging Effects
1	13	0.0	0.1%	13.0	12	1.0	8%
2	2	0.7	37.2%	1.3	0	1.3	63%
3	1	0.1	9.8%	0.9	1	-0.1	-10%
4	1	0.1	10.6%	0.9	1	-0.1	-11%
5	0	0.0		0.0	0	0.0	
6	0	0.0		0.0	0	0.0	
7	0	0.0		0.0	0	0.0	
8	0	0.0		0.0	0	0.0	
9	0	0.0		0.0	0	0.0	
10	0	0.0		0.0	0	0.0	
Total	17	1.0	5.7%	16.0	14	2.0	12%

Summer-run

Passage Period	Tags Passing Mission	Est. Catch of Tags	Pooled HR for Miss-Saw	Tags at Sawmill Pred.	Tags at Sawmill Obs.	Tags at Sawmill (tag loss) Diff.	Tagging Effects
1	0	0.0		0.0	0	0.0	
2	4	1.1	26.4%	2.9	0	2.9	74%
3	33	4.0	12.1%	29.0	22	7.0	21%
4	42	4.2	10.0%	37.8	30	7.8	19%
5	47	6.2	13.3%	40.8	34	6.8	14%
6	20	1.6	8.0%	18.4	17	1.4	7%
7	30	4.0	13.4%	26.0	21	5.0	17%
8	4	0.2	5.2%	3.8	4	-0.2	-5%
9	0	0.0		0.0	0	0.0	
10	0	0.0		0.0	0	0.0	
Total	180	21.3	11.8%	158.7	128	30.7	17%

Early Summer

Passage Period	Tags Passing Mission	Est. Catch of Tags	Pooled HR for Miss-Saw	Tags at Sawmill Pred.	Tags at Sawmill Obs.	Tags at Sawmill (tag loss) Diff.	Tagging Effects
1	3	0.0	0.1%	3.0	2	1.0	33%
2	7	1.6	23.3%	5.4	1	4.4	62%
3	23	3.8	16.7%	19.2	14	5.2	22%
4	23	3.8	16.5%	19.2	16	3.2	14%
5	27	4.8	17.9%	22.2	16	6.2	23%
6	12	2.6	21.9%	9.4	7	2.4	20%
7	16	2.5	15.4%	13.5	12	1.5	10%
8	1	0.1	6.0%	0.9	0	0.9	94%
9	0	0.0		0.0	0	0.0	
10	0	0.0		0.0	0	0.0	
Total	112	19.3	17.2%	92.7	68	24.7	22%

Late-run

Passage Period	Tags Passing Mission	Est. Catch of Tags	Pooled HR for Miss-Saw	Tags at Sawmill Pred.	Tags at Sawmill Obs.	Tags at Sawmill (tag loss) Diff.	Tagging Effects
1	0	0.0		0.0	0	0.0	
2	0	0.0		0.0	0	0.0	
3	10	0.7	7.4%	9.3	8	1.3	13%
4	37	4.2	11.4%	32.8	16	16.8	45%
5	18	2.3	12.6%	15.7	16	-0.3	-2%
6	42	5.3	12.5%	36.7	35	1.7	4%
7	47	3.9	8.4%	43.1	40	3.1	6%
8	80	1.1	1.4%	78.9	73	5.9	7%
9	9	0.0	0.0%	9.0	9	0.0	0%
10	5	0.0	0.0%	5.0	5	0.0	0%
Total	248	17.6	7.1%	230.4	202	28.4	11%

All four tables are headed "Estimation of Tagging Effects (Mission to Sawmill)".

Table 6. DNA classification accuracy for Fraser sockeye run-timing groups assessed using radio-telemetry data.

	Final Run-timing Group					
DNA Assignment	Early Stuart	Early Summer	Summer	Late-run	Birkenhead	% correct
Early Stuart	6	0	0	0	0	100.0%
Early Summer	0	34	0	1	0	97.1%
Summer	1	1	72	5	0	91.1%
Late-run	0	0	5	134	1	95.7%
Birkenhead	0	0	0	0	8	100.0%
Lake Washington	0	0	1	0	0	0.0%
Overall	85.7%	97.1%	92.3%	95.7%	88.9%	94.8%

Table 7. Estimates of median travel times to Mission and holding periods in Georgia Strait for Late-run sockeye, by entry timing group and release period. Early-entry and late-entry stocks respectively entered the Fraser River with or after the Summer-run stocks.

	Early Entry *			Late Entry **			Delay (d)		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Median travel time (d)									
Johnstone Strait - Mission[1]	8.0	9.0	7.8	21.8	14.2	12.2	13.8	5.1	4.4
Sample Size							% Early Entry		
Johnstone Strait - Mission[1]	26	18	2	7	31	74	79%	37%	3%

[1] The 1st release group included releases from Juan de Fuca and Johnstone Strait and the travel times for Juan de Fuca releases were adjusted to account for observed longer travel times to Mission for these releases (4.8 d for Late-run sockeye).

* time to Mission < 12 d for 1st and 2nd groups; < 9 d for 3rd group

** time to Mission > 12 d for 1st and 2nd groups; > 9 d for 3rd group

Table 8. Travel speeds for radio-tagged sockeye, by run-timing group, 2006.

River Reach	Early Summer	Summer-run	Late-run
Travel speed (km/d)			
Mission - Hope	31.3	31.3	27.4
Mission - Hell's Gate	27.1	28.9	23.8
Mission - Thompson Junction	28.1	29.5	22.8
Mission - Chilcotin		34.3	
Mission - Quesnel		35.3	
Thompson Junction - Spence's Bridge	19.2		13.5
Thompson Junction - Kamloops	22.2		12.8
Thompson Junction - Little River	25.3		15.6
Sample Size (n)			
Mission - Hope	62	119	158
Mission - Hell's Gate	54	99	137
Mission - Thompson Junction	50	93	134
Mission - Chilcotin	2	70	0
Mission - Quesnel	3	27	0
Thompson Junction - Spence's Bridge	46	1	168
Thompson Junction - Kamloops	14	0	123
Thompson Junction - Little River	24	0	122

Table 9. Last detection zone for radio-tagged sockeye, by stock. For each stock, fish are considered to have escaped to a spawning area if their last detection zone was one of those that are shaded in the table. Numbers in stock names correspond to run-timing groups.

	Stocks																												Run-timing Groups			
Last Detection Zone	1-Stuart	2-Adams	2-Bowron	2-Chilliwack	2-Fennell	2-Gates	2-Nadina	2-Nahat	2-Pitt	2-Raft	2-Scotch	2-Seymour	3-Chilko	3-Nechako	3-Quesnel	3-Stellako	3-Stuart	4-Adams	4-Cultus	4-Eagle	4-Harrison	4-Little River	4-Portage	4-Shuswap	4-Weaver	5-Birkenhead	6-LakeWash	n/a	Early Stuart	Early Summer	Summer-run	Late-run
Release Site			1	1	3	2			5	6	26	18	60		21	22	9	101	2	4	14	60	4	5	4	5	4	3	0	62	112	194
Crescent Island	2						2				1		2			5	2	4			2			3				1	2	3	9	9
Mission				1							2	2	3		1			3			1			2					0	5	4	6
Harrison Confluence					1					1	1		5			3	3	1			3			1	1			2	0	3	11	6
Upper Harrison (downstream)																					2				2	1			0	0	0	4
Upper Harrison (upstream)													1								2				3	7			0	0	1	5
Weaver																									0				0	0	0	0
Birkenhead																										2			0	0	0	0
Rosedale	2				2	1					5	6	2		4	4	1	1	1					1					2	14	11	3
Hope							3				2		7		1	8	1	5				2		2					0	5	17	9
Sawmill			1								1	1	2			2		3				1							0	3	4	4
Hell's Gate							2						1		1	1						2		1					0	2	3	3
Thompson Confluence	1				1						1	1	2		1	1	1	5				1		1					1	3	5	7
Spences Bridge											10	6				1		26				9		9					0	16	1	44
North Thompson					1					4																			0	5	0	0
South Thompson																		3											0	0	0	3
Little Shuswap Lake																		5				1							0	0	0	6
Little Shuswap Spawned																						1							0	0	0	1
Little River FS		1									3	5						37		0		9		5				1	0	9	0	51
Adams		0									0	0						36		0		0		0					0	0	0	36
Scotch, Shuswap, Seymour, Eagle		0									12	3						12		0		2		0					0	15	0	14
Lower Shuswap		0																0		0		0		22					0	0	0	22
Seton Confluence	2					2	1						3			1							1						2	3	4	1
Bridge River	1						1						8		3						1								1	1	11	1
Chilcotin Confluence													28		2	1													0	0	31	0
Chilko													16																0	0	16	0
Quesnel Confluence	2		2												2	4	1												2	2	7	0
Mitchell, Horsefly															12														0	0	12	0
Nechako Confluence							0							1		1	2												0	0	4	0
Stuart, Nadina, Stellako, Kynock	8						1							1		10	2												8	1	13	0
Fisheries																																
Marine Fisheries										1	5	4	6		4	3	1	7			2	7		1					0	10	14	17
Freshwater DS of Mission								1	1		3	2	5			4		9				3	1					1	0	7	9	13
Freshwater Fishery US of Mission	1		2		2	1	2			1	9	6	12		5	5	1	12		1		1		4				1	1	23	23	18
Totals																																
Total Below Mission	2	0	1	1	3	2	2	1	6	7	35	24	73	0	25	34	12	121	2	4	18	70	5	9	4	5	4	5	2	82	144	233
Total at or Above Mission	17	1	5	1	7	4	10	0	0	6	46	30	90	2	32	42	12	149	1	1	9	29	1	48	6	10	0	4	17	110	178	244
Fates																																
Above Mission Fisheries	1	0	2	0	2	1	2	0	0	1	9	6	12	0	5	5	1	12	0	1	0	1	0	4	0	0	0	1	1	23	23	18
Escapement to Spawning Grounds	8	1	2	na	1	2	1	na	na	4	15	8	44	2	14	11	4	85	na	0	2	12	na	27	0	2	na	na	8	34	75	126
Other Fate (Above Mission)	8	0	1	1	4	1	7	0	0	1	22	16	34	0	13	26	7	52	1	0	7	16	1	17	6	8	0	3	8	53	80	100

na – no survey effort in spawning area.

Table 10. Survival of radio-tagged sockeye to spawning areas, by run-timing group (and for select stocks) and by Mission passage period.

Early Stuart

Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	13	1.0	0.1	11.9	8	66.6%	67.2%	33,940	33,629	22,600
2	23 to 29 July	2	1.3	0.7	0.0	0	0%	0%	5,758	-	0
3	30 July to 5 Aug	1	-0.1	0.1	1.0	0	0%	0%	1,609	-	0
4	6 to 12 Aug	1	-0.1	0.1	1.0	0	0%	0%	0	-	0
5	13 to 19 Aug	0	0.0	0.0	0.0	0	-	-	0	-	0
6	20 to 26 Aug	0	0.0	0.0	0.0	0	-	-	0	-	0
7	27 Aug to 2 Sept	0	0.0	0.0	0.0	0	-	-	0	-	0
8	3 to 9 Sept	0	0.0	0.0	0.0	0	-	-	0	-	0
9	10 to 19 Sept	0	0.0	0.0	0.0	0	-	-	0	-	0
10	17 to 23 Sept	0	0.0	0.0	0.0	0	-	-	0	-	0
Totals (excluding shaded cells)		13	1.0	0.1	11.9	8			33,940	33,629	22,600
Weighted Average							66.6%	67.2%			

Early Summer

Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	3	1.0	0.0	2.0	2	99.8%	101.4%	13,437	13,228	13,416
2	23 to 29 July	7	4.4	1.7	0.9	1	38.0%	108.2%	38,342	13,458	14,568
3	30 July to 5 Aug	23	5.2	4.5	13.4	9	50.4%	67.3%	175,182	131,333	88,359
4	6 to 12 Aug	23	3.2	4.4	15.4	5	25.3%	32.4%	212,711	165,677	53,724
5	13 to 19 Aug	27	6.2	5.5	15.3	9	43.2%	58.7%	272,931	200,779	117,852
6	20 to 26 Aug	12	2.4	2.9	6.7	3	31.2%	44.9%	172,617	119,882	53,806
7	27 Aug to 2 Sept	16	1.5	2.8	11.7	5	34.6%	42.8%	102,468	82,704	35,414
8	3 to 9 Sept	1	0.9	0.1	0.0	0	0.0%	-	111,083	-	0
9	10 to 19 Sept	0	0.0	0.0	0.0	0	-	-	12,561	-	?
10	17 to 23 Sept	0	0.0	0.0	0.0	0	-	-	0	-	?
Totals (excluding shaded cells)		111	23.8	21.8	65.4	34			987,689	727,060	377,139
Weighted Average							38.2%	51.9%			

Summer-run

Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	0	0.0	0.0	0.0	0	-	-	1,279	-	?
2	23 to 29 July	4	2.9	1.1	0.0	0	0.0%	-	24,955	-	0
3	30 July to 5 Aug	33	7.0	6.0	20.0	12	46.2%	59.9%	161,091	124,156	74,375
4	6 to 12 Aug	42	7.8	5.3	28.9	16	46.8%	55.4%	256,501	216,709	120,027
5	13 to 19 Aug	47	6.8	8.6	31.6	21	52.2%	66.4%	353,387	277,572	184,425
6	20 to 26 Aug	20	1.4	2.3	16.3	12	64.5%	73.8%	265,060	231,752	171,028
7	27 Aug to 2 Sept	30	5.0	4.6	20.5	10	40.0%	48.9%	182,351	149,078	72,853
8	3 to 9 Sept	4	-0.2	0.3	3.9	4	95.1%	102.0%	145,502	135,652	138,331
9	10 to 19 Sept	0	0.0	0.0	0.0	0	-	-	29,710	-	?
10	17 to 23 Sept	0	0.0	0.0	0.0	0	-	-	0	-	0
Totals (excluding shaded cells)		176	27.7	27.1	121.2	75			1,363,892	1,134,919	761,039
Weighted Average							55.8%	67.1%			

Late-run

Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	0	0.0	0.0	0.0	0	-	-	689	-	?
2	23 to 29 July	0	0.0	0.0	0.0	0	-	-	6,299	-	?
3	30 July to 5 Aug	10	1.3	1.1	7.7	0	0.0%	0.0%	52,102	-	0
4	6 to 12 Aug	37	9.8	4.8	22.4	1	3.7%	4.5%	165,453	136,403	6,082
5	13 to 19 Aug	18	-1.3	3.0	16.3	3	15.6%	18.4%	473,562	400,864	73,711
6	20 to 26 Aug	42	0.7	6.7	34.5	16	38.8%	46.3%	473,913	396,752	183,771
7	27 Aug to 2 Sept	47	0.1	5.0	41.9	29	61.8%	69.2%	664,526	593,214	410,466
8	3 to 9 Sept	80	0.9	1.8	77.3	65	82.1%	84.1%	2,118,539	2,070,109	1,739,979
9	10 to 19 Sept	9	0.0	0.1	8.9	8	88.9%	90.2%	800,251	788,211	711,334
10	17 to 23 Sept	5	0.0	0.0	5.0	4	80.0%	80.3%	409,174	407,894	327,339
Totals (excluding shaded cells)		248	11.4	22.5	214.0	126			5,157,520	4,793,446	3,452,684
Weighted Average							66.9%	72.0%			

Chilko

Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
		Ev	Lv	Cv	Ev-Cv-Lv	Ov	S' = Ov/(Ev-Lv)	S = Ov/(Ev-Cv-Lv)	Epp	A/S	A=Epp*S'
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	0	0.0	0.0	0.0	0	-	-	9	-	?
2	23 to 29 July	1	0.6	0.4	0.0	0	0.0%	-	13,946	-	0
3	30 July to 5 Aug	12	0.8	1.7	9.6	7	62.5%	73.2%	100,963	86,097	63,056
4	6 to 12 Aug	20	2.3	2.3	15.4	8	45.1%	51.9%	141,928	123,388	64,050
5	13 to 19 Aug	28	3.0	4.8	20.2	12	48.1%	59.5%	220,639	178,189	106,041
6	20 to 26 Aug	9	0.4	0.9	7.7	6	69.8%	78.4%	121,514	108,160	84,798
7	27 Aug to 2 Sept	17	3.4	1.9	11.7	7	51.4%	59.8%	65,974	56,677	33,917
8	3 to 9 Sept	4	-0.2	0.3	3.9	4	95.1%	102.0%	50,811	47,371	48,307
9	10 to 19 Sept	0	0.0	0.0	0.0	0	-	-	10,778	-	?
10	17 to 23 Sept	0	0.0	0.0	0.0	0	-	-	0	-	0
Totals (excluding shaded cells)		2	0	0	2	0			1,609	0	0
Weighted Average							66.6%	67.2%			

Early Summer Shuswap

Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	0	0.0	0.0	0.0	0	-	-	5,056	-	?
2	23 to 29 July	4	2.0	1.1	0.9	1	50.1%	108.2%	26,677	12,342	13,359
3	30 July to 5 Aug	14	0.9	3.6	9.6	6	45.7%	62.8%	136,836	99,618	62,565
4	6 to 12 Aug	15	0.9	3.5	10.6	4	28.3%	37.7%	183,467	137,752	51,976
5	13 to 19 Aug	25	5.3	5.3	14.4	8	40.6%	55.6%	242,732	176,998	98,478
6	20 to 26 Aug	9	1.6	1.7	5.7	2	26.9%	34.9%	147,797	113,834	39,736
7	27 Aug to 2 Sept	10	2.8	1.4	5.8	3	41.5%	51.3%	68,328	55,185	28,331
8	3 to 9 Sept	1	0.9	0.1	0.0	0	0.0%	-	31,847	-	0
9	10 to 19 Sept	0	0.0	0.0	0.0	0	-	-	0	-	?
10	17 to 23 Sept	0	0.0	0.0	0.0	0	-	-	0	-	?
Totals (excluding shaded cells)		108	23	22	63	32			974,252	713,833	363,723
Weighted Average							38.2%	51.9%			

Late-run Shuswap

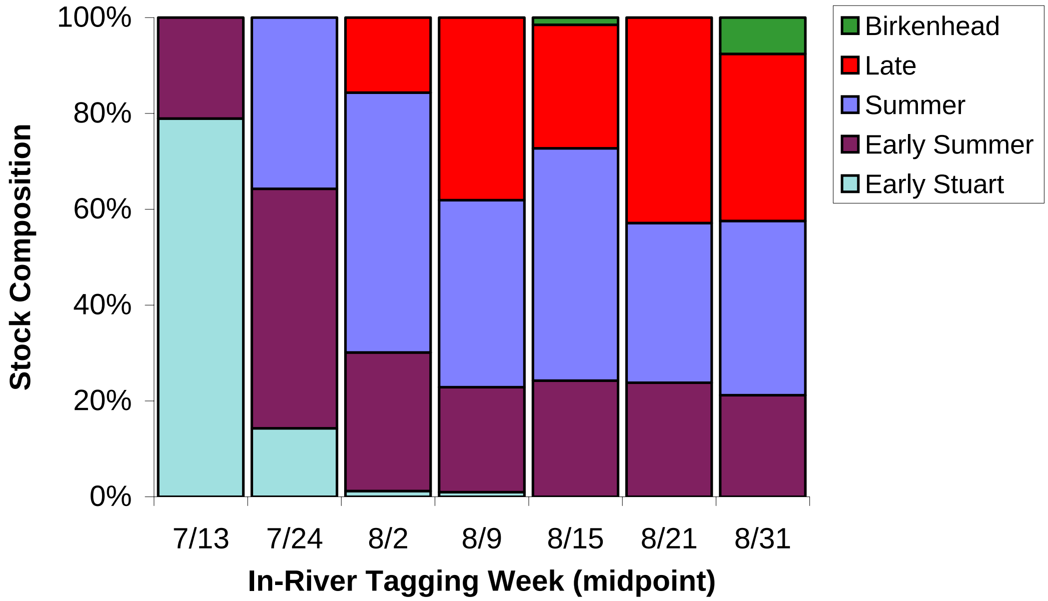
Mission Passage Periods		Radio Tagged Sockeye							Sockeye		
Number	Dates	Tags Past Mission	Tag Loss	Harvest	Tags after Harvest	Tags in Spawning Areas	Survival (Miss-Spawn)	Survival (after harvest)	Abundance at Mission	Abundance After Harvest	Est. Fish in Spawning Areas
1	9 July to 22 July	0	0.0	0.0	0.0	0	-	-	689	-	?
2	23 to 29 July	0	0.0	0.0	0.0	0	-	-	6,166	-	?
3	30 July to 5 Aug	10	1.3	1.1	7.7	0	0.0%	0.0%	49,807	-	0
4	6 to 12 Aug	31	11.0	4.6	15.4	1	5.0%	6.5%	157,579	121,292	7,863
5	13 to 19 Aug	17	-0.2	2.8	14.4	3	17.5%	20.9%	460,415	385,152	80,473
6	20 to 26 Aug	41	0.8	6.7	33.5	16	39.8%	47.7%	464,863	387,478	184,826
7	27 Aug to 2 Sept	44	0.1	5.0	38.9	28	63.8%	72.0%	640,756	567,723	408,524
8	3 to 9 Sept	75	0.9	1.8	72.3	64	86.3%	88.5%	2,032,749	1,983,779	1,755,250
9	10 to 19 Sept	9	0.0	0.1	8.9	8	88.9%	90.2%	742,806	731,630	660,272
10	17 to 23 Sept	5	0.0	0.0	5.0	4	80.0%	80.3%	394,631	393,396	315,705
Totals (excluding shaded cells)		176	28	27	121	75			1,393,602	1,134,919	761,039
Weighted Average							55.8%	67.1%			

FIGURES

Figure 1. Location of release and fixed-station sites for the 2006 sockeye radio-telemetry study.

Fixed Station sites: a: Crescent Island; b: Mission; c: Harrison confluence; d: Weaver Creek; e: Upper Harrison; f: Rosedale; g: Hope; h: Sawmill Creek; i: Hell's Gate; j: Thompson confluence; k: Spence's Bridge; l: North Thompson; m: top of Kamloops Lake; n: Little River; o: Adams Lake; p: Lower Shuswap; q: Seton confluence; r: Bridge River; s: Chilcotin confluence; t: Chilko; u: Quesnel confluence; v: Horsefly River; w: Nechako confluence; x: Stuart River.

Figure 2. Stock composition of sockeye radio-tagged in 2006, by tagging group (indicated by mid-date of tagging session). Upper panel: results for seven weeks of "in-river" tagging at Glenlyon Municipal Park. Lower panel: results for one tagging session in Juan de Fuca Strait, and three sessions in Johnstone Strait.



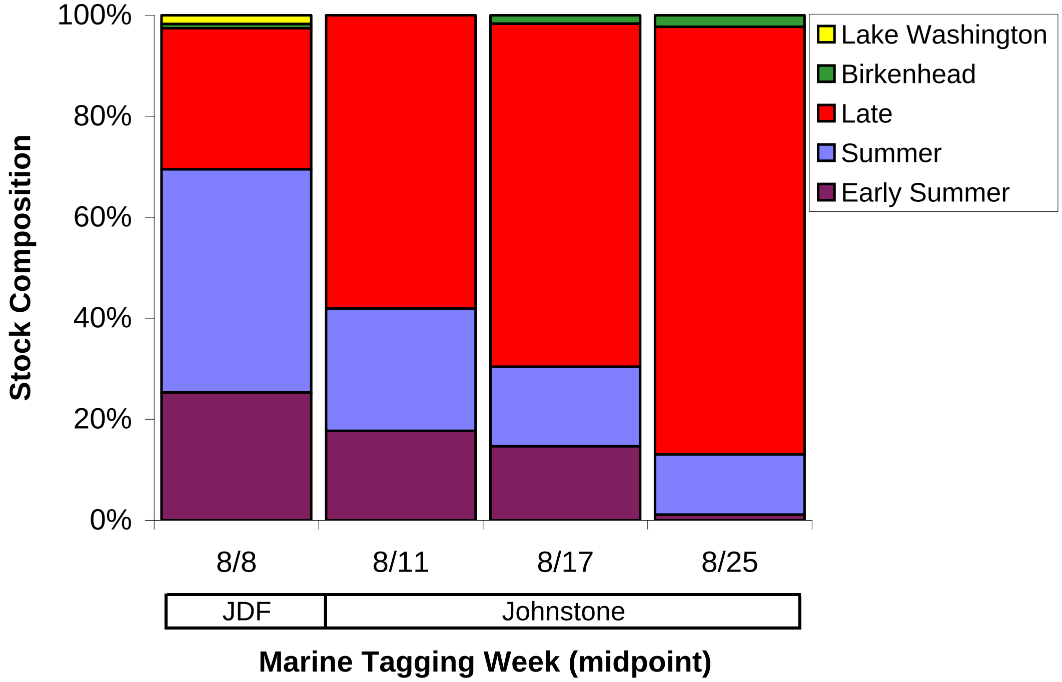


Figure 3. Detection efficiency of the Mission Site receivers, and estimated Mission escapement, by Mission Passage Period. For detection efficiencies, Periods during which fewer than 10 fish passed the site were not included in the analyses, or in the figure. Escapement estimates were provided by the PSC, and were based on data from the Mission hydroacoustic site.

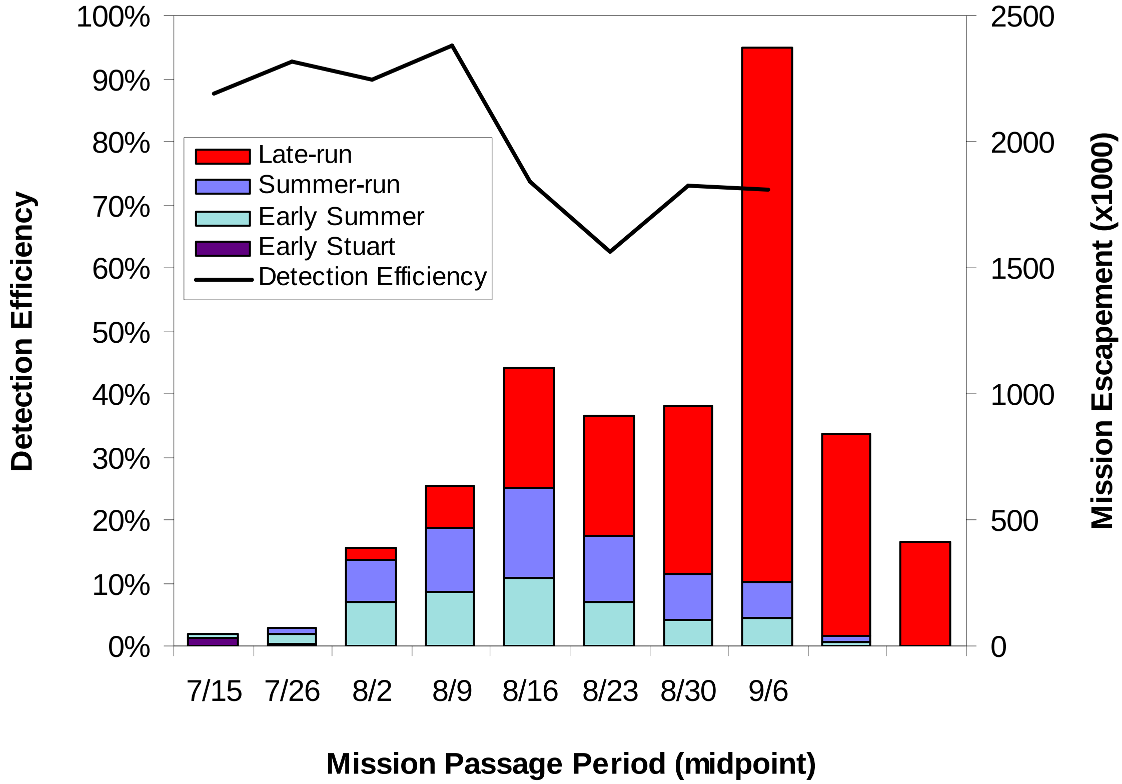


Figure 4. Reach-specific survival rates for Late-run sockeye, by release location. Reach-specific survival rates were calculated as the proportion of fish passing the downstream reach boundary that subsequently passed the upstream reach boundary.

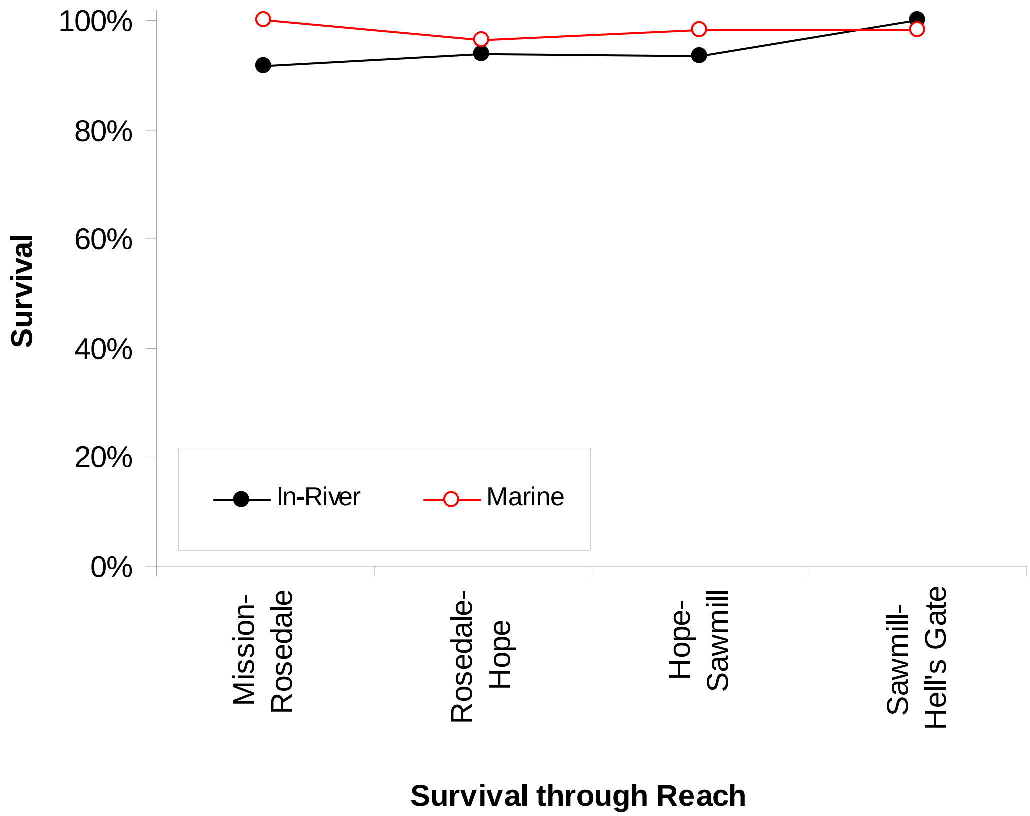


Figure 5. Variability in proportions tracked to Mission and to the Thompson junction by release group, 2006.

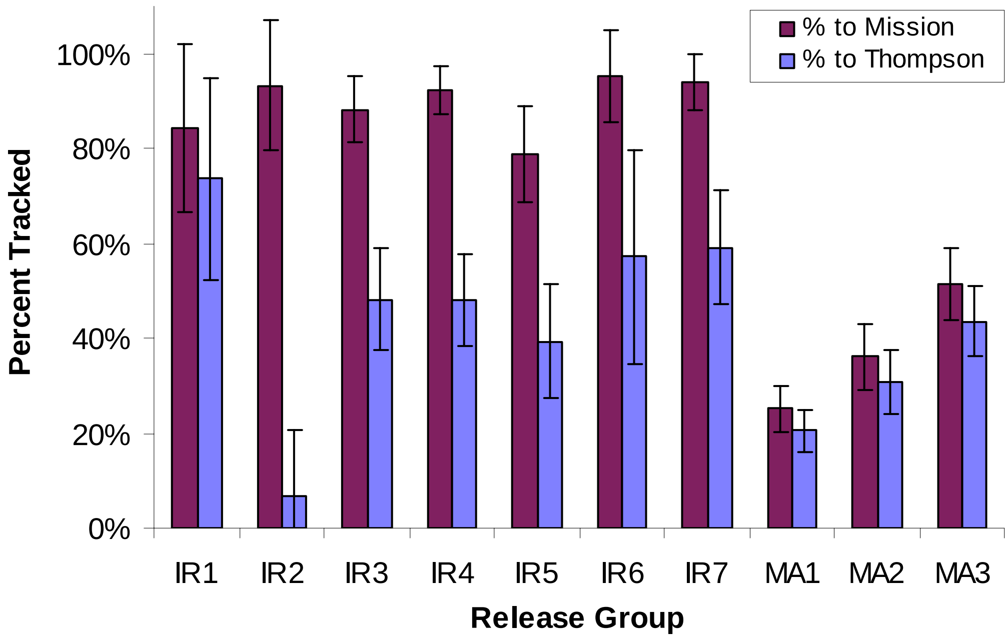


Figure 6. Variability in proportions tracked to Mission for three holding strategies tested during the first marine tagging session, 6-12 Aug 2006.

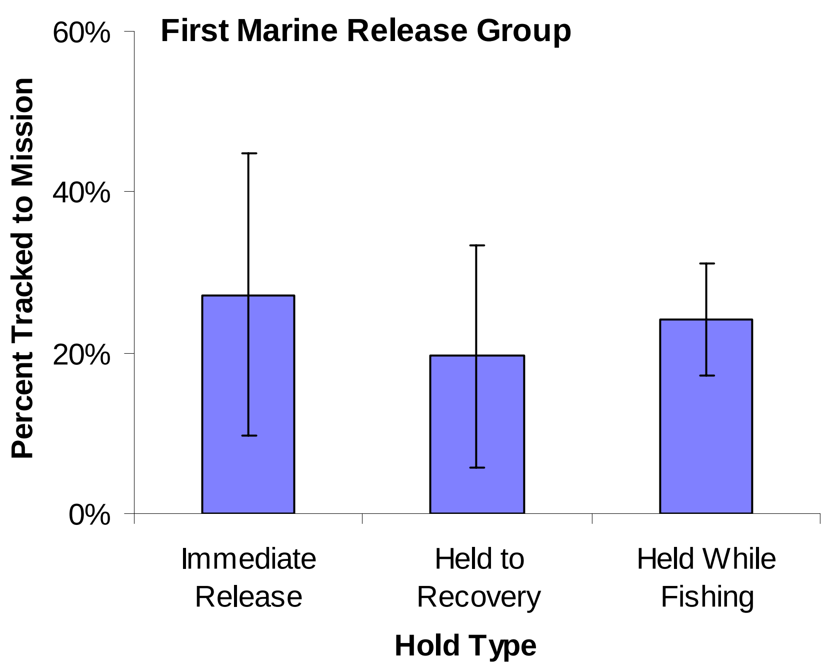


Figure 7. The probability of survival to Mission as a function of handling time for the third marine tagging session, 24-27 Aug 2006. There was no significant effect of handling time for the first two marine release groups, or for any of the in-river releases.

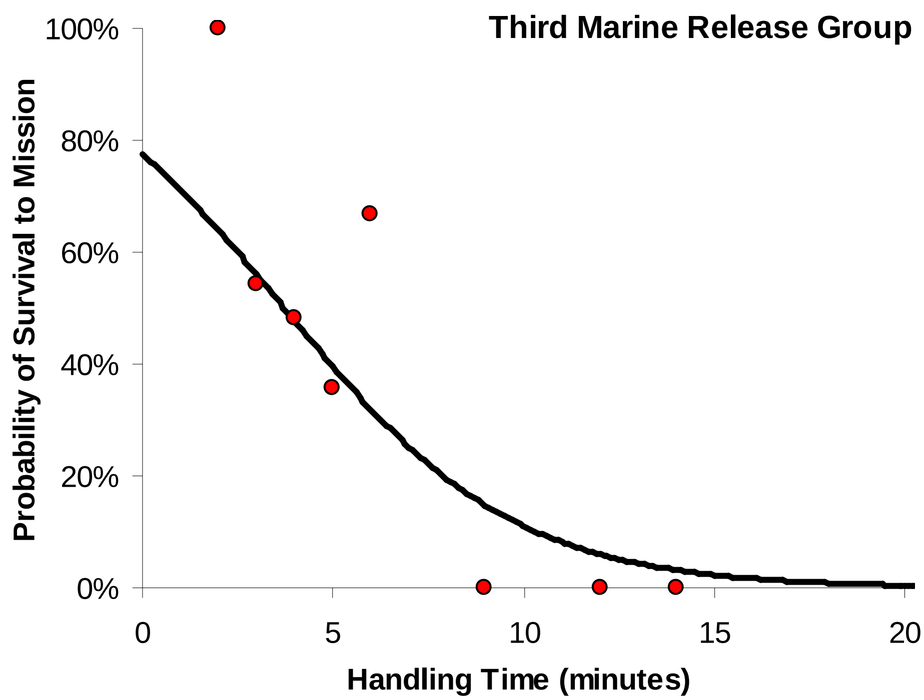


Figure 8. Holding times (from the time a fish was put into the tagging trough until it was released) for sockeye tagged in-river, and for marine-tagged fish. Marine-tagged fish are split into two groups: those that were held after tagging until they were able to regain equilibrium; and those that were released immediately after tagging.

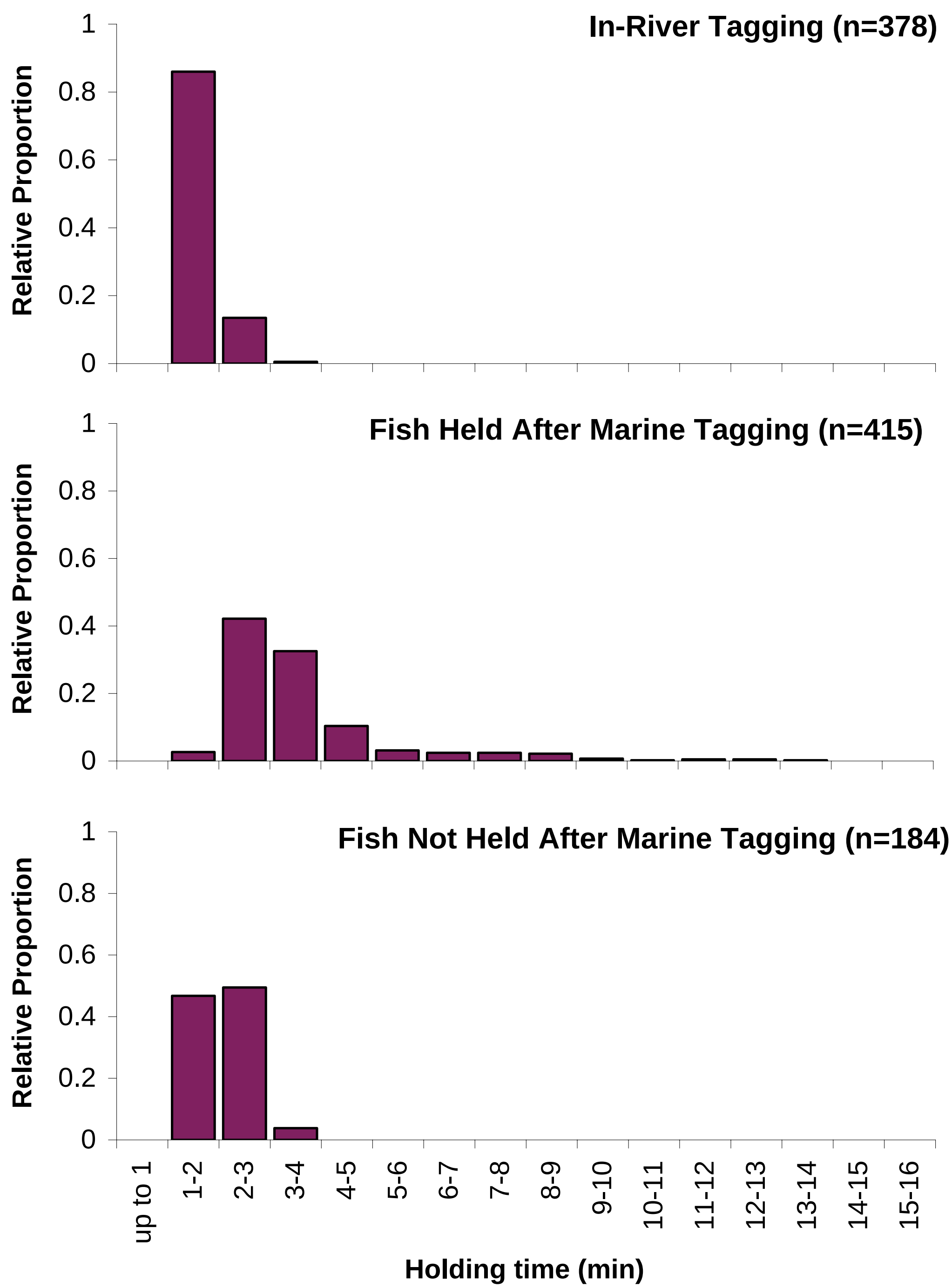


Figure 9. **Adjusted daily abundance of sockeye by run-timing group, from data collected at the Mission hydroacoustic site.**

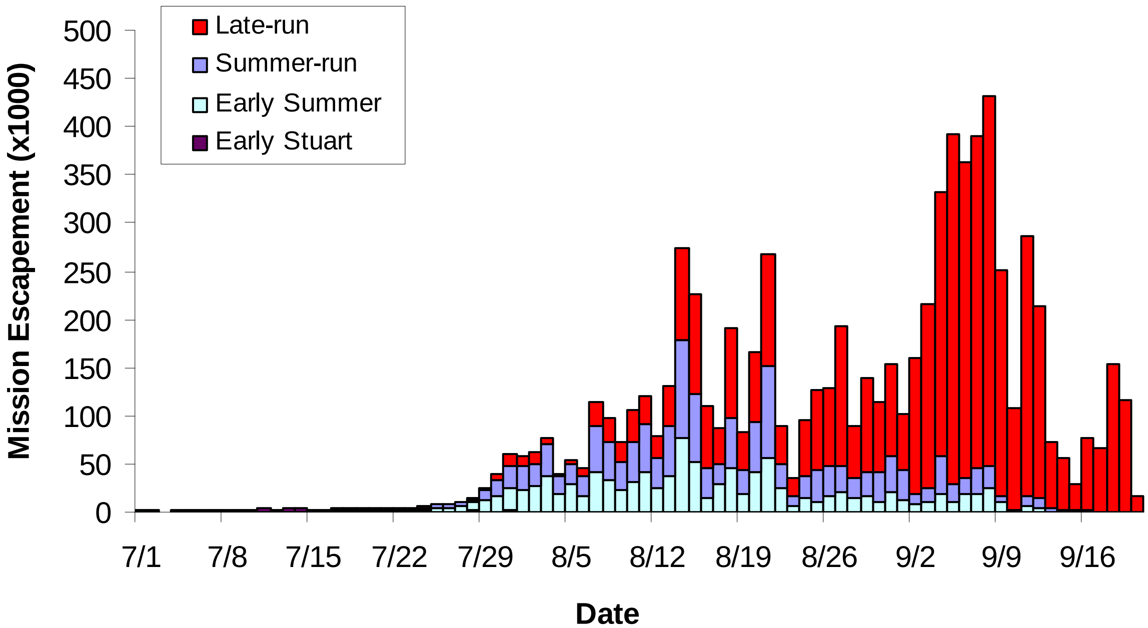
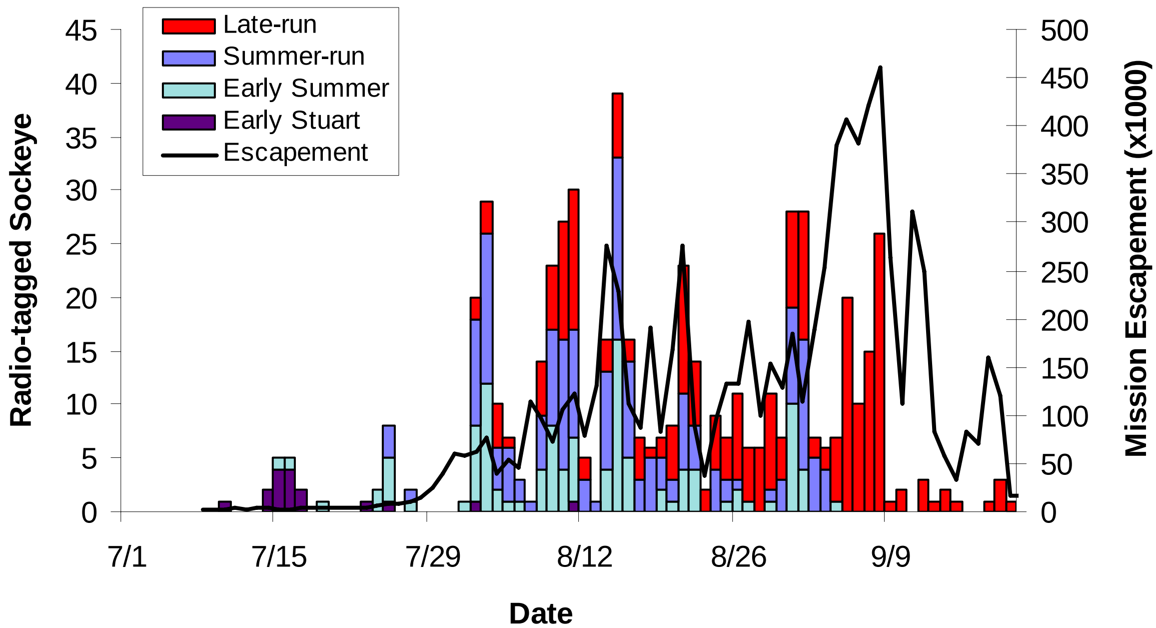


Figure 10. Daily abundance of radio-tagged sockeye detected at Mission. Upper Panel: by run-timing group; Lower Panel: by tag site. Also shown is the adjusted overall sockeye escapement as estimated from the Mission hydroacoustic site data.



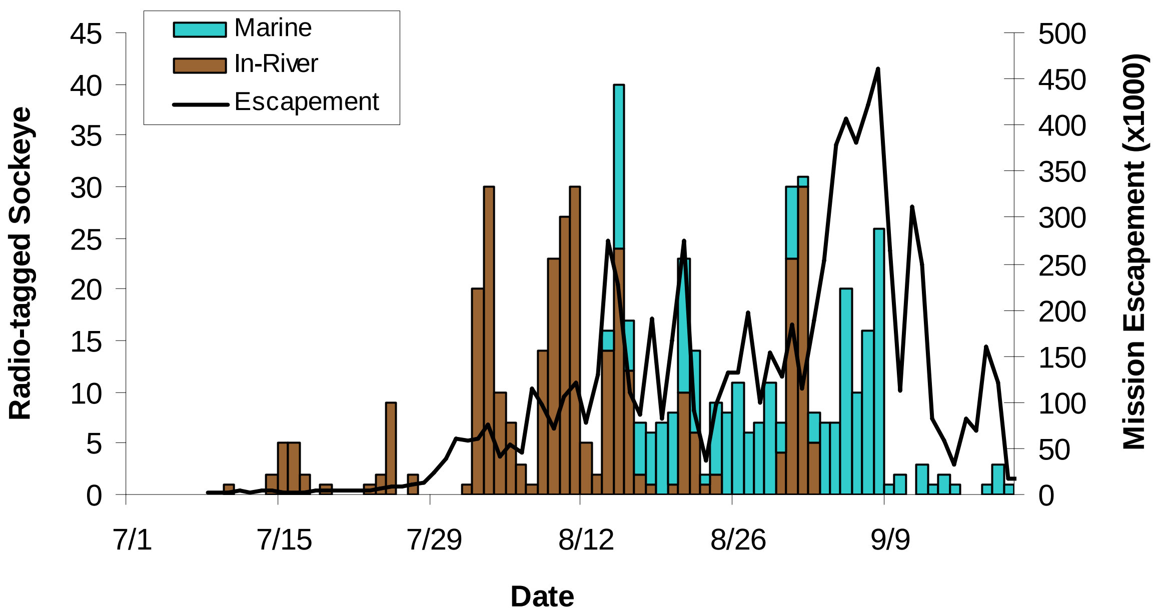


Figure 11. Daily abundance of radio-tagged sockeye detected at Mission and adjusted overall sockeye escapement as estimated from the Mission hydroacoustic site, by run-timing group.

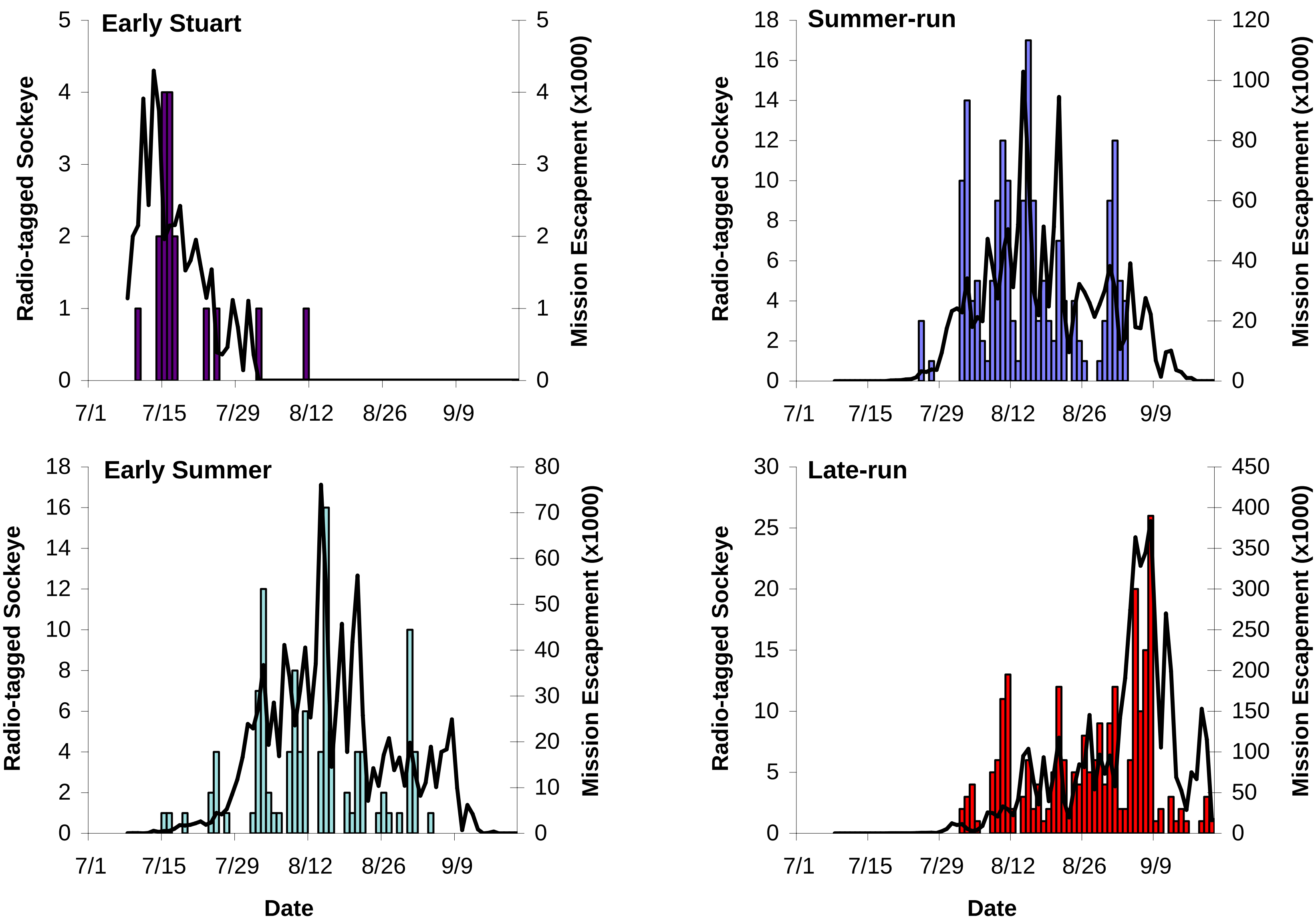


Figure 12. Number and proportion of radio-tagged sockeye of each run-timing group that passed Mission, by Mission Passage Period, 2006. The study period was broken down into 10 approximately week-long periods. Fish were assigned to one of the periods based on the date on which they were first detected the fixed-station receivers at Mission.

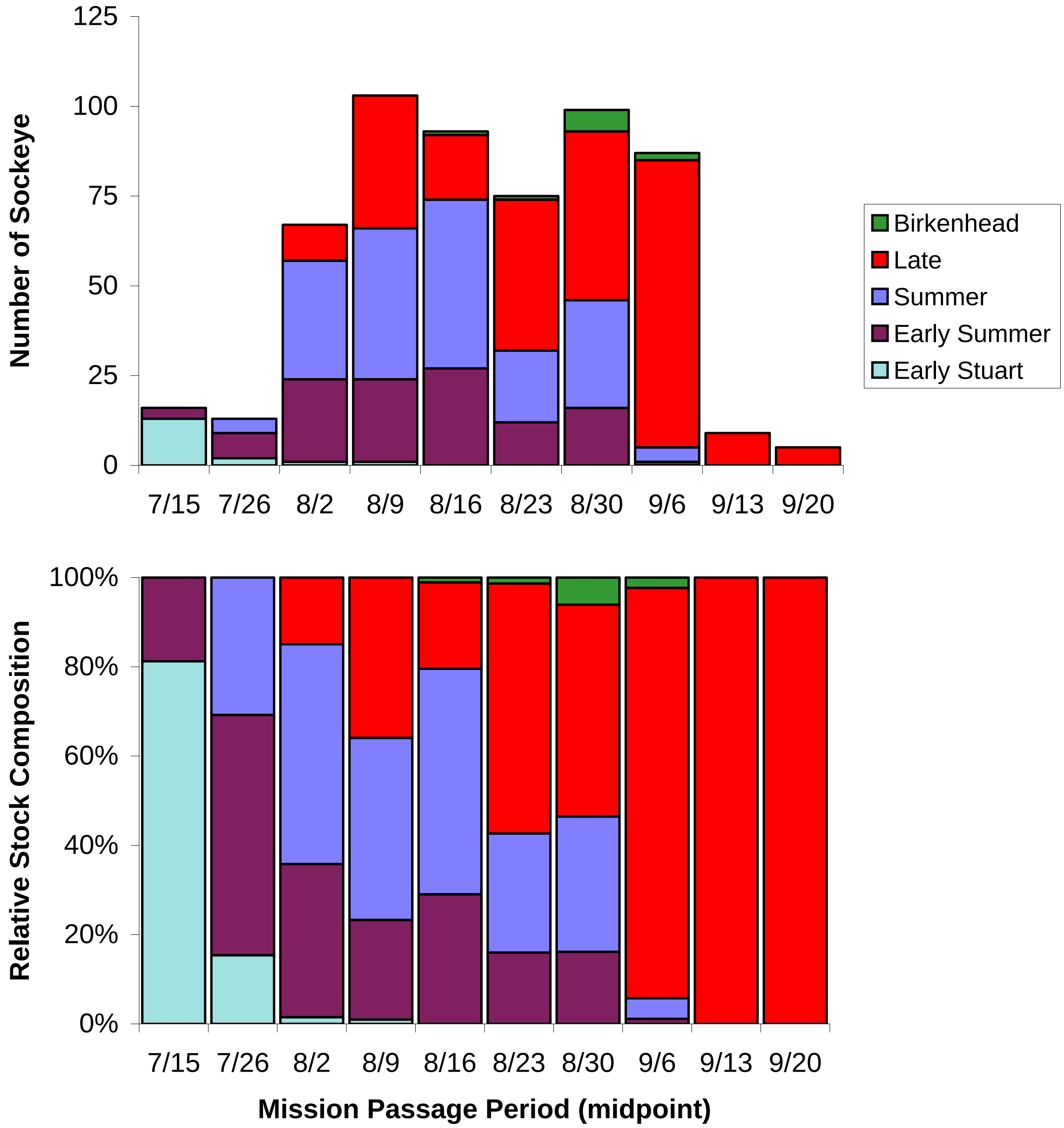


Figure 13. Number and proportion of radio-tagged Late-run sockeye of each stock that passed Mission, by Mission Passage Period, 2006. The study period was broken down into 10 approximately week-long periods. Fish were assigned to one of the periods based on the date on which they were first detected the fixed-station receivers at Mission.

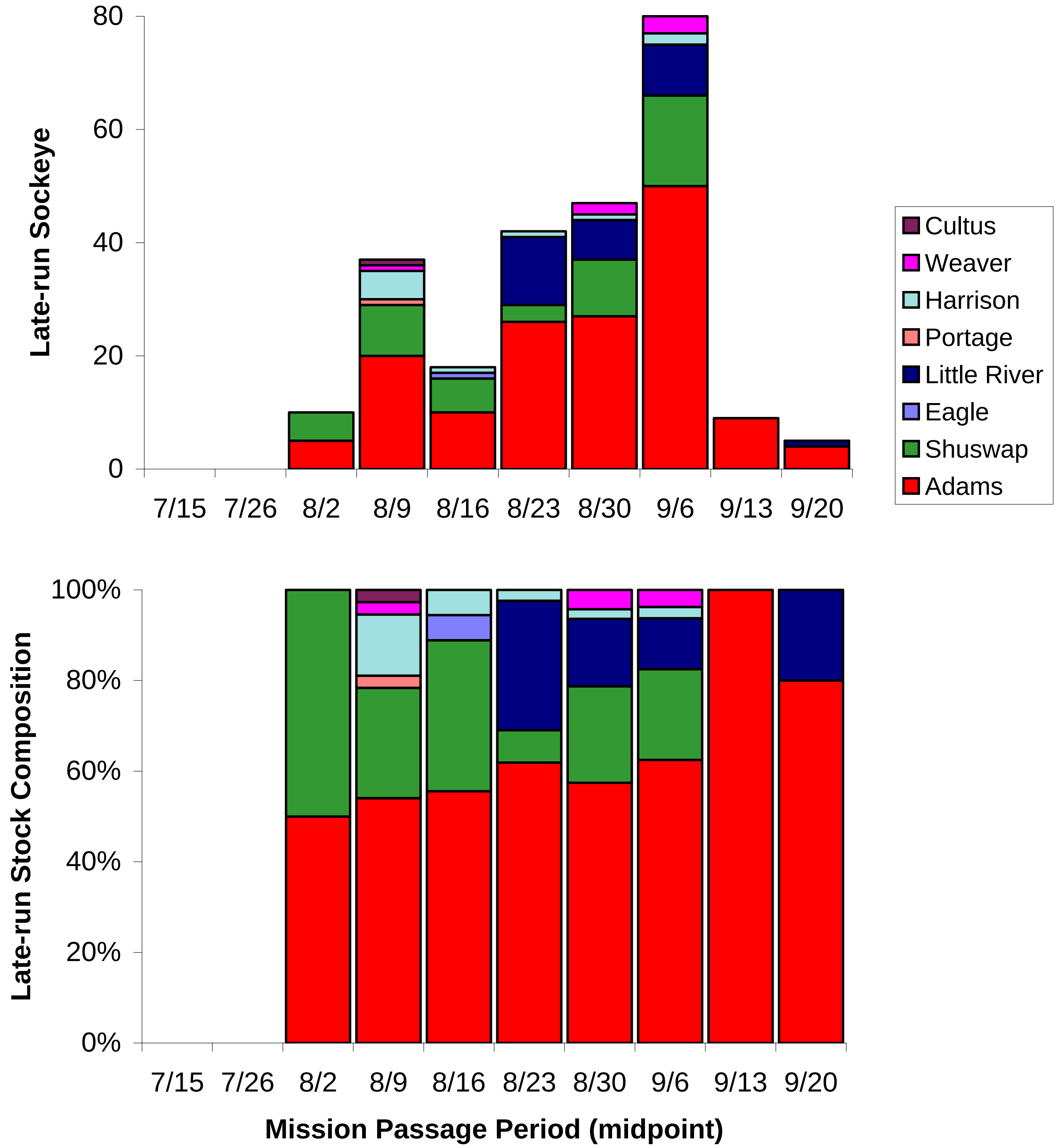


Figure 14. Frequency distribution of travel times (days) from release to Mission for radio-tagged Early-summer, Summer-run and Late-run sockeye, released during three tagging intervals in August, 2006. Travel times from Juan de Fuca were adjusted by the run-timing-group-specific median difference in first-release-group travel times between release sites.

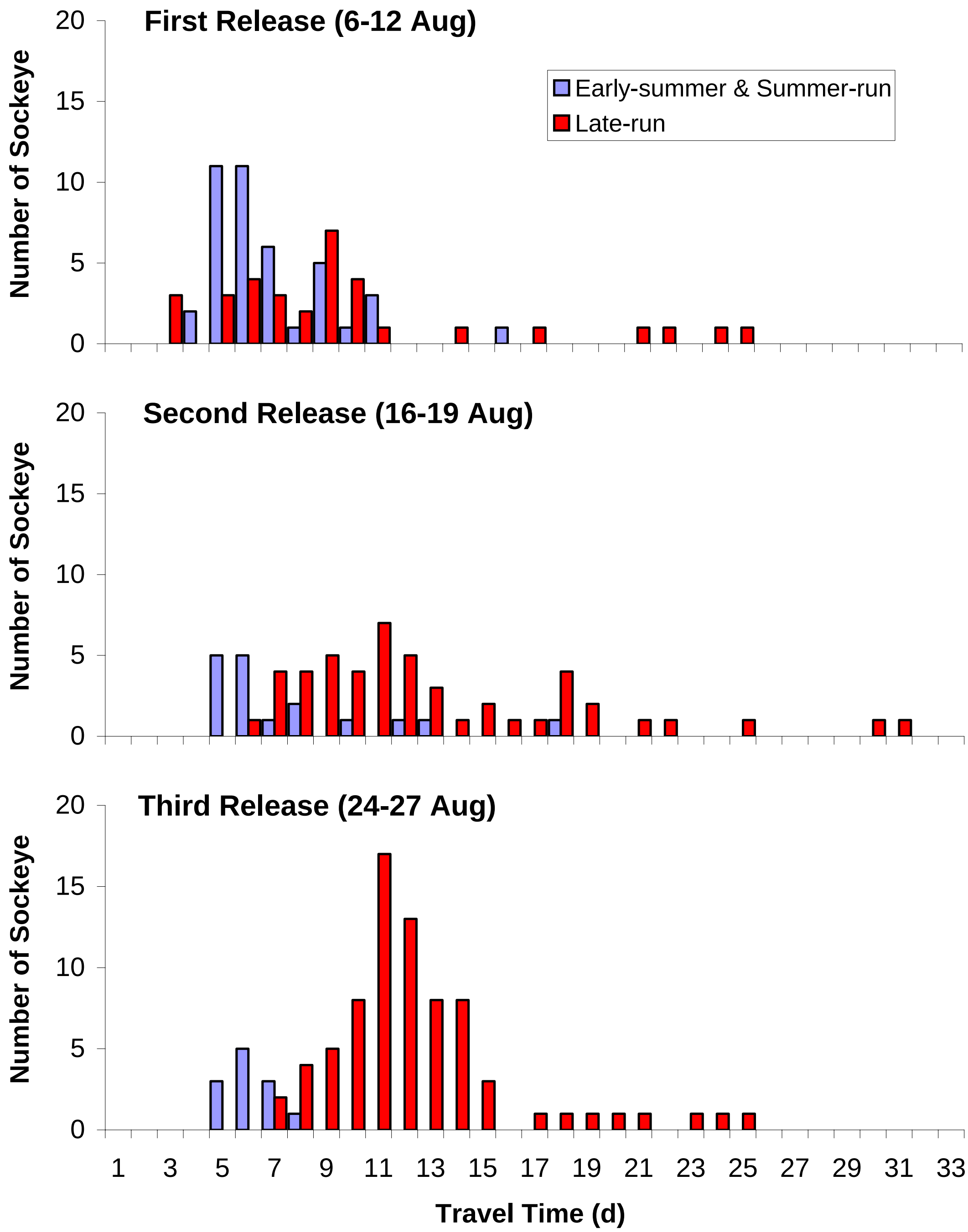


Figure 15. Number of Early-summer and Summer-run sockeye (A) released, and (B) detected at Mission by date and release group. Also on Panel B: Daily escapement estimates for Early-summer and Summer-run sockeye at the Mission hydroacoustic site. Travel times from Juan de Fuca were adjusted by the run-timing-group-specific median difference in first-release-group travel times between release sites

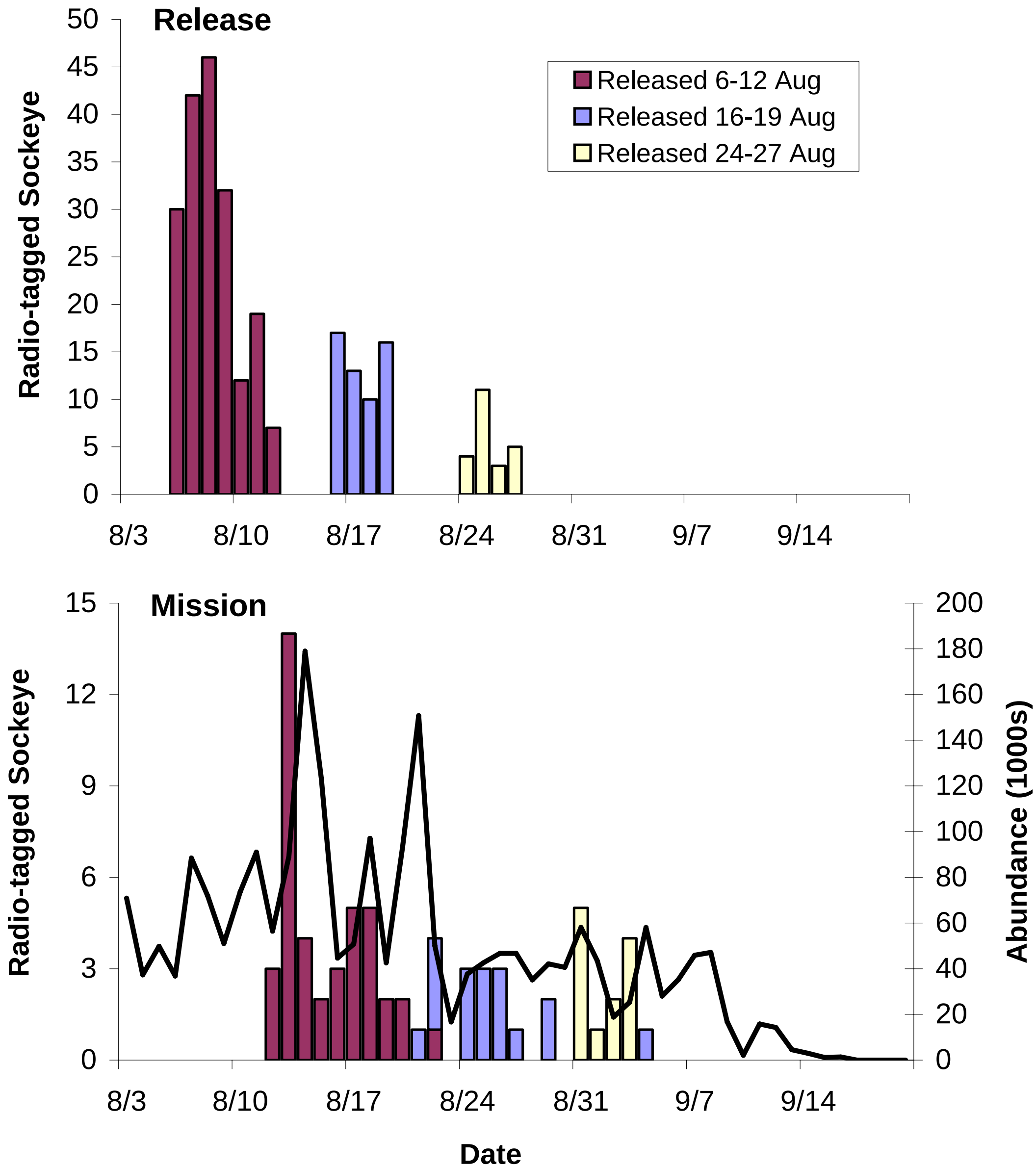


Figure 16. Number of Late-run sockeye (A) released, and (B) detected at Mission by date and release group. Also on Panel B: Daily escapement estimates for Late-run sockeye at the Mission hydroacoustic site. Travel times from Juan de Fuca were adjusted by the run-timing-group-specific median difference in first-release-group travel times between release sites.

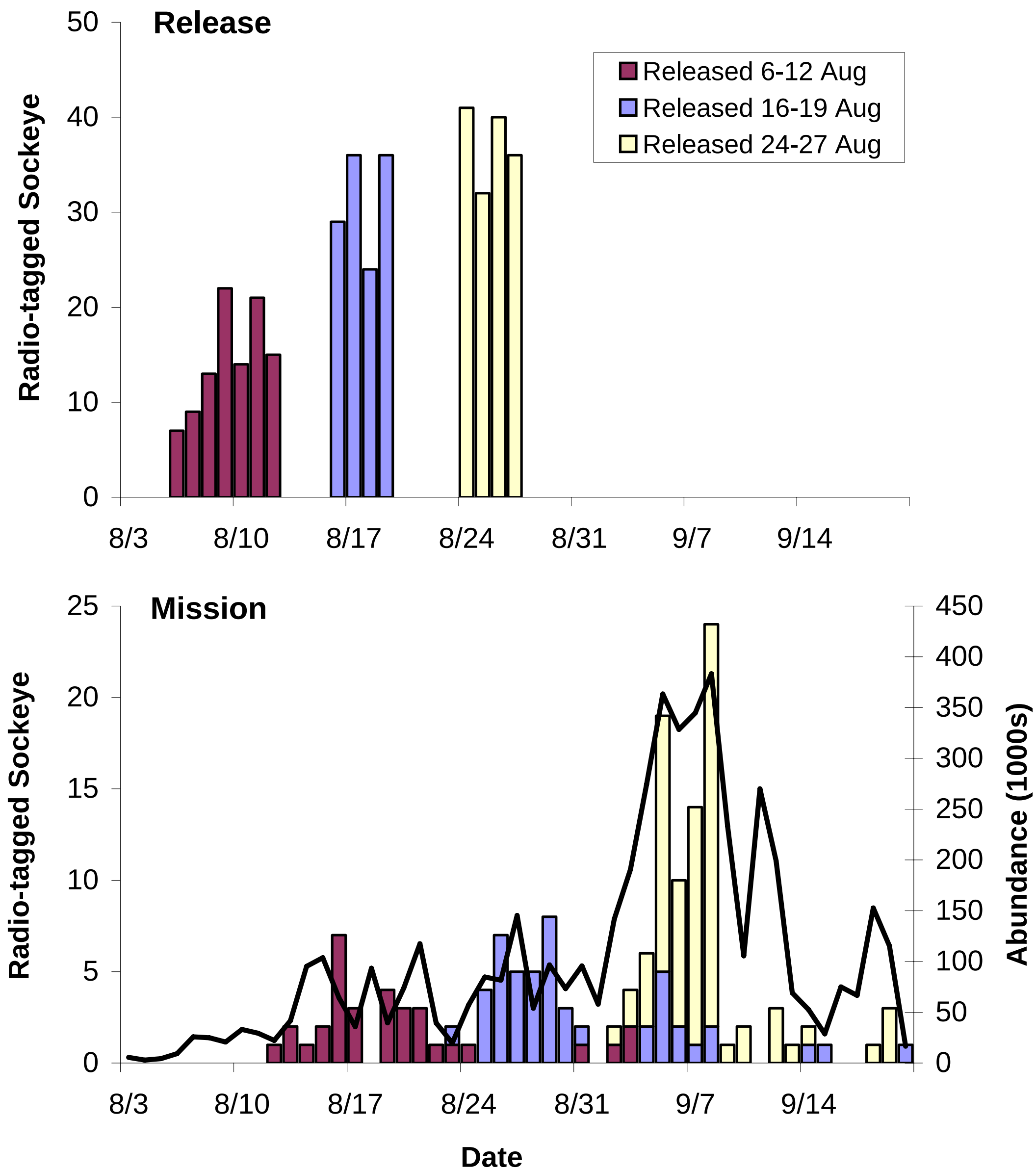


Figure 17. Migration speeds from Mission to several Fraser River destinations for radio-tagged sockeye of several different run-timing groups tagged in 2006. Error bars represent 95% confidence in the median value (generated using the method recommended in Zar, 1984). Statistical comparisons (see text) were done using non-parametric Kruskal Wallis tests; overlapping error bars do not preclude statistical significance..

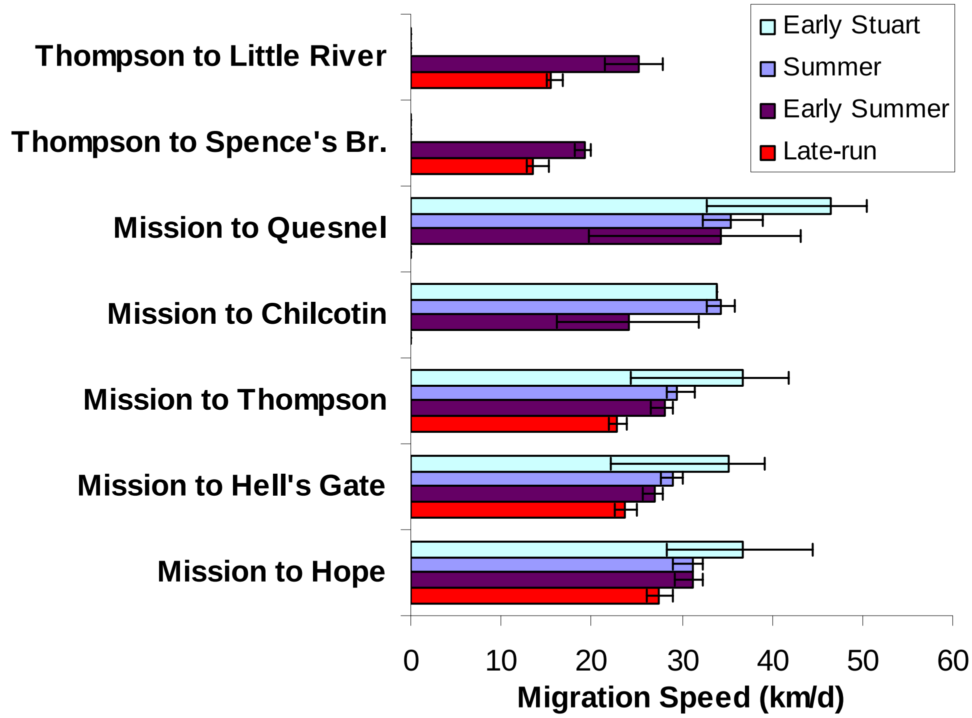
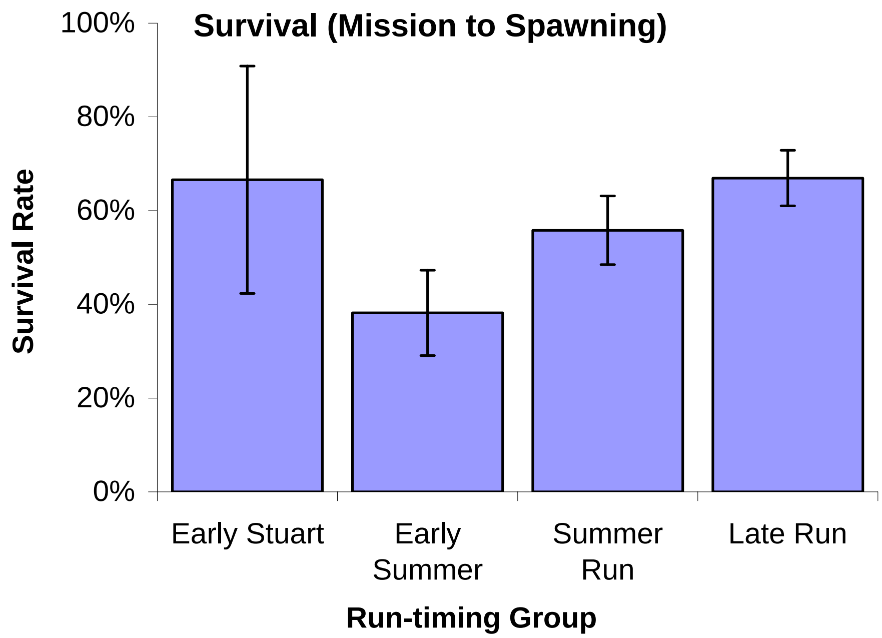


Figure 18. Survival estimates for radio-tagged sockeye by run-timing group. Top panel: survival estimates are based on the proportion of radio-tagged sockeye that passed Mission that were subsequently in spawning areas. Bottom Panel: survival estimates are based on the proportion of radio-tagged fish that survived mainstem fisheries that were subsequently detected in spawning areas. Error bars represent 95% confidence where standard errors follow the binomial distribution.



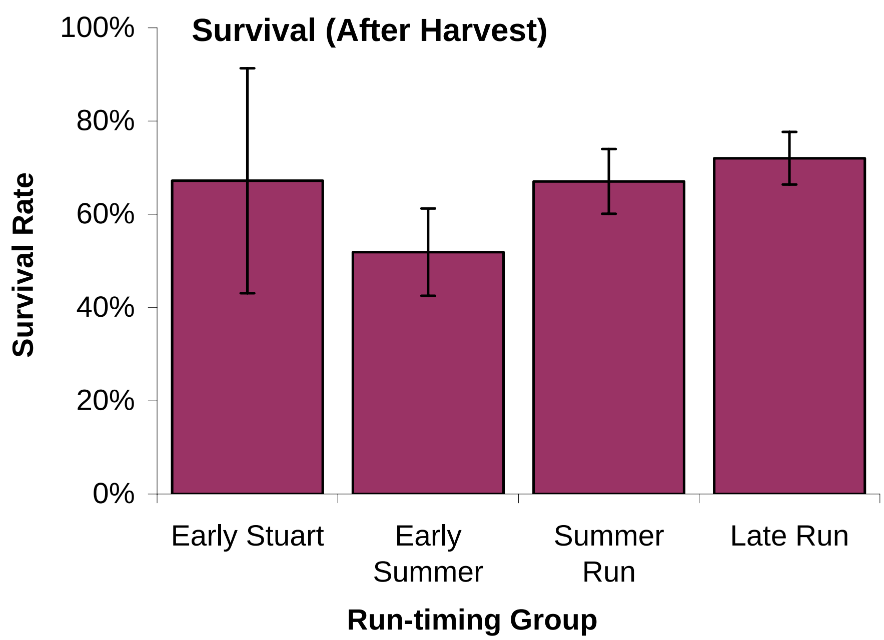


Figure 19. Survival from release to Mission for Late-run sockeye tagged and release in Johnstone Strait, by release group. Survival estimates take into account estimated release-group-specific fishery removals. Error bars represent 95% confidence where standard errors follow the binomial distribution.

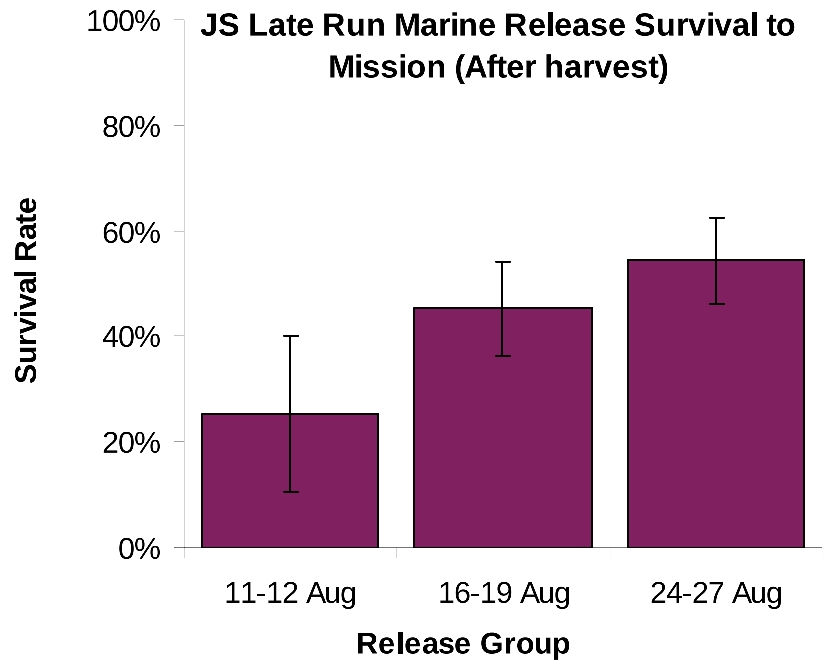


Figure 20. Date of last detection for fish that were lost downstream of Sawmill Creek, by fate.

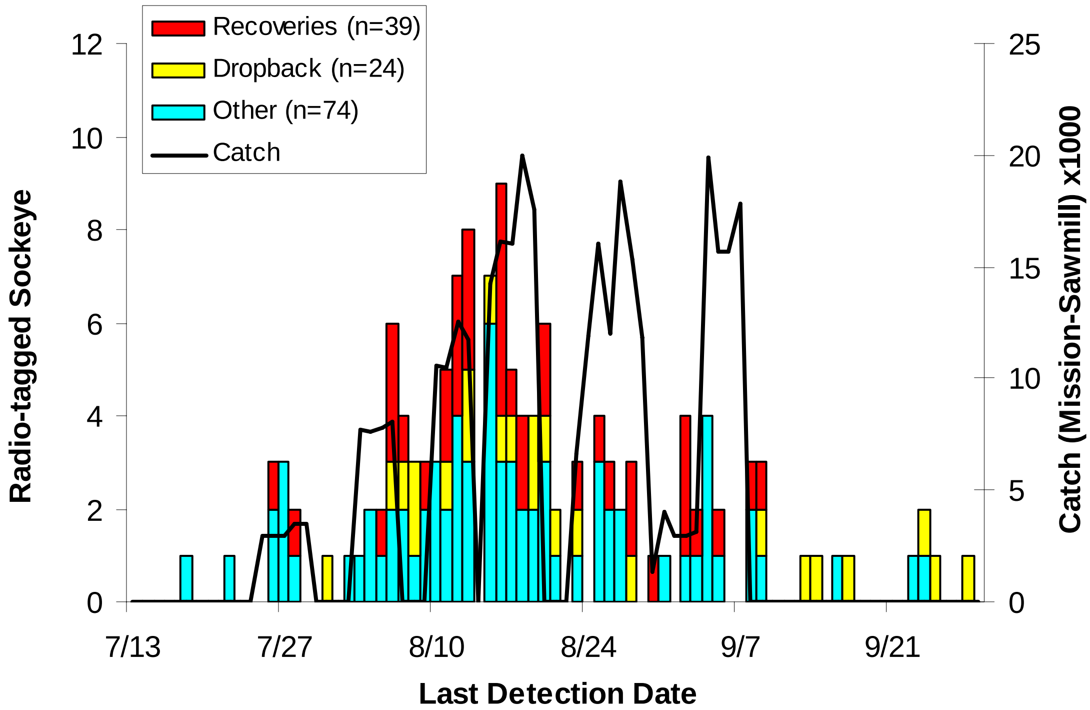


Figure 21. Fate of radio-tagged sockeye, by zone of last detection and by run-timing group. Fishery removals were assigned to zones proportionally to fishery returns. Tagging related losses were assigned to zones proportionally to last (non-fishery) detections below Sawmill.

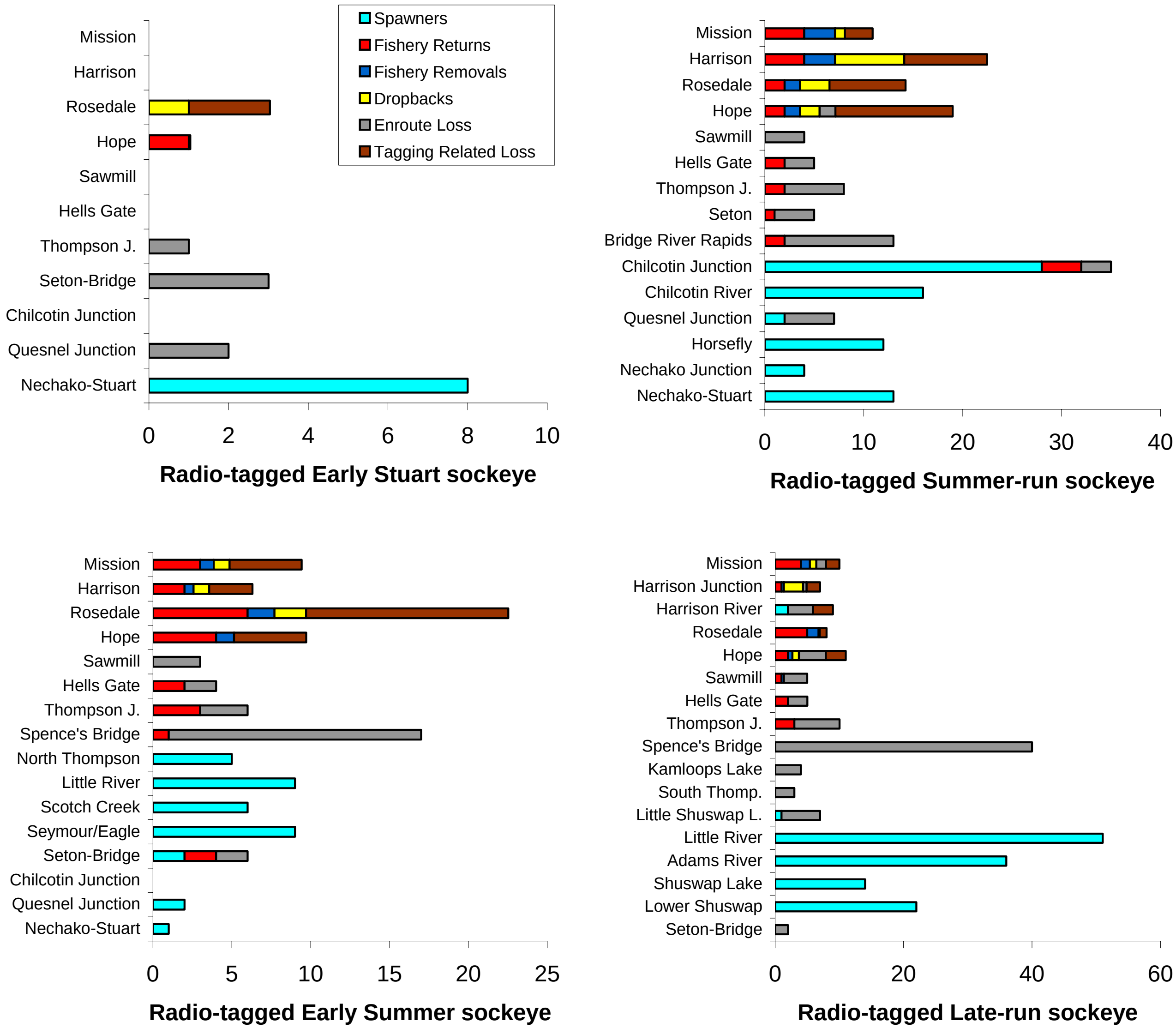


Figure 22. Date of Spence's Bridge passage and survival to Shuswap for Early Summer and Late-run sockeye. Local temperature data are shown in the lower panel.

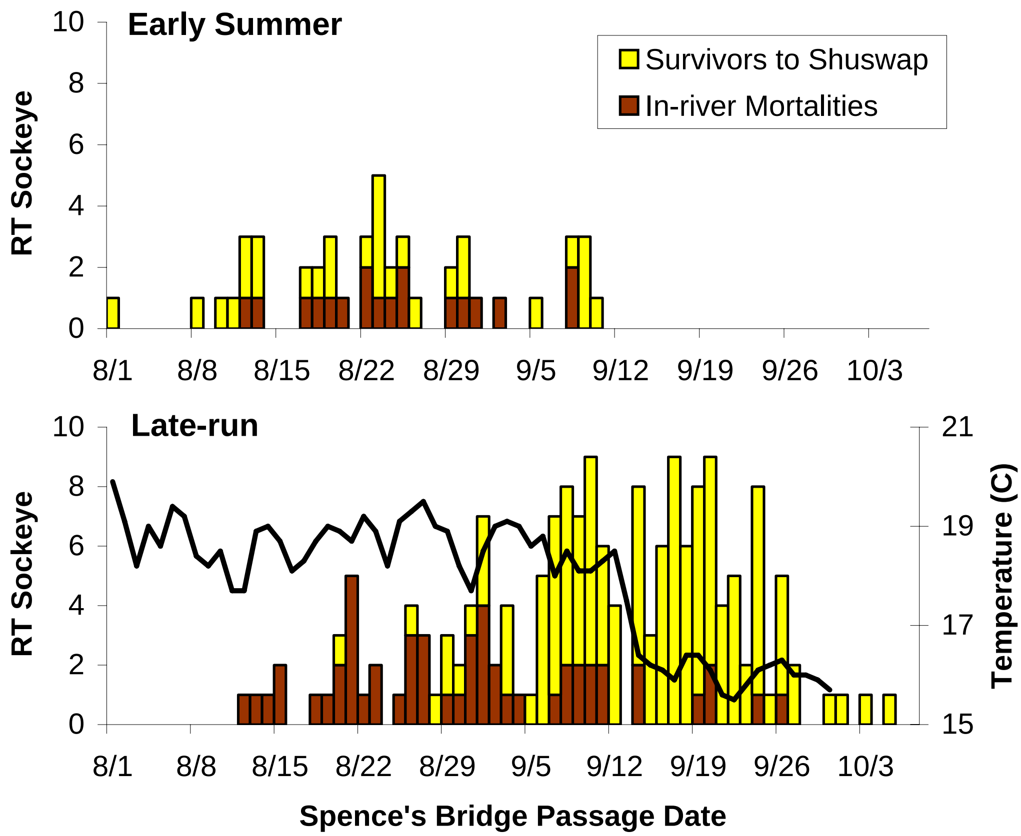


Figure 23. An example of a thermal profile experienced by a successful fish. The temperature logger, which was glued to the gastrically inserted radio tag (Channel 1, code 183), was collected from a fish on the Scotch Creek spawning ground.

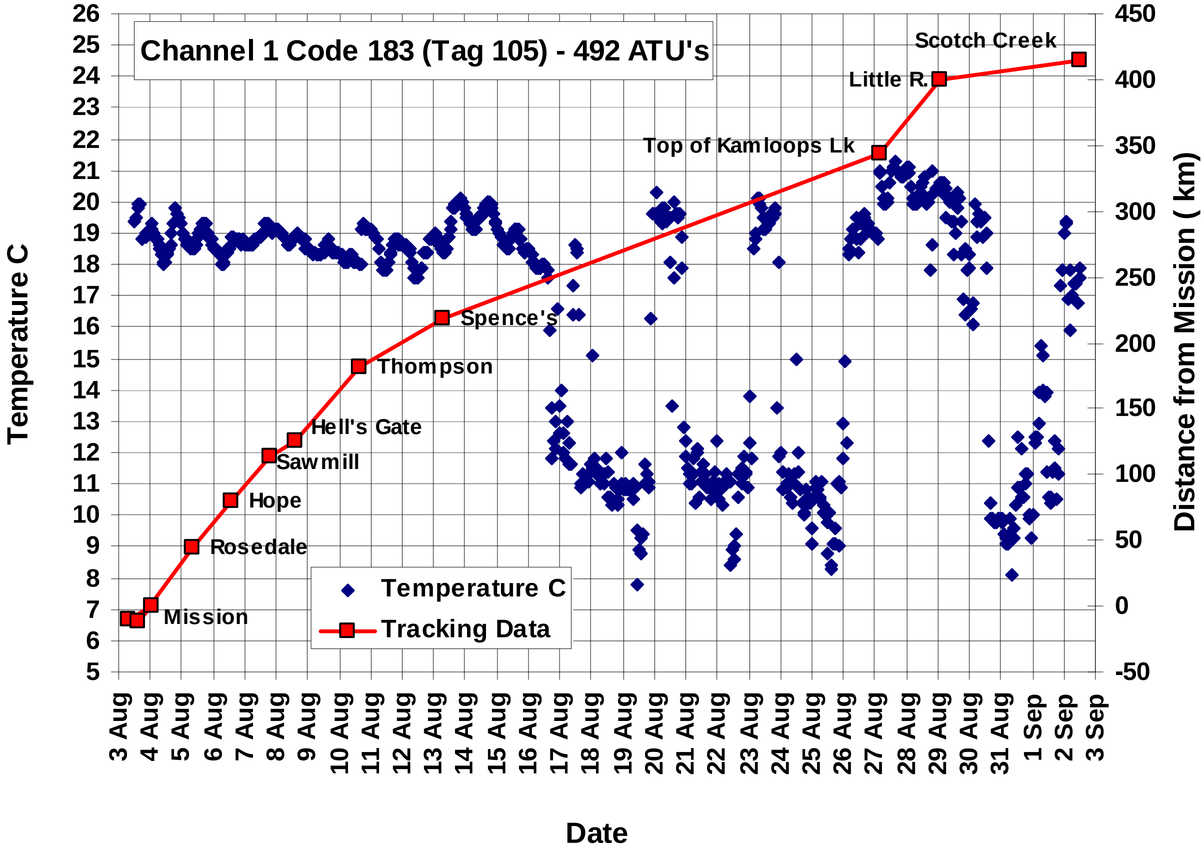


Figure 24. Relationship between the timing of Late-run sockeye passing Mission and in-river survival, excluding fishery removals. Survival rate estimates for 2002 and 2003 are for consecutive periods 5-day periods and estimates for 2006 are for consecutive 7-day periods. Error bars show 2 SE. Curves are Michaelis-Menten (MM) cut-off curves fit to the 2002 and 2003 survival estimates (from English et al. 2005).

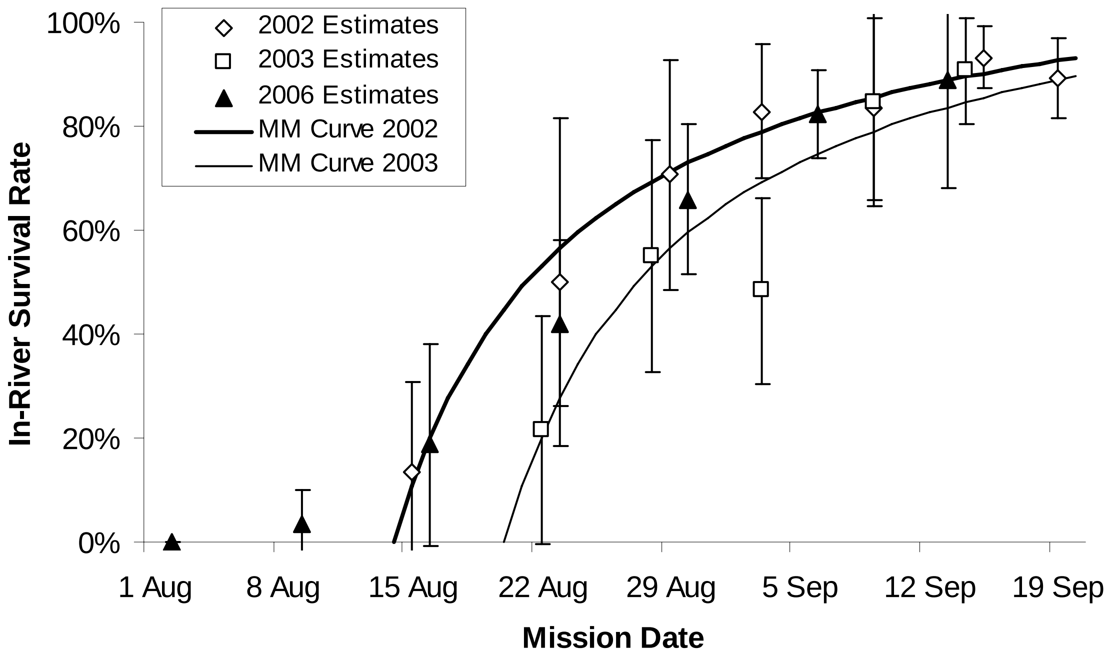


Figure 25. Travel times for 43 Late-run sockeye last detected at Spence's Bridge or Kamloops Lake. The shaded area delimits the 95th percentile travel times for 123 Late-run sockeye that successfully migrated to stock-specific spawning areas in the Thompson drainage; and the central line shows the median. Of the fish that vanished in the Spence's Bridge/Kamloops Lake area, 98% were moving upriver at the same rate as their surviving counterparts, or faster.

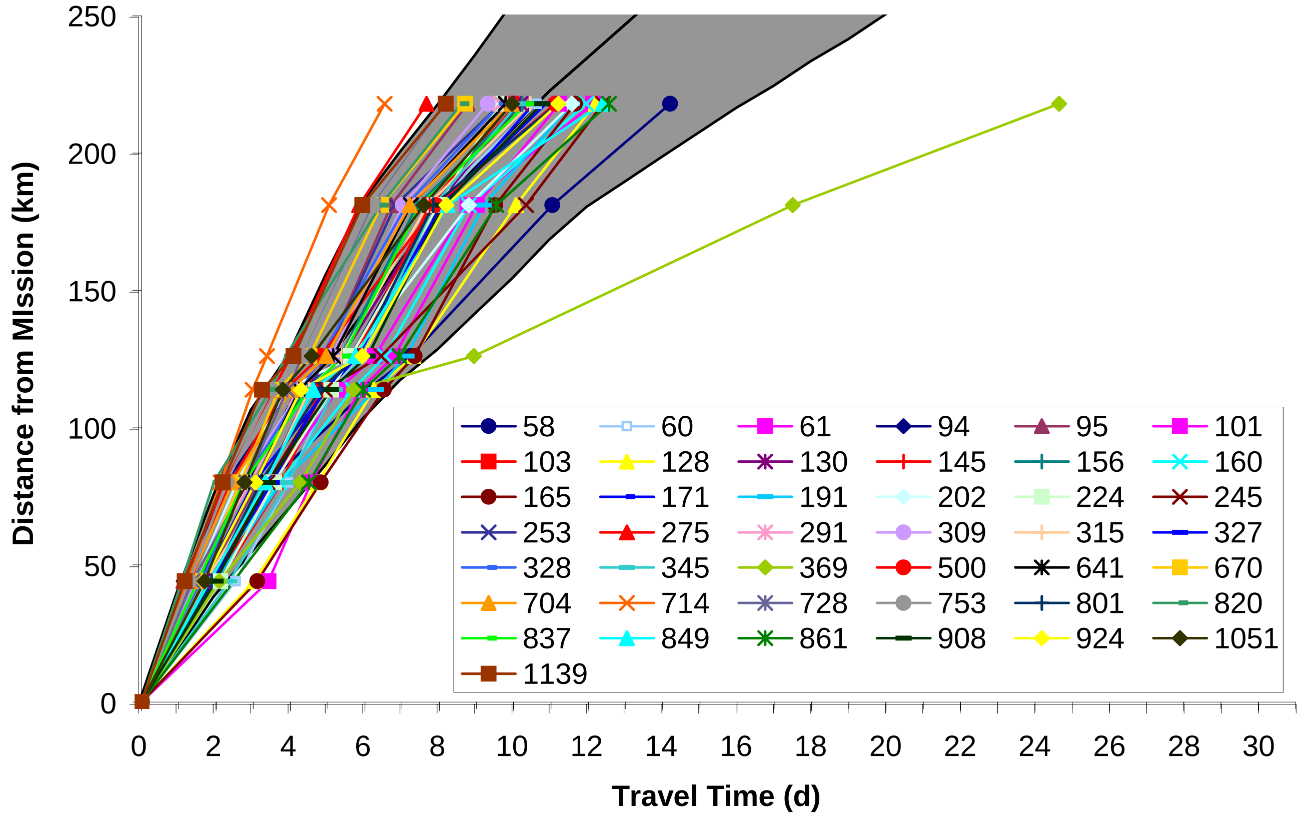
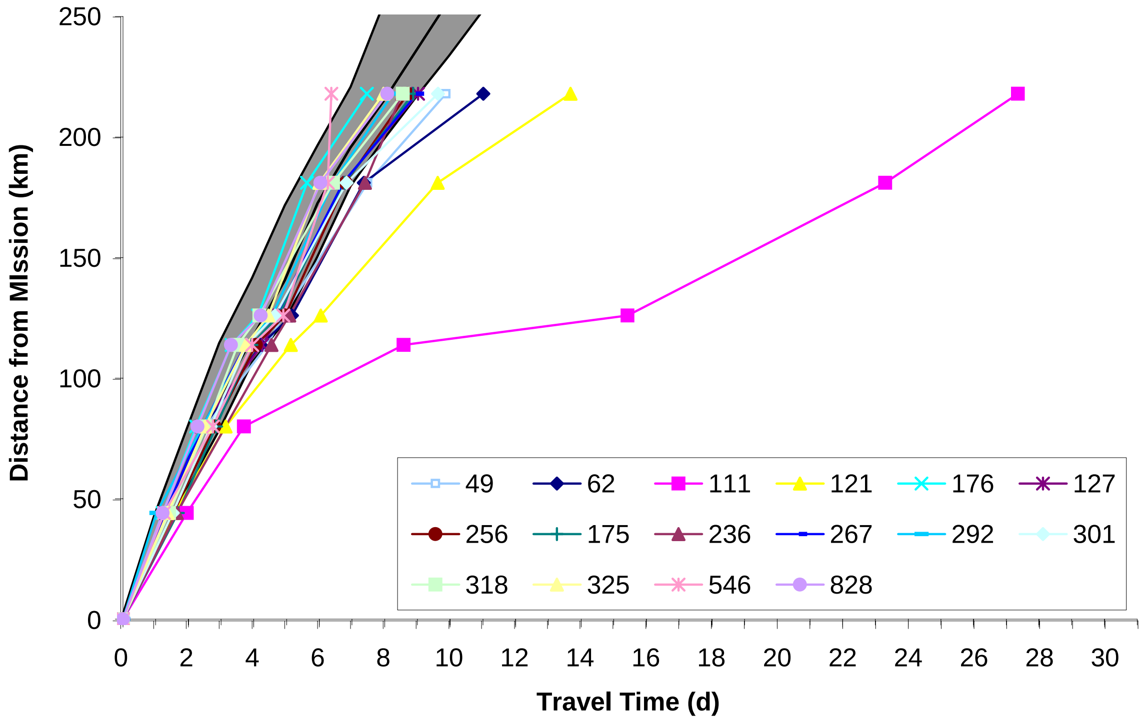


Figure 26. Travel times for 16 Early Summer sockeye last detected at Spence's Bridge or Kamloops Lake. The shaded area delimits the 95th percentile travel times for 29 Early-Summer sockeye that successfully migrated to stock-specific spawning areas in the Thompson drainage; and the central line shows the median. Of the fish that vanished in the Spence's Bridge/Kamloops Lake area, 69% were moving upriver at the same rate as their surviving counterparts, or faster.



APPENDICIES

APPENDIX A

Fixed station Receiver Locations and Performance

APPENDIX REPORT A

Description of fixed station sites

Twenty four fixed station receivers were set-up at 25 sites in 2006 to monitor radio-tagged sockeye moving up the Fraser River (Figure 1; Appendix Table A1). With the exception of the Horsefly River, Weaver, Lower Shuswap, Chilko, Nechako, Stuart, and Bridge River 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 trunk or to an aluminum pole >10 m above ground, a peripheral unit to switch between antennas, a Lotek model SRX_400 or SRX_600 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. Fifteen stations had solar panels and a voltage regulator to keep the batteries charged. Five sites (Mission South; Hell's Gate; Kamloops Lake Little River; and Nechako) 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 where possible. 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. At most fixed-station receiver sites, the antenna adjustments and detection range tests were performed in 2005 (as part of a previous study; see Robichaud and English 2006), and the antennas were left in place over the winter. In 2006, tags were walked along the banks upstream and downstream to test signal reception. 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) generally 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 1 km downstream from the release site. To access the site, travel by boat approximately 11 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. In 2005, 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 75, 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 take the trail that crosses 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.

Testing of this station involved walking the tag along the bank approximately 100 m upstream and downstream of the site. All antennas tested well with good power levels and good separation between antennas. 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. The antennas were mounted in a 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 Pacific Salmon Commission acoustic site.

This station was tested in the same manner as Mission North, with similar results. 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) while using an SRX400 receiver. The SRX400 was replaced with an SRX600 in August and the gains were then lowered to 70. The SRX600 had noise problems throughout the study period.

Harrison Confluence: Going west on Hwy #7 (Lougheed Hwy) take a left on School Rd. just before the Harrison River Bridge. Follow this then take a left on Kilby Road. Proceed until a small railway overpass on the right. Turn and go under the railway tracks. Travel through some houses on the Skowlitz Reservation up onto a dyke and turn left. Park at the gate if it is locked. Drive/walk up the dyke about 250m. The antennas were on a cottonwood tree nearest the water on the right hand side, at the most logical spot at the junction of the Harrison.

Testing of this station involved walking the tag along the dyke approximately 150 m upstream and downstream of the site. All antennas tested well with good power levels and good separation between antennas. Although there was slight concern over local train and boat traffic, the station functioned effectively at a gain setting of 75.

Upper Harrison: The upper Harrison site was moved to the east side of the river because the main channel is close to the east side and signals could not be picked up in the deeper water of the channel from the west side. It is accessible by boat and is located at the last cottage upstream of Weaver Creek and downstream of Harrison Lake.

Travelling to the site by boat, head up the Harrison until you see some active logging on the right bank. Just before this you will see a house with a green tin roof on the right bank. The station location is at the next wharf on the right bank. Pull into the wharf and travel down the beach to the north. The station is located on a fir tree high above the water on your right. There is a small path up a rocky bluff to the base of the fir tree. Two antennas were mounted approximately 10 m up the tree.

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 antennas. Background noise from motors of fishing boats was a slight concern at this station. Gains were set at 75 to begin with and later reduced to 70.

Weaver Creek: Traveling highway #7 from Mission towards Aggasiz, turn left on Morris Valley Road. Follow this road until Weaver Creek and turn right on Arbor Road. If the gate is closed, park at #17500 Arbor otherwise drive right to the site. Stay left for approximately 300 – 400 m along the road. The site was located at the base of a small conifer on the left of the road and the two antennas were mounted about 5 m up the tree.

Testing of this station involved walking the tag along the road approximately 60 m upstream and downstream of the site. The receiver for this site was that whichwas taken from the North Thompson site. At North Thompson, there were noise issues due to local train traffic. Despite a lack of potential noise sources at Weaver Creek, the gains were not reset at the time of installation: gains were set at 67. Despite the low gain settings, all antennas tested well with good power levels and good separation between antennas when checked with the test tag. Weaver creek also had a mobile track conducted from the fish hatchery to the mouth at the time of demobilization. During the mobile track, gains were set as high as 90 in attempt to pick up tag signals, however, despite the presence of spawning Sockeye in the system, no signals were detected.

Rosedale Bridge: Traveling north on Hwy #9 (Agassiz Highway), take the first right on Whelpton Road after crossing the Rosedale-Agassiz Bridge. Take another right on Bridge Road. The road eventually winds underneath the bridge. Park just beyond the intersection with the overhead bridge and proceed by foot to the seventh tree on the left. Two antennas were mounted about 13 m above water in a cottonwood tree. The first scanned downstream, and the second scanned upstream.

Testing of this station involved walking the tag along the road approximately 100 m upstream and downstream of the site. All antennas showed good power levels and good separation between antennas when checked with the test tag. Gains at this station were initially set quite high at 80, but were dropped to 40 in late September.

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.

Testing of this station involved walking the tag along the shore approximately 100 m upstream and downstream of the site. All antennas showed good power levels and good separation between antennas when checked with the test tag. Gains at this station were set quite high at 80 as there were no noise issues.

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 likely performed very efficiently. There was some noise generated by passing trains that may have hampered detection efficiency slightly. Gains for this site were set at 75 for this site and performance was good throughout the study period.

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 walking the tag to downstream end of the left bank fishway to test the downstream antennas, 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, the tag was walked to the upstream edge 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. Gains were set at 70 for each antenna array.

Fraser-Thompson Confluence: Once in Lytton, head north towards Lillooet 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).

Testing of this station involved walking the tag along the ridge approximately 100 m upstream and downstream of the site. All antennas showed good power levels and good separation between antennas when checked with the test tag. Gains at this station were set to 65 as there were some noise issues due to local train traffic.

Thompson-Nicola Confluence(Spence's Bridge): 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 large 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.

Testing of this station involved walking the tag along the ridge approximately 100 m upstream and downstream of the site. All antennas showed good power levels and good separation between antennas when checked with the test tag. Gains at this station were set to 60 as there were some noise issues due to local train traffic.

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. Results indicated good detections on both antennas. This station was initially problematic because of the proximity of local train traffic. To overcome this noise problem, the gains had to be lowered to 67.

Kamloops Lake: Take Lafarge Road about 20 km east of Kamloops. Cross the river and turn right. Follow the road past the golf course and sod farm. There is a small shed and wood fence at the entrance to address #3660 (Timber Whitehouse's house). The receiver box is along the upstream side at the back of the house and the two antennas are on the balcony above the box. .

Testing of this station involved walking the tag along the bank approximately 50 m downstream and 50 m upstream. Results indicated good detections on both antennas. Gains at this station were set to 60, once again due to the presence of environmental noise.

Little River: Take the exit to Scotch Creek/Adams Lake/Quaaout Lodge off of Highway #1. Cross the bridge over Little River and take the first left just past the bridge. Follow the road for 1.8 km and turn left onto a dirt road. Follow this road to the very end keeping to the left. There is a wooden gate with the numbers 177 and 288. The homeowner will allow access through the yard if permission is received ahead of time, otherwise, back track to the trail that enters the bush before the house and follow this down to the river. Station is to the right beside the house. The antennas are mounted about 10 m up a large conifer.

Testing of this station involved walking the tag along the bank approximately 50 m downstream and 100 m upstream. Results indicated good detections on both antennas. Gains were set to 65 to counter the effects of local vehicle and train traffic.

Adams River: Take the exit to Scotch Creek/Adams Lake/Quaaout Lodge off of Highway #1. Cross the bridge over Little River and continue straight on the main road to Scotch Creek for 6.2 km. There will be a sign indicating "Cottonwood campsite". Turn right just before that sign and go past a DFO log building on the right. Stay on the main road past the building and continue 0.6 km to a parking area. Take the trail to the left that initially parallels the lake. Go right at the first intersection (left goes down to the lake) and right at the second (the left one goes down to the river below the station). At the next intersection take a left. There should be a creek with substantial, almost still water on the left. Follow this path along the creek to the Adams River, the station is at the tree at the end. There are 4 antennas at this station. Two point downstream, one to the main channel and the other to the back channel on the other side of an island, and two point to the upstream ends of the main and back channels. The antennas were mounted about 10 m up a small tree, with a box mounted at the base of the tree.

Testing of this station involved walking the tag along the bank approximately 20 m downstream and 100 m upstream of the station. There was no way to test the tag farther downstream than 20 m as the station was located right on a point near a large side channel. Naturally, the tag was picked up strongly on all antennas from this location. Results from upstream tests indicated good detections on all antennas and good directional signal strength as well. Gains for all antennas were set to 70 and detection results were good throughout the study period. Despite the tests, the station performed disappointingly, and a taller tree will need to be used for future studies.

Lower Shuswap: Turn to the east at the main intersection (the traffic light) in Enderby. Follow Mabel Lake Road for 5.7 km from the bridge (6.1 km from traffic light). The house number is 576 and there are two steel sockeye silhouettes hanging by the driveway. The station is upstream of the house and there is a good path leading to it that starts along the upstream side of the lawn. There are 2 antennas mounted approximately 10 m above the water in a large confier.

Testing of this station involved walking the tag along the bank approximately 100 m downstream and 100 m upstream. Results indicated good detections on both antennas and good distinction between upstream and downstream signals. Gains were set to 60 and the station performed very well throughout the study period.

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 2.5 m off the ground in a tree. Three antennas were mounted approximately 10 m up a large 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 100 m downstream and 100 m upstream of the station. All three antennas tested well with good power levels and good separation between antennas and gains were set to 75. The first antenna scanned the downstream section of the Fraser River, the second scanned the Seton River, and the third scanned the upstream section of Fraser.

Bridge River: Take the road into Lillooet, turn right on Main Street, and follow it through town. Turn left on Moha Road (road to Goldbridge) and follow the road until reaching a bridge crossing the Bridge River. Immediately before the bridge there is a small concession stand off the right side of the road. Stop here first to let the staff know that you will be visiting the station and the reason. Cross the bridge and park in the parking area on the other side of the bridge. On the right side of the road just after crossing the bridge there is a trail. Follow this trail until it starts going down a slope. The main trail will appear to go straight into some fishing camps, and there will be a loose gravelly trail that appears to go off to the left and up the side of the hill. Follow the trail to the left and up the hill, crossing over a small foot bridge after a short distance. Continue along past a fish ladder on the trail side of the Fraser River. The trail will slope down again and there will be a fishing camp perched on a rocky outcropping. The station is installed at the fishing camp. There are two antennas mounted directly on the fishing camp, about 20 m above the surface of the river.

Testing of this station involved walking the tag along the bank approximately 100 m upstream and downstream of the camp. All antennas tested well with good power levels and good separation between antennas. Gains were set to 75 and noise was not an issue at this site.

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 reaching 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 conifer, 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 walking the tag along the bank approximately 200 m downstream on the Fraser mainstem and 200 m upstream in the Chilcotin mainstem (further access was not possible). All antennas tested well with good power levels and good separation between antennas. 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.

Chilko River: The station is located at the DFO field site. Take Highway 20 from Williams Lake towards Bella Coola, traveling for about 220 km. Before the town of Tatla Lake turn left, following signs to Chilko Lake Lodge. Continue along this gravel road (in parts with bad corners and crazy turns) always following signs for the Lodge. After 1h40 min, you come to an intersection where the left goes to "Ts'il?os Provincial Park" and the right goes to Chilko Lake Lodge. Go right. The road follows the Chilko River. In 3-4 minutes, the unmarked DFO driveway is on the left. Driveway goes along quite far and actually crosses a small stream at one point. It looks like a typical DFO field camp, including several buildings and a big gas tank near the driveway entrance. If you miss the entrance, you end up at Chilko Lake Lodge. The driveway is merely a road leading to the bush and is easily missed. It would probably be easiest to call Dave Willis prior to arrival so he can meet with you and show you in to the site. His number is 403-927-6030. The DFO crews stay in a cabin just outside of Chilko Lake lodge.

When the station was installed, crew flew into Chilko Lake Lodge from Victoria and was picked up at the airstrip by Dave Willis. Given the amount of driving involved to reach the site, this is likely the best way of accessing the site. The equipment is located in the smaller of 2 cabins located just downstream of the main house. The cabin is unlocked due to the remoteness of the site and the fact that there are always DFO staff on site. Two antennas are mounted approximately 10 m up a small conifer, antenna 1 scanning downstream and antenna 2 scanning upstream.

Testing of this station involved walking the tag along the bank approximately 100 m downstream and 100 m upstream of the station. Antenna 1 scanned downstream on the Chilko while antenna 2 scanned upstream. Both antennas tested well with good power levels and good separation between antennas. Noise was not an issue despite nearby boat traffic so gains were set at 80 and the station ran 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 of this station involved walking the tag along the bank approximately 100 m downstream and 100 m upstream of the station. Antenna 1 scanned downstream on the Fraser while antenna 2 scanned upstream on the Quesnel River and antenna 3 scanned upstream on the Fraser. All antennas tested well with good power levels and good separation between antennas. Noise was a potential issue due to the proximity to the city of Quesnel and local train traffic so gains were initially set at 50. Gains were later raised to 70.

Horsefly River: The station was located at a DFO fish fence site on the Horsefly river. Turn off Highway 97 on to Likely Road in 150 Mile House. Stay right past the turn-off to Likely and follow road to the community of Horsefly. At the general store the road will split. Right goes over the river, straight goes to Campbell Avenue and left goes to Boswell Road. Stay left on Boswell Road and follow a short distance, turning right on Mitchell Bay Road. The road will turn to gravel. From the start of the gravel, travel 16.7 km. At this point the road will be going around a sharp left-turning corner. On the outside of this corner you will see orange flagging tape marking a driveway with a gate and a “No Trespassing” sign. This is the road to the site. It may be locked. If so walk in to the DFO camp and have someone come unlock the gate. The station is mounted on a tree right next to the river by the DFO fish fence. The antennas were mounted to the end of a metal walkway that extended about 5 m out into the river channel and were approximately 4 m above the surface of the water. The first antenna scanned downstream in the Horsefly River and the second scanned upstream.

Testing of this station involved walking the tag along the bank approximately 100 m downstream and 100 m upstream of the station. Results indicated good detection on both antennas with the expected separation between antennas. Due to the close proximity of the station to the work being performed by the DFO crews and the DFO camp, the gains were set a little lower at 60 to avoid any noise issues. As the river at this spot is quite narrow and shallow this allowed for the station to maintain a high efficiency even at the lower gain settings.

Fraser-Nechako Confluence: This site was located at the mouth of the Nechako River at the Spruce City Wildlife Hatchery in Prince George. Take Highway 97 through Prince George and turn right on 5th Avenue. Turn left on Carney Street. Follow Carney along and it will become River Road. Continue along River Road a couple of kilometers and the Hatchery building will be on the left side of the road and is a log building. Station is set up in a rubbermaid tub in the main board room of the building. 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 Nechako River, the second scanned upstream in the Nechako River. The receiver was powered by 110 volt power supply from the building.

To test this site, a tag was walked approximately 150 m upstream and downstream of the station. Results indicated good detection on all antennas with the expected separation between antennas. Noise was a significant concern in the area due to local train traffic and nearby sawmills and pulp-and-paper plants. As a result, the gains were initially set to 45, and were later increased to 60. Despite noise concerns, the station performed effectively throughout the study period.

Nechako-Stuart Confluence: The station is located at the confluence of the Stuart and Nechako Rivers and must be accessed by boat. Take Highway 16 west towards Vanderhoof and travel approximately 40 minutes. Shortly after passing Bednesti Lake gas station, turn right on Finmore Road. Follow Finmore (11 km) until it essentially ends in a fork. Stay right. You will go around a corner and have to cross some railroad tracks. Continue along the main, well traveled portion of the road. IN the past, there has been a sign on your right made out of a pie plate attached to a stick with the words “RM Saikuz” written on it. Regardless, continue a short distance and a boat launch will be seen on the right. Launch the boat and travel several kilometers down river to the confluence with the Stuart. The site is on top of the plateau on the right bank (looking upstream on Stuart) right at the corner. Climb the sandy slope up to top of plateau. The station is next to some beetle killed pine trees. Antennas are located in 3 separate trees, two approximately 15 m above the water on top of the hill for the upstream Nechako and the upstream Stuart antennas, and one lower down the hill approximately 10 m above the water for the downstream Nechako.

To test this site, a tag was walked approximately 100 m upstream and downstream of the station. Results indicated good detection on all antennas with the expected separation between antennas. Noise was a potential concern in the area due to local train traffic so the gains were set to 65 and the station performed efficiently throughout the study period.

Appendix Table A1. Orientation of each antenna at each fixed-station receiver site, 2006.

Fixed Station Receiver Site	Antenna	Antenna Orientation
Cresent Island	1	Downstream Main Channel
Cresent Island	2	Downstream Back Channel
Cresent Island	3	Upstream Main Channel
Cresent Island	4	Upstream Back Channel
Mission North	1	Downstream
Mission North	2	Upstream
Mission South	1	Downstream
Mission South	2	Upstream
Harrison Confluence	1	Downstream Fraser
Harrison Confluence	2	Upstream Harrison River
Harrison Confluence	3	Upstream Fraser
Upper Harrison	1	Downstream
Upper Harrison	2	Upstream
Weaver	1	Downstream
Weaver	2	Upstream
Rosedale	1	Downstream
Rosedale	2	Upstream
Hope	1	Downstream
Hope	2	Upstream
Sawmill	1	Downstream
Sawmill	2	Upstream
Hells Gate	1	Downstream Below Rapids
Hells Gate	2	Upstream Below Rapids
Hells Gate	3	Downstream Above Rapids
Hells Gate	4	Upstream Above Rapids
Thompson Confluence	1	Downstream Fraser
Thompson Confluence	2	Upstream Thompson River
Thompson Confluence	3	Upstream Fraser
Spences Bridge	1	Downstream Thompson
Spences Bridge	2	Upstream Nicola River
Spences Bridge	3	Upstream Thompson

continued to right…

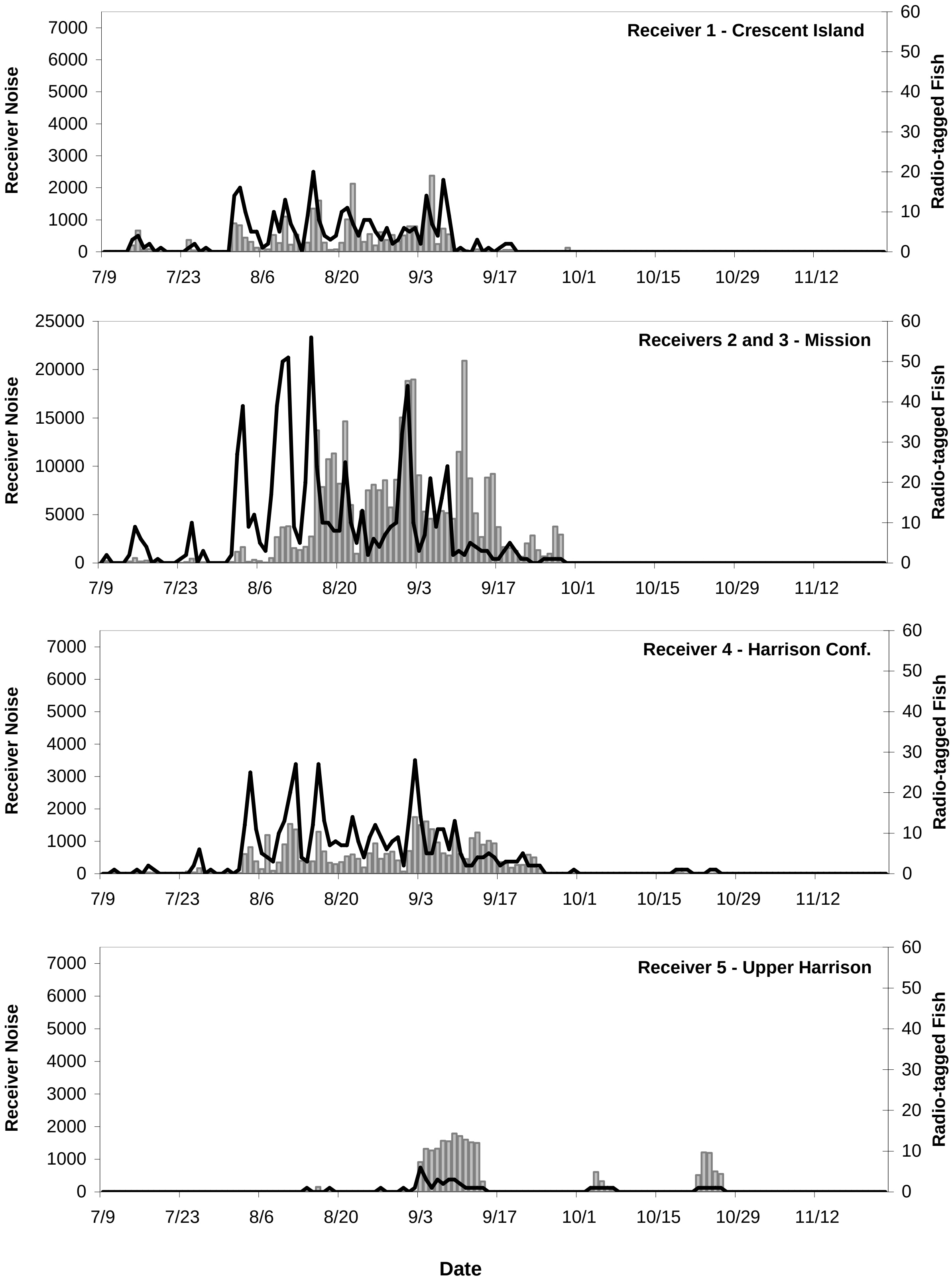
Fixed Station Receiver Site	Antenna	Antenna Orientation
North Thompson	1	Downstream
North Thompson	2	Upstream
Top of Kamloops Lake	1	Downstream
Top of Kamloops Lake	2	Upstream
Little River	1	Downstream
Little River	2	Upstream
Adams	1	Downstream Main Channel
Adams	2	Downstream Back Channel
Adams	3	Upstream Main Channel
Adams	4	Upstream Back Channel
Lower Shushwap	1	Downstream
Lower Shushwap	2	Upstream
Seton Confluence	1	Downstream Fraser
Seton Confluence	2	Upstream Seton River
Seton Confluence	3	Upstream Fraser
Bridge River	1	Downstream Fraser
Bridge River	2	Upstream Fraser
Chilcotin Confluence	1	Downstream Fraser
Chilcotin Confluence	2	Upstream Chilcotin River
Chilcotin Confluence	3	Upstream Fraser
Chilko	1	Downstream
Chilko	2	Upstream
Quesnel Confluence	1	Downstream Fraser
Quesnel Confluence	2	Upstream Quesnel River
Quesnel Confluence	3	Upstream Fraser
Horsefly	1	Downstream
Horsefly	2	Upstream
Nechako	1	Downstream
Nechako	2	Upstream
Stuart	1	Downstream Nechako
Stuart	2	Upstream Stuart
Stuart	3	Upstream Nechako

Appendix Table A2. Fixed station monitoring efficiency (percent operational) by week for all sites monitored between 6 July and 30 Nov, 2006.

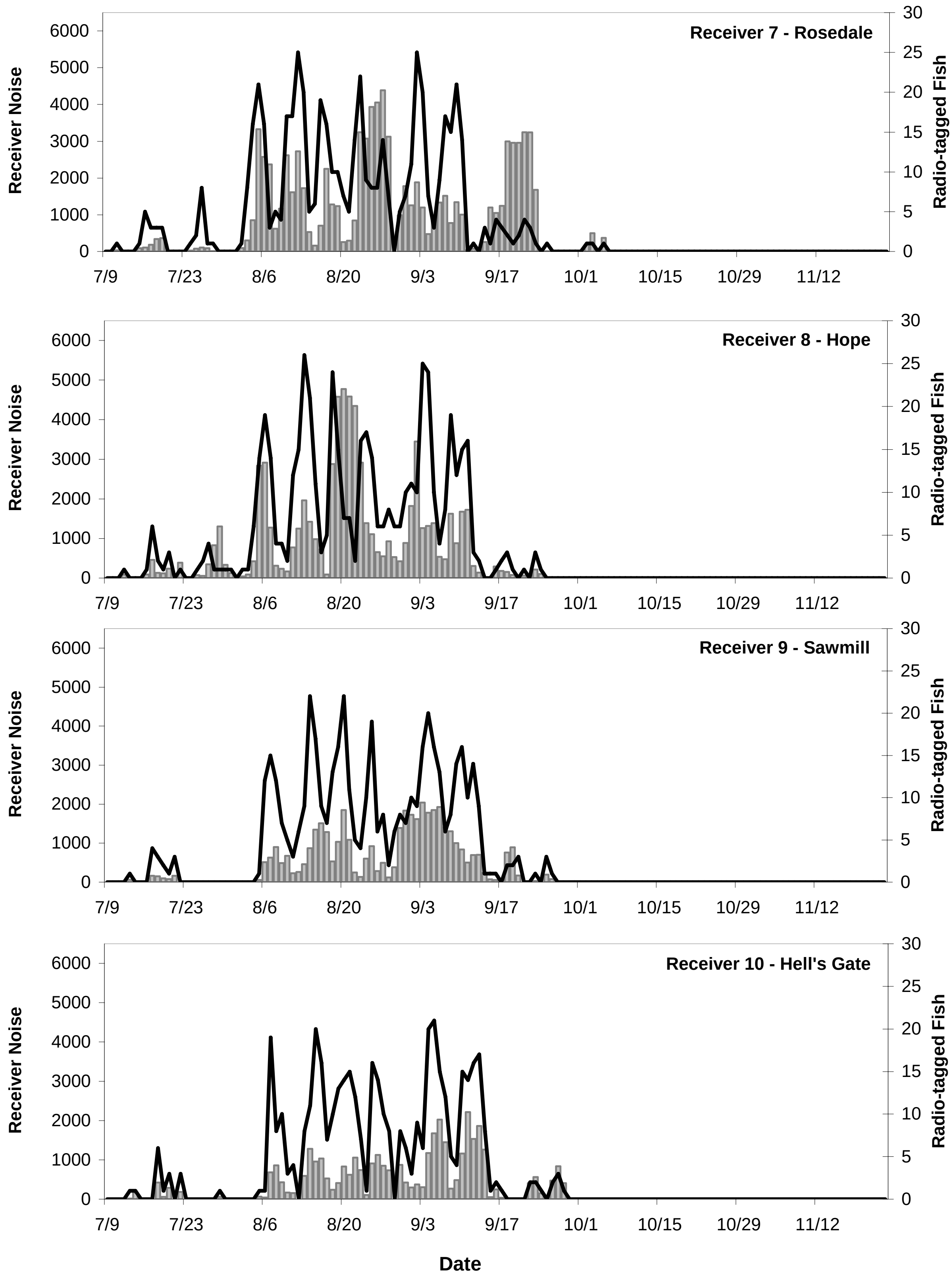
	Fixed-Station Receiver Site												
Week Start Date	Crescent Island	Mission North	Mission South	Harrison Conf.	Harrison Lake	Weaver	Rosedale	Hope	Sawmill	Hell's Gate	Thompson Conf.	Spences Bridge	North Thompson
6 Jul	100%	100%	100%	100%	100%		100%	100%	100%	100%	100%	100%	100%
13 Jul	100%	100%	100%	100%	100%		100%	99%	100%	100%	87%	100%	100%
20 Jul	99%	100%	100%	100%	100%		100%	100%	79%	100%	100%	100%	100%
27 Jul	100%	100%	100%	100%	100%		76%	100%	18%	100%	100%	99%	100%
3 Aug	100%	100%	100%	100%	100%		100%	100%	100%	100%	100%	100%	100%
10 Aug	100%	100%	100%	100%	100%		100%	91%	100%	100%	100%	100%	100%
17 Aug	100%	100%	100%	100%	100%		100%	89%	100%	100%	100%	100%	100%
24 Aug	100%	100%	100%	100%	100%		78%	100%	100%	100%	100%	100%	100%
31 Aug	100%	100%	100%	100%	100%		100%	100%	100%	100%	100%	100%	100%
7 Sep	100%	100%	99%	100%	100%		100%	100%	100%	100%	100%	100%	100%
14 Sep	100%	100%	100%	100%	63%		100%	100%	100%	53%	100%	100%	100%
21 Sep	100%	100%	100%	100%	100%	100%	100%	100%	100%	78%	99%	100%	100%
28 Sep	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
5 Oct	100%	100%		100%	39%	99%	99%	100%	100%	100%	100%	100%	
12 Oct				100%	0%	100%	100%	100%	100%	100%	100%		
19 Oct				100%	50%	100%	100%	100%	100%	100%	100%		
26 Oct				100%	100%			100%		100%	100%		
2 Nov													
9 Nov													
16 Nov													
23 Nov													
Overall	**100%**	**100%**	**100%**	**100%**	**85%**	**100%**	**97%**	**99%**	**94%**	**97%**	**99%**	**100%**	**100%**

	Fixed-Station Receiver Site											
Week Start Date	Top of Kamloops Lake	Little River	Adams River	Lower Shuswap	Seton	Bridge River	Chilcotin	Chilko	Quesnel Conf.	Horsefly River	Nechako	Stuart
6 Jul	100%	100%			100%		83%		100%			
13 Jul	100%	100%			100%		0%		100%			
20 Jul	100%	100%			100%		0%		100%			
27 Jul	100%	100%			100%		77%		100%		100%	100%
3 Aug	100%	100%			100%		100%		100%		100%	100%
10 Aug	100%	100%			100%	100%	100%		100%		100%	100%
17 Aug	65%	100%	100%	100%	100%	100%	100%		100%	100%	99%	85%
24 Aug	37%	100%	100%	100%	100%	100%	100%		100%	99%	100%	100%
31 Aug	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
7 Sep	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	60%
14 Sep	100%	100%	100%	100%	100%	100%	100%		100%	100%	100%	
21 Sep	100%	100%	100%	100%	100%	100%	100%		100%	100%	100%	
28 Sep	100%	82%	81%	100%	100%	100%	100%		100%		100%	
5 Oct	100%	34%	34%	100%	100%	100%	100%		100%		100%	
12 Oct	100%	100%	100%	100%							100%	
19 Oct	100%	100%	99%	76%								
26 Oct	100%	100%	99%	65%								
2 Nov	100%	100%	99%	100%								
9 Nov	100%	100%	100%	100%								
16 Nov	100%	100%	100%	26%								
23 Nov	100%	100%		62%								
Overall	**96%**	**96%**	**93%**	**90%**	**88%**	**100%**	**83%**	**100%**	**100%**	**100%**	**100%**	**92%**

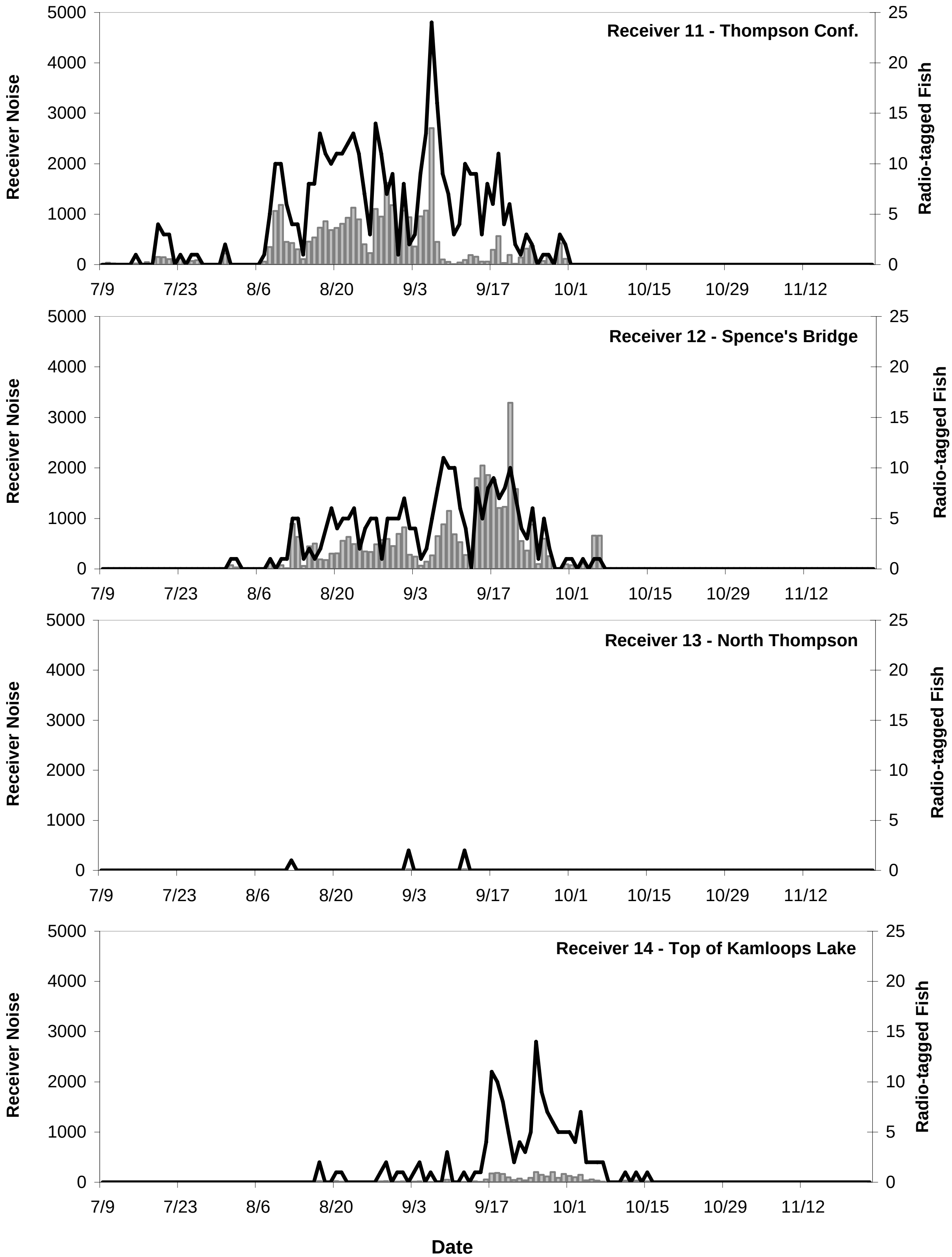
Appendix Figure A1. **Receiver noise/collisions (bars) and total number of fish detected (line) by day from 9 July-30 November, 2006.**



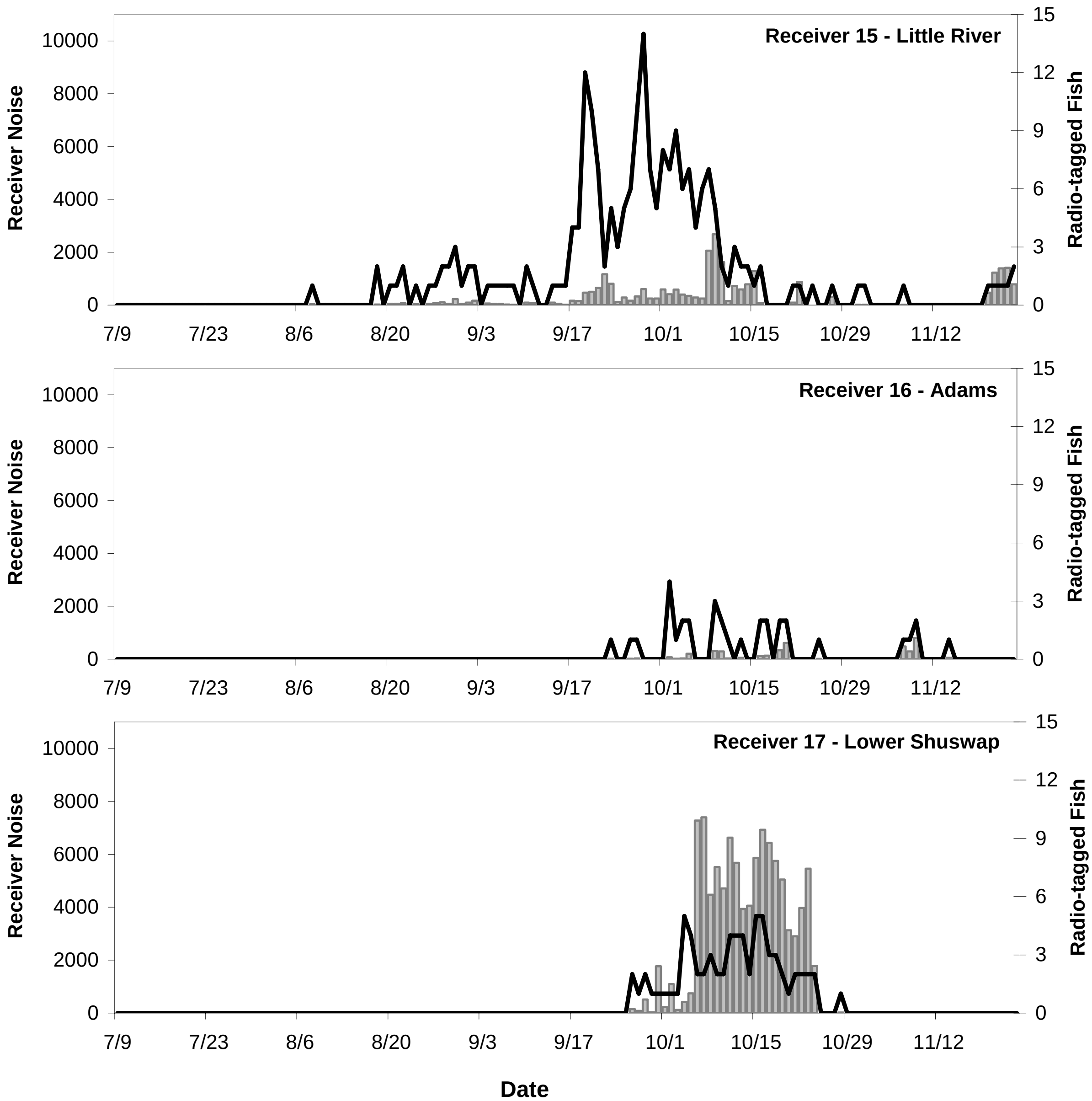
Appendix Figure A1 continued.



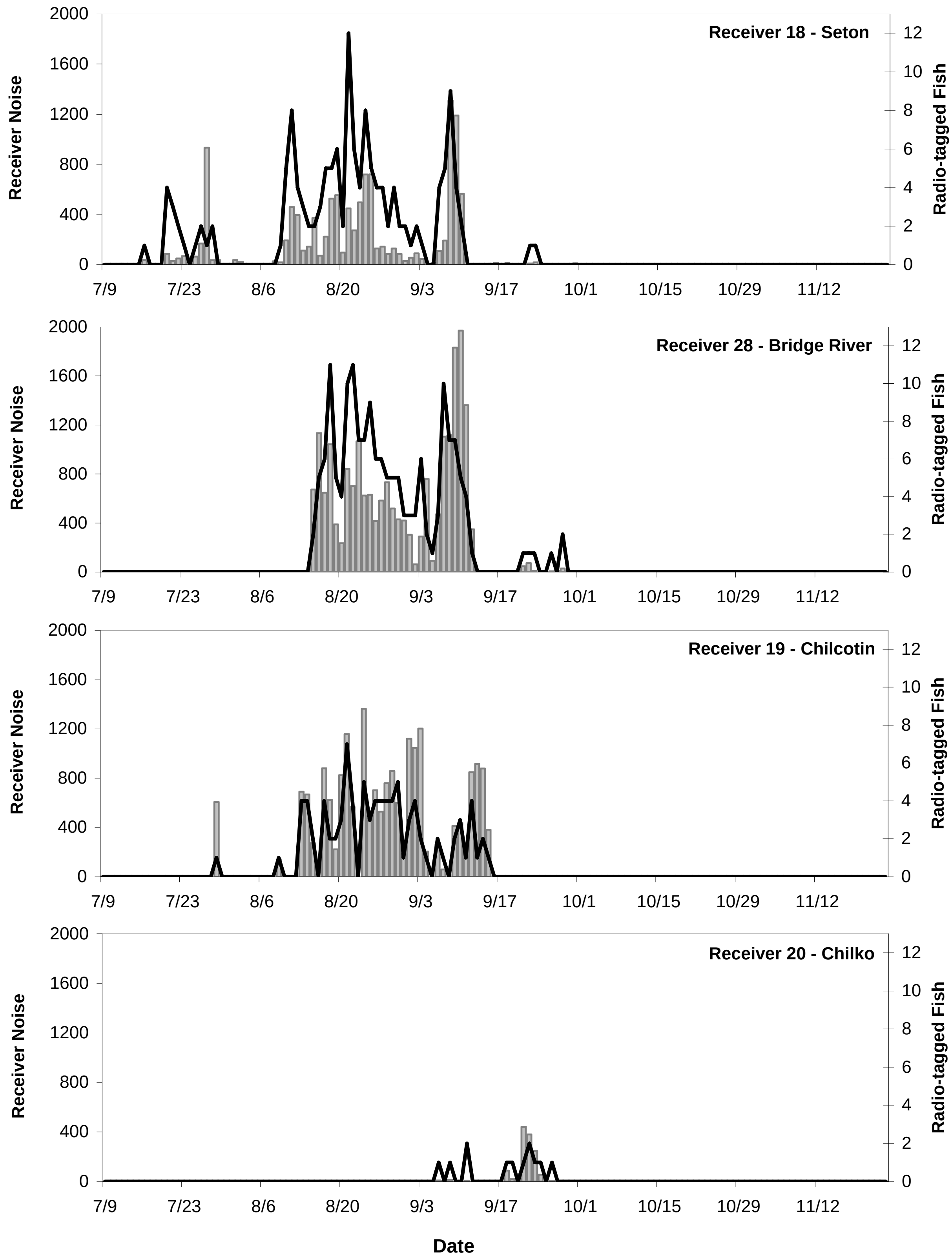
Appendix Figure A1 continued.



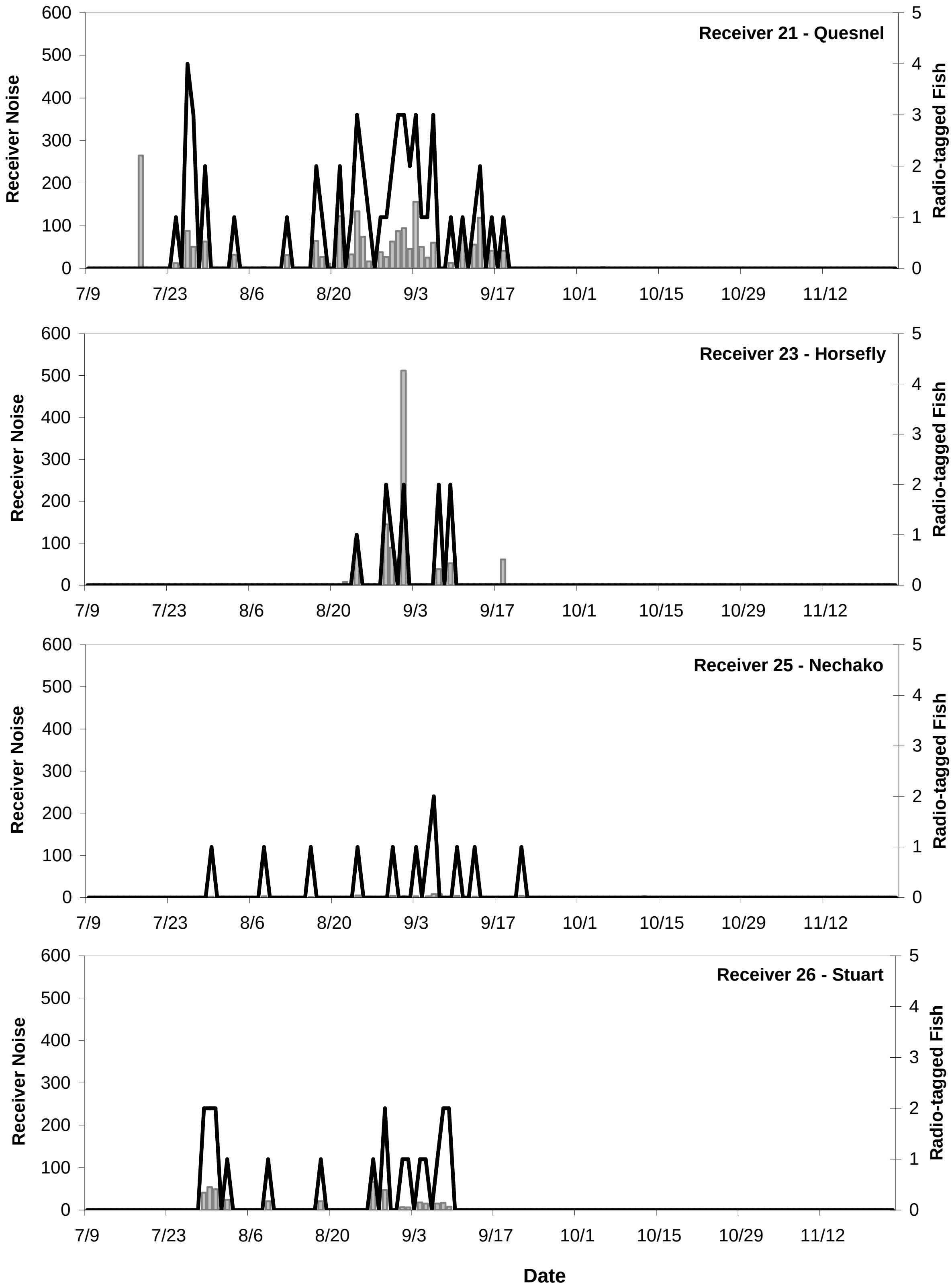
Appendix Figure A1 continued.



Appendix Figure A1 continued.



Appendix Figure A1 continued.



APPENDIX B

Mobile Detections, Spawning area Recoveries, and Fishery Returns

Appendix Table B1. **Dates, locations and survey types for mobile tracking surveys conducted in 2006, and tags detected during each survey.**

Date	Location	Survey Type	Tags Detected
2 Oct	Mitchell River	aerial survey	356, 738, 1121
5-14 Oct	Little River	truck survey	364, 975, 1131
16 Oct	Lower Shuswap	aerial survey	342, 833, 866, 884, 885, 962, 967, 973, 1005, 1066, 1082, 1109, 1151, 1165
19 Oct	Shuswap Lake	boat survey	none
19 Oct	South Thompson, Little River, Adams mouth, Kamloops Lake	aerial survey	364, 834, 1048, 1062, 1065, 1092, 1147
20 Oct	Adams mouth, Kamloops Lake, Scoth Creek, South Thompson	aerial survey	24, 245, 500, 589, 611, 667, 673, 728, 810, 975, 1128
21 Oct	Shuswap Lake	boat survey	542, 1146
22 Oct	Seymour River	boat survey	375, 604, 994
26 Oct	Weaver Creek	foot survey	none
28 Oct	Lower Shuswap, Mara Lake, Eagle River	truck survey	54, 195, 277, 330, 360, 508, 556, 845, 890, 891
29 Oct	Adams River, Scotch Creek, Shuswap Lake	boat survey	73, 82, 108, 371, 658, 941, 978, 998, 1004, 1026, 1064, 1081, 1111, 1133, 1134, 1159
1 Nov	Little Shuswap Lake, South Thompson	truck survey	364, 667, 882, 1042, 1125, 1131, 1147
4 Nov	Little River, Shuswap Lake, Little Shuswap Lake, Adams	boat & foot survey	371, 667, 702, 882, 897, 941, 992, 1060, 1125, 1147
5 Nov	Seymour River	truck survey	92

Appendix Table B2. Tags recovered from fisheries, and reported before 31 December, 2006.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Zone	Recovery Location
20	IR_2	Early Stuart	26 Jul	FN Fishery between Mission and Sawmill	Coquihalla
25	IR_2	Undetermined	28 Jul	FN Fishery between Mission and Sawmill	Hunter Creek
41	IR_3	Summer-run	4 Aug	Sport Fishery U/S Mission	1 km upstream from Harrison River conjuc
102	IR_3	Early Summer	5 Aug	Sport Fishery U/S Mission	Agassiz Bridge
38	IR_3	Summer-run	6 Aug	FN Fishery between Mission and Sawmill	Agassiz Bridge
97	IR_3	Summer-run	6 Aug	FN Fishery between Mission and Sawmill	Agassiz Bridge
91	IR_3	Early Summer	6 Aug	Sport Fishery U/S Mission	Hope - Seaburg
66	IR_3	Late-run	7 Aug	FN Fishery between Mission and Sawmill	Agassiz Bridge
56	IR_3	Summer-run	7 Aug	FN Fishery U/S Sawmill	Boston Bar
90	IR_3	Early Summer	8 Aug	FN Fishery U/S Sawmill	2 miles south of North Bend
144	MA_1	Early Summer	9 Aug	Sport Fishery U/S Mission	Grassy bar - Chilliwack
635	MA_1	Summer-run	10 Aug	Commercial Fishery Area 20	Area 20
136	MA_1	Late-run	11 Aug	FN Fishery between Mission and Sawmill	betwn Harrison River conflu and Agassiz Bridge
181	MA_1	Early Summer	11 Aug	Sport Fishery U/S Mission	Peg Leg - Chilliwack
530	MA_1	Summer-run	11 Aug	U.S. Marine Commercial Fishery	Point Roberts at spit
600	MA_1	Late-run	11 Aug	U.S. Marine Commercial Fishery	Lumi Island
523	MA_1	Summer-run	11 Aug	U.S. Marine Commercial Fishery	Rosario Strait - bluffs
170	MA_1	Early Summer	12 Aug	FN Fishery between Mission and Sawmill	just below the town of Yale
113	IR_3	Summer-run	12 Aug	FN Fishery U/S Sawmill	4 km upstream of Lilloeet
204	MA_1	Late-run	12 Aug	Sport Fishery U/S Mission	Grassy bar - Chilliwack
218	MA_1	Summer-run	12 Aug	Sport Fishery U/S Mission	Chilliwack - 1/2 mile downstream of bridge
568	MA_1	Early Summer	12 Aug	U.S. Marine Commercial Fishery	Area 7A - Homeport Seafoods
507	MA_1	Early Summer	12 Aug	U.S. Marine Commercial Fishery	Area 7A
222	MA_1	Late-run	13 Aug	FN Fishery between Mission and Sawmill	Agassiz Bridge
146	MA_1	Early Summer	13 Aug	FN Fishery between Mission and Sawmill	Yale
115	IR_3	Late-run	13 Aug	FN Fishery U/S Sawmill	Lytton - Siska Reservation
225	MA_1	Late-run	13 Aug	Sport Fishery U/S Mission	Agassiz Bridge
675	MA_1	Late-run	13 Aug	U.S. Marine Commercial Fishery	HyTide Fish Food Processing Plant
148	MA_1	Late-run	14 Aug	FN Fishery U/S Sawmill	South Anderson Creek
511	MA_1	Summer-run	14 Aug	U.S. Marine Commercial Fishery	Area 7A
713	MA_1	Early Summer	14 Aug	U.S. Marine Commercial Fishery	Area 7A
610	MA_1	Early Summer	14 Aug	U.S. Marine Commercial Fishery	Area 7A
629	MA_1	Summer-run	14 Aug	U.S. Marine Commercial Fishery	Area 7
770	MA_1	Late-run	15 Aug	Commercial Fishery Area 12-13	Area 12- recovered at Lion's Gate processing plant
537	MA_1	Late-run	15 Aug	Commercial Fishery Area 12-13	Douglas Island
720	MA_1	Summer-run	15 Aug	Commercial Fishery Area 20	1 mile west of swale rock - Barkley Sound
640	MA_1	Early Summer	15 Aug	Freshwater Commercial Fishery	5 miles from mouth of Fraser (Richmond)

…continued

Appendix Table B2 continued.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Zone	Recovery Location
281	IR_5	Late-run	15 Aug	Freshwater Commercial Fishery	Silverdale/Mt. Raymond
283	IR_5	Summer-run	15 Aug	Freshwater Commercial Fishery	Cresent Island
687	MA_1	Summer-run	15 Aug	Freshwater Commercial Fishery	1 mile upstream of Stave River confluence
617	MA_1	Late-run	15 Aug	U.S. Marine Commercial Fishery	Lumi Island
120	MA_1	Late-run	16 Aug	FN Fishery between Mission and Sawmill	Agassiz Bridge
163	MA_1	Early Summer	16 Aug	FN Fishery U/S Sawmill	Thompson River 2.5 km d/s of Nicomen Bridge
252	IR_5	Summer-run	16 Aug	Sport Fishery U/S Mission	Harrison confl
233	IR_5	Summer-run	16 Aug	Sport Fishery U/S Mission	off Jesperson Bar
248	IR_5	Late-run	16 Aug	Sport Fishery U/S Mission	Peg Leg - Chilliwack
258	IR_5	Early Summer	16 Aug	Sport Fishery U/S Mission	Peg Leg - Chilliwack
740	MA_1	Summer-run	16 Aug	U.S. Marine Commercial Fishery	Area 7 - Deception Pass
153	MA_1	Early Summer	17 Aug	FN Fishery U/S Sawmill	Fountain BC
231	IR_5	Early Summer	17 Aug	Freshwater Commercial Fishery	Hi-To Fish Processing plant
262	IR_5	Early Summer	17 Aug	Sport Fishery U/S Mission	10 Km before the Hope Bridge
929	MA_2	Late-run	18 Aug	Commercial Fishery Area 12-13	Kamish Bay - Campbell River
898	MA_2	Early Summer	18 Aug	Commercial Fishery Area 12-13	Kamish Bay - Campbell River
694	MA_1	Summer-run	18 Aug	Commercial Fishery Area 12-13	Bella Coola Fishing plant - processor picked it up
653	MA_1	Late-run	18 Aug	Commercial Fishery Area 20	Area 20
259	IR_5	Early Summer	18 Aug	FN Fishery between Mission and Sawmill	By Hope
701	MA_1	Late-run	18 Aug	FN Fishery D/S Mission	Steveston - Fraser River
700	MA_1	Summer-run	18 Aug	FN Fishery D/S Mission	?
274	IR_5	Early Summer	18 Aug	Sport Fishery U/S Mission	Fraser - Hope @ Langston (Landstran?) Bar
623	MA_1	Summer-run	18 Aug	U.S. Marine Commercial Fishery	Area 7 Point Roberts Lily Point
726	MA_1	Late-run	18 Aug	U.S. Marine Commercial Fishery	?
669	MA_1	Summer-run	18 Aug	U.S. Marine Commercial Fishery	westside of San Juan Island
622	MA_1	Early Summer	18 Aug	U.S. Marine Commercial Fishery	Area 7A
671	MA_1	Early Summer	19 Aug	FN Fishery D/S Mission	Fraser River - Walace Bar
575	MA_1	Summer-run	19 Aug	Freshwater Commercial Fishery	Steveston - Fraser River
518	MA_1	Undetermined	19 Aug	Freshwater Commercial Fishery	Hi-To Fish Processing plant
937	MA_2	Early Summer	19 Aug	Sport Fishery Marine	above Brown's Bay
53	IR_3	Early Summer	20 Aug	FN Fishery between Mission and Sawmill	Rosedale area - Cheam Beach
599	MA_1	Summer-run	20 Aug	FN Fishery D/S Mission	Port Mann Bridge
562	MA_1	Summer-run	23 Aug	FN Fishery U/S Sawmill	Caught in area D11 (person lives in Lillooet)
823	MA_2	Early Summer	20 Aug	Freshwater Commercial Fishery	Brownsville Bar
703	MA_1	Summer-run	20 Aug	Sport Fishery U/S Mission	on the Fraser above Agassiz)
626	MA_1	Summer-run	20 Aug	U.S. Marine Commercial Fishery	Area 7A
907	MA_2	Late-run	21 Aug	Commercial Fishery Area 12-13	Area 13

…continued

Appendix Table B2 continued.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Zone	Recovery Location
918	MA_2	Late-run	21 Aug	Commercial Fishery Area 12-13	Area 12
118	IR_3	Summer-run	21 Aug	Sport Fishery U/S Mission	Sheep Creek Bridge Fraser River near Williams Lake
159	MA_1	Early Summer	22 Aug	FN Fishery U/S Sawmill	Thompson River, 1 km downstream of Kamloops Lake
706	MA_1	Late-run	22 Aug	Freshwater Commercial Fishery	Steveston - Fraser River
862	MA_2	Late-run	22 Aug	Freshwater Commercial Fishery	Steveston - Fraser River
876	MA_2	Early Summer	22 Aug	Freshwater Commercial Fishery	in Fraser River (?)
794	MA_1	Late-run	22 Aug	Freshwater Commercial Fishery	Fraser River by Pit Meadows Airport
841	MA_2	Late-run	22 Aug	Freshwater Commercial Fishery	Albion
555	MA_1	Early Summer	23 Aug	FN Fishery U/S Sawmill	Thompson River near Lytton
839	MA_2	Summer-run	23 Aug	Freshwater Commercial Fishery	?
935	MA_2	Late-run	23 Aug	Sport Fishery Marine	Brown's Bay - Area 11
748	MA_1	Late-run	23 Aug	Sport Fishery U/S Mission	Flood Hope Road - Huskey Exit near Hope BC
715	MA_1	Late-run	23 Aug	U.S. Marine Commercial Fishery	Area 7
735	MA_1	Late-run	23 Aug	U.S. Marine Commercial Fishery	Area 7
570	MA_1	Summer-run	23 Aug	U.S. Marine Commercial Fishery	Area 7
864	MA_2	Early Summer	23 Aug	U.S. Marine Commercial Fishery	Area 7
900	MA_2	Late-run	24 Aug	Commercial Fishery Area 12-13	Green Sea Bay
47	IR_3	Summer-run	24 Aug	FN Fishery U/S Sawmill	Chilcoltin River
40	IR_3	Early Summer	25 Aug	FN Fishery between Mission and Sawmill	by Union Bar (person lives in Agassiz)
659	MA_1	Summer-run	25 Aug	Sport Fishery U/S Mission	across from Seaton Power House in Lilloeet, BC
85	IR_3	Summer-run	26 Aug	FN Fishery between Mission and Sawmill	Yale - Sawmill Creek
749	MA_1	Late-run	27 Aug	FN Fishery U/S Sawmill	Thompson - Kamloops Lake
620	MA_1	Early Summer	28 Aug	FN Fishery U/S Sawmill	between Spences Bridge and Lytton
282	IR_5	Summer-run	28 Aug	FN Fishery U/S Sawmill	Chilcoltin River - in Farwell Canyon
911	MA_2	Early Summer	28 Aug	Sport Fishery U/S Mission	Hope
813	MA_2	Early Summer	28 Aug	Sport Fishery U/S Mission	Hope - 1 km south of the mouth of Hunter Creek
188	MA_1	Summer-run	29 Aug	FN Fishery U/S Sawmill	caught at Henry's crossing
859	MA_2	Late-run	29 Aug	Freshwater Commercial Fishery	Alex Fraser Bridge
964	MA_2	Late-run	29 Aug	Freshwater Commercial Fishery	near Albion
979	MA_2	Late-run	29 Aug	Freshwater Commercial Fishery	Lower Fraser River (Alex Fraser Bridge)
863	MA_2	Summer-run	29 Aug	Freshwater Commercial Fishery	Area 29 near the tunnel (Steveston)
298	IR_6	Late-run	30 Aug	Sport Fishery U/S Mission	caught in Hope area
521	MA_1	Early Summer	2 Sep	Freshwater Commercial Fishery	caught in Fraser
350	IR_7	Summer-run	2 Sep	Sport Fishery U/S Mission	caught in Chilliwack area
338	IR_7	Summer-run	2 Sep	Sport Fishery U/S Mission	caught near Vedder
374	IR_7	Summer-run	2 Sep	Sport Fishery U/S Mission	Grassy bar - Chilliwack
1155	MA_3	Summer-run	3 Sep	Commercial Fishery Area 12-13	Canadian Fish Processing Plant in Prince Rupert

…continued

Appendix Table B2 continued.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Zone	Recovery Location
535	MA_1	Summer-run	3 Sep	FN Fishery U/S Sawmill	Caught in area D11 (person lives in Lillooet)
343	IR_7	Late-run	3 Sep	Sport Fishery U/S Mission	By Agassiz
858	MA_2	Late-run	4 Sep	FN Fishery U/S Sawmill	Siska Landing on Siska Reserve
351	IR_7	Late-run	5 Sep	FN Fishery between Mission and Sawmill	near Gordon Creek 21km east of Hope
977	MA_2	Late-run	5 Sep	Freshwater Commercial Fishery	caught in Area 2917
361	IR_7	Summer-run	5 Sep	Freshwater Commercial Fishery	Found at Hi-To Fishery plant
805	MA_2	Late-run	5 Sep	Sport Fishery U/S Mission	Gill Road Exit ds of Agassiz
816	MA_2	Summer-run	7 Sep	Commercial Fishery Area 12-13	Ocean Fisheries - fish processing plant
1094	MA_3	Late-run	8 Sep	Commercial Fishery Area 12-13	Area 4 - Marine recovery near Skeena
322	IR_7	Summer-run	8 Sep	FN Fishery U/S Sawmill	Bridge River
123	MA_1	Summer-run	8 Sep	Freshwater Commercial Fishery	caught near island 22 before Harrison River
969	MA_2	Late-run	8 Sep	Freshwater Commercial Fishery	caught near island 22 before Harrison River
362	IR_7	Early Summer	8 Sep	Sport Fishery U/S Mission	caught near Chilliwack
1054	MA_3	Summer-run	9 Sep	FN Fishery between Mission and Sawmill	Yale
368	IR_7	Early Summer	11 Sep	FN Fishery U/S Sawmill	Thompson (Nicomen)
365	IR_7	Summer-run	11 Sep	FN Fishery U/S Sawmill	Lyton
168	MA_1	Late-run	15 Sep	FN Fishery U/S Sawmill	Boston Bar
1040	MA_3	Late-run	21 Sep	FN Fishery U/S Sawmill	Thompson/Nicomen River
558	MA_1	Early Summer	27 Sep	Freshwater Commercial Fishery	Upper Pitt River (7.5 km upstream)
331	IR_7	Early Summer	30 Sep	Sport Fishery U/S Mission	Anderson Lake
895	MA_2	Late-run	19 Oct	Commercial Fishery Area 12-13	Hub City Fisheries - Nanaimo
954	MA_2	Late-run	19 Oct	Commercial Fishery Area 12-13	Johnstone Strait - recovered at fish Plant (?)
545	MA_1	Early Summer	19 Oct	Commercial Fishery Area 12-13	Johnstone Strait
539	MA_1	Early Summer	19 Oct	Commercial Fishery Area 12-13	Johnstone Strait
1052	MA_3	Late-run	19 Oct	Freshwater Commercial Fishery	Port Mann Bridge

Appendix Table B3. Tags recovered from spawning areas, 2006.

Tag No.	Sampling Period	Run-timng Group	Recovery Date	Zone	Recovery Location
26	IR_2	Early Summer	7 Aug	Vedder River	Vedder River
4	IR_1	Early Stuart	10 Aug	Kynock Crk.	Kynock Cr
186	MA_1	Late-run	13 Aug	Rosedale	1.5 Miles u/s of Jesperson Road
263	IR_5	Summer-run	20 Aug	Rosedale	Aggaziz/Rosedale Bridge
666	MA_1	Early Summer	20 Aug	Rosedale	Aggaziz/Rosedale Bridge
49	IR_3	Early Summer	27 Aug	Spence's Bridge	between Ashcroft & Spences Bridge
105	IR_3	Early Summer	3 Sep	Scotch Creek	Scotch Creek Fence
43	IR_3	Early Summer	4 Sep	N. Thompson	Spawning Grounds at Fennell Creek (Male)
633	MA_1	Early Summer	5 Sep	Seymour River	Early Seymour River
830	MA_2	Early Summer	14 Sep	N. Thompson	Raft River - North Thompson System
928	MA_2	Summer-run	15 Sep	Chilko River	Chilko River
654	MA_1	Summer-run	18 Sep	Horsefly River	Horsefly River
13	IR_1	Early Summer	19 Sep	Nadina/Stellako	Nadina Spawning channel
540	MA_1	Summer-run	25 Sep	Chilko River	Chilko River
737	MA_1	Late-run	28 Sep	Shuswap Lk.	Shuswap Lake
551	MA_1	Summer-run	29 Sep	Nadina/Stellako	Stellako
372	IR_7	Birkenhead	30 Sep	Birkenhead	Birkenhead River
688	MA_1	Summer-run	2 Oct	Chilko Lk.	Chilko Lake (North)
79	IR_3	Summer-run	3 Oct	Nadina/Stellako	Stellako
561	MA_1	Summer-run	6 Oct	Chilko Lk.	Chilko Lake (North)
843	MA_2	Late-run	6 Oct	Scotch Creek	Scotch Creek Delta
124	MA_1	Summer-run	7 Oct	Nadina/Stellako	Stellako River
302	IR_6	Late-run	7 Oct	Shuswap Lk.	Shuswap Lake
305	IR_6	Late-run	7 Oct	Little Shuswap Lk.	Little Shuswap Lake
678	MA_1	Late-run	7 Oct	Little Shuswap Lk.	Little Shuswap Lake
822	MA_2	Summer-run	7 Oct	Chilko Lk.	Chilko Lake (South)
1145	MA_3	Late-run	7 Oct	Adams River	Adams River
1143	MA_3	Late-run	9 Oct	Adams River	Adams River
295	IR_6	Summer-run	11 Oct	Chilko River	Chilko River
87	IR_3	Summer-run	12 Oct	Nadina/Stellako	Stellako
297	IR_6	Summer-run	12 Oct	Nadina/Stellako	Stellako
363	IR_7	Late-run	14 Oct	Lower Shuswap	Lower Shuswap river
718	MA_1	Late-run	15 Oct	Lower Shuswap	Lower Shuswap River
352	IR_7	Late-run	20 Oct	Scotch Creek	Scotch Creek Delta
1046	MA_3	Late-run	21 Oct	Adams River	Adams River
975	MA_2	Late-run	28 Oct	Shuswap Lk.	Shuswap Lake (Blind Bay East Shore)
1064	MA_3	Late-run	2 Nov	Adams River	Adams River
1088	MA_3	Birkenhead	21 Nov	Birkenhead	Birkenhead River

APPENDIX C

Post-season estimates of total return for Fraser River sockeye salmon 2006

To: Paul Ryall, Chair Fraser River Panel
Our file: 66001

Lorraine Loomis, Vice Chair, Fraser River Panel

cc: Fraser River Panel and Technical Committee members

From: Mike Lapointe, Jim Cave PSC staff

Date: May 31, 2007

Re: 2006 Post-season estimates of total return for Fraser River sockeye salmon

In 2006, Near Final spawning escapements were significantly greater than expected based on Mission abundance less in-river catches upstream of Mission. Following the work plan we provided to the Panel in January, this discrepancy resulted in a significant effort by PSC, DFO and LGL (responsible for radio tagging program) staff to determine the causes of differences and make recommendations as to the best data sets to use for post-season estimates of total run. The resulting work has been vetted through the Fraser River Panel Technical Committee at a series of meetings that concluded last week in Kamloops. The purpose of this memo is to summarize our efforts and our recommended methods to use for post-season estimates of total run. One important result from this work is the post-season estimate of Cultus exploitation rate.

Sources of Bias

Our analyses looks for sources of bias in the following possible components of total return estimates: (a) Mission escapement estimates, (b) stock proportions applied to Mission estimates (c) spawning escapement estimates, (d) Estimates of in-river survival from radio tagging (e) In-river catch estimates, and (f) expanded abundances from marine purse seine test fishery catches

a. Mission escapement estimates

An extensive analysis was conducted on potential sources of bias in the Mission escapement estimates. Conclusions from initial work were as follows: (1) Raw data collected at Mission in 2006 is consistent with past years. (2) The estimation algorithms used in 2006 are the same as past years and they generated daily estimates comparable to past years given similar data inputs. (3) Estimates from Single and Split beam systems in 2006 are similar and thus do not suggest problems with equipment. Furthermore none of the systems generated estimates during late August and September near the levels implied by upstream estimates or other indicators. (4) Single beam estimates were larger than Split estimates and deviations between the estimates increased in August and September, but the temporal pattern in deviations is consistent with increased abundance of Late-runs and milling, and the fact that Single beam estimates include downstream targets. (5) The relationship between targets per transect and total salmon abundance for the single beam system was similar for the 1998, 2002 and 2006 cycle years. This does not indicate a systematic problem with the single beam estimates of abundance which are also well below the upstream estimates. (6) There were a number of aspects of fish behavior that were different from past years including (a) a more even cross river distribution, (b) fewer fish were seen near the surface by the mobile system, (c) the fraction of fish migrating downstream was higher offshore from the left bank, (d) upstream fish speed decreased through the season. Of these fish behavior issues, items (a) and (b) pointed to the possibility that boat avoidance may have been a source of negative bias in the Mission estimates. Another possibility suggested from this initial work was a negative bias resulting from very near bottom migration behavior.

Thus more detailed investigations focused on the boat avoidance and near bottom migration effects on estimates from mobile system. These investigations also concentrated on the mid-August to September time period for the following reasons: (1) discrepancies between Mission projections and spawning escapement increased for later timed stock aggregates, (2) discrepancies between projected escapements from Marine area purse seine test fisheries and Mission abundances increased after mid-August, (3) discrepancies between Mission-based projected arrival at Chilko and Chilko Didson counts made near the spawning grounds increased after mid August. The conclusion of these more detailed analyses were first, that the near bottom blind zone represents only about 13% of the sampled area, and thus if examined in isolation could have lead to an underestimate by the mobile system of 2-18%. Second, “Common area” comparisons showed possible effects of boat avoidance on depth distribution, and upstream speed but not on downstream ratio, or the estimate. However, interpretations are confounded by fact that vessel area is 50-100m downstream of area seen by left bank system. A comparison of day vs. night distribution targets, found a similar diurnal pattern of target distribution in data collected from the left bank and the boat, which does not support a severe boat avoidance effect. Counteracting these sources of negative bias, a positive bias was generated by the application of the left bank statistics (downstream ratio and speed) to the mobile targets. When the compensating biases identified in the above analyses are quantified in the estimation, an overall high bias is indicated in the model that used left bank and mobile data, which is the opposite of what would be expected from the upstream estimates. In 2006 an experimental program was conducted on the right bank and the successful implementation of this program allowed hydroacoustic staff to generate estimates for the period July 22-Sept. 18 based on left bank, mobile and right bank sampling. The total salmon estimates from this sampling scheme were approximately 340,000 larger than those based on the current left bank - mobile sampling program. However, most of the cumulative deviation between the two estimates was due to differences on only a few days and the cumulative difference of 340,000 total salmon does not account for the large discrepancies between Mission and upstream estimates. Thus is does not appear that full implementation of a right bank program will resolve the issues that were responsible for biases at Mission in 2006. It is important to note that quantification of the magnitude of bias due boat avoidance is not possible with current data and given the extremely low flows, boat avoidance remains the most like source of negative bias in the Mission estimates.

(b) Stock proportions applied to Mission estimates

Because the overall number of fish on the spawning ground was higher than projected from the Mission hydroacoustics program, it is unlikely that these discrepancies are due to biases in stock proportions. Furthermore, our use of DNA based estimates of stock proportion do not vary between in-season and post-season like the scale based estimates did, so this effectively eliminates any significant bias and changes in stock proportion estimates. Thus, we compared estimates of stock proportion from river gill net test fisheries with those from marine purse test fisheries (lagged for travel time) to determine if there was evidence of sampling bias by the river gill net test fisheries. The temporal pattern of stock proportions estimates was very similar for the two gear types, which does not suggest significant sampling bias in the river gill net test fisheries.

c) Spawning escapement estimates

Approximately 74% of the total escapement estimates came from programs where mark-recapture (M-R) methods were used. An additional 15% came from programs using census (either spawning channel or fence counts). The remaining 11% came from programs using visual surveys. The process of generating Near Final Spawning ground estimates includes routine bias checks for areas where M-R methods are applied. Violations of M-R assumptions were found in 2 of the 7 programs (Early Summer Seymour River; and Late-run, Lower Adams). However, in both case the violations of assumptions (non-proportional application and recovery) would be expected to result in negative biases. Negative biases were also attributed to some Early Summer-run populations as a result of the visual survey methods and Quesnel sockeye in the Summer-run group due to a very small lake spawning component that was not assessed in 2006. A further negative bias in the Late-run estimates was associated an significant pre-spawn mortality in Shuswap lake. This is not a bias in spawning escapement estimates per se as this mortality did not occur in traditional areas that are part of normal surveys (i.e., the mortality occurred outside of normal spawning ground areas). However, assessment of this mortality became important to the estimates of radio tagging estimates of survival (see below). The conclusion of these analyses was that a negative bias existed in the total escapement estimates (in the opposite direction needed to explain the observed discrepancies between Mission and upstream estimates).

(d) Estimates of in-river survival from radio tagging

The estimates of in-river survival from the radio tagging were also scrutinized. Two issues were identified with the estimates in 2006. First the radio receiver at the mouth of the lower Adams River did not function properly due to the combination of a faulty wire and its physical location of the antenna (perhaps too low down in the tree to pick up fish migrating past the far channel. The consequence of this malfunction was that survival could only reliably be estimated to the Little River receiver not to individual spawning grounds. In principal survival to the Shuswap river could have been estimated (the receiver there was functioning OK), but DNA stock discrimination for Late-run populations within Shuswap Lake is not sufficiently accurate to distinguish individual streams (e.g., Lower Shuswap from Lower Adams). The implication of the receiver malfunction at Lower Adams was that estimates of the terminal run to Shuswap Lake were required including population estimates from both traditional and non traditional spawning areas (presumably mostly in-lake mortality) in order to have comparable data for the survival rates estimated through the Little River receiver. DFO and LGL staff worked together to assign fates to all radio tags passing the Little river receiver. Two alternate methods were then used to estimate the pre-spawn mortality based on the tags that could not be accounted for in spawning areas and fish/radio tag estimates for area with population estimates. The two methods varied in the number of tags assigned to spawning areas, and the fish/radio tag estimates. The resulting estimates of fish that were not accounted for in traditional spawning areas were 284,000 and 584,000 respectively. It was thought that these estimates likely bounded the true value, so the Technical Committee agreed to use the average of these two estimates (434,000) in calculations of total run. For comparison the estimates of Late-run populations in traditional spawning areas in Shuswap Lake (including Little River) totaled 2,896,000.

The second issue with the radio tagging program in 2006 revolved around a discussion about whether survival of radio tagged fish could be considered representative of the survival of untagged fish. There were two main components to this discussion. First, all radio tagged fish were physio-sampled in 2006, and results from the 2005 study had shown that physio-sampled and radio tagged fish had about 7% lower survival overall than fish that were radio tagged only. Also though this difference was not statistically significant, it was not possible to quantify this effect in 2006 (all tagged fish were physio-sampled) and suggested that the survivals implied by the radio tagged fish were likely biased low. The second component of the discussion revolved around observations made in 2006 and previous years of higher fractions of radio tags observed in areas of pre-spawn/en-route mortality compared to spawning areas. These observations included the Shuswap lakeshore in 2006 and areas like Bridge River and Williams Lake Creek (Summer run fish) in 2005. It is important to note that small numbers of tags are involved and thus the tag fractions are estimated with very low precision. Also in most cases since the observation are associated with non-traditional areas, so rigorous programs were not in place to estimate the untagged components (i.e the denominator of the tag ratio). Nonetheless these observations suggest the possibility of a chronic effect of tagging on survival of a few of the radio-tagged fish that may extend up to the near terminal areas. Survival estimates are adjusted for acute tagging effects by removal of tagged induced losses below Sawmill creek. With respect to 2006, a comparison of was made of travel times for Marine vs. in-river tagged fish. The median travel times were identical for Late-run sockeye from the marine versus in-river release sites. The travel times for early summer and summer sockeye indicated that in-river tagged fish moved slower in some reaches of the Fraser than the comparable marine-tagged sockeye, but statistically significant effects were only detected in two reaches for Summer-run sockeye. The net effect of this second component "chronic tag effects", would be that the radio tagged estimates of survival are biased low. While there was a consensus among Technical Committee members that some of the losses above Sawmill could have been due to tagging related effects, it was thought that the bias introduced by using the radio tagging estimates of survival was small relative to the discrepancies between Mission and upstream estimates and members agreed to use the tagging data as "the best data available".

(e) In-river catch estimates

Unlike past years of "missing fish", the direction of discrepancies in 2006 focused the analysis on potential sources of catch overestimates rather than underestimates. A review of potential sources of bias for In-river catches estimates was provided by DFO. For the mid and upper Fraser areas, it was thought that estimates may be biased low (by a relatively small amount) due to a combination of monitoring gaps and data pooling issues associated with some the survey methods. No source of positive bias leading to overestimates was identified for these areas. For the Lower Fraser Area, some potential sources of positive bias were investigated. These included double counting in census programs at two locations during economic opportunity fisheries, (e.g., at catch locations and mandatory landing sites), though it was thought that this would occur infrequently and not introduce a significant overall bias. For FSC fisheries there was the potential for double counting if fish were caught and included in FSC catch estimates and then subsequently sold in economic opportunity fisheries and counted at a mandatory landing site. While there is an economic incentive for this activity, there was not a lot of overlap between FSC and economic opportunity fisheries to make this a frequent occurrence or a source of large positive bias. A third source of positive bias could occur for FSC fisheries where catch estimates are expanded from catch per unit effort surveys, if the surveyed CPUE was biased high (i.e., surveying only better than average fishermen). A fourth source of positive bias could occur if fish from FSC fisheries upstream areas were landed at MLP sites in the lower area. While it was not possible to quantify the exact magnitude of these biases, the overall bias was not thought to be large relative to the magnitude of the catch estimates.

(f) Expanded abundances from marine purse seine test fishery catches

Projections from marine purse seine test fishery CPUE also suggested that more fish should have arrived at Mission than were estimated by the Mission hydroacoustics program. Thus, we generated estimates of total return based on these programs for comparison with other estimates. Expanded estimates of abundance from marine purse seine test fisheries are subject to two major sources of bias (1) catch estimation bias associated with catch hails, and (2) bias in estimates of test fishery expansion factors. In the case of catch estimation bias, a significant fraction of the late and summer run terminal abundance was associated with two very large CPUE days that occurred in Johnstone Straits during the third week of August. Discussion with DFO staff suggested that while there were likely errors associated with the estimates of CPUE made for these days, there was no reason to suspect they should be biased high and could equally likely be biased low. Similarly the expansion lines applied in 2006 were based on averages of past years and thus should not be biased in any particular direction.

Alternative estimates of post-season total run

Staff generated estimates of total return based on the following methods: (1) In-season Mission escapement estimates plus all in-river and marine catches downstream of Mission, (2) Near Final spawning ground estimates plus catches downstream of spawning areas, (3) Near final spawning escapements plus catches downstream of spawning areas and the predicted DBE from management adjustment methods, (4) Projected total abundance from Marine test fishery CPUE and historical expansion lines, (5) Near Final spawning escapements divided by the annual estimates of radio tag survival plus catches downstream, and (6) Adjusted Mission escapements based on radio tag estimates of survival plus catches downstream. The last method used the radio tagging data to generate a revised Mission profile, based on expansions applied to four main stock aggregates (Early Stuart, Early Shuswap, Summer run and Late Shuswap). Due to feedback between the weighted annual survival estimates and the Mission profile (e.g., later migrating fish tended to have higher survivals for Late Shuswap), this analysis involved and iterative process with the tag survival calculations. The estimates of total return for by stock aggregate are shown in Table 1. The total sockeye returns range from 8.5M ((1) In-season Mission plus catches downstream) to 14.5 M ((4) Marine purse seine projections). Methods that use Spawning escapements and either DBE's or tagging data were intermediate in this range. The Technical Committee recommends that the estimates from method 6 (Adjusted Mission escapements plus catches downstream) be used as the final best estimates of post-season total run for each stock group (Table 1). The caveats for this recommendation are that due to the effects of tagging and physiological sampling, the survival rates from the radio tagged fish likely underestimate the survival of un-tagged fish and thus the total return estimates should be viewed as overestimates. However, given the range of alternative estimates, the total return estimates from the radio tagging methods are within the range of other methods and thus this bias is unlikely to be severe. The fact that spawning escapement estimates are bias low (see above) would partially counteract the low bias in survival rates. The final post-season estimates of total return are Early Stuart, 56,000; Early Summer; 1,817,000; Summer, 2,519,000, Birkenhead, 633,000; and True Late-run, 7,922,000. The implications of the estimates for the Cultus Exploitation rate are show in the far right column of Table 2. The final post-season estimate of Cultus exploitation rate is 34.9%.

Table 1. Alternative estimates of Total run by Management group

	"Traditional methods"				Radio tagging methods	
	1	2	3	4	5	6
Stock Group	In-season Mission plus catch downstream	Spawning escape. plus catches downstream	Spawning Escapements Plus DBE plus catches downstream	Projected Total abundance from Marine test fisheries	Spawning escapement annual surv. plus catches downstream	Adjusted Mission plus catches downstream
Early Stuart	**67,000**	**45,000**	**134,000**	**59,000**	**56,000**	**56,000**
Early Summer	**1,424,000**	**1,202,000**	**1,400,000**	**1,994,000**	**1,630,000**	**1,817,000**
Scotch-Seymour	1,064,000			1,610,000	1,322,000	1,366,000
Early Misc	262,000			384,000	236,000	379,000
Pitt	98,000				72,000	72,000
Summer	**1,925,000**	**2,175,000**	**2,191,000**	**2,629,000**	**2,562,000**	**2,519,000**
Chilko/Quesnel	1,509,000			2,053,000	1,980,000	2,000,000
L.Stuart Stellako	416,000			576,000	582,000	519,000
Birkenhead	**353,000**	**478,000**	**478,000**	**750,000**	**633,000**	**633,000**
"True" Late	**4,804,000**	**6,210,000**	**8,278,000**	**9,118,000**	**7,913,000**	**7,922,000**
Late Shuswap	4,507,000			8,926,000	7,522,000	7,431,000
Weaver	150,000				225,000	282,000
Harrison	147,000			192,000	166,000	209,000
Totals	**8,573,000**	**10,110,000**	**12,481,000**	**14,550,000**	**12,794,000**	**12,947,000**

Table 2. In-season and Post-season estimates of Cultus Exploitation rate

Final In-season		Post-season	
Catch [a]	2,690,000	Catch [a]	2,694,000
		Spawning escapement	3,401,201
		Survival rate (Mission to spawning gro	69.9%
Mission Escapement	1,954,000	Adjusted Mission Escapement [c]	5,042,000
Catch downstream of Mission	2,668,000	Catch downstream of Mission	2,671,000
Total Run [ab]	4,622,000	Total Run [ad]	7,713,000
Cultus Exploitation rate	58.2%		34.9%
Implied Cultus Production and Catch			
Spawning escapement [e]	3,806		3,806
Total return [f]	9,105		5,849
Catch [g]	5,299		2,043

Notes:

a Run sizes are for "True Late-run" excluding Harrison, Catches are for same stocks including only those fish caught downstream of Vedder and Fraser River confluence

b Final In-season Total run = Mission escapement + catches downstream of Mission

c Adjusted Mission escapement = Revised Mission profile based on spawning escapements and survival rates from radio tags

d Final Post-season Total run = Adjusted Mission Escapement+ catches downstream of Mission

e Includes 12 Jacks and 276 Sockeye removed for brood stock

f Implied total Cultus return = escapement/(1-exploitation rate). Calculation assumes no en-route loss for Cultus

g Cultus Catch = Total return - Spawning escapement

Recommendations

Staff and the Technical Committee make the following recommendations as a consequence of this work:

1. Efforts should continue at Mission to explore sampling schemes that minimize the impacts of boat avoidance. The right bank program will be conducted again in 2007 and with full in-season implementation expected in 2008. Some experiments will be conducted in 2007 to explore estimates from a stationary vessel looking sideward. This sampling scheme would be similar to that used on the left and right banks.
2. Future radio tagging and physiological sampling programs should always include controls so that the incremental effects of sampling on survival can be quantified. If possible some comparisons of survival rates of radio tagged and conventional disk tagged fish might be used to partially quantify the effects of radio tagging on survival. This type of comparison might be possible in the future if a lower Fraser River tagging platform is implemented.
3. In cases where radio tags are observed in non-traditional areas, contingency plans should be in place to improve assessments of total populations in those locations, so that tag ratios can be accurately quantified.
4. Summaries of analyses conducted should be documented in the Fraser Panel Annual report and in notes associated with pertinent databases so that future researchers will be able to understand assumptions made in generating post-season estimates of the 2006 Fraser River sockeye return.

APPENDIX D

Late-run sockeye returns to Shuswap Lake spawning areas

Assessment of the fate of radio-tagged sockeye and estimation of pre-spawn mortalities outside major spawning areas. Prepared by Karl English and Keri Benner, 24 May 07.

Due to confirmed tag detection issues at the Adams River station in 2006, we present two methods of determining the final fate of radio-tagged sockeye in the late Shuswap system in 2006. These final fates are then used to provide estimates of total pre-spawn mortality outside of the spawning areas (not accounted for in the DFO spawning escapement estimates). The key difference between the two methods presented is the technique used to estimate the number of radio tags that entered the Adams River. The resulting estimates represent the minimum and maximum pre-spawn mortality outside the spawning areas (actual mortality is likely to lie somewhere in between the estimates produced by the two methods).

Adams River Station Detection Efficiency

Concerns were raised in mid October 2006 that the number of radio-tagged sockeye detected by the receiver at the mouth of the Adams River was substantially lower than expected and possibly due to the lower height of the antennas than in previous years. Mobile surveys were conducted by DFO staff in late October to determine if any radio-tagged fish had passed the station without being detected. The survey conducted on Oct. 29th detected 11 radio tags upstream of the Adams receiver and 5 of these tags had not been detected by the receiver. This suggested that the detection efficiency for this station was only 54.5%. Detailed examination of the fixed-station receiver data from the Adams River, Lower Shuswap River and Little River stations for 2002, 2003 and 2006, revealed a substantial difference in the total number of detections and signal strength of the detections between 2002-03 study years and the 2006 study (Figure 1).

The lack of detections at power levels below 50 was expected in 2006 because the Adams River receiver was configured not to record any detections with these power levels. Low power signals detected on properly functioning stations are generally background noise and are routinely excluded from our analyses. However, the low number of detections with power levels above 50 and virtual lack of any detections at power levels above 170 is a clear indication that there was a significant problem with the Adams station in 2006. After extensive discussions with experienced field staff, we have concluded that the unusually low number of detections above 50 power on the Adams receiver was due to a bad coax wire between the antenna switcher and the receiver. We have encountered this problem occasionally in the past and should have detected it at this site in 2006. It was not detected because the individual processing the fixed-station data during the field season was a new LGL employee in 2006 and the station downloads for the Shuswap watershed receivers were not conducted by individuals with the experience and computer software required to detect this problem. Regardless, LGL accepts full responsibility for not detecting this problem early prior to the arrival of Adams sockeye and will take all the necessary measures to ensure this type of problem never happens again.

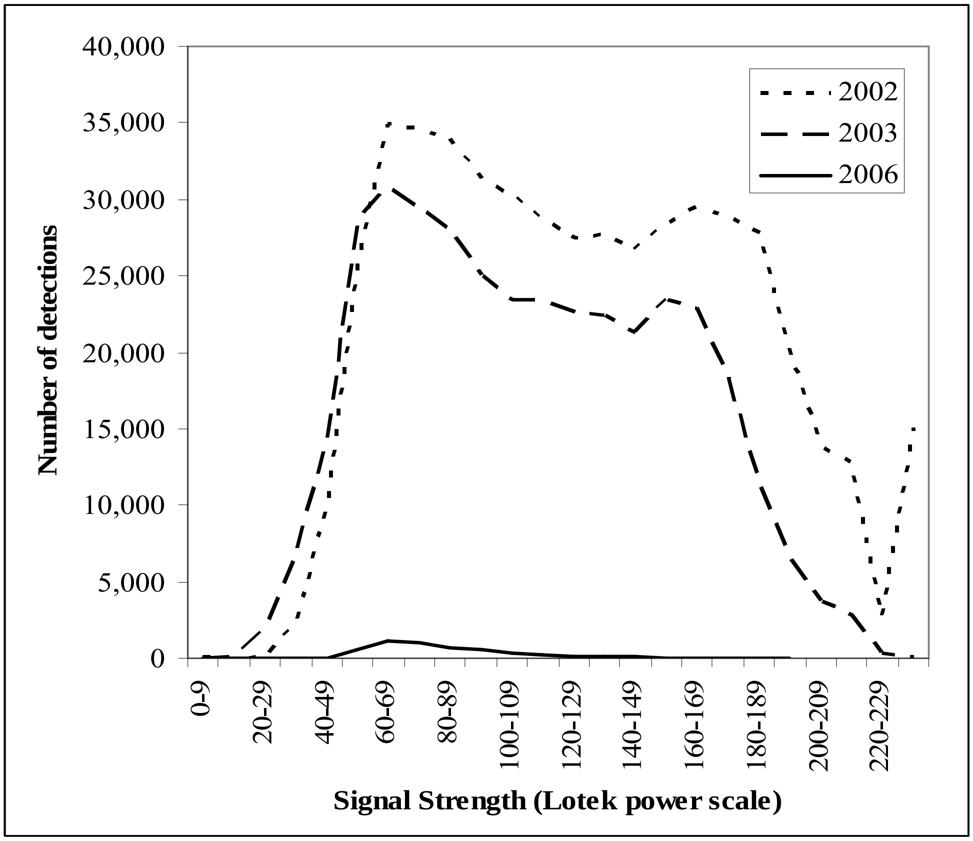


Figure 1. Frequency distribution of the signal strength and number of detections at the Adams River receiver in 2002, 2003 and 2006.

It is important to note that although there were confirmed undetected tags past the Adams receiver, there are some indications that the detection efficiency may have been higher than the 54.5% suggested by the mobile survey data. These indicators include:

i. The uncorrected number of tags detected in the Adams Study Area (40) produces a mark rate of 36,534 fish/tag which is similar to that estimated for in the Lower Shuswap River (41,187 fish/tag), where all the tags tracked above the station were detected at the station. The 54.5% detection rate estimated for the Adams receiver produces a mark rate of 26,570 fish/tag, which is much smaller than that estimated for the lower Shuswap River.
ii. In previous radio tagging study years (2002 and 2003), radio tag recovery rate by DFO crews in the Adams and Little river study area was much higher or similar to the local Petersen tag recovery rate (double the Petersen recovery rate in 2002, and similar in 2003; Figure 2). In 2006, DFO crews reported the highest Petersen tag recovery rate observed in the last three study years (15%). The 54.5% detection rate would result in a recovery rate of 8% of the tags available, which is much lower than would be expected based on patterns observed in 2002 and 2003. However, it should be noted that low number of radio tags (55-160) available for recovery during the dead pitch surveys in the

Adams/Little river study area results in wide bounds for the radio-tag recovery rate estimates.

iii. Several factors indicate that the detection efficiency for radio-tags in the dead pitch surveys should not have been an issue in 2006. A re-survey of 50% of the dead pitch sample did not recover any radio tags that were missed during the first survey. Previous radio tag miss rates in the Adams study area have ranged from 11% in 2002 to 26% in 2003. The estimated 0% miss rate based on the re-survey data is likely the result of a combination of a more experienced crew in 2006, lower than expected spawner abundance (fatigue not an issue) and the greater emphasis on the importance of the tag recovery in 2006 due to the data logger (i-button) attachment.

iv. Of the 30 tags detected by the Adams River station, 29 were detected on or before the date of the mobile survey conducted upstream of the receiver (October 29th). This suggests that 97% of the tags that entered the Adams were either present and available for detection during the mobile survey or had entered and already left the system. The 54.5% detection efficiency results in an estimated total of 53 tags passed the Adams station by October 29th. The mobile survey detected only 11 tags, suggesting either a very poor detection rate of what was actually present in the river or that up to 42 tags (79%) entered then subsequently left the system.

v. Assuming the daily pattern of abundance at Mission was unbiased, over 45% of the total late run was past Mission by September 2nd. During this same period, 62% of the total late run tags passed Mission indicating that tag application was weighted towards the front half of the late run. Tracking data determined that fish passing Mission by September 2nd were more likely to experience high temperatures and suffer mortality either en-route to the spawning grounds or pre-spawn in the near terminal areas. This is a likely explanation for large difference observed between dead pitch sample mark rates from the lakeshore areas (7,403 fish/tag) where the highest level of pre-spawn mortality was observed versus the major spawning tributaries (average of 64,481 fish/tag). The 54.5% detection efficiency at the Adams would result in 71% of the all late run tags past the Little River station being accounted for in the major spawning areas in the Shuswap system.

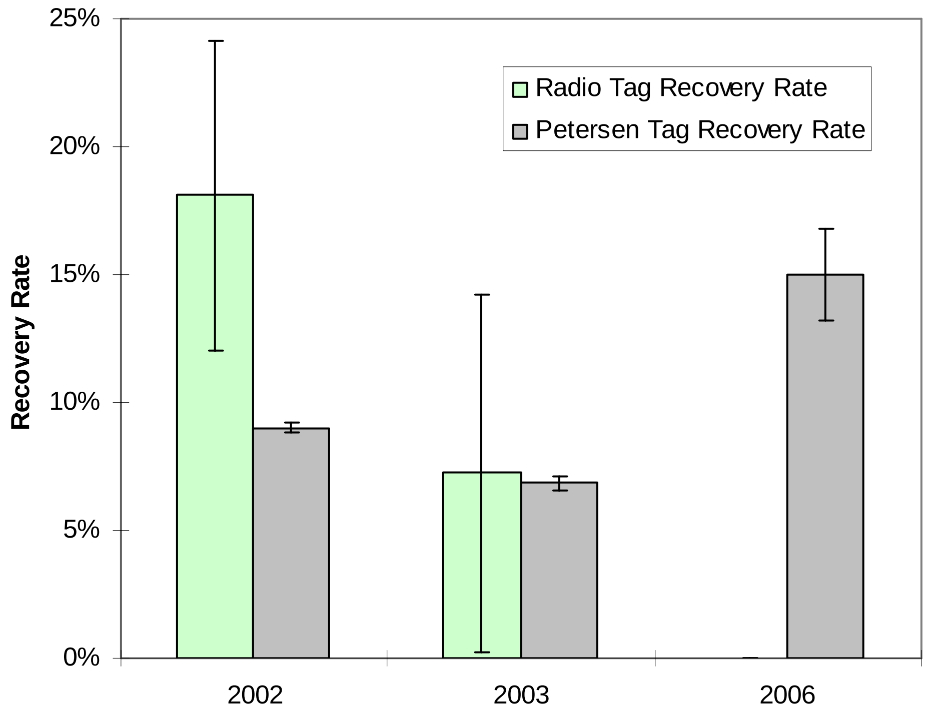


Figure 2. Average recovery rates of radio and Petersen disc tagged sockeye in the Adams/Little River study area in 2002, 2003 and 2006 (Radio tag recovery rate is unknown but estimated between 8-12% in 2006).

Fate of Radio-tagged Late-run Sockeye Detected at Little River

Of the 156 radio-tagged sockeye detected at or above the Little River site, 131 were assigned to late-run stocks based on their final spawning location or analysis of DNA samples. Table 1 provides a summary of final destination and fate for these late-run sockeye using two different methods. The first method assumes a 54.5% tag detection rate at the Adams station based on mobile survey data (as indicated above) resulting in an estimate of 55 tags in the Adams (30*11/6). Assuming the mark rate for Little River would be similar to that in the Lower Adams River (26,570 fish/tag), an estimated 16 tags would be accounted for given DFO's escapement estimate of 416,790 sockeye for Little River. This estimate of 71 tags associated with the Adams and Little River study areas is consistent with the observation that 90 of the 131 tags detected at the Little River station were last detected in the Adams/Little River study after their first detection at Little River between Sep. 17th and Oct. 16th (the Little River passage interval for all tag detected in the Adams River study area). These 90 tags do not include any of the tags last tracked along the shores of Shuswap lake outside the Adams/Little River study area but would include some tags that may have spawned or died outside the Adams/Little River study area.

The second method uses only those radio-tags detected in the Adams study area (40) and the resulting mark rate (36,534 fish/tag) divided into the DFO escapement estimate for the Little River study area (416,790) resulting in an estimate of 11 tags for the Little River study area.

Table 1. Estimated distribution of radio-tagged sockeye detected at or above the Little River station by method.

		Method 1[a]		Method 2[b]	
	Escapement DFO Est.	Total Tags	Mark Rate Fish/Tag	Total Tags	Mark Rate Fish/Tag
Late-run tags detected at Little River		**131**		**131**	
Major spawning areas					
Tags detected in Lower Shuswap	**906,105**	**22.0**	41,187	**22.0**	41,187
Including one tag with a single detection after its Little R. detections (Tag 707)					
Estimate tags to Adams Study area	**1,461,373**	**55.0**	26,570	**40.0**	36,534
Including 30 tags detected on the Adams station					
Including 5 tags detected in Adams but not on the Adams Station (Tag 658,941,998,1133,1134)					
Including 5 tags last detected near Adams R. on lake shore (Tags 667, 737, 897,1060,1147)					
Estimated tags to Little River	**416,790**	**15.7**	26,570	**11.4**	36,534
Including Little River spawners in Little Shuswap Lake (Tags 364, 992)					
Including Little River spawner in South Thompson (Tag 1131)					
Including Little Shuswap Lake pre-spawn morts (Tags 305, 678,702,1042)					
Outside major spawning areas - Spawners					
Eagle Spawners (Tags 330,845,890)		**3.0**		**3.0**	
Scotch Spawner (Tag 1128)		**1.0**		**1.0**	
Seymour Spawner (Tag 994)		**1.0**		**1.0**	
Shuswap Lake Shore Spawners (Tag 1146)		**1.0**		**1.0**	
Outside spawning areas - Pre-spawn mortalities					
Seymour pre-spawn mort. (Tag 375)		**1.0**		**1.0**	
Shuswap Lake pre-spawn mort. (Tags 302,542, 975) Scotch Cr. Delta (Tags 352, 843)		**5.0**		**5.0**	
Mouth of Lower Shuswap River pre-spawn mort. (Tag 891)		**1.0**		**1.0**	
Late Run tags unaccounted for after detection at Little River Station		**25.3**		**44.6**	
Shuswap Lake shore spawners		**3.6**		**6.4**	
Shuswap Lake shore pre-spawn mortalities		**18.1**		**31.9**	
Mouth of Lower Shuswap River pre-spawn mortalities		**3.6**		**6.4**	
Late-run tags estimated to be pre-spawn mortailities in outside major spawning areas					
Mouth of Seymour River pre-spawn mortalities		**1.0**		**1.0**	
Shuswap Lake pre-spawn mortalities		**23.1**		**36.9**	
Mouth of Lower Shuswap River pre-spawn mortalities		**4.6**		**7.4**	
Total		**28.7**		**45.2**	

a Tags to Adams Study Area estimated using 54.5% tag detection efficiency at the Adams River station (30*11/6). Resulting Adams mark rate (fish/tag = 26,570) applied to Little River.

b Tags to Adams Study Area was the actual number of tags detected at the Adams station or near the mouth of the Adams River. Resulting Adams mark rate (fish/tag = 36,534) applied to Little River.

The technique used to determine the fate of the remaining tags detected at the Little River site was identical for both methods. The Lower Shuswap River station detected 22 tags (and all of the 14 tags detected during mobile surveys above this station had been detected previously at the Lower Shuswap River station). The fate of the remaining tags outside the major spawning areas was assessed using detailed tracking data for each tag recovered or tracked during mobile surveys. A tag by tag examination of the fixed-station and mobile tracking data for each radio-tag recovered in the Shuswap watershed was conducted to determine whether there was a consistent pattern in the migration timing and spawning success for these fish. Of the 11 recoveries from late-run sockeye detected at or above the Little River station, 7 were pre-spawn mortalities, 3 were successful spawners and for 1 the carcass was not examined to determine whether the fish had spawned. The tracking data for these fish showed that all 7 of the pre-spawn mortalities detected in the Shuswap watershed passed our Mission receiver between Aug 17th and Sep. 4th, and were subsequently detected at the Spences Bridge station between Aug. 27th and Sep. 12th (high temperature period). All 3 of the successful spawners passed Mission after Sep. 6th, passed the Spences Bridge after Sep. 16th (lower temperature period; Figure 3). This consistent pattern was used to assign the spawning success of the remaining Late-run tags detected but never recovered outside the major spawning areas during mobile surveys.

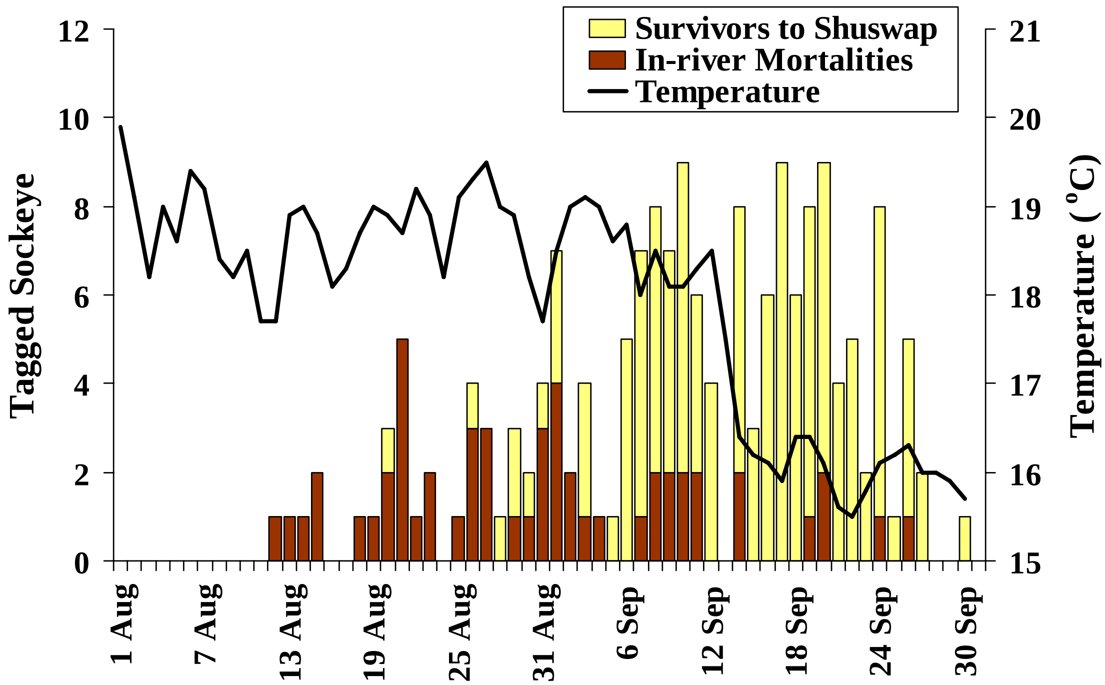


Figure 3. Timing of passage of radio-tagged sockeye at Spences Bridge, in-river mortalities, survivors to the Little River site and daily river temperatures recorded at Ashcroft, BC (32 km upstream from Spences Bridge).

Of the 13 tags tracked during mobile surveys or recovered outside major spawning areas, 6 were classified as successful spawners and 7 were likely pre-spawn mortalities. We assumed that DFO's mobile surveys in Eagle River, Scotch Creek and Seymour River detected all the radio-tags that entered those streams (6 tags). The distribution for the remaining 7 tags was used to apportion the tags not tracked, after their detection at the Little River station, into the following three categories: 1) Shuswap Lake shore spawners, 2) Shuswap Lake shore pre-spawn mortalities and 3) mouth of Lower Shuswap River pre-spawn mortalities. The results from the above analyses estimated between 29 and 45 tags (depending on method used) were associated with pre-spawn mortalities outside the major spawning areas.

Estimated Pre-spawn Mortalities Outside Major Spawning Areas

The minimum estimate of the pre-spawn mortalities for late-run sockeye outside the major spawning areas was based on Method 1 (Table 2). Comparison of the mark rates derived from dead pitch surveys with those derived from the DFO escapement estimates and tag distribution estimates (assuming a 54.5% tag detection rate at the Adams station) suggest that dead pitch surveys in the Adams/Little River and Lower Shuswap may have only detected 53% of the radio tags present in the dead pitch sample. This detection efficiency was used to define the minimum estimate for the number of pre-spawn mortalities associated with the mouth of the Seymour

River (3,889) and Shuswap Lake shore (89,772). The best estimate of the mark rate for the pre-spawn mortalities at the mouth of the Lower Shuswap River was that derived from the DFO escapement estimate and tags tracked at the Lower Shuswap station (41,187 fish/tag) resulting in an estimate of 190,128 pre-spawn mortalities associated with the lower Shuswap River.

The maximum estimate of the pre-spawn mortalities for late-run sockeye outside the major spawning areas was based on Method 2 and used the lakeshore area dead pitch sample mark rate (7,403 fish/tag) and the Lower Shuswap River mark rate derived from the DFO escapement estimate and tags past the Lower Shuswap River station (41,187 fish/tag). This defines the maximum estimates of pre-spawn mortalities associated with the mouth of the Seymour River (7,403), Shuswap Lake shore (272,798) and the mouth of the Lower Shuswap River (303,556).

Our best estimate of the number of pre-spawn mortalities outside the major spawning areas in 2006 is 283,789-583,756 sockeye.

Table 2. Estimated pre-spawn mortalities outside the major spawning areas in 2006.

		Method 1[a]				**Method 2[b]**		
	Escapement DFO Est.	Tags	Mark Rate Fish/Tag	Dead-pitch Fish/Tag	Detection Efficiency	Tags	Mark Rate Fish/Tag	
Mark Rate based on radio-tags in major spawning areas								
Adams-Little River Study Area spawners	**1,878,163**	**71**	26,570	46,278	57%	**51**	36,534	
Shuswap River System spawners	**906,105**	**22**	41,187	82,684	50%	**22**	41,187	
Average for major spawning areas			33,879	64,481	53%			
Pre-spawn Mortalities Outside Major Areas					**Minimum Estimate**			**Maximum Estimate**
Mouth of Seymour River pre-spawn mortalities		**1**	3,889		3,889	**1**	7,403	7,403
Shuswap Lake shore pre-spawn mortalities		**23**	3,889		89,772	**37**	7,403	272,798
Mouth of Lower Shuswap River pre-spawn mortalities		**5**	41,187		190,128	**7**	41,187	303,556
Pre-spawn mortalities outside major spawning areas					**283,789**			**583,756**

a Minimum estimate based on mark rate from dead pitch surveys adjusted for 53% tag detection efficiency for dead pitch surveys (assuming a 54.5% detection rate at the Adams station). The best estimate of the mark rate for Lower Shuswap River is the estimate derived by dividing the DFO escapement estimate by the number of tags detected by the Lower Shuswap station.

b Maximum estimate based on mark rate from dead pitch surveys for Shuswap Lake. The best estimate of the mark rate for Lower Shuswap River is the estimate derived by dividing the DFO escapement estimate by the number of tags detected by the Lower Shuswap station.

Mark Rate based on dead pitch surveys	**Tags**	**Sample**	**Fish/Tag**
Shuswap River/Mabel Lake	2	165,368	82,684
Adams River/Adams Lake Study Area	3	201,240	67,080
Adams/Little River Study area	6	277,669	46,278
Shuswap Lake shore only	3	22,208	7,403

The above pre-spawn mortality estimates can be combined with the other DFO spawning area escapement estimates and the radio-telemetry estimate for survival from Mission to Little River (61.3%) to derive the adjusted estimate for the number of late-run sockeye that past the Mission site (Table 3).

Table 3. Adjusted Mission escapement estimate based on spawning ground estimates and the weighted radio-telemetry estimate for the survival rate form Mission to Little River.

	Minimum	Maximum
Escapement estimates		
Major spawning Areas	2,784,268	2,784,268
Other spawners	106,628	106,628
Pre-spawn mortalities outside major spawning areas	283,789	583,756
Escapement to Little River	3,174,685	3,474,652
Survival rate from Mission to Little River	68.00%	68.00%
Mission Escapement Estimate	4,668,951	5,110,109

If we apply the above adjustment proportionally to the weekly Mission escapement estimates, we can determine the range of mark rates for each Mission passage period (Table 4). The mark rates for the Mission passage intervals (20 Aug. – 2 Sep.) associated with all the 7 confirmed pre-spawn mortalities were 14,371-15,729 fish/tag. The mark rate was 25,038-27,403 fish/tag for the Mission passage intervals associated with the 35 tags detected at or above the Adams River station (27 Aug. – 23 Sep.) and the mark rate for the period when the 22 Lower Shuswap sockeye passed Mission was 19,946-21,842. In comparison, these mark rates are much higher than those estimated in Table 2 for the pre-spawn mortalities associated with the shores of Shuswap Lake (3,889-7,403 fish/tag), similar to those estimated in Table 1 for the Adams River study area (26,570-36,534 fish/tag) and much lower than the observed mark rate in the Lower Shuswap River (41,175 fish/tag; Table 1). It should be noted that these mark rates are based on the assumption that the Mission underestimation bias was consistent over the entire migration period for late-run sockeye. These mark rate estimates will have to be recalculated after the daily or weekly Mission estimates have been corrected for the underestimation bias.

Table 4. Mark rate by Mission passage period after adjusting for the Mission underestimation bias.

Mission Passage			Mission Escapement Estimates			Mark Rate (Fish/tag)	
No.	Interval	Tags	Unadjusted	Minimum	Maximum	Minimum	Maximum
3	30 July to 5 Aug	10	52,102	52,319	57,026	5,232	5,703
4	6 to 12 Aug	37	165,453	166,139	181,086	4,490	4,894
5	13 to 19 Aug	18	473,562	475,527	518,308	26,418	28,795
6	20 to 26 Aug	42	473,913	475,881	518,693	11,330	12,350
7	27 Aug to 2 Sept	47	664,526	667,285	727,317	14,198	15,475
8	3 to 9 Sept	80	2,118,539	2,127,334	2,318,719	26,592	28,984
9	10 to 19 Sept	9	800,251	803,573	875,867	89,286	97,319
10	17 to 23 Sept	5	409,174	410,873	447,837	82,175	89,567
Total		248	5,157,520	5,178,931	5,644,853	20,883	22,762
PSM interval (20 Aug. - 2 Sep.)[1]		89	1,138,440	1,143,166	1,246,010	12,845	14,000
Adams interval (27 Aug. - 23 Sep.)[2]		141	3,992,490	4,009,065	4,369,740	28,433	30,991
Lower Shuswap (27 Aug. - 9 Sep.)[3]		127	2,783,065	2,794,619	3,046,036	22,005	23,985

[1] PSM interval = Mission passage timing for the 7 Shuswap tag recoveries that were pre-spawn mortalities.

[2] Adams interval = Mission passage timing for the 35 tags detected at or above the Adams station.

[3] Lower Shuswap interval = Mission passage timing for the 22 tags detected in the Lower Shuswap River.

APPENDIX E

Historical Mission Run Timing

Appendix Figure E1. Annual estimates of the median date for the migration of Adams, Weaver and Chilko sockeye stocks at the Mission hydroacoustic site, 1974-2003.