Characterizing migration and survival between the Upper Salmon River Basin and Lower Granite Dam for juvenile Snake River sockeye salmon, 2011-2014

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Executive Summary

During spring 2011-2014, 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 coordinated study to characterize migration and survival of juvenile sockeye to Lower Granite Dam. We estimated detection probability, survival, and travel time based on detections of fish tagged with either a passive integrated transponder (PIT) or radio transmitter and PIT tag. Passage metrics were then compared between cohorts of fish from Sawtooth vs. Oxbow Fish Hatcheries and between fish released during daytime vs. nighttime periods.

For PIT-tagged study fish in 2011, estimated survival from release to Lower Granite Dam was 72.8% for Sawtooth and 77.1% for Oxbow groups. These were among the highest estimates of survival since the sockeye salmon captive broodstock program began 16 years ago. However, for study fish with radio-tags in 2011, survival to Lower Granite Dam was only 14.2% based on estimates derived from radio-tag detections.

We determined that these low survival estimates for radio-tagged fish resulted from detrimental effects caused by a combination of factors that were not experienced by PIT-tag fish groups. First, fish designated for radio-tagging experienced a significant change in elevation shortly before the surgical procedure due to transport from rearing to tagging locations (PIT-tagged fish were not transported). Second, these fish experienced insufficient acclimation periods prior to surgery, as well as short post-surgical recovery periods. Third, these fish had attained relatively advanced levels of smoltification at the time of tagging. For these reasons, we concluded that fish radio-tagged in 2011 were not representative of the general population at either Oxbow or Sawtooth Hatcheries.

In the three remaining study years, we transferred subsets of juvenile Snake River sockeye salmon from Sawtooth and Oxbow Hatcheries to Eagle Hatchery in Eagle, Idaho. These transfers allowed us to manage growth, so that fish would meet size requirements for radio tag implantation. They also provided sufficient time for fish to acclimate to elevation changes prior to surgery and for post-surgical monitoring of tag effects prior to release.

In 2012, we observed only three mortalities during the 30 d post-surgery recovery period, and no mortality was observed after transport to Redfish Lake Creek. In subsequent study years, we observed similarly low rates of mortality after tagging and transport. We determined that the early transfer and 30-d post-surgical recovery protocols successfully resolved the problems associated with acclimation and tagging effect that were observed during the first year of study.

However, in the remaining study years, from 2012 to 2014, estimated survival to Lower Granite Dam remained lower for radio-tagged fish from both hatcheries, ranging 3.6-51.8% for radio vs. 50.5-69.4% for PIT-tag groups.

Passage distributions at Lower Granite Dam indicated that tag treatment groups traveled together through the entire study area, regardless of hatchery or release time. In general, migration rates for PIT vs. radio-tagged groups were similar and increased as fish continued downstream until they reached the confluence of the Snake and Clearwater River, where the Snake River is influenced by the hydropower system. These detection data showed that tag treatment groups experienced similar conditions throughout all study reaches during 2012-2014. However, these data provided little insight into the large differences in estimated survival to Lower Granite Dam between tag groups.

Because both tag groups experienced similar passage conditions, but mortality was higher for radio-tagged groups, we inferred that mortality related to a radio-tag effect likely developed as a factor that influenced survival. For yearling Chinook salmon, previous research has shown significant differences in survival between radio and PIT-tagged groups that traveled further than 225 km or had travel times in excess of 6 d. Our study groups traveled approximately 750 km over a period of 7-10 d. Thus, mortality associated with tag effects was a likely contributor to the lower estimated survival to Lower Granite Dam for fish with radio tags.

Despite the limitations associated with radio tags over longer distances, these tags were useful in identifying study reaches where fish experience high rates of mortality, an important objective of our study. Radio-tag data indicated two reaches in particular where estimated survival was lower for daytime and nighttime release groups and for releases from both hatcheries across all three years. The first of these reaches was between the release site and the Salmon River at its confluence with Valley Creek, about 9 rkm downstream from the release site. The second was at the confluence of the Salmon and North Fork Salmon Rivers, about 238 rkm downstream from release.

The first reach includes Little Redfish Lake, where we saw bull trout and avian predators feeding on schools of juvenile sockeye as they entered the lake. The second reach encompasses Deadwater Slough, an area known for low water velocities and good water quality. These conditions facilitate predation by piscivorous birds and fish. Both Smallmouth bass and Northern pikeminnow have been observed in this reach, which is also near a number of heron rookeries. Radio-tag data showed that juvenile sockeye salmon had considerably slower migration rates through this reach.

During the last two study years, we investigated whether estimated survival would differ between daytime vs. nighttime release groups of juvenile sockeye salmon. This investigation indicated that the sequence of release might be a more important factor for survival than light conditions at the time of release. Our results suggest that regardless of whether groups were released during daylight or darkness hours, the group released first had a lower rate of survival. It is possible that groups were subjected to greater rates of mortality because they were the first to enter areas of high predation.

Overall, our research underlined both the value and limitation of radiotelemetry technology for the study of survival and migration performance in juvenile salmon. Tag-related effects on survival impaired our ability to provide representative estimates of sockeye survival over longer reaches of the Salmon and Snake River. However, radio tag data successfully pinpointed the specific study reaches where higher mortality occurred.

Further work is needed to identify the sources of this mortality and to understand its potential impacts. Such studies will be critical to the long-term success of endangered Snake River sockeye salmon. Results from our research have provided an essential first step toward improved understanding of the challenges faced by sockeye salmon smolts during their juvenile migration.

Contents

Introduction

Anadromous sockeye salmon *Oncorhynchus nerka* that originate in lakes of the Sawtooth Valley, Idaho, make a longer seaward migration than any other sockeye population in the world, traversing a distance of nearly 1,440 km. 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 populations of sockeye salmon in the upper Snake River Basin, with natural 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 sub basin listed as endangered rather than threatened. Saul et al. (2004) and Waples et al. (1991a) reported that this ESU was on the threshold of extinction at the time of listing.

Part of the recovery strategy for Snake River sockeye salmon includes a captive broodstock program to aid in rebuilding the population. Snake River sockeye salmon would likely be extinct without this program (Kline and Flagg 2014). During more than 20 years of captive broodstock rearing, production has increased, with annual releases of between 200,000 and 300,000 juveniles.

To accommodate greater levels of production, the Idaho Department of Fish and Game (IDFG) 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 to 1 million smolts (a three to fivefold increase). Initial releases began in 2015, after this study was completed.

While captive broodstock rearing has increased production numbers for Snake River sockeye, estimated survival of these fish between the Sawtooth Valley and Lower Granite Dam has been highly variable among years, release locations, rearing strategies, and hatcheries of origin. Estimated survival for tagged juvenile sockeye has 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).

Low estimated survival may be attributed to a number of factors, including competition with non-native species, predation, environmental conditions, and rearing and release conditions. In addition, hatchery release strategies often result in large concentrations of juvenile salmonids that move downstream in shoals, which can be rapidly exploited by predators (Waples 1991b; Collis et al. 1995; Shively et al. 1996). Furthermore, the hatchery environment produces high rates of survival prior to release, so that natural culling is postponed until fish are at large (Waples 1991b). Disease levels of hatchery fish have also been shown to increase in severity during migration (Maule et al. 1996).

Thus, despite high production numbers, the successful restoration and recovery of endangered Snake River sockeye salmon will depend on understanding the magnitude of mortality, as well as its locations and causes. Such understanding is critical to measure and assess the effects of recovery strategies such as the captive broodstock program, as well as restoration efforts such as flow augmentation, habitat enhancement, predator management, and 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. For the Federal Columbia River Power System, these specific recommendations are found in both the National Marine Fisheries Service Biological Opinion (NMFS 2008) and the Adaptive Management Implementation Plan for 2008-2018 (NMFS 2009).

This study is encompassed by the broader objectives of providing insight into key uncertainties and helping to fill 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.

In our approach to evaluations of survival and travel time between the Sawtooth Valley and Lower Granite Dam, we applied a multifaceted tracking approach, using both PIT and radio-telemetry techniques to monitor migration across four consecutive years. Each approach offered different strengths and limitations for identifying the magnitude and locations of smolt mortality and for providing estimates of survival over the entire

750-km study reach.   Our approach took advantage of strengths from each tagging technology to provide a more complete understanding of migration and survival characteristics.

Specific research objectives were to:

1) Estimate survival and travel time to Lower Granite Dam using detection data from PIT- and radio-tagged juvenile Snake River sockeye salmon and compare these metrics among different hatchery production groups
2) Estimate survival and characterize migration based on radio-telemetry detections of juvenile Snake River sockeye salmon in specific reaches upstream from Lower Granite Dam.

In this report, we present complete results from this four-year study.

Methods

Study Area

In each year, our study area spanned 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.

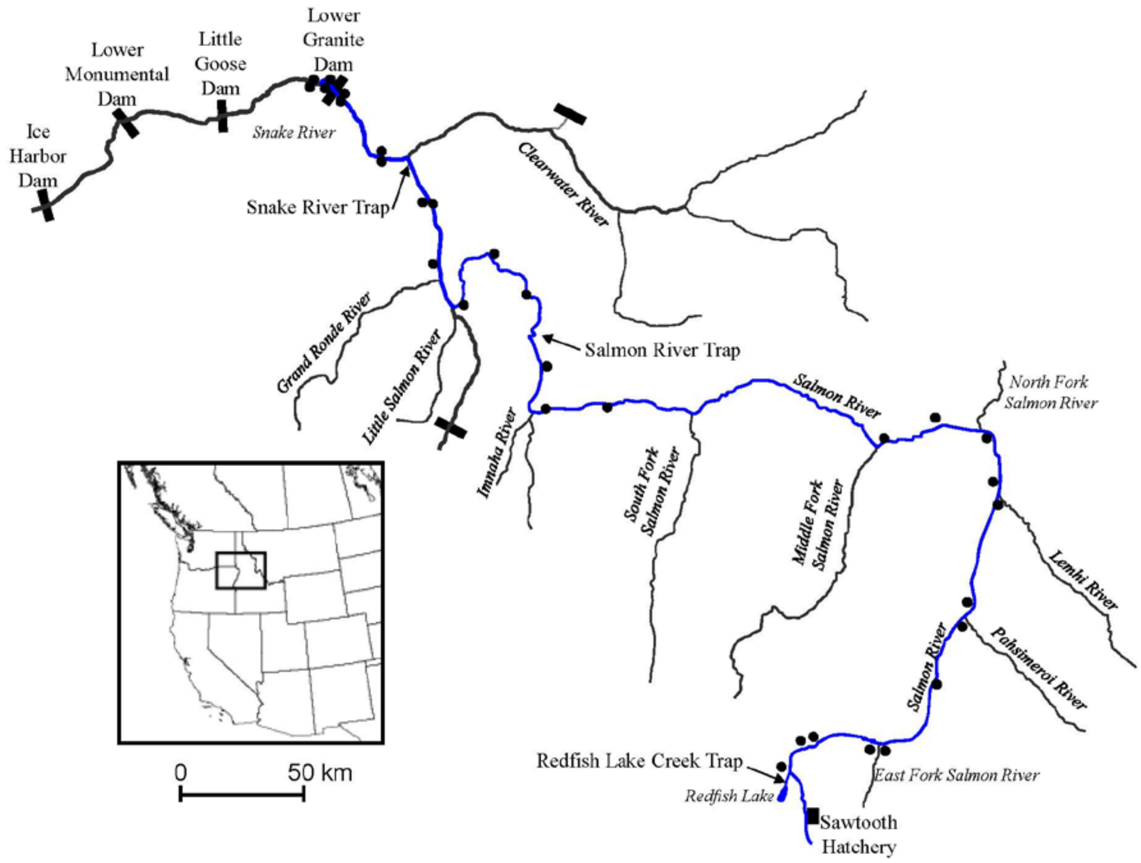

Figure 1. Map of study area showing the path of Snake River Sockeye Salmon as they migrate from release near the Redfish Lake Creek Trap to Lower Granite Dam. Black dots show locations of fixed-site telemetry receivers. Arrows show locations of smolt monitoring traps; bars indicate lower Snake River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

Passive Integrated Transponder (PIT) Tag Groups

Hatchery Releases

We did not PIT-tag fish specifically for this study. However, we estimated survival and calculated travel time for sockeye salmon smolts PIT-tagged for other studies and released from Snake River Basin hatcheries on the same dates as radio-tagged fish. Survival and travel time of these fish were compared with those of radio-tagged cohorts from the same hatchery populations.

In 2011 and 2012, juvenile sockeye salmon from both Sawtooth and Oxbow Hatchery were PIT-tagged and released for a transportation study by the U.S. Army Corps of Engineers (Richmond and McCutcheon 2011). In 2013 and 2014, groups of fish from these same hatcheries were tagged for the comparative survival study of Schaller et al. (2007) and for the Snake River sockeye salmon hatchery program (Johnson et al. 2016).

In all study years, PIT-tagging was conducted by staff from Biomark Inc., the Pacific States Marine Fisheries Commission, or the IDFG. Fish were tagged with a 12.5-mm, 134.2-kHz PIT tag (Destron Fearing TX1400 SST)[1] following IDFG protocols and using techniques similar to those described by Prentice et al. (1990a). Each tag was injected with an individual needle using an implant gun (Biomark MK 25) [1] pre-loaded with disposable, 12-gauge hypodermic needles (Biomark BIO12.BPL) [1]. This system reduced the chance of disease transmission or injury from dull needles.

In 2011, three different hatchery groups were tagged and released. A small group of smolts reared at Burley Creek hatchery was tagged in early January and remained at Burley Creek hatchery until release in May (n = 623). That same year, the production release from Oxbow Hatchery was 54,761 sockeye salmon smolts. Of these fish, 9,975 were PIT-tagged 1.5 months before release. At the time of tagging, these fish had an overall mean fork length of 145.4 mm (SD 11.0 mm). Oxbow Hatchery fish were released at the bridge approximately 0.75 km downstream from the Redfish Lake Creek trap on 12 May 2011. Groups were released at night, between 2130 and 2330 MDT.

In 2011, the production release from Sawtooth Hatchery was 135,614 sockeye salmon smolts. Of these fish, 51,762 were PIT-tagged 1 month before release. At the time of tagging, these fish had an overall mean fork length of 82.9 mm (SD 6.6 mm; Table 2). Sawtooth fish were released at the same location and on the same date as Oxbow fish, but releases were made during daylight hours, from 1046 to 1535 MDT.

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

From 2012 to 2014, Oxbow Hatchery released a total of 307,697 production sockeye salmon smolts in addition to the 1,169 smolts taken for radio-tagging (Table 1). Of these 307,697 production smolts, 14,014 were PIT-tagged approximately 57-65 d prior to release. At the time of tagging, overall mean fork length for these fish ranged 143.0-146.0 mm (Table 2). In all years, Oxbow Hatchery fish were released during the second week of May at the same bridge used in 2011, and releases were made at night between 2130 and 2355 MDT.

Table 1. Numbers of PIT- and radio-tagged juvenile sockeye salmon released to Redfish Lake Creek by hatchery, 2011-2014.

Year	Released (n)	PIT tagged (n)	Radio tagged (n)
	Sawtooth Hatchery		
2011	135,614	51,672	364
2012	79,673	51,710	398
2013 total	170,068	50,060	381
Nighttime	70,953	24,986	191
Daytime	99,133	25,070	190
2014 total	172,090	49,881	443
Nighttime	86,226	24,942	224
Daytime	85,864	24,939	219
	Oxbow Hatchery		
2011	54,761	9,975	409
2012	85,161	9,971	399
2013	100,655	1,998	394
2014	121,881	2,045	376
	Burley Creek		
2011	623	623	50

Table 2. Length at tagging for juvenile sockeye salmon reared at Sawtooth and Oxbow Fish hatcheries and PIT-tagged during 2011-2014.

	Fork length at tagging (mm)					
	Sawtooth Hatchery			Oxbow Hatchery		
	Min	Max	Mean (SD)	Min	Max	Mean (SD)
2011	56	115	82.9 (6.6)	95	192	145.4 (11.0)
2012	57	147	96.9 (11.5)	96	188	146.0 (10.1)
2013	100	154	130.1 (10.6)	86	180	145.4 (10.2)
2014	95	165	126.6 (14.3)	113	172	143.0 (10.3)

From 2012 to 2014, Sawtooth Hatchery released a total of 421,849 production sockeye salmon smolts in addition to the 2,046 smolts taken for radio-tagging (Table 1). Of these 421,849 production smolts, 151,651 were PIT-tagged. At the time of tagging, overall mean fork length for these fish ranged 96.9-130.1 mm (Table 2). In 2013 and 2104, Sawtooth Hatchery smolts were released in separate daytime and nighttime release groups to evaluate whether survival varied with diel release time. Nighttime releases were made at the same location and on the same dates each year as Oxbow fish. However, Sawtooth fish were released earlier, between 2000 and 2200 MDT.

In 2013, we released Sawtooth daytime groups first, followed by Sawtooth nighttime groups, with Oxbow fish released last. In 2014, Sawtooth nighttime groups were released first, followed by Oxbow groups. Sawtooth daytime groups were released the following day. Release order was changed to determine whether diel release timing was more or less important than order of release for the survival of hatchery sockeye salmon smolts.

Detections of PIT-Tagged Fish

Study fish marked with PIT tags were interrogated at monitoring systems in the juvenile bypass systems of collector dams on the Snake and Columbia Rivers (Prentice et al. 1990a, 1990b). Collector dams are those equipped with holding raceways to collect fish for transportation downstream. Each juvenile collection and bypass system is monitored for PIT tags to determine routes of passage. However, PIT-tagged fish must be entrained in bypass systems for detection to occur.

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. For this study we were interested primarily in PIT tag detections of study fish at Lower Granite Dam.

When a PIT tagged fish passes an interrogation monitor within the juvenile bypass system at a dam, the monitor excites the PIT tag. The tag then electronically relays the time, date, and location of the specific monitor where passage occurred. 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 annual 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 the detection of pre-coded PIT tags, and these systems route fish to various destinations. Untagged fish can also be routed, for example to a collection raceway for downstream transport. By returning fish to the river, the SbyC systems provide an opportunity for individual study fish to be detected at multiple sites downstream from release (Marsh et al. 1999).

Radio-Tag Release Groups

Radio tags were purchased from Advanced Telemetry Systems, Inc. (model F1717). Tags were coded with a 5-second pulse interval and pulse-position modulation of 12, allowing 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.

From 2012 to 2104, tags were implanted about one month before release; therefore, transmitters in these years were ordered with a duty cycle of 1 h on and 30 d off for the first 30 d, after which they remained on for the remainder of their life cycle. This allowed us to tag fish 30 d prior to release and to hold them at the hatchery to ensure adequate recovery time from the surgical process.

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). 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 would 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 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 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 fresh water 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 was used to guide the antenna through the body wall of the fish, with the hard plastic base of the catheter removed (Abbocath T 18 gauge × 51 mm or Terumo Surflo 16 gauge × 51 mm).

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 the antenna until the transmitter was directly under the incision. The incision was closed with two simple, interrupted absorbable sutures spaced evenly across the incision (5-0 Ethicon coated Vicryl braided, C-3 needle). To minimize the spread of pathogens, surgical instruments were disinfected by immersion in 70% ethanol for 8–10 minutes and rinsed in distilled between each procedure.

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 recovery 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. 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.

In 2011, fish were held in recovery tanks for 24-96 h prior to release. In all following study years, fish were held 29-32 d after surgery for recovery and determination of post-tagging mortality. 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 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. Fish with tags that did not turn back on after the 30 d recovery period were removed 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.

In 2011, fish were tagged during the second week of May. In all remaining study years, we transferred a subset of juvenile sockeye salmon from Sawtooth and Oxbow hatcheries to the Eagle Hatchery in Eagle, Idaho for acclimation holding prior to tagging. This decision was made in response to observations in 2011, wherein fish from both Sawtooth and Oxbow Hatchery exhibited higher-than-expected post-tagging mortality after 24-96 h, while fish from Burley Creek Hatchery showed no mortality after being held several months longer in holding tanks.

We hypothesized that this mortality was related to surgical implantation that occurred while fish were still adjusting to the change in altitude after transport. Thus, one purpose of these transfers was to allow sufficient time for fish to acclimate to elevation changes prior to the surgical implant procedure. The transfers also provide an opportunity to manage growth, so that fish would meet the minimum size requirement of 12.5 g for avoiding tag burdens higher than 6% (where tag burden is defined as percent tag weight/body mass).

During 2012-2014, smolts were radio-tagged during the second week of April, approximately one month prior to release. Tagging at Eagle Hatchery 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 12.4 g or less.

During the second week of May, we transported radio-tagged sockeye salmon to the release location on Redfish Lake Creek. Releases coincided with the larger releases of PIT-tagged smolts from both hatcheries. Upon arrival at the release site, radio-tagged fish were acclimated until water temperatures in the transport tank were within 1°C of river water temperatures.

All fish were released into the creek at mid-channel. Sawtooth Hatchery sockeye were released beginning mid-day in 2011 and 2012 from a site 0.25 km downstream from Redfish Lake, below the adult weir. Oxbow Hatchery fish were released at a bridge approximately 0.75 km downstream of Redfish Lake in order to accommodate the large tanker trucks used for fish transport. In both years, Oxbow fish were released later, after dark.

In 2013 and 2014, both PIT- and radio-tagged fish from Sawtooth Hatchery were divided into two groups, with one released during nighttime and the other during early daytime hours. Both PIT- and radio-tagged fish from Oxbow Hatchery were released at night in both years. All radio-tagged fish were released simultaneously with PIT-tagged cohorts to ensure fish experienced similar conditions during the downstream migration.

For radio-tagged study fish, overall mortality during the 30-d post-surgery recovery period was 0.8% for the Sawtooth groups combined (1,250 fish each) and 0.4% for the Oxbow groups combined (1,200 fish each). Fork length and weight at tagging are summarized in Table 3. Tag burden, defined as percent tag weight/body mass, ranged 0.6-6.2% and averaged 2.7% overall (Table 3).

Table 3. Fork length and weight (grams) at tagging for radio-tagged juvenile sockeye salmon from Sawtooth and Oxbow Fish hatcheries with associated tag burden, 2011-2014.

	Hatchery juvenile sockeye salmon									
	Fish	Fork length (mm)			Weight (g)			Tag burden (%)		
Year	(n)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean
	Sawtooth Hatchery									
2011*	473	109	162	132.0 (9.6)	12.4	42.5	23.0 (5.2)	1.8	6.0	3.3
2012	400	120	221	159.8 (9.3)	14.7	118.5	45.4 (12.2)	0.6	5.1	1.7
2013	400	120	188	139.1 (9.7)	15.0	60.0	24.2 (5.5)	1.3	5.0	3.1
2014	450	115	176	136.4 (11.6)	13.9	62.0	25.7 (7.5)	1.2	5.4	2.9
	Oxbow Hatchery									
2011*	410	117	217	168.3 (12.5)	15.2	111.3	45.5 (11.3)	0.7	4.9	1.6
2012	400	128	185	158.7 (9.3)	19.9	64.1	40.3 (7.3)	1.2	3.8	1.9
2013	400	125	183	150.0 (9.4)	17.0	66.0	30.7 (6.6)	1.1	4.4	2.4
2014	400	119	175	143.2 (9.7)	14.8	59.0	28.4 (6.5)	1.3	5.1	2.6

* In 2011, a test group of 50 fish from Burley Creek Hatchery was also included in this study (see Hockersmith et al. 2012 for details).

Radio Telemetry Monitoring and Data Collection

From 2011 to 2014, we positioned 44-60 fixed-site telemetry receivers at 27-30 different locations within the study area to provide 24-25 detection zones or transects. Locations of telemetry receivers are presented in Figure 1 and Table 4. Maximum distance between receivers was less than 145 km; however, receivers at the upper and lower ends of the study reach were spaced closer together than those in the middle because we hypothesized that mortality rates would be higher in these areas.

Radio-telemetry monitoring locations were selected primarily based on the locations of major tributaries, where we anticipated higher rates of mortality from predation. Nevertheless, placement was limited in some locations due to a lack of physical accessibility.

Table 4. Location and distance from release site for fixed-site radio-telemetry monitoring receivers used to characterize migration and estimate survival of radio-tagged juvenile Snake River sockeye salmon, 2011-2014. Two receivers and two antennas were situated at each site, with one oriented approximately 45° downstream and the other oriented approximately 45° upstream. The year in which the receiver was present is also noted.

Site no.	Site description	Latitude	Longitude	Distance from release (km)	Study year 2011	2012	2013	2014
1	Above Redfish Lake Cr confluence	44°09'46.82"N	114°53'09.42"W	4	x	x	x	
2	Below Little Redfish Lake	44°09'57.55"N	114°54'02.80"W	3	x	x	x	x
3	Above Valley Cr confluence	44°13'24.37"N	114°55'39.58"W	9	x		x	x
4	Below Lower Stanley	44°14'27.09"N	114°54'02.38"W	12	x	x	x	x
5	Above E Fork Salmon R confluence	44°15'12.66"N	114°20'47.16"W	63	x	x	x	x
6	Below E Fork Salmon R confluence	44°16'58.18"N	114°18'49.19"W	68	x		x	x
7	Above Pahsimeroi R confluence	44°40'35.86"N	114°04'27.98"W	126	x		x	x
8	Below Pahsimeroi R confluence	44°42'06.97"N	114°02'37.89"W	131	x	x	x	x
9	Above Lemhi R confluence	45°10'15.68"N	113°54'36.37"W	199	x	x	x	x
10	Below Lemhi R confluence	45°15'13.55"N	113°54'25.37"W	211	x		x	x
11	Above N Fork Salmon R confluence	45°24'17.96"N	113°59'34.62"W	237	x	x	x	x
12	Below N Fork Salmon R confluence	45°24'12.12"N	114°12'56.09"W	259	x	x	x	x
13	Above Mid Fork Salmon R confluence	45°18'02.36"N	114°32'03.66"W	299	x	x	x	x
14	Vinegar Cr boat launch	45°27'34.48"N	115°53'35.42"W	438	x	x	x	x
15	Above Little Salmon R confluence	45°24'51.31"N	116°18'07.64"W	476	x	x	x	x
16	Below Little Salmon R confluence	45°26'49.32"N	116°18'40.29"W	482	x		x	x
17	Hammer Cr Recreation Area	45°45'59.79"N	116°19'29.13"W	533	x		x	x
18	Rice Creek Bridge	45°54'39.95"N	116°24'41.76"W	557	x	x	x	x
19	Above Salmon R mouth	45°51'21.66"N	116°47'24.71"W	618	x			
20	Below Grande Ronde R confluence	46°08'23.83"N	116°56'06.92"W	659	x		x	x
21	Hell's Gate State Park	46°22'48.53"N	117°02'58.49"W	702	x		x	
22	Above Clearwater R. confluence	46°22'48.53"N	117°02'58.49"W	702	x	x	x	x
23	Below Clearwater R confluence	46°25'08.37"N	117°10'57.40"W	709	x	x	x	x
24	Below Clearwater R confluence	46°25'08.37"N	117°10'57.40"W	709			x	x
25	Lower Granite forebay (right bank)	46°39'45.21"N	117°25'20.18"W	747	x	x	x	x
26	Lower Granite forebay (mid-channel)	46°39'37.02"N	117°25'22.73"W	747	x	x	x	x
27	Lower Granite forebay (left bank)	46°39'24.17"N	117°25'25.63"W	747	x	x	x	
28	Lower Granite tailrace (right bank)	46°39'55.10"N	117°26'09.71"W	749	x	x	x	x
29	Lower Granite tailrace (left bank)	46°39'43.69"N	117°26'20.29"W	749	x	x	x	x
30	Lower Granite tailrace exit (right bank)	46°40'45.88"N	117°26'49.81"W	751		x	x	x
31	Lower Granite tailrace exit (left bank)	46°40'39.54"N	117°27'07.02"W	751		x	x	x

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 subsequent detections were summed where the time difference between adjacent detections was 5 minutes or less. When the time difference between adjacent detections was 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. 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.

Data Analysis

Fish with Passive Integrated Transponder Tags

***Survival*—**For PIT-tagged fish, estimated survival from the point of release to Lower Granite Dam was based on detection data from individual fish retrieved from the PTAGIS database (PSMFC 1996-). We fit these data to the "complete capture history" protocol of Burnham et al. (1987) to estimate survival and detection probabilities with 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 groups from each hatchery and diel release period. We analyzed recapture data using the *Survival with Proportional Hazards* (SURPH) statistical software, which was developed specifically for this purpose (Smith et al. 1994). Survival and detection probabilities were estimated from points of release to Lower Granite Dam tailrace.

***Travel time*—**We also calculated median travel time 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 were reported by Faulkner et al. (2015).

Radio Tagged Fish

***Survival*—**For radio-tagged fish, survival estimates were based on detections of individuals at fixed-site telemetry receivers (Figure 1 and Table 4). 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. In order to pinpoint areas of high mortality, we estimated independent probabilities of survival within each segment of the river delineated by fixed-site monitoring locations. We also estimated overall survival from release to Lower Granite Dam for each hatchery and diel release group.

Within each release year, groups were compared to one another to investigate whether there were statistically significant differences in estimated survival by tagging methodology, hatchery origin, or diel release timing. Statistical significance was assessed by comparing means with a *t*-test (Appendix Table 5).

Travel time and migration rate—For each radio-tagged fish, travel time was calculated as the time between 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 for each 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 receivers delineating that reach.

Migration rates were calculated from travel time data and reported in kilometers per hour (km/h). Tag life of the radio transmitters was tested in each study year from a random sample of 50 tags tested in water. None of the test tags shut down over the 30 d study period, though we did have some tags that did not restart the duty cycle after the 30 d shutdown. Survival estimates were not adjusted for tag life, since all transmitters tested had sufficient tag life for fish to migrate through the study area.

Results

Detection Probabilities

For PIT-tagged sockeye salmon, detection probabilities at Lower Granite Dam were generally higher for Sawtooth than for Oxbow Hatchery fish (Table 5). However, considerable annual variation was observed within hatchery groups. For Sawtooth fish, detection rates ranged from 15.3% for nighttime releases in 2014 to 41.9% for daytime releases in 2013. For Oxbow fish, detection rates ranged from 7.5% in 2014 to 25.5% in 2011 (Table 5). For fish with both tags, probabilities of detection were evaluated for both the radio and the PIT tag.

Table 5. Estimated detection probability at Lower Granite Dam for PIT and radio-tagged juvenile hatchery sockeye salmon smolts released to Redfish Lake Creek, 2011-2014. Radio-tagged fish were also implanted with a PIT tag; thus, separate probabilities of detection were estimated for the same groups of fish based on PIT- vs. radio-tag detection data. Standard errors in parenthesis. Dashes indicate no data.

Tag type, hatchery, and release period	Detection probability (%) and SE			
	2011	2012	2013	2014
	PIT-tag detections			
PIT tag				
Oxbow Hatchery (night)	25.5 (0.9)	13.1 (1.1)	25.0 (2.4)	7.5 (1.7)
Sawtooth Hatchery (day)	24.5 (0.3)	30.8 (0.4)	41.9 (0.8)	16.1 (0.8)
Sawtooth Hatchery (night)	NA	NA	38.1 (1.0)	15.3 (0.8)
Radio + PIT tag				
Oxbow Hatchery (night)	5.9 (5.7)	21.5 (4.3)	27.4 (5.8)	11.4 (7.5)
Sawtooth Hatchery (day)	--[a]	17.5 (4.7)	55.0 (10.1)	--[a]
Sawtooth Hatchery (night)	NA	NA	44.7 (8.1)	66.7 (15.7)[b]
	Radio-tag detections			
Radio + PIT tag				
Oxbow Hatchery (night)	NA	98.9 (0.8)	99.4 (0.6)	100.0 (0.0)
Sawtooth Hatchery (day)	NA	99.3 (0.7)	100.0 (0.0)	92.3 (7.4)
Sawtooth Hatchery (night)	NA	NA	98.3 (1.7)	100.0 (0.0)

[a] No fish detected

[b] Based on only 9 fish detected.

At fixed-site radio-telemetry monitoring stations, detection probabilities ranged 37.2-100.0% (Table 6) and averaged 88.0% overall from 2012-2014. For all radio-tagged fish in 2011, detection probabilities were much lower than in any other study year (data not shown). These low probabilities resulted from abnormally low rates of survival in 2011 and were not included in the averages. Mean probabilities of radio-tag detection were consistently lower in the Snake (75.7%, range 37.2-99.3%) than in the Salmon River (93.4%, range 39.6-100.0%) due to the greater width and depth of the Snake River.

Table 6. Estimated mean detection probability for radio-tagged hatchery sockeye salmon at fixed-site radio-telemetry monitoring locations, 2012-2014. Detection probabilities in 2011 were from Oxbow Hatchery releases only and are not presented here. Standard errors are in parentheses. Detailed location information for fixed-site telemetry locations is presented in Table 1 and Figure 1. NA denotes inoperable site location.

	Estimated detection probability (%) and SE		
Receiver site	2012	2013	2014
Below Little Redfish Lake	97.6 (0.9)	98.8 (0.7)	91.1 (2.2)
Above Valley Creek confluence	NA	99.4 (0.5)	93.8 (1.9)
Below Lower Stanley	39.6 (2.9)	98.9 (0.6)	93.9 (2.0)
Above East Fork Salmon R confluence	99.8 (0.2)	99.8 (0.2)	96.0 (1.6)
Below East Fork Salmon R confluence	NA	99.8 (0.2)	95.4 (1.9)
Above Pahsimeroi R confluence	100.0 (0.0)	100.0 (0.0)	94.5 (2.2)
Below Pahsimeroi R confluence	99.6 (0.3)	100.0 (0.0)	95.5 (2.5)
Above Lemhi R confluence	NA	100.0 (0.0)	95.1 (2.7)
Below Lemhi R confluence	92.0 (2.0)	100.0 (0.0)	94.0 (3.2)
Above North Fork Salmon R confluence	100.0 (0.0)	100.0 (0.0)	91.3 (4.8)
Below North Fork Salmon R confluence	91.3 (2.1)	100.0 (0.0)	87.6 (5.9)
Above Middle Fork Salmon R confluence	100.0 (0.0)	100.0 (0.0)	82.4 (7.6)
Vinegar Creek boat launch	100.0 (0.0)	100.0 (0.0)	87.9 (5.9)
Above Little Salmon R confluence	NA	100.0 (0.0)	87.1 (6.3)
Below Little Salmon R confluence	NA	100.0 (0.0)	77.6 (8.9)
Hammer Creek Recreation Area	89.8 (2.3)	100.0 (0.0)	72.9 (10.2)
Rice Creek Bridge	NA	100.0 (0.0)	75.3 (9.2)
Below Grande Ronde R confluence	75.5 (3.3)	NA	72.7 (10.1)
Above Clearwater R confluence	NA	85.6 (4.2)	47.8 (11.6)
Below Clearwater R (right bank)	NA	86.2 (4.0)	65.4 (11.6)
Below Clearwater R (left bank)	37.2 (3.8)	91.7 (3.3)	48.8 (12.0)
Lower Granite Dam forebay	92.1 (2.1)	85.5 (4.2)	51.7 (13.0)
Lower Granite Dam tailrace	99.1 (0.7)	99.3 (0.7)	97.4 (2.5)

Estimated Survival

In 2011, estimated survival was unusually low for radio-tag groups from both Sawtooth and Oxbow Hatchery. For Sawtooth Hatchery fish, telemetry data were insufficient for estimates of survival to Lower Granite Dam due to high mortality both during the post-tagging recovery period and during migration. For radio-tagged Oxbow Hatchery fish, estimated survival to Lower Granite Dam was 14.2%.

Overall, survival estimates based on radio-tag data were markedly lower than those based on PIT-tag data. Given the low survival estimated for radio-tagged fish in 2011 and the modified study design used in following years, which effectively reduced rates of mortality, we excluded the 2011 telemetry from comparisons of survival by hatchery or tag type.

For PIT-tagged groups from Oxbow Hatchery, estimated survival to Lower Granite Dam ranged 50.5-77.1%, with mean survival declining from 2012 to 2014. A similar pattern in declining survival was observed for PIT-tagged groups from Sawtooth Hatchery, with the highest survival estimated in 2012 at 59.3% (Table 7).

For radio-tagged groups, survival estimates based on PIT detections were more variable across years, but were lower than those of PIT-tag groups, indicating differences in survival related to tag type (Table 7, Appendix Table 1).

Survival estimates for radio-tagged groups based upon telemetry detections ranged 3.6-48.3%. Tests of significance yielded varying results between tag types and hatchery groups within the years examined. There were no significant differences in survival between production groups reared at Oxbow vs. Sawtooth Hatchery. In 2013, comparisons suggested lower estimated survival for daytime than for nighttime releases. However, comparisons in 2014 indicated that survival was actually lower for the group released first, and this was corroborated by test results from previous years.

For each radio-tagged release group, we estimated median survival within individual reaches between Redfish Lake Creek and Lower Granite Dam. Most observed mortality occurred between release and Little Redfish Lake and extending to the lower Stanley area (Appendix Tables 1-4, Figure 2).

Table 7. Estimated survival to Lower Granite Dam for PIT- and radio-tagged juvenile Snake River sockeye salmon 2011-2014. 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. Similar letters indicate a significant difference between estimates of survival.

Tag treatment, hatchery, and diel release period	Estimated survival to Lower Granite Dam (%) and SE			
	2011	2012	2013	2014
	Estimates based on PIT-tag detections			
PIT tag				
Oxbow Hatchery (night)	77.1 (2.1)$_{a}$	69.4 (5.3)$_{a}$	57.5 (4.8)	50.5 (10.0)
Sawtooth Hatchery (day)	72.8 (0.7)	59.3 (0.7)	51.0 (0.9)$_{a,b}$	53.5 (2.3)
Sawtooth Hatchery (night)	NA	NA	59.2 (1.0)$_{a,c}$	52.8 (2.4)$_{a}$
Radio + PIT tag				
Oxbow Hatchery (night)	NA	45.8 (7.0)	48.2 (8.8)	26.6 (16.1)
Sawtooth Hatchery (day)	NA	51.8 (11.9)	27.9 (5.0)$_{b}$	--†
Sawtooth Hatchery (night)	NA	NA	37.4 (5.8)$_{c}$	6.6 (1.9)‡
	Estimates based on radio-tag detections			
Radio + PIT tag				
Oxbow Hatchery (night)	14.2 (1.8)$_{a}$	48.3 (2.5)$_{a}$	41.6 (2.5)$_{d}$	9.3 (1.5)
Sawtooth Hatchery (day)	--	38.2 (2.5)	24.2 (3.1)$_{d}$	5.9 (1.6)
Sawtooth Hatchery (night)	--	--	31.4 (3.4)	3.6 (1.2)

† No fish detected

‡ Based on only 9 fish detected.

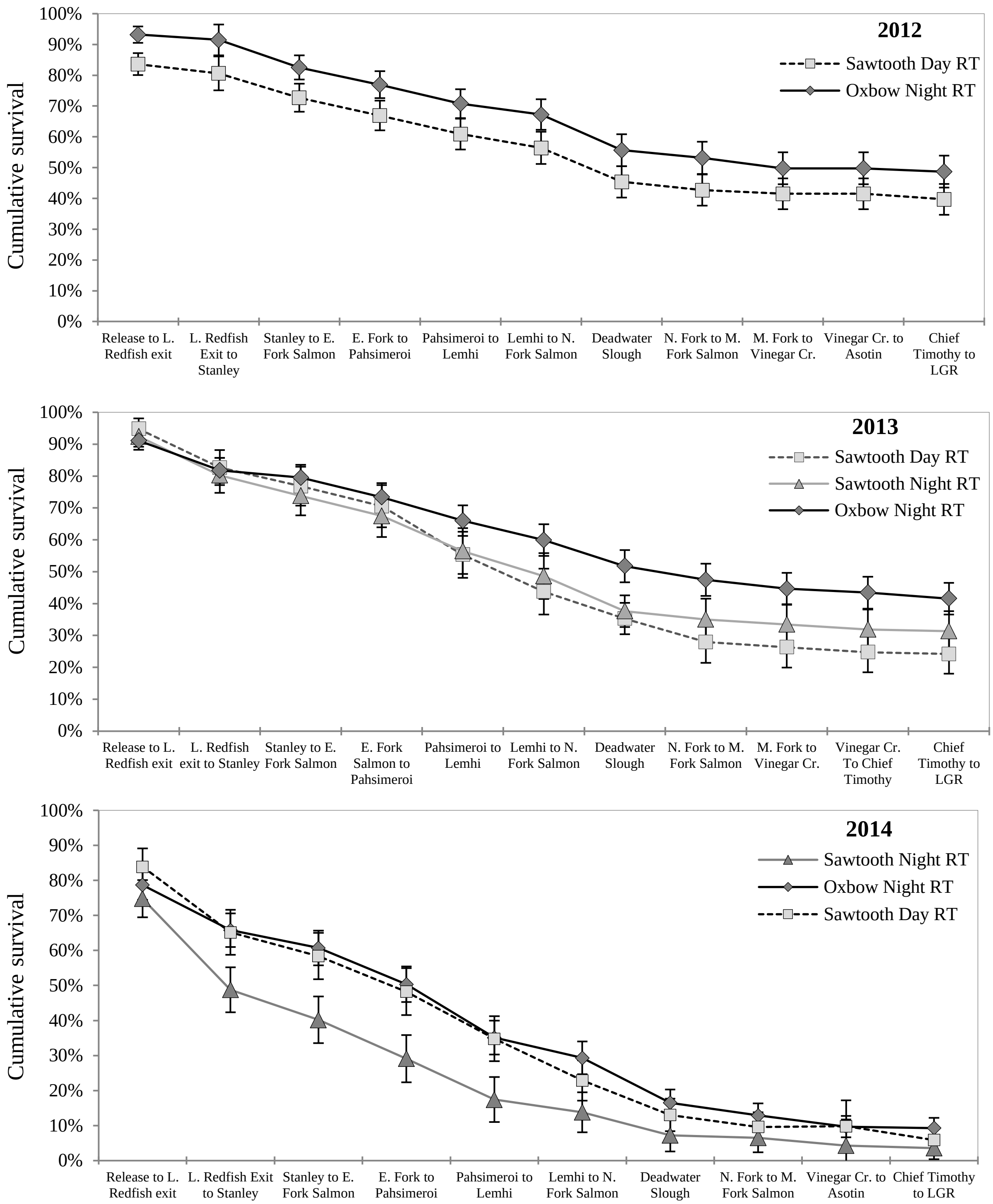

Figure 2. Cumulative survival by year and reach from release to Lower Granite Dam. Juvenile sockeye salmon were surgically implanted with both a radio transmitter and PIT tag. Whisker bars represent 95% confidence intervals. Whiskers indicate 95% CI.

Another particular reach of concern was Deadwater Slough, the area between sites 11 and 12 (12 and 13 in 2014). Our lowest survival estimates measured for all three years and for all release groups occurred within the short reach that encompasses the mouth of the North Fork Salmon River (Appendix Tables 2-4). However, based on mean survival per kilometer, the first two reaches displayed the highest levels of impact on the release groups (Figure 3).

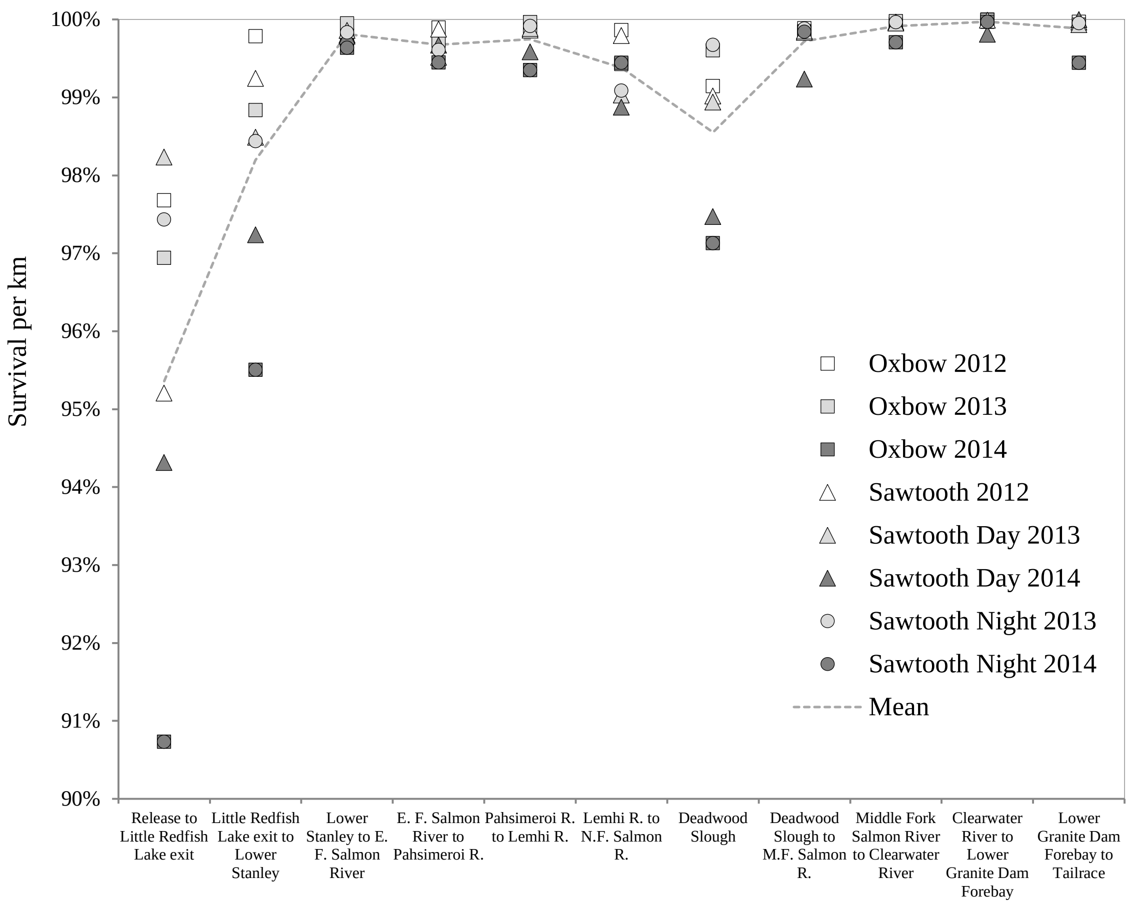

Figure 3. Mean survival per kilometer from release in Redfish Lake Creek to Lower Granite Dam for radio-tagged juvenile Snake River sockeye salmon 2012-2014.

Travel Time

In all study years, radio- and PIT-tagged groups displayed similar travel time and passage timing distributions. In 2011, the PIT tags of 11,200 sockeye smolts from Sawtooth and Oxbow Hatcheries were detected at Lower Granite Dam. Based on these PIT-tag detections, median travel time was 11.1 d for the Sawtooth group and 9.0 d for the Oxbow group. Based on radio-tag detections in 2011, median travel time was 9.5 d for the Oxbow group.

In 2012, the PIT tags of 10,671 sockeye smolts from Sawtooth and Oxbow Hatcheries were detected at Lower Granite Dam. Based on these detections, median travel time from release to Lower Granite Dam ranged 7.1-7.5 d for radio-tag groups from both hatcheries and for the PIT-tag group from Oxbow Hatchery. For PIT-tagged Sawtooth Hatchery smolts in 2012, median travel time was 10.7 d, the longest median travel time observed over the entire study period (Figure 4).

Sockeye salmon groups released in 2013 had similar migration timing, with 11,544 Sawtooth and Oxbow Hatchery fish detected at Lower Granite Dam. Median travel times were slightly shorter in 2013, ranging 6.3-7.4 d. Finally, in 2014, a total of 51,926 PIT-tagged sockeye salmon from Sawtooth and Oxbow Hatcheries were detected at Lower Granite Dam. Median travel time for these fish ranged 8.9-10.0 d.

For radio-tagged sockeye salmon overall, travel times were similar through all reaches across all years and increased as fish continued downstream until they arrived below the confluence of the Snake and Clearwater River. Below this point, Snake River is influenced by the hydropower system. We observed similar reductions in migration rate as fish encountered each major tributary to the Salmon River, namely the East Fork Salmon, Pahsimeroi, Lemhi, and Little Salmon Rivers.

In general, for radio-tagged fish from both hatcheries and all release periods, study reaches with the longest travel times and slowest migration rates were those located in the upper and lowermost sections of the study area. In addition, a reach known as Deadwater Slough, near the confluence of the Salmon and North Fork Salmon Rivers, was an area of potentially high mortality. Survival estimates for all radio-tagged groups were lower within this reach than in reaches upstream. Delays in this reach were likely due to reduced water velocity, which slows fish egress and thus increases opportunity for predation by both birds and fish.

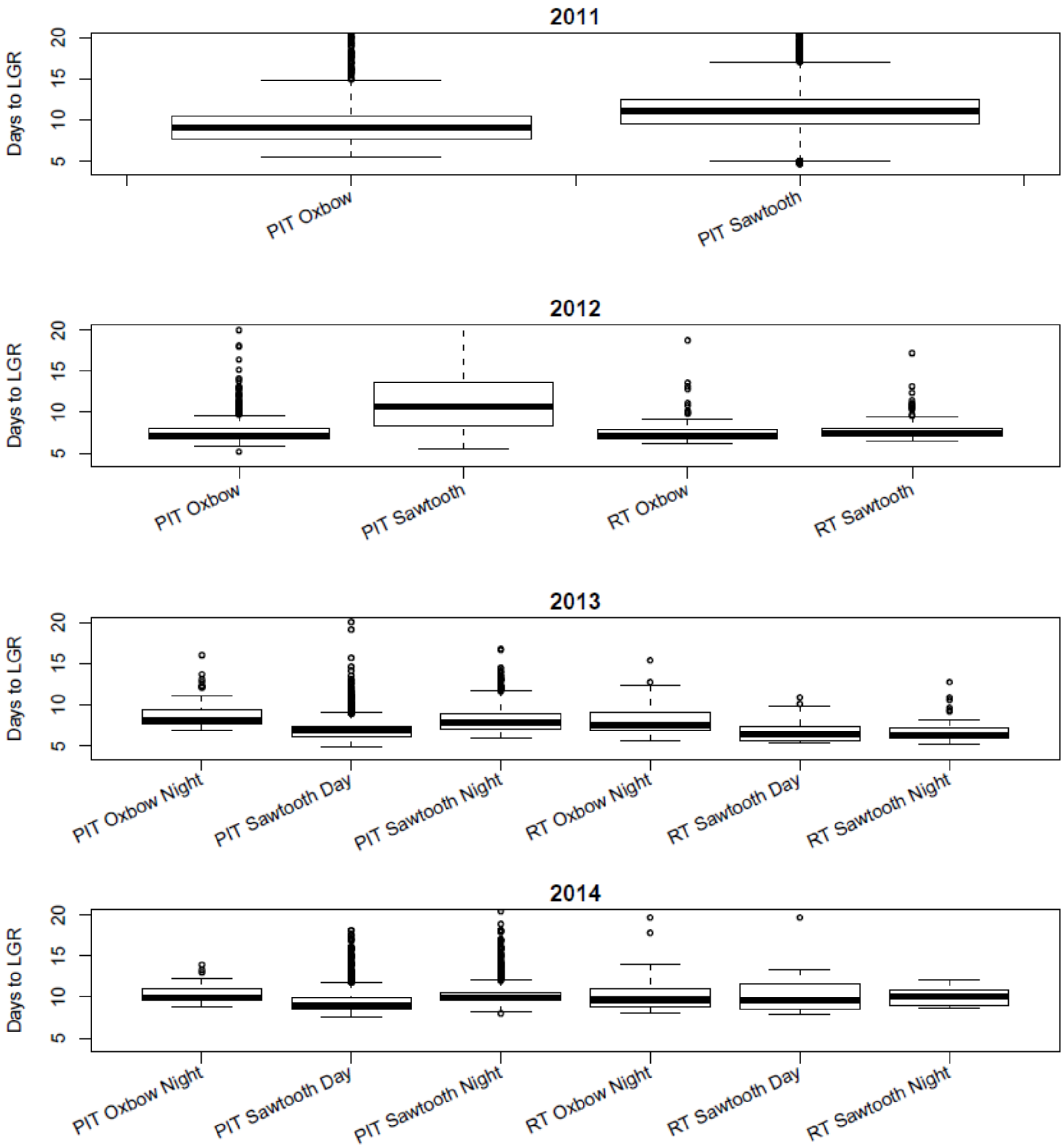

Figure 4. Travel time between Redfish Lake Creek and Lower Granite Dam for PIT-and radio-tagged hatchery sockeye salmon, 2011-2014. Solid black line represents median travel time.

Flows in the Salmon River basin differed across study years, which likely contributed to variation in migration rates, particularly between release and the confluence of the Salmon and North Fork Salmon River. Based on USGS Water Resources data (hydrological unit code 17060203), we looked at flows from Salmon Idaho, near the confluence of the Salmon and Lemhi Rivers (reach 9-10) during each study year. Average daily flows were consistently high during the mid-to-late May passage period for study fish in 2012 (Figure 5). Discharge was lower in 2013 but continued to peak when fish were moving past this transect. In 2014, flows began to decline prior to the release date, and this trend continued while fish were in the area, creating less-than-ideal conditions for survival.

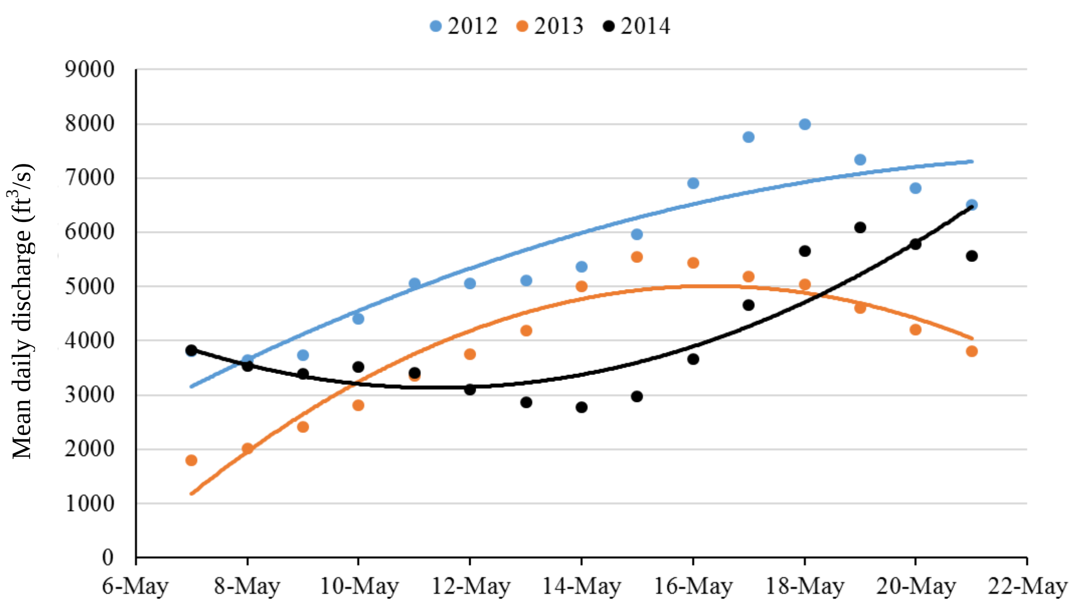

Figure 5. Mean daily discharge (ft^3/s) for the Salmon River at Salmon, Idaho during passage of radio-tagged juvenile sockeye salmon, 2012-2014.

Discussion

In release-recapture studies to characterize salmonid survival and migration within the Columbia River Basin, the most common types of tags used are PIT and radio or acoustic telemetry tags (McMichael et al. 2012). Each tag and implantation method has unique advantages and disadvantages. However, to ensure that tagged fish are representative of their respective populations, tags need to be thoroughly evaluated across multiple years for the individual salmonid species of interest.

In downstream migration studies of juvenile fish that pass Snake and Columbia River dams, PIT-tag detection data have been used to produce unbiased annual estimates of survival for several salmonid species since the mid-1990s (Skalski et al. 1998; Muir et al. 2001; Faulkner et al. 2015). In smaller salmonids, the PIT tag can effect growth, behavior, or survival, and improper implantation can result in tag loss or shedding (Knudsen et al. 2009). However, such effects are avoided by choosing fish of sufficient size and condition for tagging and by using proper injection techniques. Thus, rates of post-tagging mortality and tag loss are typically low, even in smaller PIT-tagged salmonids (Tiffan et al. 2015).

Nevertheless, PIT-tag studies of downstream dam passage survival rely on detections at fixed monitoring sites in the juvenile bypass systems of dams. Because survival is highest for fish that pass dams via the spillway, surface passage devices are used to guide juvenile fish toward this route. These devices are effective, but lack PIT-tag monitoring systems; thus, large proportions of fish passing via spillways result in lower detection probabilities for PIT-tagged fish. Therefore, to produce sufficient detection numbers for analyses, PIT-tag studies require large juvenile release groups.

In contrast, radio tags have a greater detection range, resulting in much higher detection probabilities and the potential for unbiased estimates of survival using fewer tagged fish (Skalski et al. 1998, Hockersmith et al. 2003, McMichael et al. 2012). When multiple receiver sites are available, radio tags offer high resolution for determining specific areas of mortality along fish migration corridors. Radio telemetry receivers can also be moved with little difficulty, which provides greater flexibility in the choice of receiver locations. However, the higher tag burdens experienced by fish with radio tags have been associated with impaired growth, feeding, and survival (Hockersmith et al. 2003). Larson et al. (2013) advised investigators to balance the advantage of high detection rates with the potential effects of tag burden, especially when tagging smaller juvenile fish.

We found differences in detection probability based primarily upon tag type, which was expected based on technological differences between detection methods. Over the course of this study, detection probability of radio tags was an order of magnitude larger than that of PIT tags. In survival estimates overall, precision was greater for radio-tagged groups due to these high detection probabilities.

However, detections from PIT-tagged groups of Sawtooth Hatchery fish also produced relatively precise estimates due to the large number of fish tagged and detected (~25,000), in spite of the lower detection probabilities for this tag type. Conversely, for releases of PIT-tagged Oxbow Hatchery fish, estimates of survival were less precise because smaller numbers of fish were tagged (400-2,045), resulting in even lower probabilities of detection.

Despite differences in detection probability across hatchery groups, similar estimates of survival were observed across all years for groups tagged with both a radio and PIT tag. An exception was the Sawtooth daytime release group in 2014: Survival estimates based on PIT detections could not be calculated for this group because no PIT-tags from this group were detected. Radio-tag detections of these fish indicated that only five survived to Lower Granite Dam; thus, sample sizes for estimates based on radio telemetry detections were also very low in 2014.

Differences in detection probability were also observed between the different hatchery groups. Based on PIT-tag detection probabilities, the larger smolts produced at Oxbow Hatchery had the lowest detection probability at Lower Granite Dam in all four study years. One possible explanation for the observed differences in detection probability among PIT-tagged groups was a potential size-related divergence of passage routes at Lower Granite Dam. The smaller Sawtooth Hatchery fish may have had higher detection rates because they were more easily entrained in the bypass systems at Lower Granite Dam. This has been observed in previous studies by Zabel et al. (2005) and Hostetter et al. (2015). In contrast, the larger Oxbow fish may have been more readily attracted to surface flows provided by the removable spillway weir, and thus missed being detected as they passed over the spillway.

At Lower Granite Dam, passage-route preferences related to size or tag type have not been investigated for 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 may exist, along with differences related to passage route. 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.

In developing unbiased estimates of survival based on radio telemetry data, two assumptions must be met. First, individuals tagged for a study must be representative of the population of interest. Second, the tag, tagging method, or sampling procedure cannot affect survival, behavior, or capture probabilities (Jolly 1965; Seber 1965; Mellas and Haynes 1985; Skalski et al. 1998; Hockersmith et al. 2003). To ensure these assumptions were valid, we compared characteristics such as the size of tagged fish to the average size of the overall population. Migration timing was also compared to that of the overall population to assess representativeness of the tagged population.

Based on PIT-tag detections at Lower Granite Dam, we concluded that travel time for radio-tagged study fish was representative of the sockeye salmon production populations at both Oxbow and Sawtooth Hatchery. Passage distributions at Lower Granite Dam indicated that PIT and radio-tagged cohorts from all release groups migrated together through the entire study area. Therefore, study fish experienced conditions similar to that of non-tagged fish throughout the monitored reaches, unless there were differences in buoyancy or swimming depth (Jepsen et al. 2005).

Nevertheless, overall survival estimates were much lower for radio-tagged than PIT-tag groups. In 2011, low survival of radio-tagged fish from Sawtooth and Oxbow Hatcheries resulted from a combination of factors. First, after transport from rearing to tagging locations, these fish experienced a major elevation change. Second, fish had a relatively short time to acclimate to the new elevation prior to surgery, as well as a short post-surgical recovery time. Third, these fish had attained relatively advanced levels of smoltification at the time of tagging.

To minimize tagging effects on survival in study years subsequent to 2011, we modified the tagging procedure. We transferred subsets of hatchery fish up to 90 d in advance of tagging and implemented a 30-d recovery period to observe delayed mortality after surgical implantation of radio transmitters. Tagging mortalities during the 30-d recovery period were low as a result of the change in acclimation protocol, and both protocols were retained from 2012-2014. Nevertheless, our revised protocol for surgical tagging did not control for other tag effects, and a tag burden effect that developed over extensive distances appeared to impart a negative bias to survival estimates based on radio tag data.

Furthermore, the transfer of fish to Eagle Hatchery resulted in a size disparity between Sawtooth PIT and radio-tag groups because the transferred group (radio tags) grew larger during the acclimation period than their cohorts that remained at Sawtooth Hatchery (PIT tags). This size disparity did not develop in fish transferred from Oxbow

Hatchery. Many tagging studies of juvenile salmonids have encountered challenges in balancing size requirements for tagging with size representation for the run at large (McMichael et al. 2012).

The presence of a tag effect is often associated with tag burden. Across all years of this study, 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). However, Brown et al. (2006) reported that tag burdens of 5.8-8.5% decreased critical swimming speed for juvenile sockeye salmon. For our study fish, mean tag burdens were well within the range identified as "safe" in these studies, although most evaluations were for acoustic rather than radio telemetry tags (Hall et al. 2009; Anglea et al. 2004; Chittenden et al. 2009; Collins et al. 2013).

Our surgical implantation methods were similar to those described for acoustic tag implantation in these studies; however, radio tags carry a 30-cm long external antenna, while acoustic tags do not. The presence of an external antenna has been identified as a factor with several potential impacts to fish (Murchie et al. 2004). Anglea et al (2009) found that hydraulic drag associated with a trailing antenna likely decreased swimming performance in juvenile fish. They suggested that the antenna might have presented a greater impediment to swimming performance than tag burden. Hockersmith et al. (2003) also reported that the “presence of a trailing antenna probably reduces swimming performance, foraging ability, predator avoidance, and ultimately survival.” Both researchers pointed out that for PIT- vs. radio-tagged fish groups, estimates of survival diverged with increasing distance and travel time.

Hockersmith et al. (2003) reported significant differences in estimated survival among Chinook salmon tag 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. Under these circumstances, radio tag effects may have developed as a factor that influenced survival in the later days of our study periods each year.

Given these findings, and the observed differences in survival between our PIT vs. radio-tag groups, we recommend caution in the use of radio telemetry for estimates of juvenile sockeye salmon survival over longer reaches. Unless significant advancements are made to reduce the size of tags and trailing antennae, estimates of survival from our release site to Lower Granite Dam may remain problematic for radio tagged fish.

Despite these limitations, radio telemetry was a useful and appropriate method of identifying specific areas of high mortality. Detection data from our radio tagged fish highlighted two reaches in particular where estimates of survival per km traveled were lower compared to the rest of the study area. These reaches were:

1) Between release to Redfish Lake Creek and the confluence of the Salmon River with Valley Creek (receiver sites 1-3)
2) At the confluence of the Salmon and North Fork Salmon River (receiver sites 11-12 and 12-13 in 2014)

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

Some notable features of these reaches may be contributing to higher rates of predation. In the first reach, we have seen bull trout feeding on schools of juvenile sockeye as they enter Redfish Lake. These predators may have come to rely on large releases of downstream migrant sockeye salmon as a reliable food source. In addition, avian predator populations have been active in and around Redfish Lake just after study fish were released.

The second reach of concern encompasses Deadwater Slough, a reach in central Idaho that is inhabited by raptors and other piscivorous bird species. There are several heron rookeries near this area (Schoby et al. 2006) and both smallmouth bass and northern pikeminnow have been documented in this reach through electrofishing surveys (Messner et al. In prep). Flow in the Deadwater Slough area is visibly slower, and juvenile sockeye salmon traversing this reach have been shown to travel at a considerably reduced rate. Delays we observed in this reach were likely due to reduced water velocity, which slows fish egress and thus increases opportunities for predation by both birds and fish.

While data from radio-tag detections helped identify reaches where the highest levels of mortality occurred, they provided little insight into the causes of mortality. Furthermore, radio tag effects limited our ability to discern whether mortality was due to tag burden or antenna entanglement, physiological or immunological impairment, or increased predation. These factors may also act in concert to increase mortality; for example, a trailing antenna may enhance signals of fish location to visual predators. Jepsen et al. (1998) reported that in the wild, radio-tagged smolts were more susceptible to predation than were cohorts with no radio tag.

To provide insight into the causes of mortality, avian nesting colonies are often scanned for PIT tags consumed by birds. In future studies, screw traps could be monitored for PIT tags in piscivorous fish. Research comparing transport vs. inriver migration through areas of high mortality or that uses instream PIT tag monitoring systems in reaches of suspected high predation may also help separate tag effects from predation effects (Clark et al. 2016).

During the last two study years, we investigated whether estimated survival differed with diel timing of release, specifically whether nighttime releases would improve survival. Sockeye salmon smolts generally migrate nocturnally, and this strategy is believed to be employed for predation avoidance (Clark and Levy 1998).

In 2012, PIT tagged fish from Oxbow Hatchery had higher rates of survival than those from Sawtooth Hatchery (69.4 vs. 59.3%). Radio tag groups showed a similar pattern of higher survival for Oxbow vs. Sawtooth fish in 2012 (48.3 vs. 38.2%). We speculated that size and timing of releases likely contributed to the higher rates of survival for Oxbow fish.

To test the hypothesis that nighttime release would confer a survival benefit, we divided Sawtooth tag groups into daytime and nighttime releases, while continuing to release Oxbow fish at night. In 2013, releases of both PIT- and radio-tagged groups showed that mean estimated survival to Lower Granite Dam was slightly higher for Sawtooth fish released at night compared to those released during the day, and the difference was significant.

In 2014, we examined this hypothesis in terms of the order of release groups. In 2013, we had released the daytime group first. In 2014, we released the nighttime tag groups from both Sawtooth and Oxbow hatchery first, followed by the daytime tag groups. We observed lower survival for nighttime releases of both tag types, but the difference was not significant for either tag type.

Thus, while we saw no indication that nighttime releases had higher survival than daytime releases, there was some evidence to indicate that the order of release could have influenced estimated rates of survival. It was possible that survival was depressed for the first release because they encountered high predation areas first, and were therefore subjected to greater rates of predation.

Our observations of survival by release group and order of release, particularly in the first reach through Little Redfish Lake suggested a functional response in predators similar to Holling's type III (Holling 1959). In this response, feeding rate of the predator increases in relation to prey density. If predators responded in this manner to large hatchery releases, mortality for fish would first increase with increasing prey density, and then decline as predators reached a given saturation point. However, Peterman and Gatto (1978) observed that predators normally operate on the lower end of their functional response curves, and are therefore capable of causing high mortality on larger prey populations. Intensive predation on sockeye salmon smolts by bull trout was observed immediately following the migration of smolts from Chiltko Lake (Furey et al. 2015). Furey et al. (2016) observed high rates of binge feeding by bull trout until satiation.

While we cannot determine the fate of individuals in this study, other sockeye salmon studies have indicated that predation may be a factor in the first reach, and that release timing and numbers may provide density-dependent swamping mechanisms (Furey et al. 2016) and may impact survival rates.

In summary, given the differences in observed survival, we caution against using radio telemetry to estimate survival of sockeye salmon smolts from longer distances, such as the reach between Redfish Lake Creek and Lower Granite Dam. Radio telemetry remains an effective tool for comparing relative mortality between localized areas (shorter reaches) among different populations, species, or sizes of fish.

This study did show that radio telemetry can be useful for investigating locations of high mortality relative to others and that there were differences in survival based upon the release strategy employed (hatchery origin and first release). As the infrastructure in the Columbia River basin grows and detection capabilities continue to develop and advance, our ability to obtain greater understanding of the causal mechanisms of juvenile mortality will be improved, and this understanding will help inform strategies to improve survival in general.

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Appendix

Appendix Table 1. Comparisons of estimated survival to Lower Granite Dam by hatchery, tag treatment, and diel release period from Redfish Lake Creek. Shaded values indicate significant differences between estimates of survival based on PIT and/or radio-tag detections.

Comparisons of mean survival to Lower Granite Dam			
Hatchery, release period, and tag type	Data type	*t*	*P*-value
2012			
Oxbow night PIT vs. Oxbow night radio	PIT vs. radio[a]	0.34	0.000
Sawtooth day PIT vs. Sawtooth day radio	PIT vs. radio	1.05	0.293
Oxbow night radio vs. Sawtooth day radio	PIT	0.38	0.707
Oxbow night radio vs. Sawtooth day radio[b]	Radio	2.86	0.004
Oxbow night radio vs. Oxbow night PIT[c]	PIT vs. radio	2.69	0.007
Sawtooth day radio vs. Sawtooth day PIT[c]	PIT vs. radio	0.70	0.486
Oxbow night PIT vs. Sawtooth day PIT[b]	PIT	1.89	0.059
2013			
Oxbow night PIT vs. Oxbow night radio	PIT vs. radio	0.72	0.470
Sawtooth day PIT vs. Sawtooth day radio	PIT vs. radio	0.63	0.528
Sawtooth night PIT vs. Sawtooth night radio	PIT vs. radio	0.89	0.372
Oxbow night radio vs. Sawtooth night radio[b]	PIT	1.03	0.305
Sawtooth day radio vs. Sawtooth night radio[b]	PIT	1.24	0.214
Oxbow night radio vs. Sawtooth night radio[b]	Radio	2.42	0.016
Sawtooth day radio vs. Sawtooth night radio[b]	Radio	1.56	0.118
Oxbow night radio vs. Oxbow night PIT[c]	PIT	0.93	0.353
Sawtooth day radio vs. Sawtooth day PIT[c]	PIT	4.57	0.000
Sawtooth night radio vs. Sawtooth night PIT[c]	PIT	3.70	0.000
Oxbow night PIT vs. Sawtooth night PIT[b]	PIT	0.35	0.729
Sawtooth day PIT vs. Sawtooth night PIT[b]	PIT	6.08	0.000
Oxbow night radio vs. Sawtooth night radio[b]	PIT	1.02	0.306
Oxbow night radio vs. Sawtooth day radiob	PIT	2.01	0.045
Oxbow night PIT vs. Sawtooth day PIT[b]	PIT	1.33	0.183
Oxbow night radio vs. Sawtooth day radio[b]	Radio	4.37	0.000
2014			
Oxbow night radio vs. Oxbow night radio	PIT vs. radio	1.07	0.284
Sawtooth day radio vs. Sawtooth day radio	PIT vs. radio	NA	
Sawtooth nightradio vs. Sawtooth night radio	PIT vs. radio	1.32	0.187
Oxbow night radio vs. Sawtooth night radio[b]	PIT	1.23	0.217
Sawtooth day radio vs. Sawtooth night radio[b]	PIT	NA	
Oxbow night radio vs. Sawtooth night radio[b]	Radio	2.06	0.040
Sawtooth day radio vs. Sawtooth night radio[b]	Radio	1.15	0.250
Oxbow night radio vs. Oxbow night PIT[c]	Radio vs. PIT	-1.26	0.207
Sawtooth day radio vs. Sawtooth day PIT[c]	PIT	NA	
Sawtooth night radio vs. Sawtooth night PIT[c]	PIT	-14.89	0.000
Oxbow night PIT vs. Sawtooth night PIT[b]	PIT	-0.22	0.823
Sawtooth day PIT vs. Sawtooth night PIT[b]	PIT	0.21	0.834

[a] PIT vs. radio comparisons were made to evaluate differences in survival based on tag type (PIT tag only vs. radio + PIT tag)

[b] Comparison to evaluate differences in survival based on hatchery-origin or release timing

[c] Comparison to evaluate differences in survival based on radio-tag burden

Appendix Table 2. Estimated survival for radio-tagged Oxbow Hatchery sockeye salmon within various reaches between release in Redfish Lake Creek and Lower Granite Dam, 2011. Standard errors are in parentheses. Detailed information for fixed-site telemetry receivers locations are presented in Table 3 and Figure 1.

		Estimated survival of radio-tagged fish	
Reach	Reach description	(%)	SE
Release to 2	Release to below Little Redfish Lake	0.715	0.023
2 to 3	Below Little Redfish Lake to Valley Creek	0.711	0.028
3 to 4	Valley Creek to below lower Stanley	0.956	0.016
4 to 5	Below lower Stanley to above East Fork Salmon River	0.776	0.030
5 to 6	Above to below East Fork Salmon River	0.996	0.007
6 to 7	Below East Fork Salmon River to above Pahsimeroi River	0.861	0.028
7 to 8	Above to below Pahsimeroi River	0.996	0.008
8 to 9	Below Pahsimeroi River to above Lemhi River	0.860	0.031
9 to 10	Above to below Lemhi River	0.996	0.009
10 to 11	Below Lemhi River to above North Fork Salmon River	0.940	0.034
11 to 12	Above to below North Fork Salmon R.	0.817	0.044
12 to 13	Below North Fork Salmon R to above Middle Fork Salmon R.	0.909	0.032
13 to 14	Above Middle Fork Salmon R to Vinegar Creek boat launch	0.896	0.035
14 to 15	Vinegar Creek boat launch to above Little Salmon River	0.971	0.020
15 to 16	Above to below Little Salmon River	1.000	0.001
16 to 17	Below Little Salmon River to Hammer Creek	0.971	0.021
17 to 18	Hammer Creek to Rice Creek Bridge	1.000	0.001
18 to 19	Rice Creek Bridge to above Salmon River mouth	0.971	0.021
19 to 20	Above Salmon River mouth to below Grande Ronde River	0.987	0.017
20 to 21	Below Grande Ronde River to above Clearwater River	0.970	0.049
21 to 22	Above to below Clearwater River	0.974	0.056
22 to 23-25	Below Clearwater River to Lower Granite Dam forebay	0.957	0.046

Appendix Table 3. Estimated survival (in order of release) for radio-tagged Oxbow and Sawtooth Hatchery sockeye salmon within various reaches between release in Redfish Lake Creek and Lower Granite Dam, 2012. Standard errors are in parentheses. Detailed information for fixed-site telemetry receivers locations are presented in Table 3 and Figure 1.

		Estimated survival of radio-tagged groups, % and (SE)	
Reach	Reach description	Sawtooth	Oxbow
Release to 2	Release to below Little Redfish Lake	83.6 (1.8)	93.2 (1.3)
2 to 4	Below Little Redfish Lake to below lower Stanley	93.4 (2.6)	98.1 (2.3)
4 to 5	Below lower Stanley to above E Fork Salmon R	90.3 (2.7)	90.2 (2.6)
5 to 8	Above E Fork Salmon R to below Pahsimeroi R	92.0 (1.6)	93.2 (1.4)
8 to 9	Below Pahsimeroi R to above Lemhi R	91.1 (1.8)	92.0 (1.6)
9 to 11	Above Lemhi R to above N Fork Salmon R	92.5 (2.0)	95.0 (1.5)
11 to 12	Above N Fork Salmon R to below N Fork Salmon R	80.5 (2.8)	82.8 (2.5)
12 to 13	Below N Fork Salmon R to above Middle Fork Salmon R	94.0 (1.9)	95.5 (1.5)
13 to 14	Above Middle Fork Salmon R to Vinegar Cr boat launch	97.2 (1.4)	93.6 (1.8)
14 to 15	Vinegar Cr boat launch to above Little Salmon R	100.0 (0.0)	100.0 (0.0)
15 to 18	Above Little Salmon R to Rice Cr Bridge	98.2 (1.1)	99.5 (0.5)
18 to 21	Rice Cr Bridge to above Clearwater R	99.6 (0.8)	99.4 (0.6)
21 to 24	Above Clearwater R to below Clearwater R	99.3 (1.5)	100.0 (0.0)
24 to LGR	Below Clearwater R to Lower Granite Dam forebay	98.4 (1.6)	98.5 (1.6)

Appendix Table 4. Estimated survival (in order of release) 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.

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

Appendix Table 5. Estimated survival (in order of release) for radio-tagged Sawtooth and Oxbow Hatchery sockeye salmon within various reaches between release in Redfish Lake Creek and Lower Granite Dam, 2014. Standard errors are in parentheses.

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