Characterizing Migration and Survival between the upper Salmon River Basin and Lower Granite Dam for Juvenile Snake River Sockeye Salmon, 2013

Gordon A. Axel, Mike Peterson,[†] Benjamin P. Sandford, Brian J. Burke,
Kinsey E. Frick, Jesse J. Lamb, and Matthew G. Nesbit

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Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

[†]Idaho Department of Fish and Game
1414 E. Locust Lane
Nampa, Idaho 83686

to

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EXECUTIVE SUMMARY

In 2013, 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. In addition, we evaluated release scenarios to determine if night releases would improve survival for the smaller Sawtooth Hatchery fish.

For groups of PIT-tagged fish released to Redfish Lake Creek in 2013, estimated survival to Lower Granite Dam ranged 51.0-59.2%; mean estimated survival was 8.2% higher for Sawtooth Hatchery groups released at night vs. those released during the day, and the difference was significant ($P < 0.001$). For radio-tagged groups, respective estimates of survival were 41.6, 24.2, and 31.4% for Oxbow, Sawtooth daytime, and Sawtooth nighttime releases. Mean estimated survival to Lower Granite Dam was also 7.2% higher for Sawtooth Hatchery juvenile sockeye released at night vs. those released during the day, but the difference was not significant ($P = 0.118$). For sockeye from both Oxbow and Sawtooth Hatchery, estimated survival to Lower Granite Dam was lower for radio-tagged groups than for PIT-tagged groups, although for Oxbow fish, the confidence intervals overlapped between these estimates.

Median travel time through the 750-km study reach ranged from 6.3 to 7.4 d. Passage distributions at Lower Granite Dam indicated that the PIT-only and radio-tagged fish from all three groups traveled together through the entire study area. Therefore, these three groups likely experienced similar conditions throughout the monitored reaches. In general, migration rates for radio- and PIT-tagged sockeye salmon groups were similar through all study reaches and increased as they continued downstream until reaching the section of the Snake River influenced by the hydropower system.

CONTENTS

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 returning adult and juvenile migrant sockeye salmon (Bjornn et al. 1968). Annual returns of adult sockeye salmon to this weir dropped -from 4,361 in 1955 to 1 in both 1988 and 1989. These extremely low adult returns led to a status review of sockeye salmon in the Snake River Basin (Waples et al. 1991); this was followed by the listing 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 now 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) has constructed 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 among different release locations, rearing strategies, origin, and years. Based on detections of sockeye hatchery juveniles that were tagged with a passive integrated transponder (PIT) tag and released in spring, survival estimates have ranged from 11.4% (SE 2.1) in 2000 (Zabel et al. 2001) to 77.6% (SE 13.3) 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 post-poned 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 is 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 for the Federal Columbia River Power System are the National Marine Fisheries Service Biological Opinion (NMFS 2008) and the Adaptive Management Implementation Plan for 2008-2018 (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 these recovery programs. The outcome of this study will directly contribute to management actions that play a significant part in recovery of ESA-listed Snake River sockeye salmon.

We applied a multifaceted tracking approach that used both PIT tag and radio telemetry monitoring to identify the magnitude and locations of mortality for sockeye salmon smolts between the Sawtooth Valley and Lower Granite Dam. Each of these monitoring approaches 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 characteristics for study fish. Research objectives in 2013 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 Rivers.

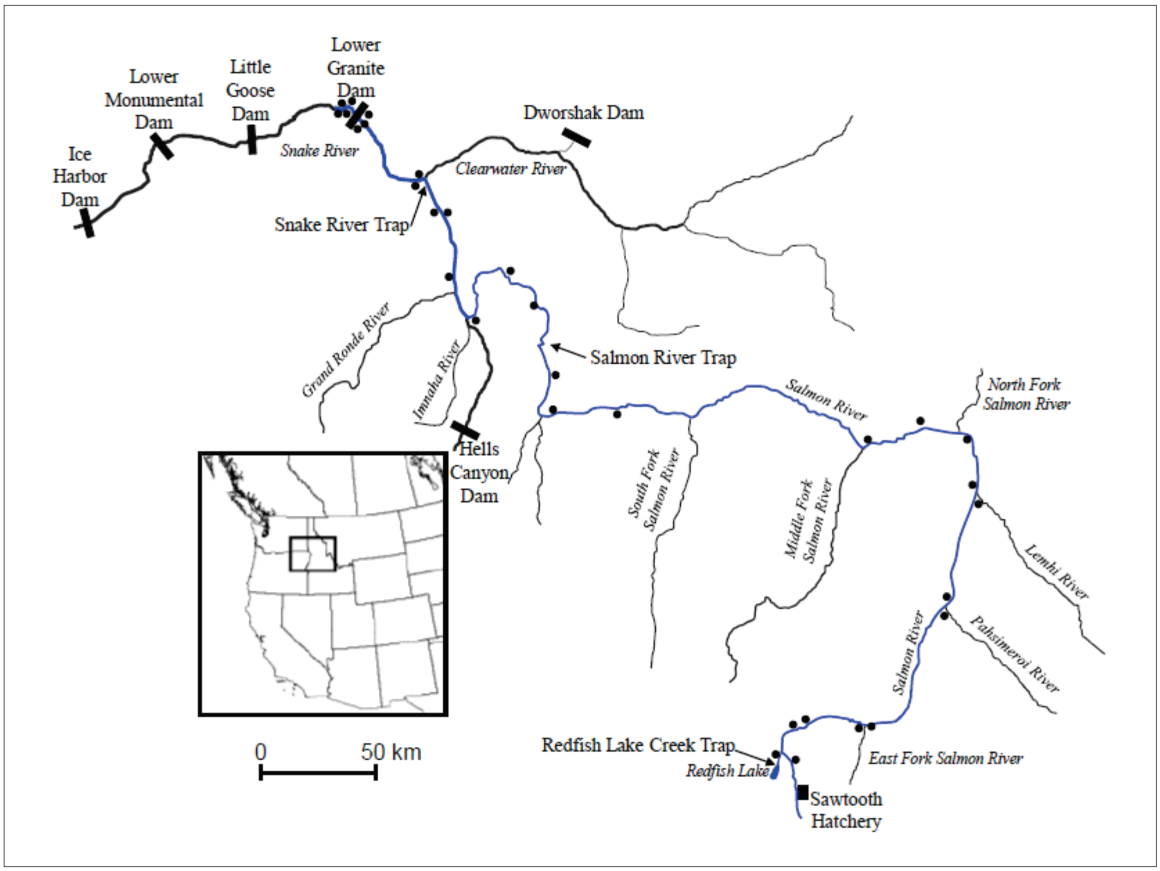

Figure 1. Map of study area showing migratory path of Snake River sockeye salmon from release near the Redfish Lake Creek Trap to Lower Granite Dam. Black dots show location of fixed-site telemetry receivers. Arrows show locations of smolt monitoring traps; bars indicate lower Snake River dams.

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 the comparative survival study (Schaller et al. 2007) and as part of the Snake River Sockeye salmon hatchery program (Peterson et al. In prep). All radio-tagged fish were also PIT-tagged.

In 2013, the Oxbow Hatchery production release was 100,755 sockeye smolts; 2,098 of these fish were PIT-tagged by personnel from IDFG. For Oxbow Hatchery fish, overall mean fork length at tagging was 145.4 mm (SD = 10.2 mm), and tagging occurred 57 d prior to release (Table 1). Oxbow Hatchery sockeye salmon were released at the bridge approximately 0.75 km downstream from the Redfish Lake Creek trap on 9 May 2013 between 2215 and 2300 MDT.

Table 1. Summary statistics of length at tagging for PIT-tagged juvenile sockeye salmon from Sawtooth (tagged on 15-17 March 2013) and Oxbow Fish Hatcheries (tagged on 13March 2013).

	PIT-tagged sockeye salmon length (mm)	
	Sawtooth Hatchery	Oxbow Hatchery
Minimum	100	86
Maximum	154	180
Mean (SD)	130.1 (10.6)	145.4 (10.2)

Sawtooth Hatchery released 170,221 sockeye production smolts in 2013. Of these fish, 50,191 were PIT-tagged prior to release; these fish had an overall mean fork length of 130.1 mm (SD 10.6) at one day prior to release (Table 1). Sawtooth Hatchery sockeye salmon were released in two separate groups to compare day and night survival. Releases occurred at the bridge approximately 0.75 km downstream from the Redfish Lake Creek trap on 9 May 2013 between 1210 and 1400 MDT and between 2125 and 2200 MDT. Daytime releases consisted of 190 radio-tagged, approximately 25,000 PIT-tagged, and 74,000 untagged Sawtooth Hatchery fish. Nighttime releases included 191 radio-tagged, approximately 25,000 PIT-tagged, and 46,000 untagged Sawtooth Hatchery fish, as well as 394 radio-tagged, 2,098 PIT-tagged, and 98,657 untagged Oxbow Hatchery fish.

At both Sawtooth and Oxbow Hatcheries, PSMFC or IDFG staff conducted PIT-tagging operations. Fish were tagged with a 12.5-mm, 134.2-kHz PIT tag (Destron Fearing TX1400 SST) following protocols mandated by IDFG 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.

Radio-Tagged Release Groups

For radio tagging, we transferred a subset (N = X) of 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 15 March 2013 and Oxbow fish on 14 March 2013. The purpose of these transfers was to manage growth, so that fish would meet 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 2013. 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. Maximum 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 recovery period, and 38 fish had lost radio tags that were pulled out during recovery. Investigation revealed that the likely cause of lost tags was catching of external antennas. All 38 fish survived and retained their PIT tags, so we released them with the rest of the fish. We tagged additional fish with the removed tags to keep sample sizes near 400 for both hatchery groups. 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 the tag in each fish to verify it was operating and to ensure that the tag code was recorded correctly in the database. During this process, we found eight fish with tags that were not operating prior to release, and we removed these fish from the analysis. Transport buckets were loaded into 1,152 L transport tanks, held overnight, and maintained with flow through hatchery water.

On the morning of 9 May 2013, we transported radio-tagged sockeye salmon from Eagle Hatchery to the release location in Redfish Lake Creek. Upon arrival at the release site, fish were acclimated until water temperatures in the holding tank and river were within 2°C. Fish were released by gently pouring the contents of the bucket into Redfish Lake Creek at mid-channel. We released all fish at a bridge approximately 0.75 km downstream from Redfish Lake. Of the fish from Sawtooth Hatchery, both radio- and PIT-tagged fish were separated into two release groups, with one released during the day at 12:10 MDT and the other after dusk at 21:25 MDT. Both the radio- and PIT-tagged fish from Oxbow Hatchery were released after dusk, at 22:15 MDT.

For radio-tagged study fish, overall mortality between tagging and release was 0.9% (4 fish) for Sawtooth groups and 0.0% for Oxbow groups. Fork length and weight at radio tagging are summarized by hatchery in Table 2. Tag burden ranged from 1.1 to 4.9% and averaged 2.9% overall.

Table 2. Summary statistics of fork length and weight at tagging for radio-tagged juvenile sockeye salmon from Oxbow and Sawtooth Fish Hatcheries, 2013.

	Fork Length (mm)		Weight (g)	
	Oxbow	Sawtooth	Oxbow	Sawtooth
Minimum	125.0	120.0	17.0	15.0
Maximum	183.0	188.0	66.0	60.0
Mean	150.0	139.1	30.7	24.2
Standard deviation	9.4	9.7	6.6	5.5

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 PIT-tag detection locations 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. An additional detection location was in the upper Columbia estuary near Jones Beach (rkm 75), where a PIT-trawl detection system is operated by NOAA Fisheries during the spring and summer migration seasons.

When a PIT-tagged fish passes an interrogation monitor, a detection record generates 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.

Of our study fish detected at dams, the majority are returned to the river (i.e., the tailrace of the dam) using separation-by-code (SbyC) systems. At collector dams, SbyC systems operate by means of a slide gate triggered by PIT-tag detection, and these systems can route fish to various destinations. For example, untagged fish can be 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 60 fixed-site telemetry receivers at 30 locations within the study area to provide 25 detection zones or transects. Locations of the telemetry receivers are presented in Table 3 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 also based on physical accessibility.

Table 3. Locations of fixed-site radio telemetry monitoring receivers used to characterize migration and estimate survival of radio-tagged juvenile Snake River sockeye salmon, 2013. 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 no.	Site description	Latitude	Longitude	Distance from release (km)
1	Above Redfish 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
3	Above Valley Creek confluence	44°13'24.37"N	114°55'39.58"W	9
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
6	Below East Fork Salmon R confluence	44°16'58.18"N	114°18'49.19"W	68
7	Above Pahsimeroi R confluence	44°40'35.86"N	114°04'27.98"W	126
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
10	Below Lemhi R confluence	45°15'13.55"N	113°54'25.37"W	211
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
16	Below Little Salmon R confluence	45°26'49.32"N	116°18'40.29"W	482
17	Hammer Creek Recreation Area	45°45'59.79"N	116°19'29.13"W	533
18	Rice Creek Bridge	45°54'39.95"N	116°24'41.76"W	557
20	Below Grande Ronde R confluence	46°08'23.83"N	116°56'06.92"W	659
21	Hell’s Gate State Park	46°22'48.53"N	117°02'58.49"W	702
22	Above Clearwater R. confluence	46°22'48.53"N	117°02'58.49"W	702
23	Below Clearwater R confluence	46°25'08.37"N	117°10'57.40"W	709
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 tailrace exit (right bank)	46°40'45.88"N	117°26'49.81"W	751
31	Lower Granite tailrace exit (left bank)	46°40'39.54"N	117°27'07.02"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. We analyzed release-recapture data 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 1993-029-00 survival study).

Radio-Tagged Fish

Survival estimates for radio-tagged fish were based on detections of individuals at fixed-site telemetry receivers (Table 3; 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, we also estimated an overall probability of survival from release to Lower Granite Dam.

Tag life of the radio transmitters was assessed from a sample of 50 tags tested in water (Appendix A1). 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.

For individual radio-tagged fish, travel time was calculated 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 travel time for all fish detected at both the upper and lower sites delineating that reach. Migration rates were calculated from travel time data as kilometers per hour (km/h).

RESULTS

Detection Probabilities

Detection at Lower Granite Dam

For PIT-tagged sockeye salmon, estimated probabilities of detection at Lower Granite Dam were 25.0% (SE = 2.4) for Oxbow Hatchery fish, 41.9% (SE = 0.8) for Sawtooth Hatchery day-released fish, and 38.1% (SE = 0.8) for Sawtooth Hatchery night-released fish. Differences between Sawtooth day and night PIT-tagged fish and Oxbow night PIT-tagged fish were statistically significant ($P < 0.001$; Tables 4 and 5). For Sawtooth Hatchery fish, PIT-tag detection probabilities at Lower Granite Dam were significantly higher than Oxbow Hatchery fish. There was not a significant difference in detection probabilities between tag treatment groups (PIT tags and radio tags) from Oxbow Hatchery ($P = 0.702$; Table 5).

Table 4. Estimated detection probability at Lower Granite Dam for PIT-and radio-tagged juvenile hatchery sockeye salmon released to Redfish Lake Creek, 2013. 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 (%) and SE
	Estimates based on PIT-tag detections
PIT-tagged fish	
Oxbow Hatchery (night)	25.0 (2.4)
Sawtooth Hatchery (day)	41.9 (0.8)
Sawtooth Hatchery (night)	38.1 (1.0)
Radio-tagged fish	
Oxbow Hatchery (night)	27.4 (5.8)
Sawtooth Hatchery (day)	55.0 (10.1)
Sawtooth Hatchery (night)	44.7 (8.1)
	Estimates based on radio-tag detections
Radio-tagged fish	
Oxbow Hatchery (night)	99.4 (0.6)
Sawtooth Hatchery (day)	100.0 (0.0)
Sawtooth Hatchery (night)	98.3 (1.7)

For Sawtooth Hatchery fish, one possible contributor to the differing probabilities of PIT-tag detection may have been the difference in mean size between PIT- and radio-tagged study groups. The smaller PIT-tagged Sawtooth fish 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 139.1 mm) may have been attracted more readily to the surface flows provided by the removable spillway weir (RSW) and were passed over the spillway. Fish passing via spillways are currently not detected by a PIT-tag monitor.

Table 5. Comparisons of PIT-tag detection probability at Lower Granite Dam for PIT- vs. radio-tagged juvenile Snake River sockeye salmon from Oxbow and Sawtooth hatcheries in 2013 (radio-tagged fish were also implanted with a PIT tag). Shaded cells indicate a significant difference between estimates of detection.

Hatchery group, release period, and tag type Comparison group	Difference in detection probability (%)	*t*	*P*
Oxbow night PIT			
vs. Sawtooth night PIT	13.1	5.24	0.000
vs. Sawtooth day PIT	16.9	6.74	0.000
vs. Oxbow night radio	2.4	0.38	0.702
Sawtooth night PIT			
vs. Sawtooth night radio	6.6	0.81	0.416
Sawtooth day PIT			
vs. Sawtooth night PIT	3.8	3.47	0.001
vs. Sawtooth day radio	13.1	1.29	0.196
Oxbow night radio			
vs. Sawtooth night radio	17.3	1.74	0.082
vs. Sawtooth day radio	27.6	2.37	0.018

For Oxbow Hatchery sockeye salmon, the difference in mean fork length was smaller between PIT-tag (145.4 mm) and radio-tag treatment groups (150.0 mm). 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 80.9 to 100.0% (Table 6) and averaged 99.0% overall. Mean probabilities of radio-tag detection were lower in the Snake (91.4, range 80.9-100.0%) than in the Salmon River (99.8, range 97.2-100.0%), due to river width and depth.

Table 6. Estimated mean detection probability for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon at fixed-site radio telemetry monitoring locations, 2013. Standard errors are in parentheses. Detailed location information for fixed-site telemetry locations is presented in Table 1 and Figure 1.

Receiver site		Estimated detection probability (%) and SE		
No.	Description	Oxbow (night)	Sawtooth (day)	Sawtooth (night)
2	Below Little Redfish Lake	99.7 (0.3)	994 (0.6)	97.4 (1.3)
3	Above Valley Creek confluence	99.4 (0.4)	100.0 (0.0)	98.7 (0.9)
4	Below Lower Stanley	99.4 (0.4)	100.0 (0.0)	97.2 (1.4)
5	Above East Fork Salmon R confluence	99.4 (0.4)	100.0 (0.0)	100.0 (0.0)
6	Below East Fork Salmon R confluence	99.3 (0.4)	100.0 (0.0)	100.0 (0.0)
7	Above Pahsimeroi R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
8	Below Pahsimeroi R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
9	Above Lemhi R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
10	Below Lemhi R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
11	Above North Fork Salmon R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
12	Below North Fork Salmon R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
13	Above Middle Fork Salmon R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
14	Vinegar Creek boat launch	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
15	Above Little Salmon R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
16	Below Little Salmon R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
17	Hammer Creek Recreation Area	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
18	Rice Creek Bridge	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
20	Below Grande Ronde R confluence	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
22	Above Clearwater R confluence	89.0 (2.4)	80.9 (5.7)	86.9 (4.3)
23	Below Clearwater R (right bank)	86.5 (2.6)	85.1 (5.2)	86.9 (4.3)
24	Below Clearwater R (left bank)	94.0 (1.8)	89.4 (4.5)	91.8 (3.5)
25-27	Lower Granite Dam forebay	89.0 (2.4)	82.6 (5.6)	85.0 (4.6)
28-29	Lower Granite Dam tailrace	100.0 (0.0)	97.8 (2.2)	100.0 (0.0)

Estimated Survival

Survival to Lower Granite Dam

Estimated survival to Lower Granite Dam for PIT-tagged sockeye salmon was 57.5% for Oxbow nighttime releases, 51.0% for Sawtooth daytime releases, and 59.2% for Sawtooth nighttime releases (Table 7). For radio-tagged sockeye salmon, estimated survival to the dam was 48.2% for Oxbow nighttime releases, 27.9% for Sawtooth daytime releases, and 37.4% for Sawtooth nighttime releases. For fish from Sawtooth Hatchery, the difference in estimated survival between daytime vs. nighttime releases was 8.2% for PIT-tag groups and 7.2% for radio-tagged groups (Table 8). The difference in survival between daytime and nighttime release groups was not statistically significant for estimates based on telemetry detections, but was statistically significant for estimates based on PIT detections (Table 8).

The largest difference in estimated survival was observed in the comparison between Sawtooth PIT- and radio-tag groups based on PIT detections at Lower Granite Dam. These could be related to differences in detection probability and passage distribution through the juvenile bypass system.

Table 7. Estimated survival from release in Redfish Lake Creek to Lower Granite Dam for PIT- and radio-tagged juvenile Snake River sockeye salmon in 2013. 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.

Tag treatment, hatchery, and diel release period	Estimated survival (%) and SE
	Estimates based on PIT-tag detection
PIT-tag	
Oxbow Hatchery	57.5 (4.8)
Sawtooth Hatchery (day)	51.0 (0.9)
Sawtooth Hatchery (night)	59.2 (1.0)
Radio-tag	
Oxbow Hatchery	48.2 (8.8)
Sawtooth Hatchery (day)	27.9 (5.0)
Sawtooth Hatchery (night)	37.4 (5.8)
	Estimates based on radio-tag detection
Radio-tag	
Oxbow Hatchery	41.6 (2.5)
Sawtooth Hatchery (day)	24.2 (3.1)
Sawtooth Hatchery (night)	31.4 (3.4)

Table 8. Comparisons of estimated survival to Lower Granite Dam by hatchery, tag treatment, and diel release period from Redfish Lake Creek. Study fish were PIT-and radio-tagged juvenile Snake River sockeye salmon reared at Oxbow and Sawtooth Hatcheries in 2013. Shaded values indicate significant differences between estimates of survival based on PIT vs. radio-tag detections.

Hatchery group, release period, and tag type Comparison group	Difference in estimated survival (%)	*t*	*P*
	Estimates based on PIT-tag detection		
Oxbow night PIT			
vs. Sawtooth night PIT	1.7	0.35	0.729
vs. Oxbow night radio	9.3	0.93	0.353
vs. Sawtooth day PIT	6.5	1.33	0.183
Oxbow night radio			
vs. Sawtooth night radio	10.8	1.02	0.306
vs. Sawtooth day radio	20.3	2.01	0.045
Sawtooth night PIT			
vs. Sawtooth night radio	21.8	3.70	0.000
Sawtooth day PIT			
vs. Sawtooth day radio	23.1	4.57	0.000
vs. Sawtooth night PIT	8.2	6.08	0.000
	Estimates based on radio-tag detection		
Sawtooth night radio			
vs. Sawtooth day radio	7.2	1.56	0.118
Oxbow night radio			
vs. Sawtooth night radio	10.2	2.42	0.016
vs. Sawtooth day radio	17.4	4.37	0.000

Survival in Partitioned Reaches

For all radio-tagged releases from Oxbow Hatchery, and for day and night releases from Sawtooth Hatchery, we estimated median survival within individual reaches between Redfish Lake Creek and Lower Granite Dam. Most observed mortality for all three groups occurred between release and the North Fork of the Salmon River (Table 9). Sawtooth Hatchery sockeye were released during mid-day and after dusk. Oxbow sockeye groups were released at night, when the trucks arrived from the hatchery. Based on findings from the previous year, we hypothesized that predation on Sawtooth Hatchery sockeye could be reduced considerably by scheduling their release time closer to dusk. While we did not observe a significant difference in survival in the first reach, overall survival to Lower Granite was lowest for fish released during the day. In the individual reaches downstream from Vinegar Creek, survival was greater than 94% for all three groups.

Survival for radio-tagged Sawtooth Hatchery fish was consistent between daytime and night release groups, with most observed mortality occurring between the release site and the North Fork Salmon River. One reach to examine in particular is the area between the Pahsimeroi and Lemhi River (Table 9; sites 8-9), where both Sawtooth releases encountered larger losses than the Oxbow group. After passing this reach, the nighttime releases of both Oxbow and Sawtooth fish had reduced mortality once they made it to the North Fork Salmon River. Sawtooth daytime releases encountered 12% higher mortality than both of the other groups in the first reach they encountered below the North Fork Salmon River (Table 9; sites 12-13). From the Middle Fork Salmon River to Lower Granite Dam, survival remained consistent for all three groups.

Table 9. Estimated survival for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon within various reaches between release in Redfish Lake Creek and Lower Granite Dam, 2013. Standard errors are in parentheses.

Receiver site number	Site description	Estimated survival of radio-tagged groups (%) and SE		
		Oxbow (night)	Sawtooth (day)	Sawtooth (night)
Release–2	Release–Below Little Redfish Lake	91.1 (1.4)	94.8 (1.6)	92.4 (2.0)
2–3	Below Little Redfish Lake–Valley Creek confluence	91.4 (1.5)	89.4 (2.3)	87.8 (2.5)
3–4	Valley Creek confluence–Below Lower Stanley	98.2 (0.7)	97.5 (1.2)	98.9 (0.9)
4–5	Below Lower Stanley–Above East Fork Salmon R	97.5 (0.9)	93.6 (2.0)	92.6 (2.1)
5–6	Above East Fork Salmon R–Below East Fork Salmon R	99.7 (0.3)	99.3 (0.7)	99.3 (0.7)
6–7	Below East Fork Salmon R–Above Pahsimeroi R	93.2 (1.4)	92.5 (2.2)	92.2 (2.3)
7–8	Above Pahsimeroi R–Below Pahsimeroi R	99.0 (0.6)	99.3 (0.7)	99.2 (0.8)
8–9	Below Pahsimeroi R–Above Lemhi R	90.0 (1.8)	78.4 (3.6)	83.7 (3.3)
9–10	Above Lemhi R–Below Lemhi R	97.7 (0.9)	92.4 (2.6)	94.4 (2.2)
10–11	Below Lemhi R–Above North Fork Salmon R	92.9 (1.6)	85.6 (3.6)	91.2 (2.8)
11–12	Above North Fork Salmon R–Below North Fork Salmon R	86.4 (2.2)	80.7 (4.3)	77.4 (4.3)
12–13	Below North Fork Salmon R–Above Middle Fork Salmon R	91.7 (1.9)	79.1 (5.0)	93.1 (3.0)
13–14	Above Middle Fork Salmon R–Vinegar Creek boat launch	94.1 (1.7)	94.3 (3.2)	95.5 (2.5)
14–15	Vinegar Creek boat launch–Above Little Salmon R	100.0 (0.0)	100.0 (0.0)	98.4 (1.6)
15–16	Above Little Salmon R–Below Little Salmon R	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
16–17	Below Little Salmon R–Hammer Creek Recreation Area	98.9 (0.8)	100.0 (0.0)	100.0 (0.0)
17–18	Hammer Creek Recreation Area–Rice Creek Bridge	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
18–20	Rice Creek Bridge–Below Grande Ronde R	99.4 (0.6)	94.0 (3.4)	96.8 (2.2)
20–22	Below Grande Ronde R–Above Clearwater R	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
22–24	Above Clearwater R–Below Clearwater R	99.4 (0.7)	100.0 (0.0)	100.0 (0.0)
24–LGRF	Below Clearwater R–Lower Granite Dam forebay	98.4 (1.1)	100.0 (0.0)	100.0 (0.0)
LGRF—LGRT	Lower Granite Dam forebay–Lower Granite Dam tailrace	97.3 (1.3)	97.4 (2.5)	98.1 (1.9)

Cumulative Survival

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 a 10-17% difference in estimated survival between Sawtooth and Oxbow hatchery fish based on radio telemetry. This difference was similar for the same radio-tagged fish using PIT tag detection (10-20%). Note that survival estimates using the same fish but different tag types resulted in a 4-7% higher survival with PIT estimates.

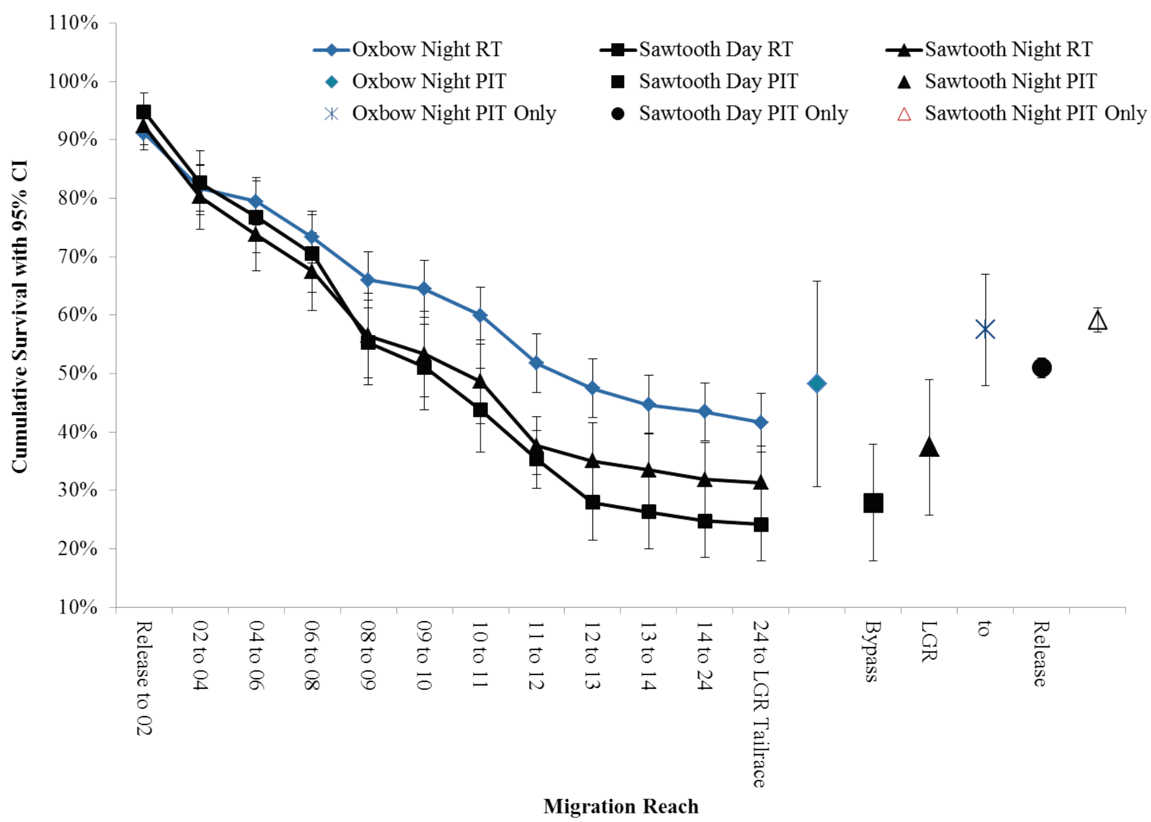

Figure 2. Line chart showing cumulative survival by reach from release to the tailrace of Lower Granite Dam. To the right of the cumulative estimates, point estimates of survival from release to the bypass system of Lower Granite Dam are shown by hatchery and tag treatment. Juvenile sockeye salmon were surgically implanted with a radio transmitter (RT) and PIT tag (PIT) or injected with only a PIT tag (PIT only) and released into Redfish Lake Creek on 9 May 2013. Whisker bars represent 95% confidence intervals.

Travel Time

The PIT tags implanted in 11,544 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 ranged from 6.3 to 7.4 d (Table 10). Passage distributions at Lower Granite Dam indicated that the PIT only and hatchery/release time paired radio-tagged groups traveled together through the entire study area. Therefore, these three groups likely experienced similar conditions throughout (Figure 3).

Table 10. Summary statistics of travel time to Lower Granite Dam (in days) by PIT detection for Snake River sockeye salmon released in Redfish Lake Creek on 9 May 2013 (radio-tagged fish were also PIT-tagged).

	Travel time (d)					
	Oxbow Hatchery (night)		Sawtooth Hatchery (day)		Sawtooth Hatchery (night)	
Passage percentile	PIT tag (n = 288)	Radio tag (n = 162)	PIT tag (n = 5,336)	Radio tag (n = 45)	PIT tag (n = 5,655)	Radio tag (n = 58)
5	6.0	6.0	5.9	6.0	6.0	5.6
10	6.0	6.2	5.9	6.0	6.0	5.9
20	6.2	6.8	6.0	6.1	6.0	6.0
30	6.9	7.0	6.7	6.3	6.2	6.0
40	7.0	7.1	6.9	6.5	6.7	6.1
50	7.2	7.4	6.9	6.9	7.0	6.3
60	8.0	8.0	6.9	6.9	7.1	7.0
70	8.1	8.7	7.1	7.1	7.7	7.0
80	9.0	9.3	7.8	7.9	8.1	7.3
90	9.2	10.3	8.2	9.1	9.0	8.4
95	10.0	10.9	9.0	10.2	9.3	9.7
min	5.9	5.5	4.9	5.7	5.0	5.2
mean	7.7	8.1	7.1	7.2	7.2	6.9
mode	6.0	6.0	6.9	6.0	6.0	7.0
maximum	15.1	21.1	38.4	11.3	38.0	12.7

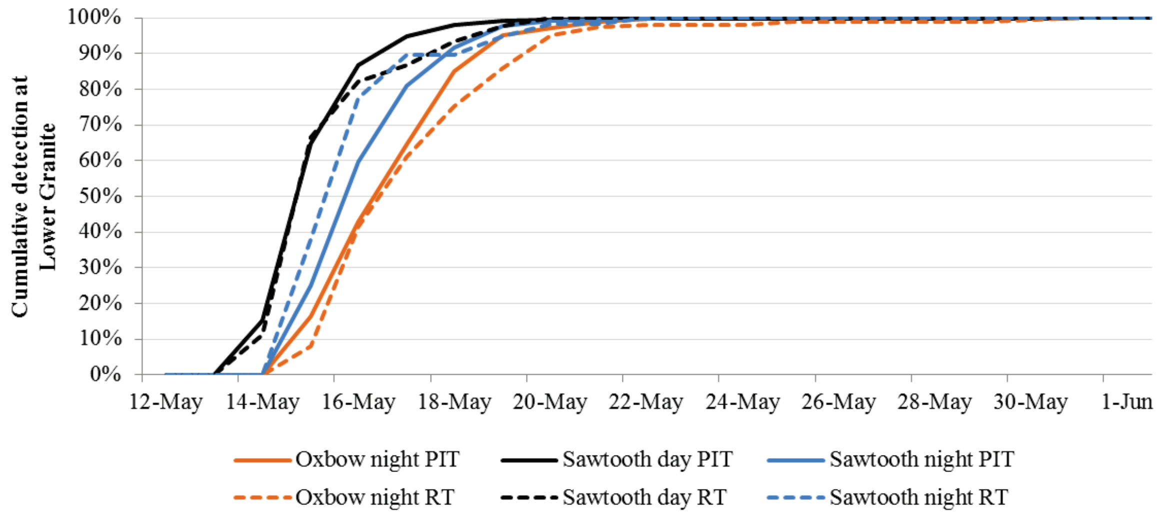

Figure 3. Cumulative PIT-tag detection at Lower Granite Dam of PIT- and radio-tagged (RT) juvenile hatchery sockeye salmon released to Redfish Lake Creek, 9 May 2013.

In general, migration rates for radio-tagged sockeye salmon were similar through all of the reaches and increased as they continued downstream until reaching the section of the Snake River influenced by the hydropower system (i.e, below the confluence of the Snake and Clearwater River; Figure 4). Migration rate doubled at the confluence with the East Fork of the Salmon River with increasing flow in this area.

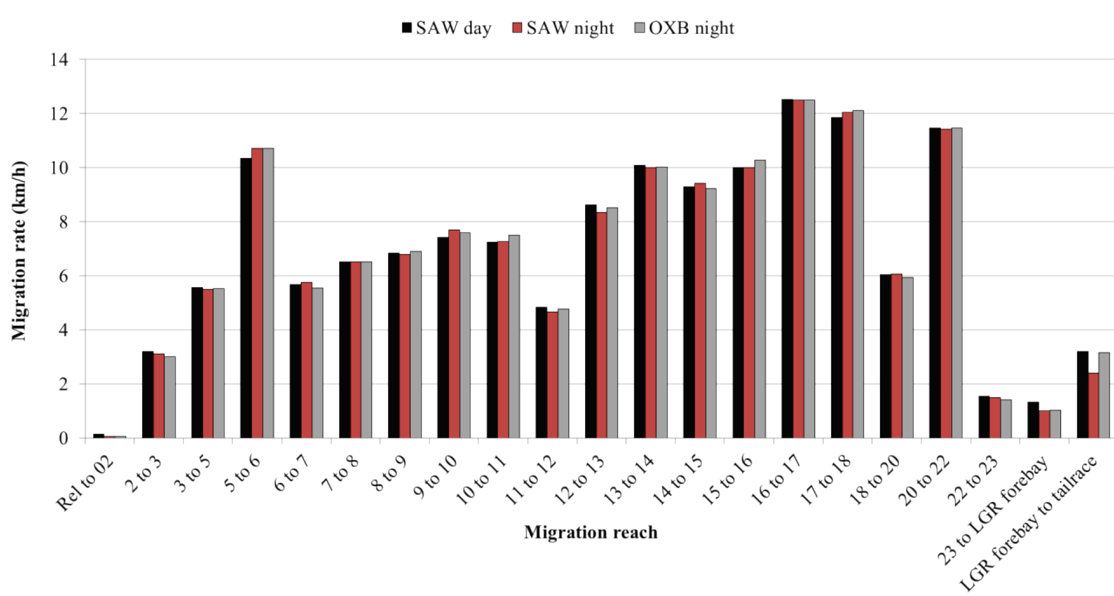

Figure 4. Migration rates of radio-tagged hatchery sockeye salmon within individual reaches between Redfish Lake Creek and the tailrace of Lower Granite Dam (LGR), 2013. Reach descriptions, travel time and migration rates by site number are shown in Table 11.

One other notable reach was between sites 11 and 12; this partition encompasses the area known as Deadwater Slough. Deadwater Slough is one of east-central Idaho's best birding locations due to quality riparian habitat, good water quality, and adjacent diverse upland habitats for raptors and other species, according to Idaho Fish and Game Watchable Wildlife Program. This reach also is of note because we estimated lower survival for all three release groups within this reach than in the reaches above it. Delays in the lower portions of the study area (sites 23 and above) were likely due to reduced water velocities associated with the hydropower system.

For all three groups of radio-tagged 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 11).

Table 11. 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, 2013.

Reach	Reach description	Reach length (km)	Median travel time (d) Oxbow night	Median travel time (d) Sawtooth day	Median travel time (d) Sawtooth night	Median travel rate (km/h) Oxbow night	Median travel rate (km/h) Sawtooth day	Median travel rate (km/h) Sawtooth night
Rel–02	Release to below Little Redfish Lake	3	1.1	0.4	1.0	0.1	0.1	0.1
2–3	Below Little Redfish Lake to Valley Creek	6	0.1	0.1	0.1	3.0	3.2	3.1
3–5	Valley Creek to above E Fork Salmon R	54	0.4	0.4	0.4	5.5	5.6	5.5
5–6	Above to below East Fork Salmon R	5	0.0	0.0	0.0	10.7	10.3	10.7
6–7	Below E Fork Salmon R to above Pahsimeroi R	58	0.4	0.4	0.4	5.5	5.7	5.8
7–8	Above to below Pahsimeroi R	5	0.0	0.0	0.0	6.5	6.5	6.5
8–9	Below Pahsimeroi R to above Lemhi R	68	0.4	0.4	0.4	6.9	6.8	6.8
9–10	Above to below Lemhi R	12	0.1	0.1	0.1	7.6	7.4	7.7
10–11	Below Lemhi R to above N. Fork Salmon R	26	0.1	0.1	0.1	7.5	7.2	7.3
11–12	Above to below N Fork Salmon R	22	0.2	0.2	0.2	4.8	4.8	4.7
12–13	Below N Fork Salmon R to above Middle Fork Salmon R	40	0.2	0.2	0.2	8.5	8.6	8.3
13–14	Above Middle Fork Salmon R to Vinegar Cr boat launch	139	0.6	0.6	0.6	10.0	10.1	10.0
14–15	Vinegar Cr boat launch to above Little Salmon R	38	0.2	0.2	0.2	9.2	9.3	9.4
15–16	Above to below Little Salmon River	6	0.0	0.0	0.0	10.3	10.0	10.0
16–17	Below Little Salmon R to Hammer Cr	51	0.2	0.2	0.2	12.5	12.5	12.5
17–18	Hammer Cr to Rice Cr Bridge	24	0.1	0.1	0.1	12.1	11.9	12.1
18–20	Rice Cr Bridge to below Grande Ronde R	102	0.4	0.4	0.4	5.9	6.0	6.1
20–22	Below Grande Ronde R to above Clearwater R	43	0.2	0.2	0.2	11.5	11.5	11.4
22–24	Above to below Clearwater R	7	0.2	0.2	0.2	1.4	1.5	1.5
24–LGRF	Below Clearwater River to Lower Granite Dam forebay	38	1.6	1.3	1.7	1.0	1.3	1.0
LGRF–LGRT	Lower Granite Dam, forebay to tailrace	2	0.0	0.0	0.0	3.2	3.2	2.4
Rel–LGRT	Release to Lower Granite Dam tailrace	751	7.4	6.4	6.3	4.2	4.9	5.0

Predation

During fish releases, we observed multiple predation events on recently released juvenile sockeye. Common merganser *Mergus merganser*, osprey *Pandion haliaetus*, double-crested cormorant *Phalacrocorax auritus*, and western grebe *Aechmophorus occidentalis* were actively feeding in Little Redfish Lake, located below the release site, as fish were moving through the area. In addition, we observed bull trout *Salvelinus confluentus* chasing juvenile sockeye schools as they migrated through Little Redfish Lake. 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.

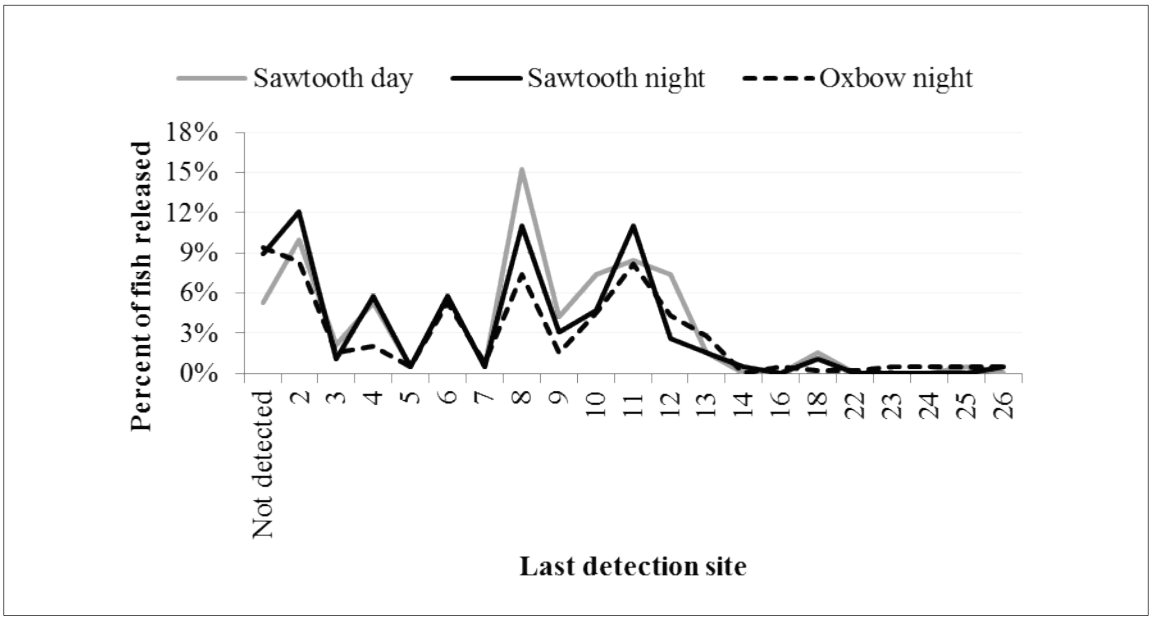

Figure 5. Last known telemetry locations of radio-tagged Oxbow and Sawtooth hatchery sockeye salmon between Redfish Lake Creek and the forebay of Lower Granite Dam, 2013. Detailed location information for fixed-site telemetry locations are in Table 3 and Figure 1.

Prior to the programmed shutdown of the radio transmitters, we intensively mobile tracked from the release site to the East Fork of the Salmon River to determine locations of missing radio tagged fish. We identified 50 tags, with 44 located within Little Redfish Lake and Redfish Lake Creek (Figure 6).

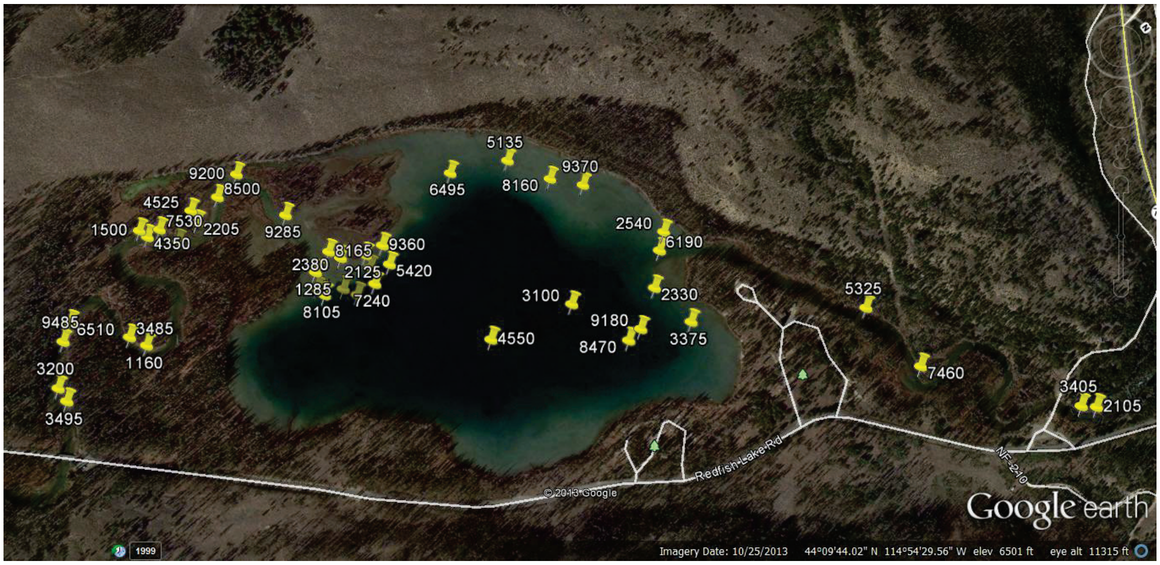

Figure 6. Final resting locations of radio transmitters between the Redfish Lake Creek bridge release site and the mouth of Redfish Lake Creek, 2013. Transmitters had been implanted in Oxbow and Sawtooth Hatchery juvenile sockeye salmon.

DISCUSSION

For groups of PIT-tagged fish released to Redfish Lake Creek in 2013, estimated survival to Lower Granite Dam ranged 51.0-59.2%; mean estimated survival was 8.2% higher for Sawtooth Hatchery groups released at night vs. those released during the day, and the difference was statistically significant ($P < 0.001$). For radio-tagged groups, survival ranged 31.4-41.6%. Mean estimated survival to Lower Granite Dam was also 7.2% higher for Sawtooth Hatchery radio-tagged juvenile sockeye released at night vs. those released during the day, but the difference was not statistically significant ($P = 0.118$) due to lower-than-expected survival for both groups. For both Oxbow and Sawtooth hatchery sockeye salmon, survival estimates from release to Lower Granite Dam were lower for radio-tagged than for PIT-tagged release groups, though for Oxbow fish, the confidence intervals for these estimates overlapped.

Four reaches in particular revealed lower survival for both daytime and nighttime release groups and for releases from both hatcheries:

1) From release to the Valley Creek confluence (sites 1-3)
2) From below the East Fork Salmon River to just above the Pahsimeroi River (sites 6-7)
3) From below the Pahsimeroi River to the confluence with the Lemhi River (sites 8-9)
4) From the site below the Lemhi River to the Middle Fork Salmon River (sites 10-13)

The first reach includes passage through Little Redfish Lake, where we have visually observed bull trout actively feeding on juvenile sockeye schools entering the lake. In addition, the avian predator populations were very active in and around the lake. The last reach encompasses the area known as Deadwater Slough, which is one of east-central Idaho's best birding locations due to quality riparian habitat, good water quality, and adjacent diverse upland habitats for raptors and other species. Flow in this area is visibly slower, and juvenile sockeye were shown to travel at a considerably reduced rate.

Fish experienced slightly higher flows throughout the Salmon River basin during the first week after releases in 2013 when compared to 2012 (mean daily flow at Whitebird, ID was 12,500 ft^3/s higher). On 16 May, flows were reduced, and this may have influenced survival for fish migrating later in the season. We hypothesized that for all release groups during May 2013, high flows in the upper Salmon River likely contributed to short travel times between release in Redfish Lake Creek and Lower Granite Dam. Although travel times for juvenile sockeye were similar between years, survival estimates were lower this year for all groups except PIT-tagged Sawtooth Hatchery fish released at night.

Based on PIT-tag detections at Lower Granite Dam, we concluded that travel time data for radio-tagged juvenile sockeye salmon during 2013 was representative of the production populations at both Oxbow and Sawtooth Hatchery. Median travel times through this 750-km reach ranged from 6.3 to 7.4 d. Passage distributions at Lower Granite Dam indicated that the PIT-only and radio-tagged cohorts from all three release groups traveled together through the entire study area. Therefore, they likely experienced similar conditions throughout the monitored reaches. Juvenile Snake River sockeye salmon have exhibited an active migration similar to that of other sockeye populations (Groot 1965; Johnson and Groot 1963), with migration rates close to maximum sustained swimming speed.

The tagging protocols that we began in 2012 allowed us to tag fish at Eagle Hatchery near Boise, Idaho, 30 d prior to release so that fish could be held for an adequate time to recover from the surgical process. In 2013, we observed only four mortalities during the recovery period and no mortalities after transport to Redfish Lake Creek. Tag burden for these fish ranged from 1.1 to 4.9% and averaged 2.9% overall. Several studies have shown that tag burdens within this range did not influence swimming performance of juvenile salmonids (Hall et al. 2009; Moore et al. 1990; Anglea et al. 2004; Chittenden et al. 2009b) and more specifically, of juvenile sockeye salmon (Collins et al. 2013). Furthermore, Brown et al. (2006) determined that tag burdens 5.8-8.5% decreased critical swimming speed (U_{crit}) for juvenile sockeye. Based on these findings, results from this study should represent the hatchery population released in the Sawtooth Basin.

In 2014, we propose to continue radio tagging juvenile sockeye salmon at Eagle Fish Hatchery 30 d prior to release to provide a sufficient post-surgical recovery period. We also plan to install an additional telemetry site near Challis, Idaho, to investigate a reach that has revealed increased mortality for juvenile sockeye. We plan to break this 58-km reach into two smaller reaches to help determine contributing factors.

Based on the differences in estimated survival observed between the Oxbow and Sawtooth release groups in 2012 and 2013, IDFG plans to re-evaluate the release time of Sawtooth Hatchery juvenile sockeye groups in 2014. Sawtooth Hatchery fish will be released in two separate groups, with one release during daylight hours and the other after dusk to avoid initial avian predation. Data collected in 2014 will help to validate this adaptive management effort and may provide guidance 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 0.894 to 1.000 and averaged 0.990 overall (see Table 6). Detection probabilities were in excess of 90% at all but one of the 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. With such high detection probabilities for all fish, there was no practical disparity between detection probabilities of individual fish

For PIT-tagged fish, detection probabilities 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 over two to four days within roughly ten days of release (Figure 3). This short timeframe 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 affects 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, spill patterns 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 not 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 fork length and weight are presented in Tables 1-2. For sockeye salmon from Oxbow Fish Hatchery, the fork length of PIT-tag groups was measured 57 days before release. Sawtooth Hatchery fish were transferred to Eagle Hatchery on 15 March 2013 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, measured one day prior to release, and was slightly smaller than that of radio-tagged groups.

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 850 tags allocated for this study, 3 (0.4%) could not be activated and were therefore not used. Five tags (0.6% of 800 implanted in Snake River sockeye salmon) did not restart after the 30-d shutdown to save battery life during the surgical recovery period prior to release.

We tested 50 radio transmitters 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 26-39 d and averaged 33 d (Appendix Table A1). Travel time from release to Lower Granite Dam for radio-tagged sockeye salmon ranged 5.2-21.1 d (Table 12) with a median of 7.0 d. Therefore, with the minimum tag life of 26 d, and maximum travel time through the study area of 21.1 d, it was 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, 99% of the PIT-tagged hatchery Snake River sockeye salmon released in Redfish Lake Creek on 9 May 2013 migrated to Lower Granite Dam in less than 12 d (Fig. 3).

A total of 189 (24.4% of the 775 fish released) radio-tagged sockeye salmon were detected on at least one downstream PIT-tag monitor. Radiotelemetry detection histories for these fish were examined for tag failure or loss within the study area. Of these fish, 11 (5.8%) had radio transmitters that ceased to be 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, 2013.

Tags (n)	Tags (%)	Battery life (d)
0	0.0	24
0	0.0	25
2	4.0	26
2	4.0	27
1	2.0	28
3	6.0	29
4	8.0	30
0	0.0	31
8	16.0	32
5	10.0	33
7	14.0	34
6	12.0	35
6	12.0	36
2	4.0	37
3	6.0	38
1	2.0	39

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.

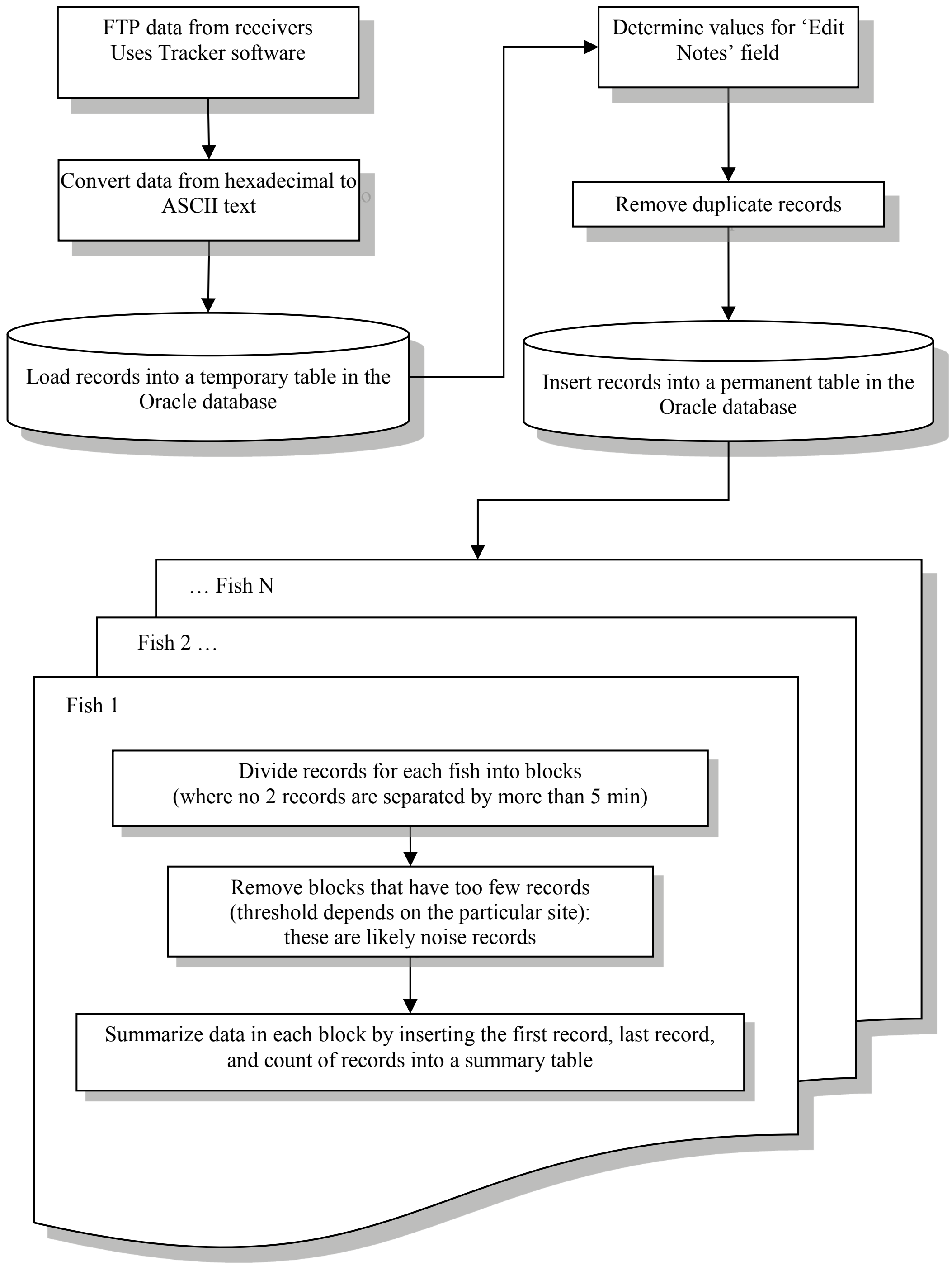
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: these records are produced by radio frequency noise.

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, 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 study year has been determined for a record, it is matched with records in the site table based on study year, site, and antenna.

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.