Characterizing Migration and Survival between the upper Salmon River Basin and Lower Granite Dam for Juvenile Snake River Sockeye Salmon, 2012

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EXECUTIVE SUMMARY

In 2012, we tagged and released groups of juvenile hatchery Snake River sockeye salmon *Oncorhynchus nerka* to Redfish Lake Creek in the upper Salmon River basin for studies to characterize migration and survival to Lower Granite Dam. We compared detection and survival probabilities as well as travel time between cohorts of PIT-tagged (passive integrated transponder) vs. radio-tagged fish from Sawtooth and Oxbow Fish Hatcheries.

For groups of PIT-tagged fish released to Redfish Lake Creek in 2012, estimated survival to Lower Granite Dam ranged 0.593-0.694; mean estimated survival was 10.1% higher for Oxbow than for Sawtooth Hatchery groups, but the difference was not significant (P = 0.059). For the radio-tagged groups, survival was 0.483 and 0.382 for Oxbow and Sawtooth hatchery fish, respectively. Mean estimated survival to Lower Granite Dam was also 10.1% higher for Oxbow than for Sawtooth Hatchery juvenile sockeye, and the difference was significant (P = 0.004). Survival estimates from release to Lower Granite Dam of the radio-tagged groups from both Oxbow and Sawtooth Hatcheries were lower than that of the PIT-tagged groups of sockeye salmon from these hatcheries, but within the confidence bounds of each.

For study groups in 2012, we were able to mitigate the significant effects of radio tagging observed in 2011 by allowing more time for fish to recover from surgery and to acclimate to changes in elevation after transport to the release area. Therefore, data on performance metrics obtained from radio-tagged sockeye salmon during 2012 is likely more representative of the production population at Oxbow Hatchery. Radio-tagged sockeye groups were moved from Sawtooth to Eagle Hatchery earlier than in 2011 and were held there longer. Therefore, they attained a larger size, which contributed to faster migration rates than those of the smaller PIT-tag only study groups. These larger fish also had lower detection rates due to less utilization of the juvenile bypass systems. Because of these differences, we believe that the migration rates of radio-tagged Sawtooth Hatchery groups were not comparable to those of the PIT-tagged groups.

Fish were radio-tagged in early April, and three tagging mortalities occurred during the 30 d between tagging and release. These fish likely benefited from a longer post-surgical recovery period than that experienced by radio-tagged fish from Sawtooth and Oxbow Hatcheries in 2011.

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INTRODUCTION

Anadromous sockeye salmon *Oncorhynchus nerka* that originate from lakes in Sawtooth Valley, Idaho, make a longer seaward migration (~1,440 km) than any population of sockeye salmon in the world. Natal areas for these fish are also at higher elevations (~2,000 m) and located further south than those of any other sockeye population (Bjornn et al. 1968; Foerster 1968). The Sawtooth Valley population is the only extant population of sockeye salmon in the upper Snake River Basin, with wild production occurring primarily in Redfish Lake. Extirpated sockeye salmon populations from the Snake River Basin include fish that historically spawned in Wallowa Lake (Grand Ronde River drainage, Oregon), Payette Lake (Payette River drainage, Idaho), and Warm Lake (South Fork Salmon River drainage, Idaho; Waples et al. 1997).

In the 1950s, a weir was installed downstream from Redfish Lake to enumerate adult sockeye salmon returns and juvenile migrants (Bjornn et al. 1968). Annual adult returns of sockeye salmon during 1954-1989 ranged from 4,361 in 1955 to 1 in both 1988 and 1989. These extremely low adult returns led to a status review of Snake River sockeye salmon in the Snake River Basin (Waples et al. 1991); this was followed by the listing in 1991 of Snake River sockeye salmon as an endangered ESU (evolutionarily significant unit) under the Endangered Species Act of 1973 (NMFS 1991).

Snake River sockeye salmon is the only Pacific salmon ESU in the Salmon River subbasin that is currently listed as endangered (NWPPC 2004), and Waples et al. (1991) described Snake River sockeye salmon on the threshold of extinction. Part of the recovery strategy for this ESU includes a captive broodstock program to aid in rebuilding the population. Snake River sockeye salmon would likely be extinct without this program (Hebdon et al. 2000).

During the 17 years of the captive broodstock program, hatchery production of Snake River sockeye salmon has increased steadily, with current annual production between 200,000 and 300,000 juveniles. The Idaho Department of Fish and Game (IDFG) is developing a new sockeye salmon hatchery with funding from the Bonneville Power Administration (BPA). The goal of this hatchery is to increase annual production of Snake River sockeye salmon to one million juveniles (a three- to five-fold increase). The first juvenile migration year for fish from the new hatchery is targeted for 2015.

For hatchery juvenile sockeye salmon, estimated survival between the Sawtooth Valley and Lower Granite Dam has been highly variable between release locations, rearing strategies, origin, and years. Based on detections of sockeye hatchery juveniles tagged with a passive integrated transponder (PIT) tag and released in spring, estimates of survival have ranged from 0.114 (SE 0.021) in 2000 (Zabel et al. 2001) to 0.776 (0.133) in 2008 (Faulkner et al. 2008).

Low estimates of survival may be related to competition with non-native species, predation, environmental conditions, or rearing and release strategies. Hatchery release strategies often result in large concentrations of juvenile salmonids (Waples 1991), which can be rapidly exploited by predators (Shively et al. 1996; Collis et al. 1995). Disease, particularly bacterial kidney disease (BKD), has been shown to increase in severity during migration (Maule et al. 1996). Furthermore, the hatchery environment results in high survival prior to release, with natural culling postponed until after release (Waples 1991).

Measuring the magnitude of mortality, as well as determining where and why mortality is occurring, is critical to successful restoration and recovery of endangered Snake River sockeye salmon. Without such knowledge, it will be difficult to measure and assess the effects of possible restoration strategies, such as flow augmentation, habitat enhancement, predator management, or rearing and release strategies.

Several regional management and recovery programs recommend tracking survival to investigate the highly variable rates of mortality for juvenile sockeye between the Sawtooth Valley and Lower Granite Dam. Two such programs are the 2008 Federal Columbia River Power System (FCRPS) biological opinion (BiOp; NMFS 2008) and 2009 FCRPS Adaptive Management Implementation Plan for 2008-2018 (AMIP; NMFS 2009). Smolt travel time and survival estimates from this study will provide insight into key uncertainties and help fill the data gaps identified by the BiOp and AMIP. The outcome of this study will directly contribute to management actions, which will play a significant part in recovery of ESA-listed Snake River sockeye salmon.

We used a multifaceted tracking approach that used both PIT and radio telemetry monitoring systems to identify the magnitude and locations of mortality for sockeye salmon smolts between the Sawtooth Valley and Lower Granite Dam. Each of these monitoring systems has differing strengths and limitations in characterizing migration and survival over the 750-km reach of interest. Our approach took advantage of the strengths of each technology for a more complete understanding of migration and survival for these fish. Research objectives in 2012 were:

1) Estimate survival and travel time to Lower Granite Dam with PIT and radio telemetry and compare these metrics among the different hatchery production groups of juvenile Snake River sockeye salmon
2) Estimate survival and characterize migration based on radio telemetry detections of juvenile Snake River sockeye salmon upstream from Lower Granite Dam

METHODS

Study Area

The study area was a 750-km river reach of the upper Snake River Basin. Radio telemetry receivers were located along the Salmon River from Redfish Lake Creek in Sawtooth Valley, Idaho, to the tailrace of Lower Granite Dam on the Snake River, Washington (Figure 1). Monitoring systems for PIT tags were located in the juvenile bypass systems of collector dams on the Snake and Columbia River.

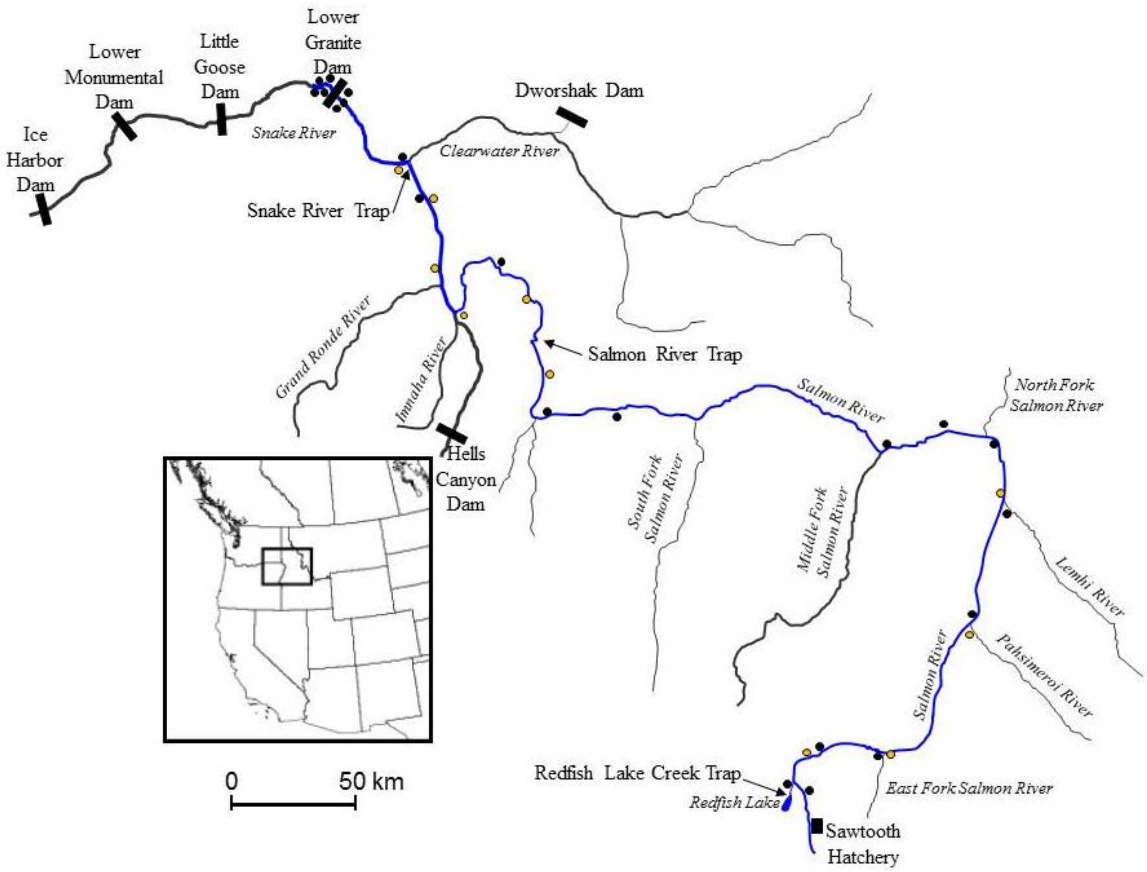

Figure 1. Map of study area showing migratory path of Snake River sockeye salmon from release near the Redfish Lake Creek Trap to Lower Granite Dam. Black dots show location of fixed-site telemetry receivers. Yellow dots show locations of fixed-site telemetry receivers used in 2011 but not installed in 2012 due to permitting restrictions. Arrows show locations of smolt monitoring traps; bars indicate lower Snake River dams.

Tagging and Release of Study Fish

Passive Integrated Transponder (PIT-Tagged) Release Groups

We tracked and analyzed survival and travel time of PIT-tagged hatchery sockeye salmon smolts in order to compare these metrics with those of radio-tagged cohorts from the same hatchery populations. However, no PIT-tagged (only) fish were designated specifically for this study: the Sawtooth and Oxbow Hatchery groups were PIT-tagged for a transportation study by the U.S. Army Corps of Engineers (USACE). All radio-tagged fish were also implanted with a PIT-tag.

The Oxbow Hatchery production release was 85,161 sockeye smolts; 10,551 of these fish were PIT-tagged by personnel from Biomark Inc. for a transportation study by the U.S. Army Corps of Engineers (Richmond and McCutcheon 2012). For Oxbow Hatchery fish, overall mean fork length at tagging was 146.0 mm (SD = 10.1), and tagging occurred 65 days prior to release (Table 2). Oxbow Hatchery sockeye salmon were released at the bridge approximately 0.75 km downstream from the Redfish Lake Creek trap on 10 May 2012 between 2130 and 2300 (MDT).

Table 2. Summary statistics of length at tagging for PIT-tagged juvenile sockeye salmon from Sawtooth (tagged on 19-22 March 2012) and Oxbow Fish Hatcheries (tagged on 6 March 2012).

	PIT-tagged sockeye salmon length (mm)	
	Sawtooth Hatchery	Oxbow Hatchery
Minimum	57	96
Maximum	147	188
Mean (SD)	96.9 (11.5)	146.0 (10.1)

Sawtooth Hatchery released 79,673 sockeye production smolts in 2012. Of these fish, 52,352 were PIT-tagged for the USACE transportation study 49 days prior to release (Richmond and McCutcheon 2012); these fish had an overall mean fork length of 96.9 mm (SD 11.5) at tagging (Table 2). Sawtooth Hatchery sockeye salmon were released just below the Redfish Lake Creek trap on 10 May 2012 between 1105 and 1445 (MDT).

At both Sawtooth and Oxbow Hatcheries, PIT-tagging operations were conducted by Biomark Inc.[1] (Richmond and McCutcheon 2012). Fish were tagged with a 12.5-mm, 134.2-kHz PIT tag (Destron Fearing TX1400 SST) following protocols mandated by

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

IDFG and USACE and using techniques similar to those described by Prentice et al. (1990a). Tags were injected using an implant gun (Biomark MK-25) pre-loaded with a 12-gauge hypodermic needle (Biomark BIO12.BPL). This injection system allowed each fish to be tagged with a single-use disposable needle, thus reducing the chance of disease transmission or injury from dull needles. In addition, the system required fewer personnel for each tagging operation. Complete details of the tagging operations at both hatcheries were reported by Richmond and McCutcheon (2012).

Radio-Tagged Release Groups

For radio tagging, we transferred juvenile Snake River sockeye salmon from Sawtooth and Oxbow Hatcheries (elevation 2,012 and 30 m MSL, respectively) to Eagle Hatchery in Eagle, Idaho (elevation 792 m MSL). Sawtooth fish were transferred on 23 November 2011 and Oxbow fish on 6 March 2012. The purpose of these transfers was to accelerate growth, so that fish would meet minimum size requirements for radio tagging, and to allow sufficient time for fish to acclimate to elevation changes prior to the surgical implant procedure.

At Eagle Hatchery, we surgically implanted radio tags into 400 sockeye salmon from Sawtooth and 400 from Oxbow Hatchery during 8-11 April 2012. Tagging was conducted simultaneously at three surgical stations. Fish were excluded for radio tagging if they had been previously PIT tagged, had visible signs of disease or injury, or weighed 12 g or less. Radio tags (model F1717) used for the study were purchased from Advanced Telemetry Systems Inc. Tags were pulse-coded for identification of individual fish with a 5-second pulse interval (12 ppm). Radio tags measured 13 mm in length by 5 mm in diameter, had a volume of 230 mm^3, weighed 0.75 g in air, and had a 30-cm long external antenna.

For each procedure, the individual fish was anesthetized in a bath containing 70 mg/L tricaine methanesulfonate (MS 222) and then weighed to the nearest 0.10 g and measured to the nearest 1 mm (fork length). After measuring, a radio transmitter was surgically implanted using techniques described by Adams et al. (1998). A PIT tag was also inserted with each radio transmitter so that any radio-tagged study fish that entered the juvenile bypass system of a downstream dam could be identified, separated by code, and returned to the river (Marsh et al. 1999).

A neoprene foam pad with a groove cut in the center was used to stabilize fish during surgery. The foam pad was coated with a water conditioner (PolyAqua, Kordon LLC, Hayward, California) to minimize impacts to the protective mucus layer (Harnish et al. 2010). Fish were placed ventral side up on the pad, and the gills were continuously irrigated with a maintenance dose of anesthetic (40 mg/L MS-222) fed through a tube placed in the mouth. About 30 seconds before completion of each surgical procedure, the flow of anesthetic solution was replaced with oxygenated freshwater to begin the recovery process.

To implant the transmitter, a 7- to 9-mm incision was made approximately 3 mm anterior to the pelvic girdle on the linea alba. The incision was no deeper than needed to penetrate the peritoneum (Summerfelt and Smith 1990). To provide an outlet in the body wall for the antenna, we used a shielded-needle technique similar to that described by Ross and Kleiner (1982). An intravenous catheter and needle (Abbocath-T 18-gauge × 51 mm or Terumo Surflo 16-guage × 51 mm) was used to guide the antenna through the body wall of the fish, with the hard plastic base of the catheter removed.

Transmitters were implanted by first threading the antenna through the incision end of the catheter. Both the antenna and catheter were then gently pulled toward the posterior while the transmitter was simultaneously inserted into the body cavity. The position of the transmitter inside the fish was adjusted by gently pulling on the antenna until the transmitter was directly under the incision. The incision was closed with two simple, interrupted absorbable sutures (5-0 Ethicon coated Vicryl braided, C-3 needle) evenly spaced across the incision. Between each procedure, surgical instruments were disinfected by immersion in 70% ethanol for 8–10 minutes and rinsed in distilled water to minimize the spread of pathogens.

Immediately following tagging, fish were placed into a 19-L bucket containing oxygenated freshwater until they recovered from the anesthesia. Holding fish in oxygenated water has been shown to reduce the stress associated with handling and anesthesia (Hoar and Randall 1971). Each bucket contained a maximum of two fish to minimize the possibility of tangling radio tag antennas. After recovery, fish were transferred to a circular tank supplied with river water by gently pouring contents of the buckets into the tank. Circular holding tanks were 4 m wide by 4 m long by 0.66 m deep and had a volume of approximately 9,084 L. Holding density was 200 fish per tank.

Fish were held 29 to 32 d for recovery and determination of post-tagging mortality. Four post-tagging mortalities occurred during the 30-d recovery period. However, one of these mortalities was caused by a storm: high winds blew a net into one of the circular tanks, and a tagged fish became entangled in the net. After the holding and recovery period, radio-tagged fish were moved from recovery tanks to 19-L freshwater transport buckets. Transport buckets had several 1.3-cm-diameter perforations in the top 18-cm for water exchange. Each transport bucket contained only two fish to minimize the possibility of tangling radio tag antennas.

During the transfer of fish to transport buckets, we checked the radio transmission of each fish to verify that the tag was operating and to ensure that the tag code had been recorded correctly in the database. During this process, 10 fish had antennas that became tangled, and 3 of these fish died; we removed the transmitters from the remaining 7 fish and released them alive. We also found 33 fish with tags that were not operating prior to release, and we removed these fish from the study. Transport buckets were loaded into 1,152 L transport tanks, held overnight, and maintained with flow through river water.

On the morning of 10 May 2012, radio tagged sockeye salmon were transported from Eagle Hatchery to the release location in Redfish Lake Creek. Upon arrival at the release site, fish were acclimated until water temperatures of the holding tank and the river were within 2°C. Fish were released by gently pouring the contents of the bucket into Redfish Lake Creek at mid-channel. Sawtooth Hatchery fish were released just below the Redfish Lake Creek trap along with the hatchery production release between 1205 and 1405 (MDT). Oxbow Hatchery fish were released at a bridge approximately 0.75 km downstream from Redfish Lake Creek; these fish were released between 2145 and 2300 along with the hatchery production release.

For radio-tagged study fish, overall mortality between tagging and release was 1.25% (5 fish) for Sawtooth groups and 0.5% (2 fish) for Oxbow groups. Fork length and weight at radio tagging are summarized by hatchery in Table 3. Tag burden ranged from 0.6 to 5.1% and averaged 1.7% overall.

Table 3. Summary statistics of length and weight at tagging for radio tagged juvenile sockeye salmon from Oxbow and Sawtooth Fish Hatcheries, 2012.

	Radio-tagged hatchery sockeye salmon length and weight			
	Length (mm)		Weight (g)	
	Oxbow	Sawtooth	Oxbow	Sawtooth
minimum	128.0	120.0	19.9	14.7
maximum	185.0	221.0	64.1	118.5
mean	158.7	159.8	40.3	45.4
standard deviation	9.3	13.0	7.3	12.2

Monitoring and Data Collection

PIT-Tagged Fish

Study fish marked with PIT-tags were interrogated at monitoring systems within the juvenile bypass systems of collector dams on the Snake and Columbia Rivers (Prentice et al. 1990a,b). Collector dams are those equipped with juvenile collection and bypass and PIT-tag monitoring systems. Thus, potential detection locations for PIT-tagged fish were Lower Granite (rkm 695), Little Goose (rkm 635), Lower Monumental (rkm 589), and Ice Harbor Dams (rkm 538) on the Snake River and McNary (rkm 470), John Day (rkm 347), and Bonneville Dams (rkm 235) on the Columbia River.

When a PIT-tagged fish passes an interrogation monitor at these dams, a detection record is generated that includes the time and date of passage and the location of the monitor where the passage event was recorded. Detection records are stored on a computer and automatically uploaded to the PTAGIS database (PSMFC 1996-present). The PTAGIS database is a long-term repository for records of detection from PIT-tagged fish throughout the Columbia River Basin. These records are publicly available and can be retrieved remotely from the PTAGIS database.

Of our study fish detected at the dams, the majority were returned to the river (i.e., the tailraces of dams) using separation-by-code (SbyC) systems. At collector dams, the SbyC systems operate by means of a slide gate triggered by PIT-tag detection, and these systems can route fish to various destinations (e.g., at some dams, untagged fish are routed to a collection system for barging or trucking downstream). The SbyC systems allow the possibility of detecting an individual fish at multiple sites downstream from release (Marsh et al. 1999). However, for this study we were concerned primarily with PIT-tag detection data from Lower Granite Dam.

Radio-Tagged Fish

We positioned 41 fixed-site telemetry receivers at 21 locations within the study area to provide 17 detection zones or transects. Locations of the telemetry receivers are presented in Table 4 and Figure 1. Minimum distance between receivers was less than 145 km; however, receivers at the upper and lower ends of the study area were spaced closer together than those in the middle because we hypothesized that the highest mortality would occur in these areas. Radio-telemetry monitoring locations were selected primarily based on the locations of major tributaries where we anticipated mortality may occur, but were also selected based on physical accessibility.

Table 4. Locations of fixed-site radio telemetry monitoring receivers used to characterize migration and estimate survival of radio-tagged juvenile Snake River sockeye salmon. Survival was estimated between the Sawtooth Valley in the upper Salmon River basin and Lower Granite Dam. The distance from release to each site is also shown. Two receivers and two antennas were situated at each site, with one oriented approximately 45° downstream and the other oriented approximately 45° upstream.

Site number	Site description	Latitude	Longitude	Distance from release (km)
1	Above Red Fish Lake Creek confluence	44°09'46.82"N	114°53'09.42"W	4
2	Below Little Redfish Lake	44°09'57.55"N	114°54'02.80"W	3
4	Below Lower Stanley	44°14'27.09"N	114°54'02.38"W	12
5	Above East Fork Salmon R confluence	44°15'12.66"N	114°20'47.16"W	63
8	Below Pahsimeroi R confluence	44°42'06.97"N	114°02'37.89"W	131
9	Above Lemhi R confluence	45°10'15.68"N	113°54'36.37"W	199
11	Above North Fork Salmon R confluence	45°24'17.96"N	113°59'34.62"W	237
12	Below North Fork Salmon R confluence	45°24'12.12"N	114°12'56.09"W	259
13	Above Middle Fork Salmon R confluence	45°18'02.36"N	114°32'03.66"W	299
14	Vinegar Creek boat launch	45°27'34.48"N	115°53'35.42"W	438
15	Above Little Salmon R confluence	45°24'51.31"N	116°18'07.64"W	476
18	Rice Creek Bridge	45°54'39.95"N	116°24'41.76"W	557
21	Above Clearwater R confluence	46°22'48.53"N	117°02'58.49"W	702
24	Below Clearwater R confluence	46°25'08.37"N	117°10'57.40"W	709
25	Lower Granite Dam forebay (right bank)	46°39'45.21"N	117°25'20.18"W	747
26	Lower Granite Dam forebay (mid-channel)	46°39'37.02"N	117°25'22.73"W	747
27	Lower Granite Dam forebay (left bank)	46°39'24.17"N	117°25'25.63"W	747
28	Lower Granite Dam tailrace (right bank)	46°39'55.10"N	117°26'09.71"W	749
29	Lower Granite Dam tailrace (left bank)	46°39'43.69"N	117°26'20.29"W	749
30	Lower Granite Dam tailrace (right bank)	46°39'55.10"N	117°26'09.71"W	751
31	Lower Granite Dam tailrace (left bank)	46°39'43.69"N	117°26'20.29"W	751

Telemetry data were downloaded manually from most fixed-site receivers at least once per week. After downloading, individual data files were compressed as follows: the first detection of a radio tagged fish was recorded, and the number of subsequent detections was counted where the time difference between adjacent detections was 5 minutes or less. When the difference between adjacent detections became greater than 5 minutes, a new line of data was created. All compressed data were combined and loaded into a database, where automated queries and algorithms were used to remove erroneous data. Data processing and reduction procedures are detailed in Appendix B.

Using the cleaned data set, we created detailed detection histories for each radio tagged fish. These detection histories were then used to calculate arrival and departure timing at fixed-site receiver locations for individual radio-tagged fish.

Estimates of Survival and Travel Time

PIT-Tagged Fish

The PIT tag detection data for individual study fish were retrieved from the PTAGIS database. We used the "complete capture history" protocol of Burnham et al. (1987) to estimate survival and detection probabilities by applying the single release-recapture model, or CJS model (Cormack 1964; Jolly 1965; Seber 1965; Skalski et al. 1998). Independent estimates of survival were made for each release group. Release-recapture data were analyzed using the Survival with Proportional Hazards (SURPH) statistical software developed at the University of Washington (Smith et al. 1994). Survival and detection probabilities were estimated from the point of release to Lower Granite Dam tailrace for each release group. Survival between groups was compared using a two-sample *t*-test ($\alpha = 0.05$). The CJS model assumptions and methods used to evaluate them are detailed in Appendix A.

Median travel time in days was also calculated from release to Lower Granite Dam for each group of PIT-tagged fish. Analyses of survival and travel time in reaches downstream from Lower Granite Dam will be reported elsewhere (BPA Project 199302900 survival study and USACE sockeye salmon transportation study).

Radio-Tagged Fish

Survival estimates for radio-tagged fish were based on detections of individuals at fixed-site telemetry receivers (Table 4; Figure 1). Detection histories were used with the CJS model to estimate probabilities of detection and survival in the same manner as described above for PIT-tag data. Independent probabilities of survival were estimated for each segment of the river as delineated by fixed-site monitoring locations in order to pinpoint areas of high mortality. For each group, an overall probability of survival from release to Lower Granite Dam was also estimated.

Tag life of the radio transmitters was assessed from a sample of 93 tags tested in water (Appendix A5). Survival estimates were not adjusted for tag life, since all transmitters tested had sufficient tag life for fish to migrate through the study area. Survival estimates were compared between groups and tag types using two-sample *t* tests.

Travel time for radio-tagged fish was calculated for an individual fish as the time between the last detection at a given telemetry receiver and the first detection at the next receiver downstream. Summary statistics of travel time between release and Lower Granite Dam were calculated by release group. For individual reaches upstream from Lower Granite Dam, travel time was estimated as the median of the travel time distribution for fish detected at both the upper and lower sites delineating that reach. Migration rates were calculated from travel time data as kilometers per day (km/d).

RESULTS

Detection Probabilities

Detection at Lower Granite Dam

For PIT-tagged sockeye salmon, estimated probabilities of detection at Lower Granite Dam were 0.131 (SE = 0.011) for Oxbow Hatchery groups and 0.308 (SE = 0.004) for Sawtooth Hatchery groups, and the difference was statistically significant (*P* = 0.000; Tables 5 and 6). For Sawtooth Hatchery fish, PIT-tag detection probabilities were significantly different between PIT-tagged (0.308) and radio-tagged groups (0.175; *P* = 0.005). However, a significant difference in PIT-tag detection probabilities was not observed between tag treatment groups from Oxbow Hatchery (*P* = 0.058; Table 6) or between the two radio-tagged groups (*P* = 0.530; Table 6).

Table 5. Estimated detection probability at Lower Granite Dam for PIT-and radio-tagged juvenile hatchery sockeye salmon released to Red Fish Lake Creek, 2012. Radio-tagged fish were also implanted with a PIT-tag; thus, separate probabilities of detection were estimated for these fish based on PIT vs. radio-tag detection data. Standard errors are in parenthesis.

	Detection probability of juvenile Snake River sockeye salmon (SE)
Estimates based on PIT-tag detection	
PIT-tagged fish	
Oxbow Hatchery	0.131 (0.011)
Sawtooth Hatchery	0.308 (0.004)
Radio-tagged fish	
Oxbow Hatchery	0.215 (0.043)
Sawtooth Hatchery	0.175 (0.047)
Estimates based on radio-tag detections	
Radio-tagged fish	
Oxbow Hatchery	0.989 (0.008)
Sawtooth Hatchery	0.993 (0.007)

For Sawtooth Hatchery fish, one possible contributor to the differing probabilities of PIT-tag detection between tag treatments may have been the difference in mean size between PIT- and radio-tagged study groups. The smaller PIT-tagged fish (mean FL 96.9 mm) likely had higher detection rates because they were more easily entrained in the bypass systems at Lower Granite Dam. In contrast, the larger radio-tagged fish (mean FL 159.8 mm) may have been attracted more readily to the surface flows provided by the removable spillway weir (RSW) and passed over the spillway. Fish passing via spillways are not detected by a PIT-tag monitor.

Table 6. Comparisons of PIT-tag detection probability at Lower Granite and Little Goose dams for PIT- vs. radio-tagged juvenile Snake River sockeye salmon from Oxbow and Sawtooth hatcheries, 2012 (radio-tagged fish were also implanted with at PIT tag). Shaded cells indicate a significant difference between estimates of detection.

	PIT-tag detection probability at Lower Granite Dam		
Hatchery group and tag type	Difference in detection (%)	*t*	*P*
Oxbow radio-tagged vs. Sawtooth radio-tagged	4.0	0.63	0.530
Oxbow PIT-tagged vs. Oxbow radio-tagged	8.4	1.89	0.058
Sawtooth PIT-tagged vs. Sawtooth radio-tagged	13.3	2.82	0.005
Oxbow PIT-tagged vs. Sawtooth PIT-tagged	17.7	15.27	0.000

For Oxbow Hatchery sockeye salmon, the difference in mean fork length between PIT (146.0 mm) and radio-tag treatment groups (158.7 mm) was smaller. This may partially explain why no significant difference in PIT-tag detection probability was seen between tag treatment groups from this hatchery.

Detection in Partitioned Reaches

Detection probabilities at fixed-site radio telemetry monitoring stations ranged from 0.397 to 1.000 and averaged 0.871 overall (Table 10). Mean probabilities of radio-tag detection were lower in the Snake (0.775, range 0.397-0.993) than in the Salmon River (0.918, range 0.401-1.000).

Table 10. Estimated detection probability for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon at fixed-site radio telemetry monitoring locations, 2012. Standard errors are in parentheses. Detailed location information for fixed-site telemetry locations is presented in Table 1 and Figure 1.

Receiver site number	Site description	Detection probability of radio-tagged fish
2	Below Little Redfish Lake	0.983 (0.008)
4	Below Lower Stanley	0.401 (0.029)
5	Above East Fork Salmon River confluence	1.000 (0.000)
8	Below Pahsimeroi River confluence	1.000 (0.000)
9	Above Lemhi River confluence	0.991 (0.007)
11	Above North Fork Salmon River confluence	0.932 (0.018)
12	Below North Fork Salmon River confluence	1.000 (0.000)
13	Above the Middle Fork Salmon River confluence	0.946 (0.017)
14	Vinegar Creek boat launch	1.000 (0.000)
15	Above Little Salmon River confluence	1.000 (0.000)
18	Rice Creek Bridge	0.913 (0.021)
21	Above Clearwater River confluence	0.789 (0.033)
24	Below Clearwater River confluence	0.397 (0.040)
25-27	Lower Granite Dam forebay	0.922 (0.020)
28-29	Lower Granite Dam tailrace	0.993 (0.007)

Estimated Survival

Survival to Lower Granite Dam

Estimated survival to Lower Granite Dam for PIT-tagged groups was 0.694 for Oxbow and 0.593 for Sawtooth Hatchery sockeye salmon (Table 7). For radio-tagged fish, mean estimated survival was 0.483 for Oxbow and 0.382 for Sawtooth Hatchery groups. The difference in estimated survival to Lower Granite Dam between Oxbow and Sawtooth fish was 10.1% for comparisons between both PIT and radio-tag groups (Table 8). However, the difference in estimated survival based on telemetry detections was statistically significant, while the difference based on PIT detections was not. Although sample sizes were smaller in the radio-tag treatment groups, these groups had far higher detection probabilities, which increased the precision of survival estimates.

The largest difference in estimated survival was observed in the comparison between Oxbow PIT- and radio-tag groups based on PIT detections at Lower Granite Dam (23.6%). These higher differences in survival to Lower Granite were most likely related to differences in detection probability and passage distribution through the juvenile bypass system.

Table 7. Estimated survival from release in Red Fish Lake Creek to Lower Granite Dam for PIT- and radio-tagged juvenile Snake River sockeye salmon, 2012. Radio-tagged fish were also implanted with a PIT-tag; thus, separate probabilities of survival were estimated for these fish based on PIT vs. radio-tag detection data. Standard errors are in parenthesis.

	Estimated survival of juvenile Snake River sockeye salmon to Lower Granite Dam (SE)
Survival estimates based on PIT-tag detection	
PIT-tagged fish	
Oxbow Hatchery	0.694 (0.053)
Sawtooth Hatchery	0.593 (0.007)
Radio-tagged fish	
Oxbow Hatchery	0.458 (0.070)
Sawtooth Hatchery	0.518 (0.119)
Survival estimates based on radio-tag detection	
Radio-tagged fish	
Oxbow Hatchery	0.483 (0.025)
Sawtooth Hatchery	0.382 (0.025)

Table 8. Comparison of estimated survival using each tag type from release in Redfish Lake Creek to Lower Granite Dam for PIT-tagged and radio-tagged juvenile Snake River sockeye salmon from Oxbow and Sawtooth hatcheries, 2012. Shaded values indicate significantly different estimates of survival.

	Juvenile Snake River sockeye salmon		
Hatchery group and tag type	Difference in est. survival (%)	*t*	*P*
PIT-tag detection at Lower Granite Dam			
Oxbow PIT-tagged vs. Sawtooth PIT-tagged	10.1	1.89	0.059
Oxbow radio-tagged vs. Sawtooth radio-tagged	6.0	0.38	0.707
Oxbow PIT-tagged vs. Oxbow radio-tagged	23.6	2.69	0.007
Sawtooth PIT-tagged vs. Sawtooth radio-tagged	8.3	0.70	0.486
Radio-tag detection at Lower Granite Dam			
Oxbow radio-tagged vs. Sawtooth radio-tagged	10.1	2.86	0.004

Therefore, for most treatment groups, the reach survival estimates presented here are likely representative of those for the general population. The exception was for the Sawtooth PIT-tagged group, which had significantly smaller fork lengths at release than the other three groups. This size difference likely led to larger proportions of the smaller group being directed into the juvenile bypass systems (Table 7) and to observed differences in migration rate.

Survival in Partitioned Reaches

Survival was partitioned into smaller reaches for radio-tagged groups from Oxbow and Sawtooth Hatcheries; a description of these reaches is presented in Table 9. For radio-tagged Oxbow and Sawtooth hatchery sockeye salmon combined, estimated survival within various reaches between Redfish Lake Creek and Lower Granite Dam are presented in Table 11. Most observed mortality for both groups occurred between release and the North Fork of the Salmon River. Radio-tagged fish from Sawtooth Hatchery encountered nearly 10% higher mortality than those from Oxbow Hatchery between release and the first telemetry site below Little Redfish Lake.

Sawtooth Hatchery sockeye releases were made during mid-day, and these releases were made 1 km upstream from the Oxbow Hatchery release location. In addition, the Oxbow sockeye groups were released at night, when the trucks arrived from the hatchery. We hypothesized that predation on Sawtooth Hatchery sockeye could be reduced considerably by scheduling their release time closer to dusk. Estimated survival in the individual reaches downstream from Vinegar Creek were greater than 98% for both hatchery groups.

Table 9. Reach descriptions used for partitioning survival and travel time for radio-tagged Oxbow and Sawtooth Hatchery sockeye salmon between release in Redfish Lake Creek and Lower Granite Dam, 2012. Detailed location information for fixed-site telemetry locations are in Table 1 and Figure 1.

Reach	Reach distance (km)	Reach description
Release to 2	3	Release to below Little Redfish Lake
2 to 4	9	Below Little Redfish Lake to below lower Stanley
4 to 5	51	Below lower Stanley to above E. Fork Salmon River
5 to 8	68	Above E. Fork Salmon River to below Pahsimeroi River
8 to 9	68	Below Pahsimeroi River to above Lemhi River
9 to 11	38	Above Lemhi River to above N. Fork Salmon River
11 to 12	22	Above N. Fork Salmon River to below N. Fork Salmon River
12 to 13	40	Below N. Fork Salmon River to above Middle Fork Salmon River
13 to 14	139	Above Middle Fork Salmon River to Vinegar Creek boat launch
14 to 15	38	Vinegar Creek boat launch to above Little Salmon River
15 to 18	81	Above Little Salmon River to Rice Creek Bridge
18 to 21	145	Rice Creek Bridge to above Clearwater River
21 to 24	7	Above Clearwater River to below Clearwater River
24 to 25	38	Below Clearwater River to Lower Granite Dam forebay

Table 11. Estimated survival for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon within various reaches between release in Redfish Lake Creek and Lower Granite Dam, 2012. Standard errors are in parentheses. Detailed information for fixed-site telemetry receivers locations are presented in Table 4 and Figure 1.

		Estimated survival	
Reach	Reach description	Oxbow	Sawtooth
Release to 2	Release to below Little Redfish Lake	0.932 (0.013)	0.836 (0.018)
2 to 4	Below Little Redfish Lake to below lower Stanley	0.981 (0.023)	0.934 (0.026)
4 to 5	Below lower Stanley to above E Fork Salmon R	0.902 (0.026)	0.903 (0.027)
5 to 8	Above E Fork Salmon R to below Pahsimeroi R	0.932 (0.014)	0.920 (0.016)
8 to 9	Below Pahsimeroi R to above Lemhi R	0.920 (0.016)	0.911 (0.018)
9 to 11	Above Lemhi R to above N Fork Salmon R	0.950 (0.015)	0.925 (0.020)
11 to 12	Above N Fork Salmon R to below N Fork Salmon R	0.828 (0.025)	0.805 (0.028)
12 to 13	Below N Fork Salmon R to above Middle Fork Salmon R	0.955 (0.015)	0.940 (0.019)
13 to 14	Above Middle Fork Salmon R to Vinegar Cr boat launch	0.936 (0.018)	0.972 (0.014)
14 to 15	Vinegar Cr boat launch to above Little Salmon R	1.000 (0.000)	1.000 (0.000)
15 to 18	Above Little Salmon R to Rice Cr Bridge	0.995 (0.005)	0.982 (0.011)
18 to 21	Rice Cr Bridge to above Clearwater R	0.994 (0.006)	0.996 (0.008)
21 to 24	Above Clearwater R to below Clearwater R	1.000 (0.000)	0.993 (0.015)
24 to LGR	Below Clearwater R to Lower Granite Dam forebay	0.985 (0.016)	0.984 (0.016)

Cumulative survival for juvenile sockeye salmon to Lower Granite Dam is shown in Figure 2, along with point estimates of survival by tag type and hatchery. Higher mortality rates resulted in an observed 10.1% difference in estimated survival between Oxbow and Sawtooth hatchery fish. This mortality occurred for the most part between release and our first detection site located just below the outlet from Little Redfish Lake. In reaches downstream from this first detection site, survival was consistent between Oxbow and Sawtooth radio-tagged groups, with most additional mortality occurring between release and the North Fork Salmon River.

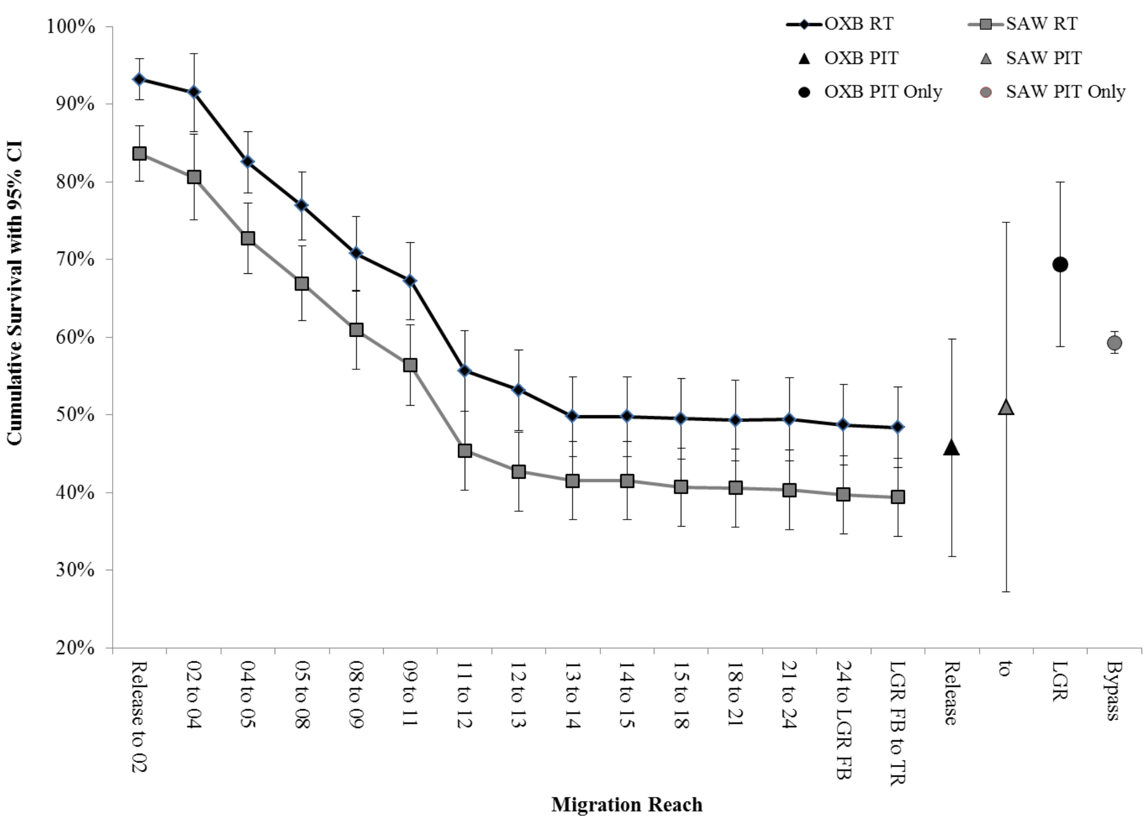

Figure 2. Line chart showing cumulative survival by reach from release to the tailrace of Lower Granite Dam (LGR FB to TR). To the right of the cumulative estimates, point estimates of survival from release to the bypass system of Lower Granite Dam are shown by hatchery and tag treatment. Juvenile sockeye salmon were surgically implanted with a radio transmitter and PIT tag (PIT) or injected with only a PIT tag (PIT only) and released into Redfish Lake Creek on May 10, 2012. Whisker bars represent 95% confidence intervals.

Travel Time

The PIT tags of 10,671 sockeye salmon from Sawtooth and Oxbow hatcheries were detected in the juvenile bypass system at Lower Granite Dam. Median travel times through this 750-km reach were within 0.4 d for all groups except the PIT-tagged group from Sawtooth Hatchery, which had the longest median travel time (10.7 d; Table 12). Passage distributions at Lower Granite Dam indicated that the PIT only and radio-tagged groups from Oxbow Hatchery traveled together through the study area, along with the radio-tagged group from Sawtooth Hatchery. Therefore, these three groups likely experienced similar conditions (Figure 3). The PIT-tagged only group from Sawtooth Hatchery migrated more slowly and reached Lower Granite a few days later (9-10 d for the 90th percentile).

In general, migration rates for radio-tagged sockeye salmon increased for both Oxbow and Sawtooth groups as they continued downstream until reaching the section of the Snake River influenced by the hydropower system (below the confluence of the Snake and Clearwater River; Figure 4). Delays in the lower portions of the study area were likely due to reduced water velocities associated with the hydropower system.

Table 12. Summary statistics of travel time to Lower Granite Dam for Snake River sockeye salmon released in Redfish Lake Creek, 2012. Travel time is shown by hatchery and tag type (radio-tagged fish were also PIT-tagged).

	Oxbow Hatchery		Sawtooth Hatchery	
Passage	PIT tag	Radio tag	PIT tag	Radio tag
percentile	n = 906	n = 177	n = 9,443	n = 145
5	6.2	6.3	6.7	6.6
10	6.9	6.5	7.3	6.8
20	7.0	6.7	7.6	7.0
30	7.0	6.8	8.5	7.2
40	7.1	7.0	9.6	7.3
50 (median)	7.2	7.1	10.7	7.5
60	7.6	7.2	11.6	7.6
70	8.0	7.4	12.6	7.9
80	8.5	8.0	15.6	8.4
90	9.9	8.4	19.0	9.3
95	11.0	9.9	22.0	10.7
min	5.1	6.1	5.6	6.4
mean	7.9	7.6	11.9	7.9
mode	7.0	7.1	8.6	7.3
maximum	27.1	24.0	61.6	17.2

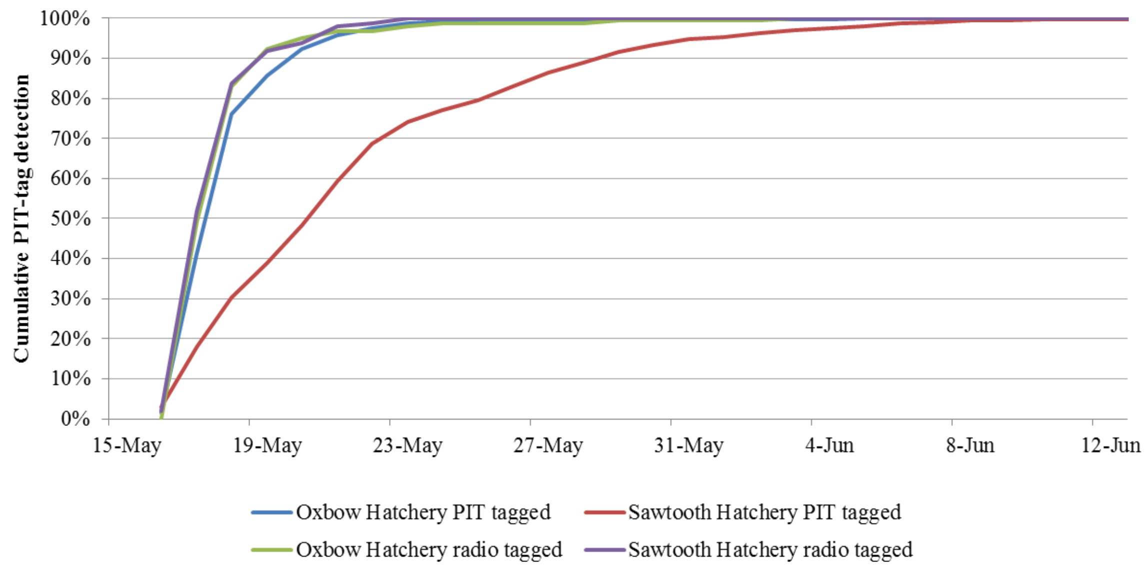

Figure 3. Cumulative PIT-tag detection at Lower Granite Dam of PIT- and radio-tagged hatchery sockeye salmon released into Redfish Lake Creek, 2012.

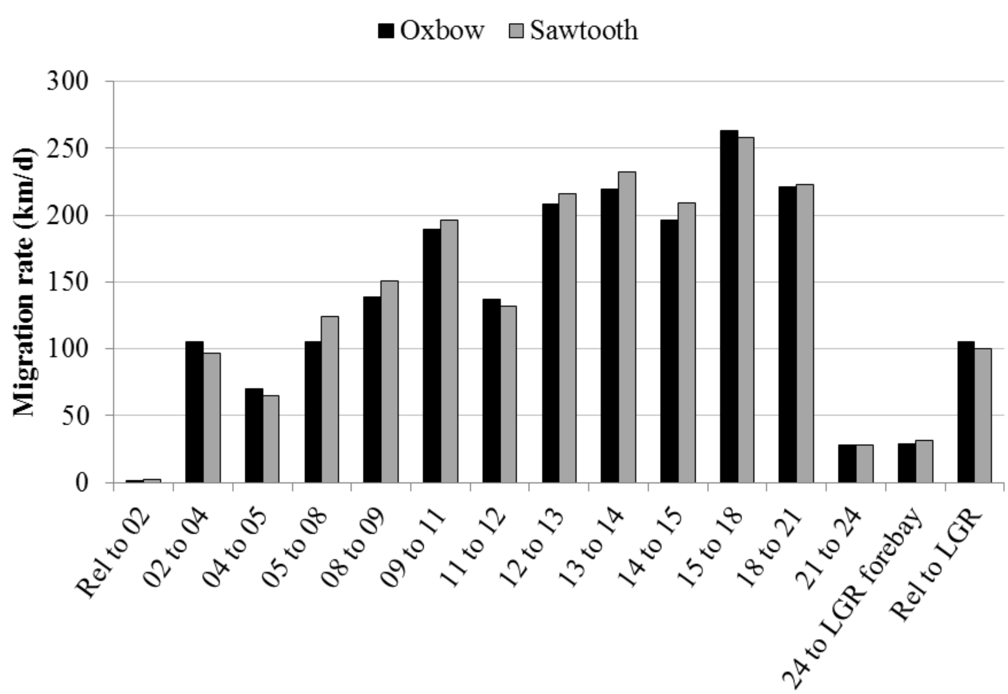

Figure 4. Migration rates of radio-tagged hatchery sockeye salmon within individual reaches between Redfish Lake Creek and the tailrace of Lower Granite Dam (LGR), 2012. Reach descriptions by site number are shown in Table 13 with travel time and migration rates for each.

For both groups of hatchery fish, partitioned reaches with the longest travel times and slowest migration rates were those located in the upper- and lowermost sections of the study area (Table 13). Both groups exhibited slower migration rates between release in Redfish Lake Creek and the confluence of the North Fork of the Salmon River. This section of river has a higher gradient, which does not support slower travel time based on estimates of water particle movement.

Table 13. Travel time and migration rate for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon within selected reaches between release into Redfish Lake Creek and the tailrace of Lower Granite Dam, 2012.

Reach	Reach description	Reach length (km)	Median travel time (d)		Migration rate (km/d)	
			Oxbow	Sawtooth	Oxbow	Sawtooth
Release to 2	Release to below Little Redfish Lake	3	1.0	1.4	1.5	2.5
2 to 4	Below Little Redfish Lake to below lower Stanley	9	0.1	0.1	105.6	97.0
4 to 5	Below lower Stanley to above E Fork Salmon R	51	0.7	0.8	69.9	64.7
5 to 8	Above E Fork Salmon R to below Pahsimeroi R	68	0.7	0.6	105.2	124.1
8 to 9	Below Pahsimeroi R to above Lemhi R	68	0.5	0.5	138.5	150.5
9 to 11	Above Lemhi R to above N Fork Salmon R	38	0.2	0.2	189.6	196.5
11 to 12	Above N Fork Salmon R to below N Fork Salmon R	22	0.2	0.2	136.7	131.8
12 to 13	Below N Fork Salmon R to above Middle Fork Salmon R	40	0.2	0.2	208.7	216.2
13 to 14	Above Middle Fork Salmon R to Vinegar Cr boat launch	139	0.6	0.6	219.1	232.3
14 to 15	Vinegar Cr boat launch to above Little Salmon R	38	0.2	0.2	196.6	209.0
15 to 18	Above Little Salmon R to Rice Cr Bridge	81	0.3	0.3	262.9	258.1
18 to 21	Rice Cr Bridge to above Clearwater R	145	0.7	0.7	221.5	223.2
21 to 24	Above Clearwater R to below Clearwater R	7	0.3	0.3	27.7	27.8
24 to LGR	Below Clearwater R to Lower Granite forebay	38	1.3	1.2	28.5	31.2
LGR to TR	Lower Granite Dam forebay to tailrace	2	0.0	0.0	93.4	89.1
Overall	Release to Lower Granite Dam tailrace	751	7.1	7.5	105.3	100.3

Predation

During fish releases, we observed multiple avian predation events on recently released juvenile sockeye. Two common mergansers were actively feeding 0.9 km downstream from the Idaho Fish and Game weir as fish were moving through the area. We also observed two radio-tagged fish preyed upon by two ospreys patrolling the same area of Redfish Lake Creek. Figure 5 shows last known locations by reach of radio-tagged fish that did not survive to Lower Granite Dam, representing potential zones of high predation for juvenile sockeye.

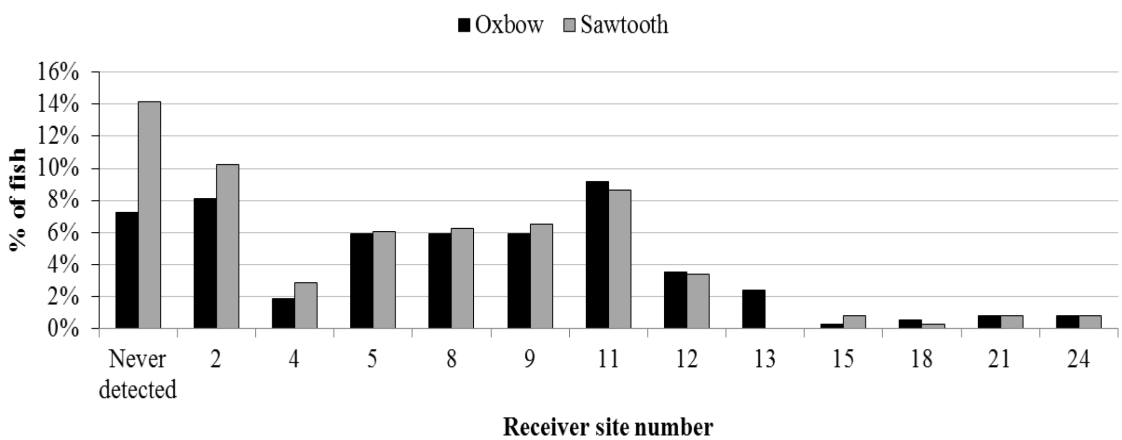

Figure 5. Last known telemetry locations of radio-tagged Oxbow and Sawtooth hatchery sockeye salmon between Redfish Lake Creek and the forebay of Lower Granite Dam, 2012. Detailed location information for fixed-site telemetry locations are in Table 1 and Figure 1.

During the last week of the study, we intensively mobile tracked from Redfish Lake to the East Fork of the Salmon River to determine locations of missing fish. We identified 48 tags in total, with 32 located within Little Redfish Lake (Figure 6) and Redfish Lake Creek (Figure 7).

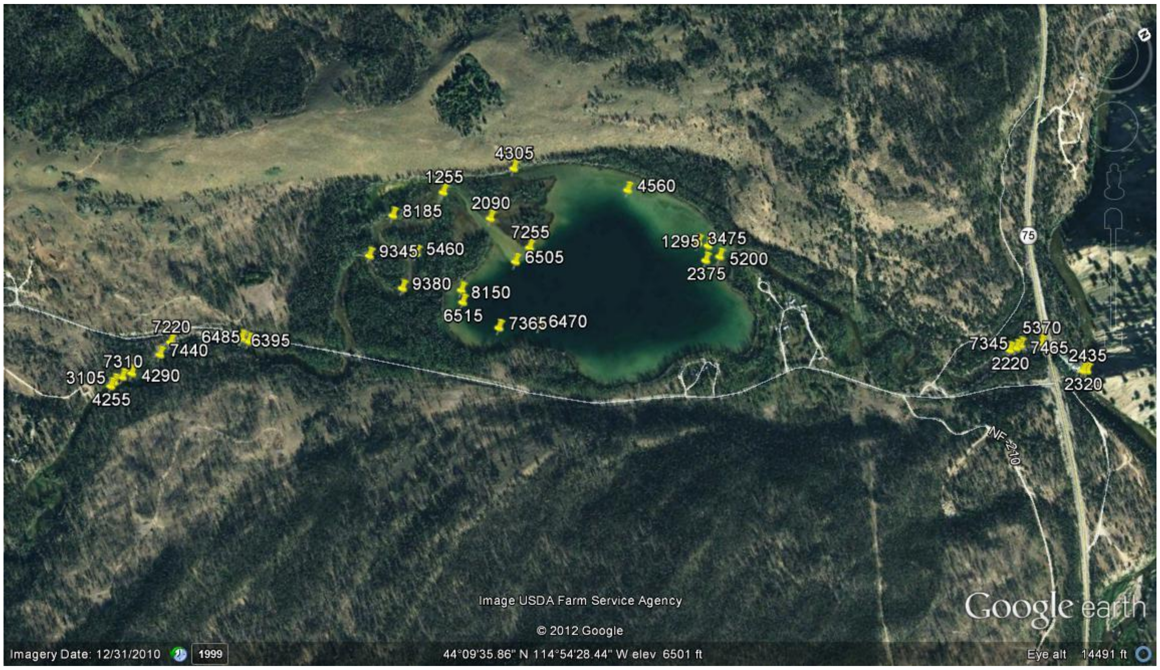

Figure 6. Last known telemetry locations of radio-tagged Oxbow and Sawtooth hatchery sockeye salmon between the Redfish Lake weir and the mouth of Redfish Lake Creek, 2012.

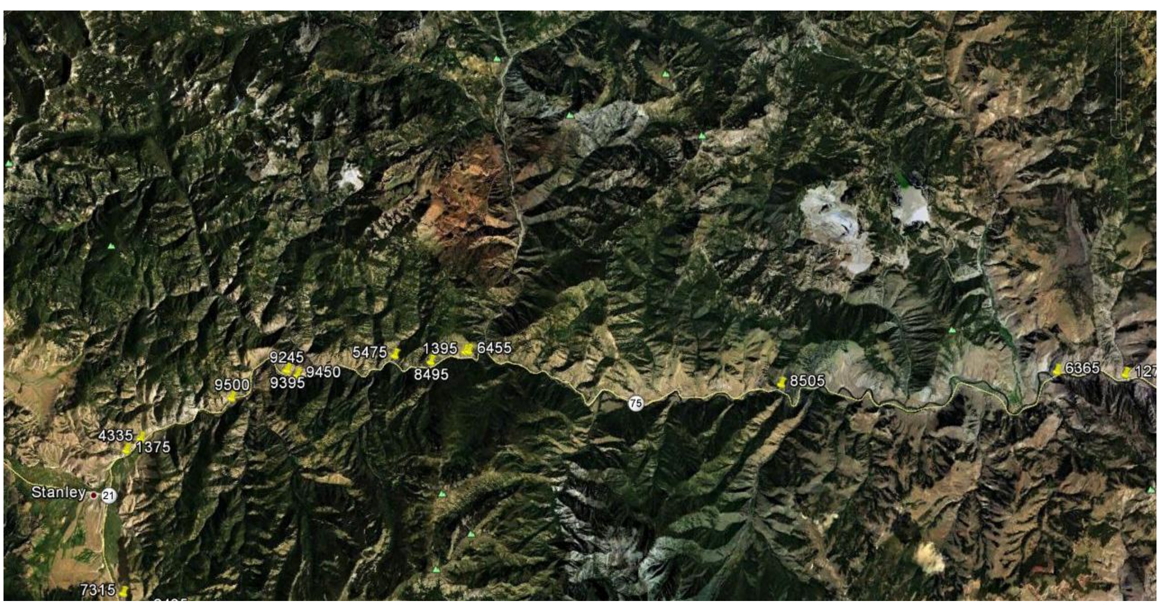

Figure 7. Last known telemetry locations of radio-tagged Oxbow and Sawtooth hatchery sockeye salmon between the mouth of Redfish Lake Creek and the East Fork of the Salmon River, 2012.

DISCUSSION

Estimated survival to Lower Granite Dam ranged 0.593-0.694 for PIT-tagged hatchery Snake River sockeye salmon released into Redfish Lake Creek in 2012. For PIT-tagged fish, survival estimates were 10.1% higher for Oxbow than for Sawtooth Hatchery groups, but the difference was not statistically significant ($P = 0.059$). For radio-tagged groups, estimated survival to the dam was also 10.1% higher for Oxbow than for Sawtooth Hatchery juvenile sockeye salmon; in this case, the difference was statistically significant ($P = 0.004$).

In 2012, average daily Snake River flow recorded by the USGS gauge at Anatone was 70,951 ft^3/second during May and 55,382 ft^3/second during June 2012. These flows were far lower than those in 2011, which averaged 102,258 ft^3/second during May and 123,382 ft^3/second during June. Among the last 50 years, 2011 had the 6th highest flow during May (50% higher than the 50-year May average) and 3rd highest flow during June (72% higher than the 50-year June average).

We hypothesized that these high May and June flows likely contributed to short travel times and high survival between release in Redfish Lake Creek and Lower Granite Dam in 2011. Griswold et al. (2012) reported similar relationships between increased survival and shorter travel times during years with higher flows for sockeye salmon smolts. In comparison, lower flows occurred throughout the Salmon and Snake River basins in 2012, and although 2012 travel times for juvenile sockeye were similar to those of 2011, survival estimates were lower.

In 2011, we observed post-tagging mortality rates of 23% prior to release for radio-tagged sockeye salmon from Sawtooth Hatchery. Over 95% of these mortalities were found floating on the surface. Gross necropsy showed full or overinflated swim bladders in these fish, which may have caused pressure or damage to internal organs. Handling and tagging mortality rates prior to release were minimal for radio-tagged hatchery fish in 2011, at 0.0% for Burley Creek fish and 0.2% for Oxbow fish. Overinflated swim bladders in Sawtooth Hatchery fish may have resulted from a combination of factors, including a short post-surgical recovery period, high levels of smoltification prior to tagging, and a relatively short acclimation period (15-24 h) from low to high elevations prior to surgical tagging.

Both the Oxbow and Sawtooth Hatchery groups were transported from relatively low elevations (30 and 793 m MSL, respectively) to an elevation of 2,012 m MSL at the tagging location (Sawtooth sockeye salmon had been reared at Eagle Creek Hatchery prior to radio tagging). Sawtooth Hatchery fish were radio tagged within 15-48 h after this transport and elevation change. We concluded that tagging effects observed in Sawtooth Hatchery groups were likely exacerbated by short post-surgical recovery times, as well as the same factors that contributed to their overinflated swim bladders.

To mitigate for these tagging effects in 2012, we ordered radio transmitters with a duty cycle of 1 h on and 30 d off before coming back on for the duration of their life cycle. This allowed us to tag Sawtooth Hatchery fish at Eagle Hatchery 30 days prior to release and to hold them at the hatchery for adequate recovery time from the surgical process. In 2012, we observed only three mortalities during the recovery period and no mortalities after transport to Redfish Lake Creek. We were confident that the new tagging protocol successfully resolved the issues we observed during the first year of this study.

For radio-tagged groups from both Oxbow and Sawtooth Hatchery, estimated survival from release to Lower Granite Dam was lower than that of the PIT-tagged groups from these hatcheries. However, each of these estimates fell within their respective 95% confidence bounds. Differences in survival dropped significantly by the time fish arrived at Little Goose Dam. In the absence of any significant tagging effects, such as those seen in 2011, we concluded that survival data from radio-tagged Oxbow sockeye salmon obtained during 2012 is likely representative of the production population at Oxbow Hatchery.

In 2012, we moved Sawtooth Hatchery radio-tagged sockeye to Eagle Hatchery earlier and held them there longer. Their resulting larger size at release likely contributed to faster rates of migration due to higher use of spillway passage and lower rates of detection due to less utilization of the juvenile bypass systems. As a result of these differences, we could not conclude that radio-tagged fish behaved similarly to PIT-tagged fish groups from Sawtooth Hatchery. In 2013, we intend to repeat this study while maintaining the Sawtooth population at a smaller, more representative size.

In 2013, we propose to continue radio tagging the juvenile sockeye salmon at Eagle Fish Hatchery 30 d prior to release to provide a sufficient post-surgical recovery period. This protocol clearly reduced the deleterious effects of both post-surgical recovery and acclimation to elevation change. In addition, fish will be less smolted at the time of surgical tagging. We also plan to install additional telemetry receivers in 2013 at sites that we were not able to use in 2012 due to permitting issues. This will allow us to fill in additional reach information that we were unable to collect in 2012.

Based on the differences in estimated survival between the Oxbow and Sawtooth release groups in 2012, IDFG plans to change the release time and potentially the release location of Sawtooth Hatchery juvenile sockeye groups in 2013. Initial suggestions include releasing Sawtooth groups closer to dusk to avoid avian predation. Data collected in 2013 will help to validate this mitigation effort and help provide valuable information for future releases planned for Springfield Hatchery juvenile sockeye salmon.

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APPENDIX A

Evaluation of Study Assumptions

We used the CJS single-release model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival of radio-tagged and/or PIT-tagged juvenile Snake River sockeye salmon between the Sawtooth Valley in the upper Salmon River basin and Lower Granite Dam. Evaluation of critical model and biological assumptions of the study are detailed below.

A1. All tagged fish have similar probabilities of detection at a detection location.

For radio-tagged fish, the detection probability at survival arrays ranged from 0.397 to 1.000 and averaged 0.884 overall (see Table 10). Detection probabilities were in excess of 90% at 11 of the 14 radio telemetry monitoring transects upstream from Lower Granite Dam. These high detection rates resulted in few radio-tagged fish being detected downstream from the dam without first having been detected at most survival arrays. These very high detection rates imply fairly complete spatial coverage by antennae arrays. With such high detection probabilities for all fish, there was an extremely low likelihood of any disparity between detection probabilities of individual fish

For PIT-tagged fish, detection probabilities can vary for multiple reasons. The PIT-tagged fish in this study were only detected in bypass systems at hydroelectric dams on the Snake and Columbia Rivers. Therefore, detection probability could vary with environmental change (e.g., river flow), among individual fish (e.g., fork length), or among differing project operations (e.g., percent of water spilled), as each of these factors may affect the probability of a fish entering the bypass system at a given dam. The majority of sockeye salmon in this study were detected at Lower Granite Dam within roughly one week of release (Figure 2). This relatively high proportion of detections lessened the variability in our estimates of PIT-tag detection probability.

A2. Event probabilities for each individual fish are independent from those for all other fish and conditionally independent from all other probabilities.

Violation of the assumption of independent detection probability can occur in situations where fish do not behave independently, particularly when fish behave differently after encountering a detection event. However, the radio-tagged fish in our study were not affected by the presence of detection antennae, and thus were unlikely to have reacted to its presence. For this reason, assumption A2 was unlikely to have been violated for our radio-tagged individuals. In addition, the very high rates of detection on nearly every telemetry array provided de facto validation of the assumption of independent probability of detection. Clearly, if nearly all radio-tagged fish were detected at any given array, then each fish had a detection probability that was very high and similar to that of others in the cohort (near 100%).

However, if the release cohort exhibited natural schooling behavior, assumption A2 could have been violated. This violation would not likely affect survival estimates, but could result in variance estimates that are biased smaller. For PIT-tagged fish, schooling behavior could potentially cause a bias, since this behavior affect detection rates by crowding fish into a relatively small area (e.g., a gatewell or separator tank). However, it is likely that their decision to enter the powerhouse and the gatewell was primarily based on flow and structural cues.

For PIT-tagged fish, as stated previously, assumption A2 could potentially have been violated, since the PIT-tag detection systems at dams cannot detect fish that do enter the juvenile collection and bypass system. If passage through a particular route at a dam differentially affected survival or route of passage at subsequent downstream dams, then those probability estimates and their variances would be biased; however, in this report we were concerned primarily with passage through only Lower Granite Dam. Since Lower Granite was the first dam encountered by our study fish, behavioral changes associated with previous passage were not at issue here.

A3. Individuals tagged for the study are a representative sample of the population of interest.

Dates of tagging and summary statistics of length and weight are presented in Tables 2-3. For sockeye salmon from Oxbow and Sawtooth Fish Hatcheries, the fork-length of PIT-tag groups was measured one month before that of radio-tagged groups. Sawtooth Hatchery fish were transferred to Eagle Hatchery on 23 November 2011 to accelerate their growth so that they would be large enough to radio tag. For Sawtooth Hatchery fish, mean fork length of PIT-tagged groups was significantly smaller than that of radio-tagged groups because fork lengths for these groups were measured at different times. Therefore, we compared the shape of fork length distributions rather than comparing average fork length by tag type as a better indicator of representativeness. The shapes of the distributions by hatchery were similar except that distributions for PIT-tagged groups were narrower, consistent with an expected broadening of distribution for the radio-tagged group based on growth (Richmond and McCutcheon 2012).

A4. The tag and/or tagging method do not significantly affect the subsequent behavior or survival of the marked individual.

Assumption A4 was not tested for validation for the PIT-tagged sockeye salmon in this study. Assumption A4 was tested for radio-tagged sockeye salmon by comparing survival and travel time of these fish to that of PIT-tagged fish from the same group. These analyses are presented in the results section. In general, survival from release to Lower Granite Dam for radio-tagged groups was lower than that of PIT-tagged sockeye salmon groups from both Oxbow and Sawtooth Hatchery.

A5. The radio transmitters functioned properly and for the predetermined period.

All transmitters were checked upon receipt from the manufacturer, prior to implantation into fish and prior to release, to ensure that the transmitter was functioning properly. Of 900 tags allocated for this study, 7 (0.8%) could not be activated and were therefore not used. A total of 800 tags were implanted in Snake River sockeye salmon; 33 tags (4.1%) did not restart after the 30-d shutdown to save battery life during the surgical recovery period prior to the release.

A total of 86 radio transmitters were tested for tag life throughout the study by allowing them to run in river water and checking them daily to determine how long they functioned. Tag life ranged 24-37 d and averaged 31 d (Appendix Table A1). Travel time from release to Lower Granite Dam for radio-tagged sockeye salmon ranged 6.1-24.0 d (Table 13) with a median of 7.3 d. Therefore, with the minimum tag life of 24 d, and maximum travel time through the study area of 24.0 d, it was quite unlikely that any radio-tagged fish migrated through the study area after the battery powering the transmitters had expired. Maximum travel times were longer for PIT-tagged than for radio-tagged fish groups; however, 95% of the PIT-tagged hatchery Snake River sockeye salmon released in Redfish Lake Creek on 10 May 2012 migrated to Lower Granite Dam in less than 23 d.

A total of 191 (25.4% of the 753 fish released) radio-tagged sockeye salmon were detected on at least one downstream PIT-tag monitor. Radiotelemetry detection histories for these 191 fish (Appendix Table A2) were examined for tag failure or loss within the study area. Of these fish, 11 (5.8%) had radio transmitters that were never detected, either because they malfunctioned or were lost (expelled) while fish were in the study area. These fish could also have been missed due to degraded signal transmission. Since tag-life testing did not indicate any premature tag failure, the most likely explanation is that some tag expulsion occurred during the study.

Appendix Table A1. Tag-life testing results for radio transmitters used to characterize migration and estimate survival of Snake River sockeye salmon, 2012.

Tags (n)	Tags (%)	Battery life (d)
2	2.3	24
2	2.3	25
2	2.3	26
2	2.3	27
6	7.0	28
5	5.8	29
17	19.8	30
7	8.1	31
12	14.0	32
20	23.3	33
5	5.8	34
4	4.7	35
1	1.2	36
1	1.2	37
0	0.0	38
0	0.0	39

Appendix Table A2. Radio tag code, PIT tag code, detection history, and travel time from release to first PIT-tag detection for Snake River sockeye salmon released in the Sawtooth Valley of the upper Salmon River basin in 2012. Shaded records indicate radio tag failure or loss.

Radio tag code	PIT tag code	Detection history	Travel time to first PIT-tag detection (d)
1225B	3D9.1C2DDAD06B	1110111111011101111111001111100111111111	17.1
1235B	3D9.1C2DDA7109	1111111111011101111101110011101001111111	7.1
1310B	3D9.1C2DDABD86	1110111111011101111101100000000000111111	7.1
1355B	3D9.1C2DDAB9E1	1110111100000000000000000000000000000000	7.2
1380B	3D9.1C2DD9E081	1010111111011100111101110000010001110 11	7.1
1410B	3D9.1C2DDA338A	1111111111011101111111111000000000111111	6.2
1450B	3D9.1C2DDA89DF	1111111111011100111111111001110000111111	15.5
1475B	3D9.1C2DDA7894	1101111111011101111111111001010000111111	14.2
1510B	3D9.1C2DDA5F93	1101111111011101111111100111001100111111	11.0
1545B	3D9.1C2DDA253A	1110111111011101111110100111100000111111	14.7
1555B	3D9.1C2DDAD80F	0010111111001101111111111001110111111111	16.7
1560B	3D9.1C2DDA96DA	1111111111111101111111111001000000111111	6.6
2100B	3D9.1C2DDAABBC	1101111111011101111111111001110000111111	7.2
2110B	3D9.1C2DDAAEE4	1111111111001101111111101110000000000000	8.5

Appendix Table A2. Continued.

Radio tag code	PIT tag code	Detection history	Travel time to first PIT-tag detection (d)
2135B	3D9.1C2DDAEF11	100011111101110111111110111100000111101	7.0
2140B	3D9.1C2DDAEAD0	100011111101110111110010000000000111111	7.2
2235B	3D9.1C2DDA2556	110011111111110111111111001110100111111	10.0
2280B	3D9.1C2DDAA411	110011111101110111111111000001000011111 1	11.4
2285B	3D9.1C2DDA8671	110011111111110111111111111110000111111	13.3
2305B	3D9.1C2DDAB78D	110011111111110111111111000110001111101	11.0
2325B	3D9.1C2DD9D44B	110011111101110111111010111111000111111	9.8
2355B	3D9.1C2DDA8427	000011111111110111110110001001100111011	10.5
2365B	3D9.1C2DDA90A1	110011111101110111110110001100000111111	7.0
2385B	3D9.1C2DDA180D	110011111101110111110110001110000111011	12.4
2405B	3D9.1C2DDB5433	110111111101110011111111000000011111101	10.4
2410B	3D9.1C2DDABD8B	110011111101110111111111001100010111111	15.3
2420B	3D9.1C2DDAA337	110011111101110111111110100010000111101	9.9
2425B	3D9.1C2DD9FD72	110011111111111111110110111010000111101	21.1
2440B	3D9.1C2DDA322B	110011111101110111111111001110001101101	14.9
2455B	3D9.1C2DDA601E	110011111111110111111111000111001111101	20.6
2470B	3D9.1C2DDA81AB	110011111111110111111101100000000111111	10.4
2480B	3D9.1C2DDAA49B	110111111111110111110110011110000111111	9.3
2515B	3D9.1C2DDABFC5	110011111101110111110111001110000111111	8.6
2520B	3D9.1C2DDACD46	110011111101110111111111001100010111111	21.6
3085B	3D9.1C2DDA905E	110011111101110111111110000111000011101 1	10.6
3140B	3D9.1C2DDAB91A	110011111101110111111110010111000011111 1	12.0
3150B	3D9.1C2DD9FD31	110011111101110111111110011000100011111 1	7.1
3180B	3D9.1C2DDADAC4	110111111101110111111110111111111111111	16.5
3195B	3D9.1C2DDAC0AA	110111111111110111110110111010000111111	7.4
3200B	3D9.1C2DDA81D2	110011111111110111110100111110010111111	9.9
3205B	3D9.1C2DDAC551	110011111111110111111100011110000111111	7.0
3210B	3D9.1C2DDABB93	110111111101110111111111111100000101111	13.5
3280B	3D9.1C2DDA9F09	110011111101110111111111001110000111011	10.5
3295B	3D9.1C2DDAA90A	110011111101110111111100000000000111111	7.0
3330B	3D9.1C2DDAA154	110011111101110111110100111110000111101	9.4
3395B	3D9.1C2DDA8C0B	110011111101110111111110001110000111101	23.5
3430B	3D9.1C2DD9E171	110011111101110111110011001110000111011	10.9
3440B	3D9.1C2DD9FAF1	100011111101110111111111111000000111011	7.3
3455B	3D9.1C2DDAAA86	110011111101110111111100001111100111111	14.2
3470B	3D9.1C2DDA08AA	000000000000000000000000000000000000000	13.6

Appendix Table A2. Continued.

Radio tag code	PIT tag code	Detection history	Travel time to first PIT-tag detection (d)
3490B	3D9.1C2DDA6439	110011111111110111111110001110010111111	8.5
3495B	3D9.1C2DDA3423	11001111101110111110100001110000111011	7.6
3500B	3D9.1C2DDAAC6F	11001111101110111111110000011000111011	8.4
3555B	3D9.1C2DDAB1A8	11001111100110011110010000001000111011	6.4
3565B	3D9.1C2DDABD81	11001111101110111111111001110000111010	7.0
4080B	3D9.1C2DD9FACC	100011111111110111111111001110000111111	11.0
4100B	3D9.1C2DDAA5A0	110011111111110111111111000000000000000	8.0
4120B	3D9.1C2DDA8866	110111111111110111110111000000000111011	7.4
4195B	3D9.1C2DDAABE2	11001111101111111110111000010000111111	10.4
4245B	3D9.1C2DDABD4C	11001111100110111111110100011100111111	11.0
4285B	3D9.1C2DDA249B	11001111101110111111111001100000111011	13.8
4320B	3D9.1C2DDAB73E	11001111101110111111110110000000111111	7.3
4340B	3D9.1C2DDAB141	11001111101110111111010001110000111111	7.0
4360B	3D9.1C2DDA6D11	110011111111110111110111111110000101111	7.6
4380B	3D9.1C2DD9EEE4	11001111101110111110100000000000111101	10.4
4390B	3D9.1C2DDAD423	110011111011101111111111000000000111111	7.0
4395B	3D9.1C2DDA68DF	11001111101110111110110001010100111111	9.2
4420B	3D9.1C2DDAA731	110000111101110111110110100000000111011	7.4
4435B	3D9.1C2DDAD579	110011111001101111111110000010000111101	10.4
4445B	3D9.1C2DDA93F4	110011111111110111111110001110010111111	23.4
4460B	3D9.1C2DDA7566	110011111001100111111110000011100111111	23.0
4470B	3D9.1C2DDA624A	110111111011100111111111000000000111011	9.4
4490B	3D9.1C2DDAC558	110011111011101111111100001110000111111	13.2
4495B	3D9.1C2DDA3F28	110011111111110111110011001011000111111	10.5
4515B	3D9.1C2DD9D376	110011111011101111111111101111100111011	11.1
4555B	3D9.1C2DDA2619	110011111111110111110111001000001110000	7.4
4565B	3D9.1C2DDAA129	11001111101110111110011001100000111011	25.8
5070B	3D9.1C2DD9FB18	11011111101110111110000001011100111101	11.4
5085B	3D9.1C2DDACBD3	110111111111111111111110110001000111111	10.4
5110B	3D9.1C2DDA756A	110111111111110111111110110010000111111	9.1
5150B	3D9.1C2DDA76BD	110011111111110111111110001110010111111	8.6
5160B	3D9.1C2DDA7CEC	000000000000000000000000000000000000000	26.4
5165B	3D9.1C2DDAD88B	110011111011101111101111111110000111101	9.4
5175B	3D9.1C2DDA90D9	110000000000000000000000000000000000000	12.9
5205B	3D9.1C2DD9FB9A	110111111100111111111101011000000001101	22.4
5270B	3D9.1C2DDAB9E8	11001111100110111111111001011000111011	15.9
5275B	3D9.1C2DDAD398	110111111111110111110111001000000111111	8.4

Appendix Table A2. Continued.

Radio tag code	PIT tag code	Detection history	Travel time to first PIT-tag detection (d)
5325B	3D9.1C2DDA9401	110011111011101111111001100010001111101	8.2
5335B	3D9.1C2DDA94A7	110011111111110111111110111010000111101	13.7
5350B	3D9.1C2DDAD651	110011111111110111111100001110000111111	8.4
5355B	3D9.1C2DD9DF99	110011111111110111111110001110000111111	8.5
5390B	3D9.1C2DDA6D13	110011111011101111111100001110000111101	8.2
5410B	3D9.1C2DDA81DB	110011111111110111110011111101100111011	7.0
5430B	3D9.1C2DDAB7DD	110011111011101111101100000000000111001	6.2
5450B	3D9.1C2DDAECCF	110011111011101111111100001110000111011	8.1
5490B	3D9.1C2DDA5CE0	110111111011100111111101111000000111011	8.3
5555B	3D9.1C2DD9E12B	110011111111110111110100111111100111011	9.0
5560B	3D9.1C2DDACEB5	110011111011101111111000001110000111001	8.2
5565B	3D9.1C2DDA267E	110111111011101111101111111010010111101	8.2
6075B	3D9.1C2DDA787F	110111111111110111110100001110000111111	12.9
6100B	3D9.1C2DDADFDB	110011111011101111111111000010000111011	6.4
6220B	3D9.1C2DDADFCB	110111111011101111111110111110010111101	13.9
6225B	3D9.1C2DDA868A	110111111111110111111110111010100111111	16.8
6230B	3D9.1C2DDAA487	100111111011101111100001111100000111101	9.1
6260B	3D9.1C2DDB546C	110111111011101111111110001110000111111	10.4
6265B	3D9.1C2DDAB64D	100111111111110111111100001110000111111	9.1
6285B	3D9.1C2DDAEFA9	100111111011101111111100001111100110001	7.0
6355B	3D9.1C2DDA7C3B	000111111011101111111111001110000111111	9.0
6360B	3D9.1C2DDAB1BB	110011111011101111101000010000000111111	7.6
6375B	3D9.1C2DD9E178	110011111011101111111100001110000111111	9.0
6380B	3D9.1C2DDADA39	110111111011101111111100101100000111101	11.4
6385B	3D9.1C2DDA730C	110011111011101111101001111100000111101	11.8
6435B	3D9.1C2DDA68B8	111111111011101111101000010111110111101	10.3
6485B	3D9.1C2DDA07EB	000000000000000000000000000000000000000	8.6
6550B	3D9.1C2DDAD2E8	110111111100110111111100111010000111101	10.0
7070B	3D9.1C2DDAA1C6	111111111111110111111110101111010111111	8.0
7075B	3D9.1C2DDAA001	000000000000000000000000000000000000000	17.4
7095B	3D9.1C2DDAA730	110111111011101111110110011110001111111	10.0
7110B	3D9.1C2DD9E14C	111111111011101111110110010110001111111	7.9
7115B	3D9.1C2DDAB917	110011111011101111111111110010000111111	8.6
7125B	3D9.1C2DDAB787	110111111111110111111111101100000111111	8.4
7155B	3D9.1C2DD9E065	111111111011101111111110001111100111111	7.0
7160B	3D9.1C2DD9FCDB	110011111011101111111111001100000111111	7.5

Appendix Table A2. Continued.

Radio tag code	PIT tag code	Detection history	Travel time to first PIT-tag detection (d)
7175B	3D9.1C2DD9D46E	111111111111111011111111100001000011100‌1	7.1
7180B	3D9.1C2DDB4640	110011111011101111111000011111001111111	9.4
7185B	3D9.1C2DDA996F	111111111100110111111100111011000111111	9.1
7200B	3D9.1C2DDA6ABE	111111111111111011111111100111000011000‌1	9.9
7230B	3D9.1C2DDA26F8	110011111011101111111110010111001111111	10.0
7235B	3D9.1C2DDAA398	110011111111110011111110001111100111111	8.0
7240B	3D9.1C2DD9E0DC	110111111111110111111100001011110111111	16.2
7245B	3D9.1C2DDAF271	110011111011101111101100010100001110‌11	8.1
7270B	3D9.1C2DD9E02E	110011111011101111111001111100001111‌11	11.0
7295B	3D9.1C2DDB6280	110011111001101111101110011100001111‌11	9.6
7300B	3D9.1C2DDA6AD1	111111111011101111100111110100001111‌11	10.6
7305B	3D9.1C2DDA67EF	111111111011101111111111110100001111‌11	7.1
7320B	3D9.1C2DDA4AA7	110111101101110111110011110000000111111	7.6
7335B	3D9.1C2DD9D372	111111111011101111111000011100101110‌11	15.1
7350B	3D9.1C2DDA7023	110011111011101111111000011100001111‌11	8.0
7370B	3D9.1C2DDA3358	110011111011101111111110011111000011‌11	14.8
7385B	3D9.1C2DDA7BD1	000011111011101111111110010111101111‌11	12.0
7445B	3D9.1C2DDAE761	110011111111110111110111111111111111‌11	29.3
7450B	3D9.1C2DDA3295	110011111011101111111000000100001111‌11	10.0
7460B	3D9.1C2DD9E0FC	111111111011101111111110001110011111101	15.7
7495B	3D9.1C2DDA3385	110011111011101111100100010100101111‌11	14.9
7500B	3D9.1C2DDA7551	111111111011101111100100011100001111‌11	13.2
7505B	3D9.1C2DDB2B4F	110011111011101111111000000010001111‌11	7.0
7515B	3D9.1C2DDB2B54	110111111011101111111110000000100111011	7.0
7540B	3D9.1C2DDA9EFD	110011111011101111111100011111001111‌11	18.1
7550B	3D9.1C2DDA6054	110111111001101111100100011011001111‌11	7.4
7560B	3D9.1C2DDB4619	000000000000000000000000000000000000000	12.6
8070B	3D9.1C2DDA6420	110011111111110111111111101110000111111	11.4
8090B	3D9.1C2DDA09C9	110011111011101111100101011100001111‌00	24.4
8110B	3D9.1C2DDAC69F	110011111011101111110000010000001111‌11	11.2
8115B	3D9.1C2DDA940C	110011111111110111111111001110000111111	9.8
8140B	3D9.1C2DDAAA40	110011111111110111110110111111100111111	24.0
8160B	3D9.1C2DDA97BD	110011111111110111111110111100001101111	8.2
8185B	3D9.1C2DDA9818	000000000000000000000000000000000000000	12.0
8205B	3D9.1C2DDA8593	110011111111110111110111111110001111111	10.0
8210B	3D9.1C2DDA82C7	110011111011101111101100010101001111‌11	10.1

Appendix Table A2. Continued.

Radio tag code	PIT tag code	Detection history	Travel time to first PIT-tag detection (d)
8215B	3D9.1C2DDA99F4	11001110111111011111100000111110011111	8.3
8235B	3D9.1C2DDA81E4	11001111110111011111010000110000011111	7.4
8240B	3D9.1C2DDA85C4	11001111110111011111111110111110011111	16.4
8250B	3D9.1C2DDA9989	01011111110111011111111010111110011110 0	7.1
8260B	3D9.1C2DDA2520	11001111110111011111111011111000011111	8.5
8275B	3D9.1C2DDAD0E4	11011111110111001111001110101000011111	24.4
8295B	3D9.1C2DDA5E9D	11011111111111111111001100000110011111	11.3
8310B	3D9.1C2DDAA8CC	00001111111111011111111000101010011111	9.0
8320B	3D9.1C2DDA8437	11001111110011011111010011111000011111	10.9
8365B	3D9.1C2DDAC086	11001111111111011111001100111000011111	7.5
8370B	3D9.1C2DD9D514	11011111111111011111011100101000011101 1	17.2
8380B	3D9.1C2DDB1CFE	11001111111111011111011100000000011111	7.4
8410B	3D9.1C2DDA9170	11011111110111011111111000000000011111	6.5
8435B	3D9.1C2DDA8395	11001111111111011111010010001000110110 1	14.9
8450B	3D9.1C2DDAAF16	11001111111111011111010000111100111111 1	19.5
8460B	3D9.1C2DD9E10D	11001111111111011111011000111000011110 1	14.2
8470B	3D9.1C2DDB38A3	11001111110111011111001000000000011111	7.4
8540B	3D9.1C2DDA2680	11001111111111011111010000111100011111 1	26.2
8555B	3D9.1C2DDAE6B9	11011111110111011111011111111000000000 0	8.1
9090B	3D9.1C2DDA4A04	11011111111111011111111100110000011111 1	12.3
9140B	3D9.1C2DDA2463	11011111111111011111111011110001110111 1	8.4
9165B	3D9.1C2DDA74FF	11011111110011011111111001111100001111 1	10.4
9175B	3D9.1C2DDAC94F	11011111110011011111000000001110011111 1	7.4
9190B	3D9.1C2DDAD44C	11011111110011001111110010001111111110 0	13.4
9215B	3D9.1C2DDA1803	11001111111111011111010011100000011110 1	12.4
9325B	3D9.1C2DDA7943	11011111110111001111101000111110011110 0	7.6
9330B	3D9.1C2DDA0A7B	11001111110111011111111000111000011110 1	6.7
9360B	3D9.1C2DDA7AF8	01001111110111011111000000111000011110 1	35.7
9365B	3D9.1C2DDA973E	11011111111111011111001111111001011111 1	10.9
9400B	3D9.1C2DDAB789	11001111110011011111001000110000011001 1	9.8
9465B	3D9.1C2DD9E0D7	11001111110011001101111110010111001111 1	9.0
9555B	3D9.1C2DDAD5CA	10001111110111011111001111111000011101 1	11.4

APPENDIX B

Telemetry Data Processing and Reduction

Data Collection and Storage

Data from radio telemetry studies are stored in the Juvenile Salmon Radio Telemetry project, an interactive database maintained by staff of the Fish Ecology Division at the NOAA Fisheries Northwest Fisheries Science Center. This project tracks migration of juvenile salmon and steelhead within the Columbia River Basin using a series of radio receivers to record signals emitted from radio transmitters ("tags") implanted into the fish. The database includes tagging data, observations of tagged fish and the locations and configurations of radio receivers and antennas.

The majority of data supplied to the database are observations of tagged fish recorded at the various radio receivers, which the receivers store in hexadecimal format. The files are saved to a computer and placed on a FTP server automatically once per day for downloading into the database.

In addition, data in the form tagging files were collected. These files contain the attributes of each fish tagged, along with the channel and code of the transmitter used and the date, time, and location of release after tagging.

Data are consolidated into blocks in a summary form that lists each fish and the receiver on which it was detected. This summary includes the specific time of the first and last detection and the total number of detections in each block, with individual blocks defined as sequential detections having no more than a 5 min gap between detections. These summarized data were used for analyses.

The processes in this database fall into three main categories or stages in the flow of data from input to output; loading, validation, and summarization. These are explained below and summarized in Appendix Figure B1.

The loading process consists of copying data files from their initial locations to the database server, converting the files from their original format into a format readable by SQL, and having SQL read the files and stores the data in preliminary tables.

Data Validation

During the validation process, the records stored in the preliminary tables are analyzed. We determine the study year, site identifier, antenna identifier, and tag identifier for each record, flagging them as invalid if one or more of these identifiers cannot be determined. Records are flagged by storing brief comments in the edit notes field. Values of edit notes associated with each record are as follows:

Null: denotes a valid observation of a tag

Not Tagged: denotes an observation of a channel code combination that was not in use at the time. Such values are likely due to radio frequency noise being picked up at an antenna.

Noise Record: denotes an observation where the code is equal to 995, 997, or 999. These are not valid records, and relate to radio frequency noise being picked up at the antenna.

Beacon Record: hits recorded on channel = 5, code = 575, which indicate a beacon being used to ensure proper functioning of the receivers. This combination does not indicate the presence of a tagged fish.

Invalid Record Date: denotes an observation whose date/time is invalid (occurring before we started the database, i.e., prior to 1 January 2004, or sometime in the future). Due to improvements in the data loading process, such records are unlikely to arise.

Invalid Site: denotes an observation attributed to an invalid (nonexistent) site. These are typically caused by typographical errors in naming hex files at the receiver end. They should not be present in the database, since they should be filtered out during the data loading process.

Invalid Antenna: Denotes an observation attributed to an invalid (nonexistent) antenna. These are most likely due to electronic noise within the receiver.

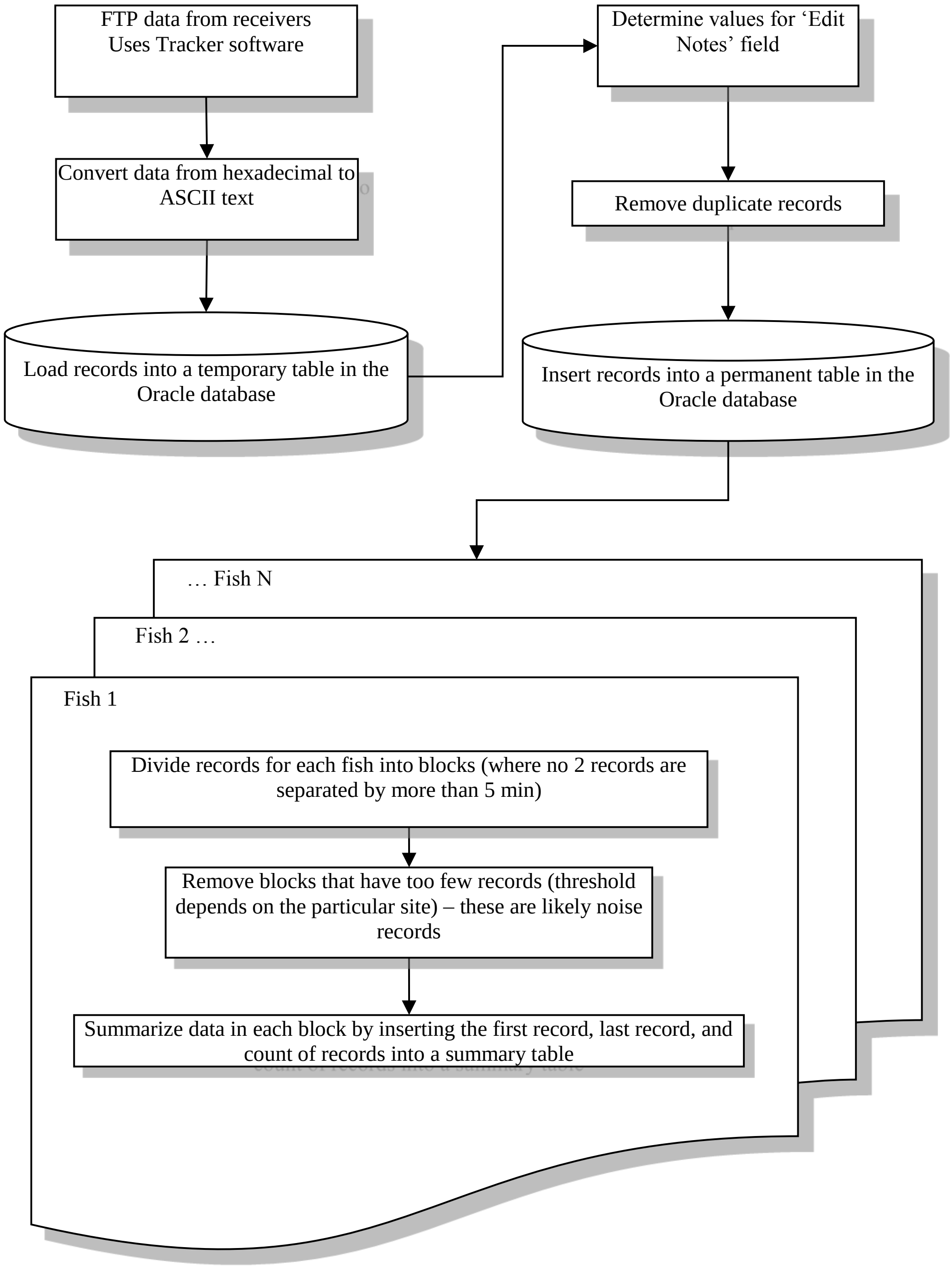
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: these records are produced by radio frequency noise.

Gt end time: Assigned to records occurring after the end time on a tag (tags run for 10 d once activated). Note: these records are produced by radio frequency noise.

In addition, duplicate records (records for which the channel, code, site, antenna, date and time are the same as those of another record) are considered invalid. Finally, the records are copied from the preliminary tables into the appropriate storage table based on study year. The database can accommodate multiple years with differing sites and antenna configurations. Once a record's study year has been determined, its study year, site, and antenna are used to match it to a record in the sites table.

Generation of Summary Tables

The summary table summarizes the first detection, last detection, and count of detections for blocks of records within a site for a single fish where no two consecutive records are separated by more than a specified number of minutes (currently using 5 min).



Appendix Figure B1. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival for juvenile sockeye salmon, 2012.