Characterizing migration and survival between the Upper Salmon River Basin and Lower Granite Dam for juvenile Snake River sockeye salmon, 2014

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Abstract

In 2014, we tagged and released groups of juvenile hatchery Snake River sockeye salmon *Oncorhynchus nerka* to Redfish Lake Creek in the upper Salmon River Basin. These releases were part of a continuing study to characterize migration and survival of juvenile sockeye to Lower Granite Dam. We estimated detection probabilities, rates of survival, and travel time based on detections of fish tagged with passive integrated transponders (PIT-tags) or with both a radio telemetry and PIT tag. We compared passage metrics between cohorts of fish from Sawtooth and Oxbow Fish Hatcheries. In addition, we evaluated release timing to determine if nighttime releases would improve survival for the smaller Sawtooth Hatchery fish.

For groups of PIT-tagged fish released to Redfish Lake Creek, estimated survival to Lower Granite Dam ranged 50.5-53.5%. Mean estimated survival was 0.7% higher for Sawtooth Hatchery groups released during daytime than for those released the previous night, but this difference was not significant.

For radio-tagged groups, respective estimates of survival were 9.3, 5.9, and 3.6% for Oxbow, Sawtooth daytime, and Sawtooth nighttime releases. Mean estimated survival to Lower Granite Dam was 2.3% higher for radio-tagged Sawtooth Hatchery fish released during daytime than for those released the previous night, but this difference also was not significant.

For sockeye salmon from both hatcheries, estimated survival to Lower Granite Dam was lower for groups with both a PIT and radio-tag than for those with only a PIT-tag. Passage distributions at Lower Granite Dam indicated that all release groups traveled together through the entire study area, regardless of tag treatment or release time. Therefore, study groups likely experienced similar conditions throughout the monitored reaches.

In general, migration rates for radio-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. From the second year of investigation between daytime vs. nighttime release strategies, results suggest that the group released first had a higher rate of survival, regardless of whether the release occurred during daylight or darkness hours. Thus, the sequence of release may be a more important factor for survival than light conditions at the time of release.

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 more southern latitudes than those of any other sockeye salmon population (Bjornn et al. 1968; Foerster 1968).

The Sawtooth Valley is home to 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 to this weir dropped from 4,361 in 1955 to 1 in both 1988 and 1989. These extremely low returns led to a biological status review of sockeye salmon in the Snake River Basin (Waples et al. 1991a). This status review was followed by the listing of Snake River sockeye salmon as an endangered ESU (evolutionarily significant unit) under the U.S. 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 rather than threatened (Saul, et al. 2004), and Waples et al. (1991a) reported that this ESU is 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 more than 20 years of captive broodstock rearing, hatchery production of Snake River sockeye salmon has increased, with current annual production between 200,000 and 300,000 juveniles.

To accommodate these levels of production, the Idaho Department of Fish and Game (IDFG) has constructed a new hatchery with funding from the Bonneville Power Administration (BPA). The goal of this hatchery is to increase annual production of Snake River sockeye salmon smolts to 1 million (a three- to fivefold increase). The first migration year for juvenile 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, hatcheries of origin, and years. Based on detections of hatchery juvenile sockeye 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 78.0% (SE 13.7) in 2007 (Peterson et al. 2008).

These low estimates of survival may be related to competition with non-native species, predation, environmental conditions, or rearing and release conditions. Low rates of survival may also be related to hatchery release strategies, which often result in large concentrations of juvenile salmonids (Waples 1991b) that can be rapidly exploited by predators (Shively et al. 1996; Collis et al. 1995). Disease, particularly bacterial kidney disease, has also 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 1991b).

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 salmon between the Sawtooth Valley and Lower Granite Dam. Two such recommendations are documented for the Federal Columbia River Power System: the National Marine Fisheries Service Biological Opinion (NMFS 2008) and the Adaptive Management Implementation Plan for 2008-2018 (NMFS 2009).

A major goal of this study to evaluate smolt travel time and survival estimates, which can provide insight into key uncertainties and help fill the data gaps identified by these regional recovery programs. Results from this study will contribute to management decisions that can play a significant part in the recovery of ESA listed Snake River sockeye salmon.

We applied a multifaceted tracking approach, using both PIT and radio-telemetry monitoring to identify the magnitude and locations of smolt mortality 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. Specific research objectives in 2014 were:

1) Estimate survival and travel time to Lower Granite Dam using PIT and radio telemetry and compare passage performance metrics among 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

The study area was a 750-km reach of the Salmon and Snake Rivers in 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 dams on the Snake and Columbia River.

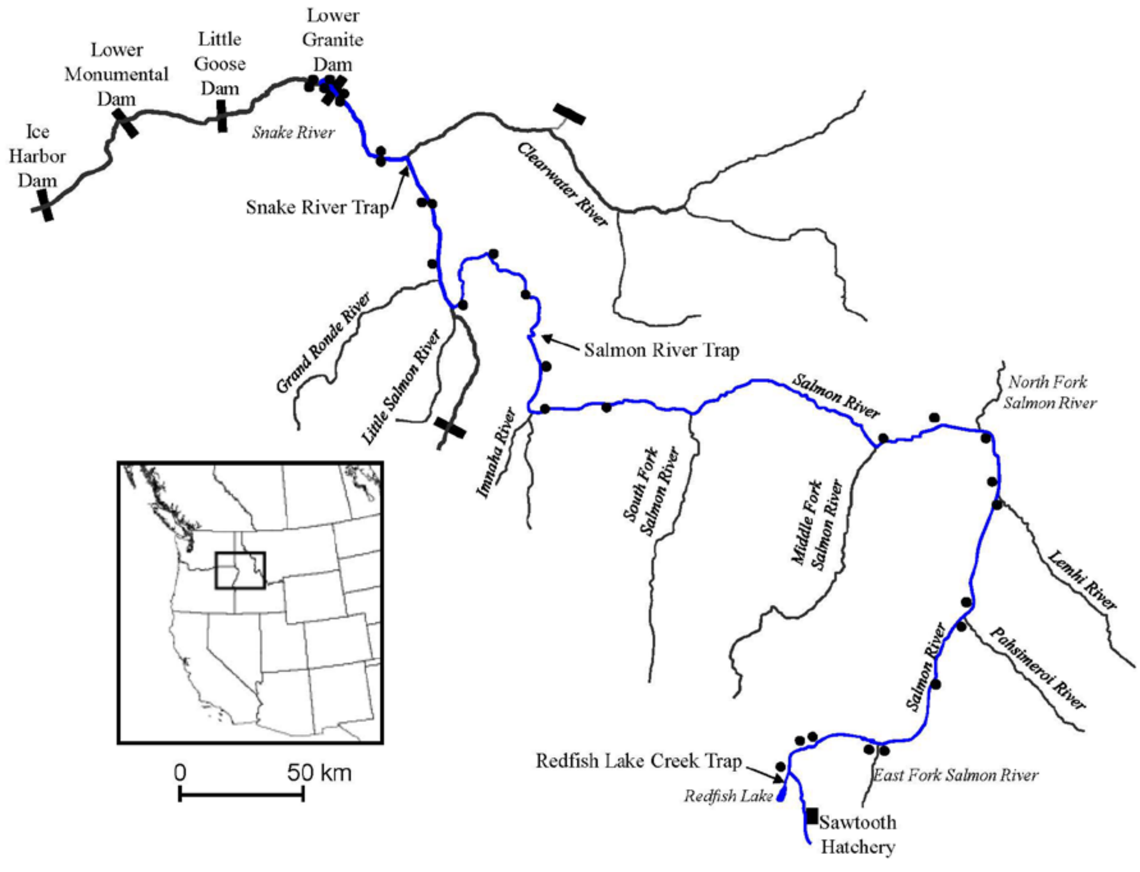

Figure 1. Map of study area showing migratory path of Snake River sockeye salmon from release near the Redfish Lake Creek Trap to Lower Granite Dam. Black dots show approximate locations of fixed-site telemetry receivers. Arrows show locations of smolt monitoring traps; bars indicate lower Snake River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

PIT-Tag Release Groups

We tracked and analyzed survival and travel time of PIT-tagged hatchery sockeye salmon smolts and compared these metrics with those of radio-tagged cohorts from the same hatchery populations. However, no fish were PIT-tagged specifically for this study. Groups of fish from Sawtooth and Oxbow Hatchery were 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).

In 2014, the Oxbow Hatchery production release totaled 122,004 sockeye salmon smolts (excluding radio-tagged smolts); 2,045 of these fish were PIT-tagged by personnel from IDFG. For PIT-tagged Oxbow Hatchery fish, overall mean fork length at tagging was 143.0 mm (SD 10.3 mm), and tagging occurred 58 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 8 May 2014 between 2300 and 2355 MDT.

Sawtooth Hatchery released 172,250 sockeye salmon production smolts (excluding radio-tagged smolts) in 2014. Of these fish, 49,881 were PIT-tagged during 14-16 March; these fish had an overall mean fork length of 126.6 mm (SD 14.3) when measured on 7 May, 1 d prior to release (Table 1). Sawtooth Hatchery smolts were released in two separate groups (day and night release) to compare survival.

Sawtooth Hatchery nighttime releases were made at the same location and on the same night as Oxbow fish; however, these fish were released earlier, between 2000 and 2045 MST. The Sawtooth nighttime release consisted of 224 radio-tagged fish, 24,942 PIT-tagged fish, and 61,284 non-tagged fish. The Oxbow release consisted of 376 radio-tagged fish, 2,045 PIT-tagged fish, and 119,959 non-tagged fish.

On the following morning, we released the Sawtooth Hatchery daytime group, which was comprised of 219 radio-tagged fish, 24,939 PIT-tagged fish, and 61,085 non-tagged fish. This group was released at the same location as the Oxbow and Sawtooth nighttime groups, but between 1000 and 1040 on 9 May 2014.

At both Sawtooth and Oxbow Hatcheries, PIT-tagging was conducted by staff of PSMFC or IDFG. Fish were tagged with a 12.5-mm, 134.2-kHz PIT tag (Destron Fearing TX1400 SST)[1] following protocols mandated by IDFG and using techniques similar to those described by Prentice et al. (1990a).

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

Tags were injected with an implant gun (Biomark MK 25) that used pre-loaded, 12-gauge hypodermic needles (Biomark BIO12.BPL). This system allowed each fish to be implanted with an individual single-use disposable needle, reducing the chance of disease transmission or injury from dull needles. The system also required fewer personnel for tagging operations.

Table 1. Summary statistics of length at tagging for PIT-tagged juvenile sockeye salmon reared at Sawtooth (tagged on 14-16 March 2014) and Oxbow Fish hatcheries (tagged on 11 March 2014).

	PIT-tagged sockeye salmon length (mm)	
	Sawtooth Hatchery	Oxbow Hatchery
Minimum	95	113
Maximum	165	172
Mean (SD)	126.6 (14.3)	143.0 (10.3)

Radio-Tag Release Groups

For radio tagging, we transferred a subset 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 2014 and Oxbow fish on 12 March 2014. One purpose of these transfers was to manage growth, so that fish would meet size requirements for radio tagging (minimum size of 12.5 g to avoid a tag burden of greater than 6%). A second purpose was 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 450 smolts from Sawtooth (225 for daytime and 225 nighttime release) and 400 from Oxbow Hatchery during 7-10 April 2014. 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 with a 5-second pulse interval (12 ppm) for identification of individual fish. Radio tags measured 13 mm in length by 5 mm in diameter and had an average volume of 230 mm^3 and average weight of 0.75 g in air. Each tag also 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 implanted using techniques described by Adams et al. (1998). Surgeons inserted a PIT tag 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 aid in fish stabilization during surgery. The foam pad was coated with a water conditioner (PolyAqua, Kordon LLC, Hayward, California) to minimize impacts to the fish's 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. Approximately 30 seconds before completion of each surgical procedure, we replaced the flow of anesthetic solution with oxygenated freshwater to begin the recovery process.

To implant the transmitter, a 7-9 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 gauge × 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 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 recovery 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 29-32 d for recovery and determination of post-tagging mortality. During the recovery period, 4 mortalities occurred when fish jumped out of the holding tank, and 15 fish shed radio tags. Investigation revealed that these tags were likely pulled out due to catching of external antennas. All 15 fish survived and retained their PIT tags, so we released them with the rest of the fish. We re-implanted the 15 tags using additional fish to retain planned sample sizes 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 correct in the database. During this process, we found 14 fish with tags that were not operating, and we removed these fish from the analysis. Transport buckets were loaded into 1,152-L transport tanks where fish were held overnight and maintained with flow-through hatchery water.

On the morning of 8 May 2014, we transported radio-tagged sockeye salmon from Eagle Hatchery to the release location on Redfish Lake Creek. Upon arrival at the release site, fish were acclimated until water temperatures in the transport tank and river were within 1°C. Fish were released into the creek at mid channel. We released all fish at a bridge approximately 0.75 km downstream from Redfish Lake.

Sawtooth Hatchery fish with either PIT or radio-tags (and a PIT tag) were separated into two groups, with one released during the night at 2000 MST and the other the next morning at 1000. Both the radio and PIT-tagged fish from Oxbow Hatchery were released on 8 May at 2300.

For radio-tagged study fish, overall mortality between tagging and release (30 d) was 0.2% (1 fish) for both Sawtooth groups combined and 0.8% (3 fish) for the Oxbow group. Fork length and weight at tagging are summarized by hatchery in Table 2. Tag burden (as measured by percent tag weight/body mass) ranged 1.2-5.4% and averaged 3.0% overall.

Table 2. Summary statistics of fork length and weight at tagging for radio-tagged juvenile sockeye salmon from Oxbow and Sawtooth Fish Hatcheries, 2014.

	Fork length (mm)		Weight (g)	
	Oxbow	Sawtooth	Oxbow	Sawtooth
Minimum	119.0	115.0	14.8	13.9
Maximum	175.0	176.0	59.3	62.2
Mean	143.2	136.4	28.4	25.7
Standard deviation	9.7	11.6	6.5	7.5

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 Figure 1. Maximum 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 limited in some locations based on physical accessibility.

Survival Estimation and Travel Time

Survival estimates for PIT-tagged fish were based on detection data from individual study fish 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 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, and survival between groups was compared using a two sample *t*-test ($\alpha = 0.05$).

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).

Survival estimates for radio-tagged fish were based on detections of individuals at fixed-site telemetry receivers (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 survival from release to Lower Granite Dam.

Tag life of the radio transmitters was tested from a sample of 50 tags tested in water. None of the 50 test tags shut down over the 30-d study period. Survival estimates were not adjusted for tag life, since all transmitters tested had sufficient tag life for fish to migrate through the study area.

For individual radio-tagged fish, travel time was calculated as the time between the last detection at a given telemetry receiver and 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 calculated from travel time data are reported in kilometers per hour (km/h).

Results

Detection probabilities

For PIT-tagged sockeye salmon, estimated probabilities of detection at Lower Granite Dam were 7.5% (SE 1.7%) for Oxbow Hatchery fish. Detection probabilities for Sawtooth fish were 16.1% (SE 0.8%) for daytime releases and 15.3% (SE 0.8%) for nighttime releases. Detection probabilities at Lower Granite Dam were higher for Sawtooth than for Oxbow Hatchery fish (Table 3).

Detection probabilities at fixed-site radio telemetry monitoring stations ranged from 23.1 to 100.0% (Table 4) and averaged 82.0% overall. Mean probabilities of radio-tag detection were lower in the Snake (64.0%, range 23.1-100.0%) than in the Salmon River (88.0%, range 55.6-100.0%) due to the greater width and depth of the Snake River.

Table 3. Estimated detection probability at Lower Granite Dam for PIT and radio-tagged juvenile hatchery sockeye salmon smolts released to Redfish Lake Creek, 2014. 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)	7.5 (1.7)
Sawtooth Hatchery (day)	16.1 (0.8)
Sawtooth Hatchery (night)	15.3 (0.8)
Radio-tagged fish	
Oxbow Hatchery (night)	11.4 (7.5)
Sawtooth Hatchery (day)	No fish detected
Sawtooth Hatchery (night)	*66.7 (15.7)
	Estimates based on radio-tag detections
Radio-tagged fish	
Oxbow Hatchery (night)	100.0 (0.0)
Sawtooth Hatchery (day)	92.3 (7.4)
Sawtooth Hatchery (night)	100.0 (0.0)

* Based on 9 fish detected.

Table 4. Estimated mean detection probability for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon at fixed-site radio telemetry monitoring locations, 2014. 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		
		Sawtooth	Oxbow	Sawtooth
No.	Description	(night)	(night)	(day)
2	Below Little Redfish Lake	85.8 (3.2)	94.7 (1.4)	92.7 (2.1)
3	Above Valley Creek confluence	88.6 (3.0)	97.7 (0.9)	95.1 (1.8)
4	Below Lower Stanley	87.6 (3.3)	98.7 (0.7)	95.4 (1.8)
5	Above East Fork Salmon R confluence	91.5 (2.9)	98.7 (0.7)	97.7 (1.3)
6	Below East Fork Salmon R confluence	89.7 (3.4)	99.1 (0.7)	97.4 (1.5)
7	Challis Bridge	75.0 (5.3)	70.3 (3.2)	71.0 (4.4)
8	Above Pahsimeroi R confluence	89.1 (3.9)	97.3 (1.2)	97.1 (1.7)
9	Below Pahsimeroi R confluence	90.5 (4.5)	98.5 (1.0)	97.4 (1.8)
10	Above Lemhi R confluence	89.7 (4.9)	98.4 (1.1)	97.1 (2.0)
11	Below Lemhi R confluence	87.9 (5.7)	98.2 (1.2)	96.0 (2.8)
12	Above North Fork Salmon R confluence	78.9 (9.4)	98.4 (1.6)	96.6 (3.4)
13	Below North Fork Salmon R confluence	76.5 (10.3)	100.0 (0.0)	86.4 (7.3)
14	Above Middle Fork Salmon R confluence	73.3 (11.4)	97.8 (2.1)	76.2 (9.3)
15	Vinegar Creek boat launch	73.3 (11.4)	100.0 (0.0)	90.5 (6.4)
16	Above Little Salmon R confluence	71.4 (12.1)	100.0 (0.0)	90.0 (6.7)
17	Below Little Salmon R confluence	66.7 (13.6)	97.6 (2.4)	68.4 (10.7)
18	Hammer Creek Recreation Area	72.7 (13.4)	85.0 (5.7)	61.1 (11.5)
19	Rice Creek Bridge	72.7 (13.4)	97.5 (2.5)	55.6 (11.7)
20	Below Grande Ronde R confluence	80.0 (12.6)	82.5 (6.0)	55.6 (11.7)
22	Above Clearwater R confluence	60.0 (15.5)	50.0 (8.1)	33.3 (11.1)
23	Below Clearwater R (right bank)	70.0 (14.5)	73.0 (7.3)	53.3 (12.9)
24	Below Clearwater R (left bank)	55.6 (16.6)	67.6 (7.7)	23.1 (11.7)
25-27	Lower Granite Dam forebay	50.0 (17.7)	66.7 (7.9)	38.5 (13.5)
28-29	Lower Granite Dam tailrace	100.0 (0.0)	100.0 (0.0)	92.3 (7.4)

Estimated Survival

Estimated survival to Lower Granite Dam for PIT-tagged sockeye salmon from Oxbow hatchery was 50.5%. For Sawtooth Hatchery fish, estimated survival was 53.5% for daytime releases and 52.8% for nighttime releases (Table 5). For radio-tagged sockeye salmon, estimated survival to the dam was 9.3% for Oxbow night releases, 5.9% for Sawtooth daytime releases, and 3.6% for Sawtooth nighttime releases.

For fish from Sawtooth Hatchery, the difference in estimated survival between daytime and nighttime releases was 0.7% for PIT tag groups and 2.3% for radio-tagged groups. The difference in survival between these release groups was not statistically significant based on either telemetry (P = 0.298) or PIT detections (P = 0.457).

Table 5. Estimated survival from release in Redfish Lake Creek to Lower Granite Dam for PIT- and radio-tagged juvenile Snake River sockeye salmon in 2014. 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	50.5 (10.0)
Sawtooth Hatchery (day)	53.5 (2.3)
Sawtooth Hatchery (night)	52.8 (2.4)
Radio-tag	
Oxbow Hatchery	26.6 (16.1)
Sawtooth Hatchery (day)	No fish detected
Sawtooth Hatchery (night)	6.6 (1.9)
	Estimates based on radio-tag detection
Radio-tag	
Oxbow Hatchery	9.3 (1.5)
Sawtooth Hatchery (day)	5.9 (1.6)
Sawtooth Hatchery (night)	3.6 (1.2)

For each radio-tagged release group, we estimated median survival within individual reaches between Redfish Lake Creek and Lower Granite Dam. For all three groups, most observed mortality occurred between release and the North Fork of the Salmon River (Table 6).

Table 6. Estimated survival for radio-tagged Oxbow and Sawtooth hatchery sockeye salmon within various reaches between release in Redfish Lake Creek and Lower Granite Dam, 2014. Standard errors are in parentheses.

Receiver site		Estimated survival of radio-tagged groups (%) and SE		
number	Site description	Sawtooth (night)	Oxbow (night)	Sawtooth (day)
Release–2	Release—Below Little Redfish Lake	77.5 (3.2)	79.5 (2.1)	83.6 (2.6)
2–3	Below Little Redfish Lake—Valley Creek confluence	69.6 (3.8)	85.7 (2.1)	81.0 (3.0)
3–4	Valley Creek confluence—Below Lower Stanley	96.4 (2.4)	97.4 (1.0)	96.2 (1.7)
4–5	Below Lower Stanley—Above East Fork Salmon R	83.6 (3.7)	92.1 (1.7)	90.6 (2.5)
5–6	Above East Fork Salmon R—Below East Fork Salmon R	98.5 (2.1)	99.2 (0.6)	98.7 (1.1)
6–7	Below East Fork Salmon R—Challis Bridge	84.9 (4.6)	92.6 (2.2)	91.4 (3.1)
7–8	Challis Bridge—Above Pahsimeroi R	84.2 (4.8)	89.6 (2.5)	90.6 (3.2)
8–9	Above Pahsimeroi R—Below Pahsimeroi R	96.8 (3.8)	96.7 (1.4)	96.8 (2.0)
9–10	Below Pahsimeroi R—Above Lemhi R	63.9 (6.3)	72.1 (3.3)	74.5 (4.4)
10–11	Above Lemhi R—Below Lemhi R	94.1 (4.7)	91.9 (2.4)	91.7 (3.5)
11–12	Below Lemhi R—Above North Fork Salmon R	92.2 (9.0)	90.9 (2.8)	71.6 (5.7)
12–13	Above North Fork Salmon R—Below North Fork Salmon R	53.4 (9.7)	56.3 (4.7)	59.3 (7.5)
13–14	Below North Fork Salmon R—Above Middle Fork Salmon R	90.4 (9.7)	79.9 (5.0)	74.1 (8.9)
14–15	Above Middle Fork Salmon R—Vinegar Creek boat launch	84.6 (10.0)	90.0 (4.2)	94.1 (5.7)
15–16	Vinegar Creek boat launch—Above Little Salmon R	100.0 (0.0)	93.5 (3.6)	100.0 (0.7)
16–17	Above Little Salmon R—Below Little Salmon R	97.4 (11.0)	100.0 (0.0)	96.9 (5.8)
17–18	Below Little Salmon R—Hammer Creek Recreation Area	82.5 (13.4)	95.6 (3.3)	96.0 (7.9)
18–19	Hammer Creek Recreation Area—Rice Creek Bridge	88.9 (10.5)	97.1 (2.8)	91.7 (8.0)
19–20	Rice Creek Bridge—Below Grande Ronde R	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
20-22	Below Grande Ronde R—Above Clearwater R	88.9 (10.5)	100.0 (0.0)	100.0 (0.0)
23-24	Above Clearwater R— Below Clearwater R	100.0 (0.0)	96.4 (3.5)	100.0 (0.0)
24–LGRF	Below Clearwater R—Lower Granite Dam forebay	92.6 (20.1)	100.0 (0.0)	60.0 (21.9)
LGRF-LGRT	Lower Granite Dam forebay—Lower Granite Dam tailrace	80.0 (17.9)	96.0 (3.9)	100.0 (0.0)

Sawtooth Hatchery nighttime releases were made after dusk (2000), Oxbow Hatchery fish later that night (2300), and Sawtooth daytime releases were made the following morning (1000). Based on findings from the previous year, we had hypothesized that predation on Sawtooth Hatchery sockeye salmon could be reduced by scheduling their release time immediately after dark. However, while we did not observe a significant difference in survival in the first reach, overall survival from release to Lower Granite was lowest for fish released first (Sawtooth nighttime release).

For radio-tagged fish, survival was lower in both nighttime release groups, with most observed mortality occurring between the release site and the North Fork Salmon River. We observed nearly a 20% loss for all three release groups between the release location in Redfish Lake Creek (receiver site 1) and the exit site below Little Redfish Lake (receiver site 2).

One reach of particular concern is the area between the Pahsimeroi and Lemhi River (Table 6; receiver sites 8-9), where all three groups encountered larger losses than they had in the previous reaches. Survival also dropped considerably for all three groups within the short reach that encompasses the mouth of the North Fork Salmon River (Table 6; receiver sites 12-13).

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. Estimated mortality for the Sawtooth nighttime release was 5.7% higher than that of the Oxbow release (later that night) and 2.3% higher than that of the Sawtooth daytime release based on radio telemetry. Higher estimated mortality rates were also observed for the Sawtooth nighttime release of PIT-tagged fish; however, the difference was much smaller (0.7%). Note that survival estimates from the same Oxbow Hatchery fish, but based on PIT rather than radio-telemetry data, resulted in a 17.3% higher rate of survival.

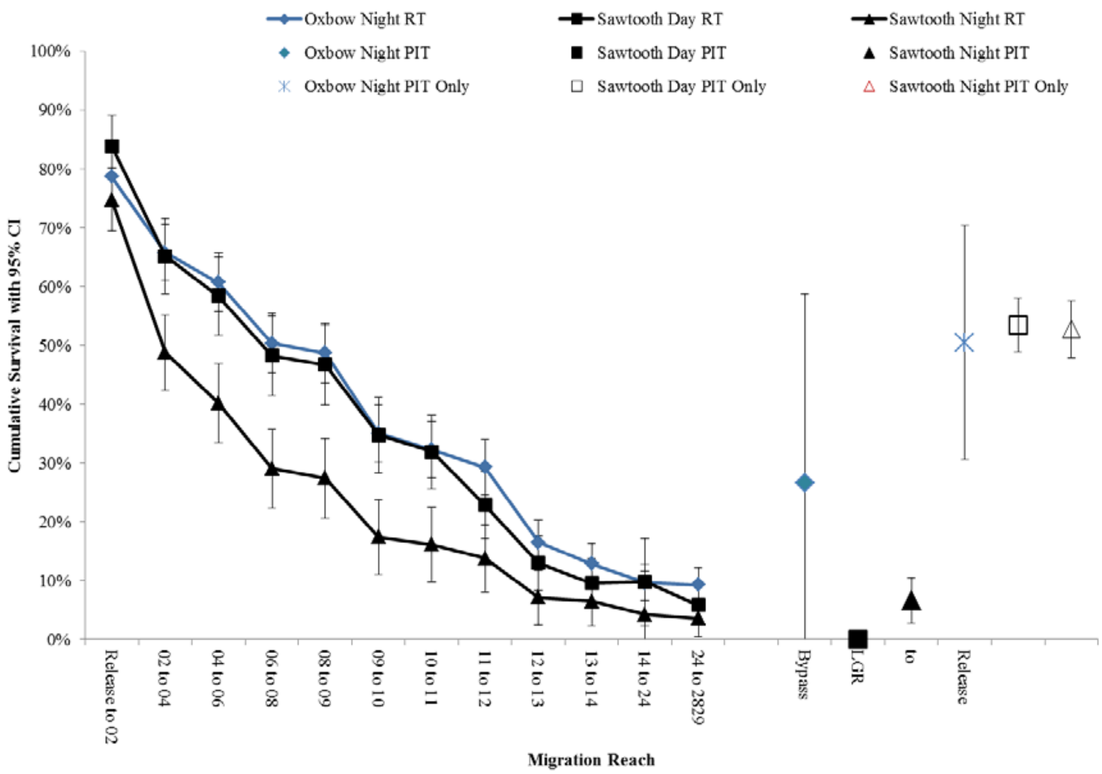

Figure 2. Left side shows cumulative survival by reach from release to the tailrace of Lower Granite Dam. To the right of the cumulative estimates, point estimates of survival from release to the bypass system of Lower Granite Dam are shown by hatchery and tag treatment. Juvenile sockeye salmon were surgically implanted with both a radio transmitter (RT) and PIT tag (PIT) or injected with only a PIT tag (PIT only). Fish were released into Redfish Lake Creek on 8-9 May 2014. Whisker bars represent 95% confidence intervals.

Travel Time

A total of 51,926 PIT-tagged 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 8.9-10.0 d. Passage distributions at Lower Granite Dam indicated that both PIT only and radio-tagged groups traveled together through the entire study area. The only observed timing difference was between PIT- and radio-tagged fish from the Sawtooth daytime release. Therefore, these fish likely experienced similar conditions throughout the migration areas monitored (Figure 3).

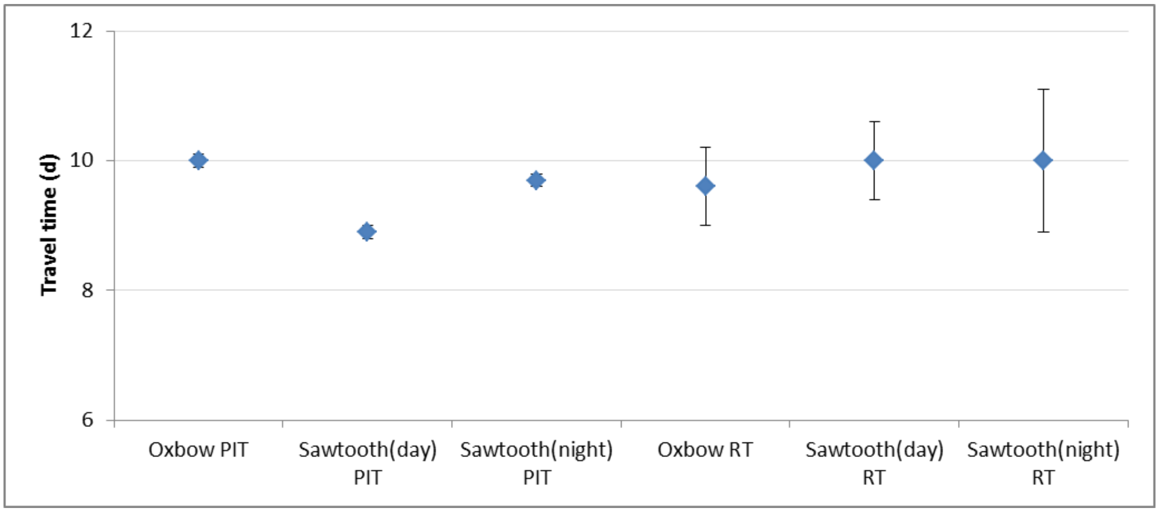

Figure 3. Median travel time to Lower Granite Dam of PIT- and radio-tagged (RT) juvenile hatchery sockeye salmon released to Redfish Lake Creek, 8-9 May 2014.

In general, migration rates for radio-tagged sockeye salmon were similar through all of the reaches and increased as they continued downstream until fish arrived in the section of the Snake River influenced by the hydropower system (i.e, below the confluence of the Snake and Clearwater River; Figure 4). However, reductions in migration rate occurred at tributaries to the Salmon River (i.e. East Fork Salmon, Pahsimeroi, Lemhi, and Little Salmon Rivers).

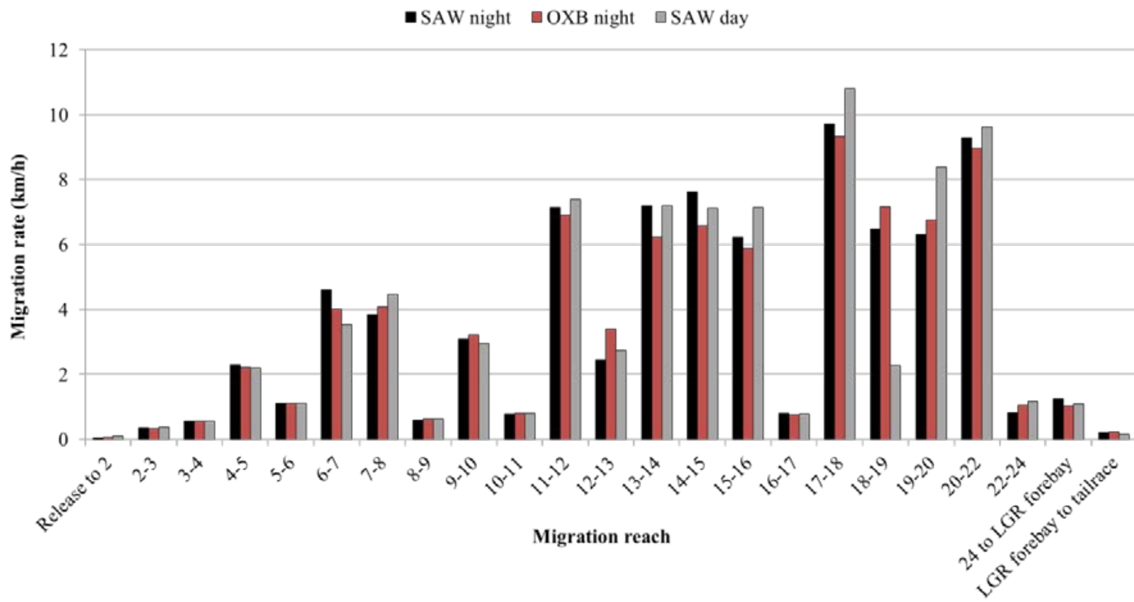

Figure 4. Migration rates of radio-tagged hatchery sockeye salmon within individual reaches between Redfish Lake Creek and the tailrace of Lower Granite Dam (LGR), 2014.

An additional reach of concern was between receiver sites 12 and 13. This partition encompasses the area known as Deadwater Slough, one of east central Idaho's best birding locations. Deadwater Slough is attractive to various bird species due to its quality riparian habitat, good water quality, and adjacent diverse upland habitats. The area is recommended by the Idaho Fish and Game Watchable Wildlife Program for viewing raptors and other bird species. 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 (receiver sites 23 and above) were likely due to reduced water velocities associated with the hydropower system.

In general, 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.

Discussion

We continued to investigate detection probabilities, survival, and migration timing for cohorts of PIT- and radio-tagged hatchery smolts for the third consecutive migration year. In 2014, we compared survival between daytime and nighttime releases for the second consecutive year. Each tagging method and release strategy has potential advantages and disadvantages that need to be thoroughly investigated across multiple years and for each species of salmon in order to ensure precise estimates of survival.

For example, PIT tags have been shown to work well for estimating survival of juvenile salmonids migrating through the Snake and Columbia River hydrosystem overall (Muir et al. 2001; Skalski et al. 1998). However, PIT detection requires large release groups of tagged smolts and relies mostly on stationary detection facilities at the dams. There may also be losses due to shed tags or mortalities associated with tagging (Hockersmith et al. 2003).

In contrast, radio-tags have longer reading range with higher detection probabilities, and therefore require fewer tagged fish. When multiple detectors are available, radio tags offer very high resolution in determining areas of mortality along fish migration corridors. However, impaired growth, feeding, and survival have been associated with the higher tag burdens experienced by fish with these tags (Hockersmith et al. 2003).

In 2014, we continued to observe higher probabilities of detection for radio-tagged fish (>90%) than for PIT-tagged fish (<20%) at Lower Granite Dam. Detection probabilities ranged from 7.5% for the Oxbow Hatchery PIT-tag group to 66.7% for the Sawtooth Hatchery radio-tagged group (night release). However, the latter estimate was based on only nine fish. This year marks the third year that larger smolts produced at Oxbow Fish Hatchery have been observed with the lowest detection probability at Lower Granite Dam based on PIT-tag data.

One possible explanation for differing detection probabilities within PIT-tagged fish groups is a possible divergence of passage routes at Lower Granite Dam related to fish size. 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 Oxbow fish may have been attracted more readily to the surface flows provided by the removable spillway weir (RSW) and passed over the spillway.

At present, fish passing via spillways cannot be detected by PIT tag monitoring systems. However, preferred passage routes at Lower Granite Dam for fish of different sizes or tag types have not been investigated for Snake River sockeye salmon. Adams et al. (2014) suggested that physiological and behavioral differences observed at Lower Granite Dam and their relation to migration timing and environmental factors (e.g. flow) are not well understood for species other than steelhead. It is reasonable to assume that such differences, as well as differences related to passage route, may well exist.

Further investigation is warranted to determine whether survival estimates for Snake River sockeye salmon are biased due to differences in detection probability (i.e., passage route) among fish of different sizes. There is a direct relationship between precision of survival estimates and detection probability.

For fish from either hatchery, we obtain high precision in survival estimates for radio-tagged groups due to their high probabilities of detection. For Sawtooth Hatchery releases of PIT-tagged fish, relatively precise estimates are obtained due to the large number of fish tagged (~25,000 fish are PIT-tagged), even with lower probabilities of detection. Conversely, for Oxbow Hatchery releases of PIT-tagged fish, the precision of survival estimates is lower because smaller numbers of fish are tagged (400-2,045) with a lower probability of detection for each tagged fish.

For sockeye salmon from both Oxbow and Sawtooth Hatchery, estimated survival from release to Lower Granite Dam in 2014 was considerably lower for radio-tagged than for PIT-tagged groups. For groups of PIT-tagged fish released to Redfish Lake Creek in 2014, estimated survival to the dam ranged 50.5-53.5%; for radio-tagged groups, survival ranged only 3.6-9.3%. However, estimated survival differed by tag type for Oxbow Hatchery fish marked with both a radio and PIT tag: for the same fish, estimated survival was 23.9% higher based on PIT-tag than based on radio-tag detections.

These estimates of survival based on radio-tag data were the lowest obtained during our 3-year evaluation. Based on PIT-tag detections at Lower Granite Dam, we concluded that travel time data for radio-tagged juvenile sockeye salmon during 2014 was representative of the production populations at both Oxbow and Sawtooth Hatchery.

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. However, this knowledge provides no insight as to the major differences observed between radio-tag and PIT-tag survival estimates.

Mortality associated with radio tags may be contributing to the lower estimates of survival for fish with these tags. The tagging protocol that we began in 2012 involved tagging fish at Eagle Hatchery near Boise, Idaho, 30 d prior to release. The purpose of this protocol was to allow fish adequate time to recover from the surgical process. In 2014, we observed only four mortalities during the recovery period, and we observed no mortalities after transport to Redfish Lake Creek. All four mortalities occurred when fish jumped out of the tank and were not related to the tagging procedure. Tag burden for radio-tagged fish ranged 1.2-5.3% and averaged 3.0% 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. 2009), and more specifically, of juvenile sockeye salmon (Collins et al. 2013).

Brown et al. (2006) reported that tag burdens of 5.8-8.5% decreased critical swimming speed for juvenile sockeye salmon. While tag burdens for our fish were well within the range identified as "safe" in the studies above, these studies were based on acoustic telemetry tags (Hall et al. 2009; Anglea et al. 2004; Chittenden et al. 2009; Collins et al. 2013). Acoustic tags in these studies were surgically implanted using methods similar to those used here; however, acoustic tags do not carry a 30-cm long external antenna.

Studies have identified potential impacts related to the presence of an external antenna. Anglea et al (2009) suggested that hydraulic drag associated with an antenna likely decreased swimming performance of juvenile fish and may present more of a burden than tag weight. Hockersmith et al. (2003) also reported that the "presence of a trailing antenna probably reduces swimming performance, foraging ability, predator avoidance, and ultimately survival." They also pointed out that estimates of survival based on PIT and radio-tags diverged with increasing distance and travel time.

Hockersmith et al. (2003) reported significant differences in estimated survival of Chinook salmon treatment groups that traveled further than 225 km or that had travel times in excess of 6 d. Our study groups travel approximately 750 km over a period of 8.9-10 d. These findings suggest that tag effects may have developed as a factor that influenced survival over the length of our study period. Investigation of a potential increase in tag effects is warranted, considering the geographical distance and travel times being evaluated for this study.

Notwithstanding the limitations associated with radio tags, they have been useful in identifying areas of high mortality in the study reaches. In 2014, 60 fixed receivers were placed. Based on data from these receivers, we were able to identify three reaches in particular where estimates of survival were lower, compared to the rest of the study area. These reaches were:

1) From release to the Valley Creek confluence (receiver sites 1-3)
2) From below the Pahsimeroi River to the confluence with the Lemhi River (receiver sites 9-10)
3) At the confluence with the North Fork Salmon River (receiver sites 12-13)

In the first reach, fish passed through Little Redfish Lake, where we have observed bull trout actively feeding on schools of juvenile sockeye salmon as they enter the lake. In addition, avian predator populations were very active in and around the lake just after study fish were released.

The third reach encompasses the area known as Deadwater Slough, a well-known birding area in central Idaho inhabited by raptors and other piscivorous bird species. Flow in this area is visibly slower, and juvenile sockeye salmon traversing this reach have been shown to travel at a considerably reduced rate.

Since the initiation of our study in 2012, we have estimated lower rates of survival for sockeye salmon study fish in all three of these reaches compared to the reaches surrounding them (Axel et al 2013; Axel et al 2014).

Lastly, in 2014 we continued to investigate whether there is any benefit to nighttime release of the smaller Sawtooth Hatchery smolts. For PIT-tagged groups of these fish, mean estimated survival to Lower Granite Dam was 0.7% higher for fish released at night compared to those released during the day, but the difference was not statistically significant. For radio-tagged groups of these fish, mean estimated survival to the dam was 2.3% higher for nighttime than for daytime releases, but again, the difference was not significant.

In 2014, we released the nighttime group before the daytime group to evaluate whether order of release had a greater influence on survival than time of day. We observed lower survival for nighttime releases of both tag types, but the difference was not significant for either tag type. In 2013, we released the nighttime group after the daytime group, and estimated survival was higher for fish released at night.

However, based upon the results and patterns of release for both years, there is no indication that nighttime releases had higher survival than daytime releases. However, there is some evidence to indicate that the order of release is important. It is possible that the first release of fish may have lower rates of survival because they enter areas of high predation prior to the other groups, and thus may be subjected to greater rates of predation.

Other factors such as detection probabilities associated with tag, size at release, flow conditions, and other environmental factors also interact and influence survival through the migration corridor. Data collected in 2014 will further contribute to our understanding of the influence of tagging methods on survival, and this understanding may inform our methods for future releases planned for Springfield Hatchery juvenile sockeye salmon.

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