Technical Report 2014-7

ADULT PACIFIC LAMPREY MIGRATION BEHAVIOR AND ESCAPEMENT IN THE BONNEVILLE RESERVOIR AND LOWER COLUMBIA RIVER MONITORED USING THE JUVENILE SALMONID ACOUSTIC TELEMETRY SYSTEM (JSATS), 2013

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Department of Fish and Wildlife Sciences
University of Idaho, Moscow, ID 83844-1136

for

U.S. Army Corps of Engineers
Portland District

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Executive Summary

In 2013, we continued our evaluation of the Juvenile Salmon Acoustic Telemetry System (JSATS) for monitoring the migration and final fates of adult Pacific lamprey (*Entosphenus tridentatus*) in Bonneville tailrace and reservoir and upstream of The Dalles Dam to the Deschutes River. With the main focus on Bonneville tailrace and reservoir, two areas with high unaccounted loss in past telemetry studies. We tagged adult Pacific lamprey with Juvenile Salmon Acoustic Telemetry System (JSATS) tags and half-duplex (HD) PIT tags and monitored their upstream passage and migration behaviors. Our objectives were to calculate lamprey travel times, to estimate escapement past the monitored sites, to evaluate JSATS detection efficiency, and to determine final fates of tagged lamprey.

We double-tagged 400 adult Pacific lamprey collected at Bonneville Dam with both JSATS (expected 400 d transmitter life) and HD-PIT transmitters from 29 June through 23 September. All fish were trapped and tagged at the Adult Fish Facility at Bonneville Dam and were released at one of two tailrace locations: Tanner Creek (rkm 232.0) or Hamilton Island boat ramp (rkm 232.6) or one of two Bonneville reservoir loctions: Stevenson boat ramp (rkm 242.7) or Cascades Locks (rkm 239.1). We deployed 33 JSATS autonomous receivers between the Bonneville Dam tailrace and The Deschutes River. Receivers were deployed singly or as detection gates of up to five allowing us to calculate travel times and estimate distribution and final lamprey fates for multiple reaches within Bonneville Reservoir.

Estimated detection efficiencies for all of the acoustic receiver gates were 94% or higher, and reached 98% at Miller Island near the Deschutes River.

The escapement estimate for lampreys released into the Bonneville Dam tailrace past the dam was 63.5% (n = 125), higher than estimates from previous HD-PIT studies (41-53%). The escapement estimate from release in Bonneville Reservoir past The Dalles Dam was 57.6% (n = 117). This was higher than JSATS-tagged adults released in the Reservoir in 2011 (n = 24, 38.7%), and similar to those in 2012 (n = 88, 60.3%). We note that the 2013 JSATS sample was biased towards the second half of the run, compromising direct among-year comparisons.

Travel rates for tagged fish were variable and were higher in reservoirs than in dam reaches. Reservoir-released lamprey had a median travel time of 7.2 days (9.0 km/d; *range* = 2.1 – 28.2 km/d) from release to The Dalles Dam ladder top. Tailrace-released fish moved rapidly once they passed Bonneville Dam. The median travel time for tailrace-released fish from release to the top of Bonneville Dam was 5.4 days (0.5 km/d; *range* = 0.04 – 10.8 km/d), and was 10.2 days (7.5 km/d; *range* = 1.4 – 17.4 km/d) from release to the top of The Dalles Dam. Movement through Bonneville Reservoir was rapid (Stevenson to The Dalles Dam tailrace: *median* = 44.8 km/d, n = 140).

Distributions of tagged fish through summer and fall 2013 were similar to those seen in previous years. The majority of adults (82%) entering or released into Bonneville Reservoir were detected in the upper reservoir or tailrace of The Dalles Dam indicating low mortality rates in the lower reservoir.

Acoustic receivers were deployed starting in mid-March 2013 and monitoring continued through October 2013. Receivers will be redeployed in spring 2014 in the Bonneville and The Dalles Dam tailraces and at tributary sites. The 400 d battery life transmitters are still active as of this writing and we anticipate collecting additional data on spring 2014 movements of tagged lamprey, which we will report on in early fall 2014.

Introduction

The populations of anadromous Pacific lamprey (*Entosphenus tridentatus*) in the Pacific Northwest, particularly in the Columbia River Basin, have been in a decades-long decline (Columbia River Inter-Tribal Fish Commission 2011; Columbia Basin Research 2013). Pacific lamprey are an important prey species for other fish (Poe et al. 1991) and may act as a buffer against predation on endangered salmon by fish, birds and marine mammals (Moser and Close 2003). As with many other anadromous fish species, it is likely that Pacific lamprey are important in nutrient cycling pathways (Gresh et al. 2000; Wilcove and Wikelski 2008). Pacific lamprey have also played a major role in the culture of many Native American tribes, particularly those of the Columbia Basin (Vladykov 1973; Close et al. 1995, 2002; Palacios 2007).

Results from both radiotelemetry (RT) and HD-PIT studies have indicated that Pacific lamprey do not readily pass dams compared to anadromous salmonids and their poor passage efficiency may represent a critical limitation to their migration success (e.g., Moser et al. 2002b; Keefer et al. 2009c; Luzier et al. 2011). Specifically, Moser et al. (2002a, 2002b, 2003, 2005), Johnson et al. (2012), Clabough et al. (2011), and Keefer et al. (2013b) found that fishway entrances, collection channel/transition areas, diffuser gratings, and serpentine weirs impede adult Pacific lamprey passage at lower Columbia River dams. These data have been used to design, implement, and test a number of passage improvements including Lamprey Passage Structures (LPS, Moser et al. 2011), and modified nighttime operations (Johnson et al. 2012).

In addition to identifying specific passage bottlenecks, these studies observed that many tagged adults failed to re-initiate upstream migration after tagging and that substantial proportions of tagged samples were unaccounted for between dams. For instance, dam counts, RT, and HD-PIT telemetry results all suggest considerable numbers of adult lamprey that enter Bonneville Reservoir do not pass The Dalles Dam (TDA). Escapement estimates past The Dalles Dam for tagged fish that entered or were released into Bonneville Reservoir from studies in 2007 and 2008 were 25.3-62.8%, comparable to or higher than the conversion rates estimated from ladder counts, and were generally higher in the HD-PIT than in the RT samples (Keefer et al. 2009b, 2009c). The HD-PIT method probably provides the best estimate of inter-dam conversion, because of smaller tag effects than observed when using RT. Nonetheless, all estimates indicate considerable (>50%) loss in the Bonneville Reservoir in most years. In 2008, a year with the highest level of RT coverage (including at tributary mouths), 42% of RT adults that passed Bonneville Dam (BON) subsequently passed TDA, 22% were recorded at TDA but were not recorded passing, 5% were recorded in tributaries, and 35% had records indicating a final fate in Bonneville Reservoir (Keefer et al. 2009b). Values for 2009-2011 were similar based on evaluations using PIT-tagged (Keefer et al. 2010b, 2011a, 2012; Fox 2012) or JSATS-tagged adult lamprey (Noyes et al. 2012, 2013).

The unknown fate of many Pacific lamprey during their migration through tailraces and/or reservoirs may be attributed to: (1) overwintering in the reservoir and resuming upstream migration the following spring; (2) pre-spawn or predation mortality (3) undetected spawning in reservoir tributaries; and/or (4) spawning in the tailrace of The Dalles Dam or elsewhere in the Reservoir. Lamprey are an attractive prey item to predators, and it is possible that these unaccounted for fish represent predation mortalities. White sturgeon (*Acipenser transmontanus*) are abundant in Bonneville and The Dalles Dam tailraces, and sea lions (*Zalophus californicus*, *Eumetopias jubatus*) are seasonally abundant in Bonneville Dam tailrace. However, unsuccessful dam passage does not necessarily represent mortality or that lamprey fail to spawn. Lamprey pass many spawning tributaries during their migration up the Columbia River including those terminating in reservoirs on the main stem river, and it is possible that a substantial proportion of the fish unaccounted for in reservoirs may have successfully spawned. Similarly, spawning in the tailraces of Columbia River dams has been observed by fall Chinook salmon (Mueller 2004; Skalicky 2009) and it is possible some lamprey also spawn in tailraces. Exploring these hypotheses requires knowing the final distribution of lamprey after the overwintering period.

Unfortunately, the deep bathymetry of Federal Columbia River Power System (FCRPS) reservoirs and the river below Bonneville Dam limits the ability to detect radio transmitters and thereby limits the ability to determine the final fates of many RT-tagged lamprey. Acoustic telemetry has several advantages over RT and PIT technologies, including the ability to detect signals in deep water (>10 m). Acoustic transmitters also do not require a trailing antenna which may affect behavior and ultimately survival (Keefer et al. 2009d; Mesa et al. 2011). Until recently, transmitter design and battery size have precluded use of longer-lived acoustic transmitters on smaller species. However, development of the juvenile salmonids acoustic telemetry system (JSATS; see McMichael et al. 2010 for description) has produced relatively small transmitters that are suitable for Pacific lamprey. In 2010, we performed a pilot study with thirty JSATS-tagged adult Pacific lamprey to evaluate the technology for monitoring with fixed-site and mobile tracking hydrophone receivers (Naughton et al. 2011). In 2011, we continued the evaluation with a larger sample of tagged lamprey (n = 85) and increased monitoring effort (Noyes et al. 2012). In the 2012 study, we increased the sample (n = 299), deployed additional fixed receiver sites, and added three release locations (in the Bonneville Dam tailrace at Hamilton Island and the mouth of Tanner Creek, and in Bonneville Reservoir at the Cascade Locks Marina). The results demonstrated that the technology could be adapted readily to adult lamprey studies in deep water habitats.

In the 2013 study, we continued the evaluation with a larger sample of tagged lamprey (n = 400). Our primary objectives were to characterize adult Pacific lamprey migration behavior, including migration rates and distributions, estimate the fate of lamprey in Bonneville Reservoir and tailrace using a larger array of stationary acoustic JSATS receivers, and to evaluate the efficiency of the JSAT system for monitoring tagged lamprey.

Methods

Fish capture and tagging

Pacific lamprey were captured at night using two traps installed in the Washington-shore fishway that collected fish as they passed weirs. We also deployed two portable pot traps between the two fixed traps in the fishway. A complete description of the collection and tagging methods is presented in Moser et al. (2002b) and Keefer et al. (2009c, 2012). Lamprey were collected under the authority of Washington State Scientific Collection Permit #13-153a. Collected fish were anesthetized with 60 ppm (3 mL/50 L) clove oil, measured (length and girth to the nearest mm) and weighed (nearest g).

Lamprey were surgically implanted with a 4-mm × 32-mm glass-encapsulated HD-PIT transmitter (134.2 kHz; Texas Instruments, Dallas, TX) and a modified JSATS transmitter (Advanced Telemetry Systems, Isanti, MN). The JSATS transmitter was 4.0 mm × 8.0 mm × 23.0, weighed 1.7 g in air, and had an estimated battery life of 400 d with a 10 s burst rate. Both the JSAT transmitter and HD-PIT tag were inserted through a small (<1 cm) incision in the body cavity along the ventral midline, in line with the anterior insertion of the first dorsal fin. Incisions were closed with a single suture (3-0 surgical monofilament), and fish were placed in a post-surgery holding tank. Lamprey surgical protocol was approved by the University of Idaho Institutional Animal Care and Use Committee (#2012-37).

Tagged adults were allowed to recover for at least 2 h post-surgery and were released between 1900 and 2300 h. Lamprey were released in either the Bonneville Dam tailrace or Bonneville Reservoir. Tailrace release sites included two located at rkm 232.3: Hamilton Island on the Washington shore and near the mouth of Tanner Creek on the Oregon shore. Lamprey were released at two sites in Bonneville Reservoir: the Stevenson boat ramp on the Washington shore (rkm 242.7) and the Cascade Locks Marina on the Oregon shore (rkm 239.1). The reservoir sites were selected as the nearest sites to the dam that also minimized the potential for tagged fish to fallback over Bonneville Dam. The Hamilton Island and Tanner Creek tailrace sites have been frequently used in RT and HD PIT studies.

Telemetry monitoring

JSATS-tagged fish were monitored with autonomous receivers (Advanced Telemetry Systems, Trident SR5000) which contained an internal rechargeable lithium battery pack (rated for 34 d), an externally-mounted hydrophone, water temperature and pressure sensor, and analog and digital circuit boards (see McMichael et al. 2010). The receivers were deployed to position the hydrophone about 3 to 4 m above the river or reservoir bottom. The standard deployment configuration consisted of the receiver affixed at a single point to a short section of wire cable (3/16 in. stainless steel) with two small floats for additional buoyancy. The receiver was then attached to an acoustic release mechanism (Inter-Ocean Model 111 or Teledyne Model 875-TD). JSATS receivers (n = 31) were deployed in Bonneville and The Dalles Dam tailraces, within or at the mouths of major tributaries, and within Bonneville Reservoir. Monitoring in tailraces and at tributary locations began in March 2013. These locations were selected to detect overwintering movement and tributary entry of the 2012 cohort of tagged lamprey. Receivers were deployed at reservoir and release sites in mid-April 2013. Monitoring at all locations continued through October 2013. Data obtained from the autonomous receivers were used to record final locations, to partition final locations within the reservoir, and to estimate reach travel times of tagged lamprey.

The study area encompassed the lower Columbia and Snake rivers monitored by HD-PIT antennas. JSATS monitoring included the reach from the Bonneville Dam tailrace to the tailrace of The Dalles Dam (rkm 304.9) (Figure 1). JSATS receivers were deployed as gates of one to five nodes mid-channel or on either the Washington or Oregon shores of the Columbia River, at each of fourteen locations (Table 1).

Lamprey detections on HD-PIT antennas were also used to monitor passage at Columbia and Snake River dams, and to determine final locations of Pacific lamprey. HD-PIT antennas were located at the tops of fish ladders at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Wanapum, Rock Island, and Rocky Reach Dams on the Columbia River, and at Ice Harbor, Lower Monumental, and Lower Granite Dams on the Snake River. These sites were maintained by UI (lower Columbia and Snake River dams), and the Chelan and Grant County PUD's (upper Columbia River dams). Additional HD-PIT antennas were located in Fifteenmile Creek, a small tributary that empties into the Columbia River in The Dalles Dam tailrace, Hood River, Deschutes River, and in some Deschutes River tributaries (maintained by the Confederated Tribes of Warms Springs Reservation of Oregon [CTWSRO]).

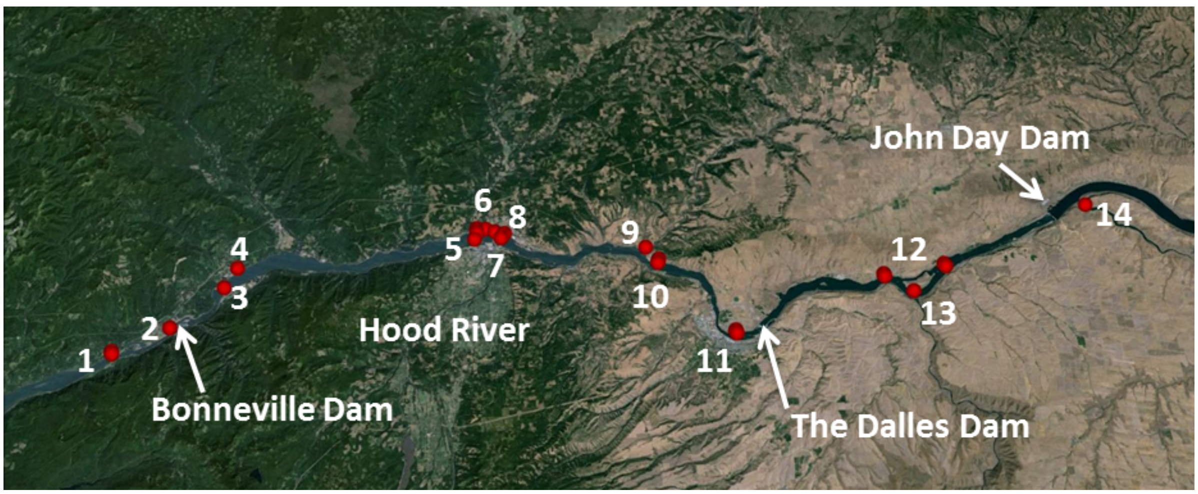

Figure 1. Receiver locations (numbered circles) used to monitor JSATS-tagged adult Pacific lamprey in 2013: 1) Dodson/Skamania; 2) Bonneville Dam tailrace; 3) Cascade Locks; 4) Stevenson; 5) White Salmon R.; 6) White Salmon R. mouth; 7) Hood R. mouth; 8) Hood R.; 9) inside Klickitat R., 300m from the mouth; 10) Lyle; 11) The Dalles Dam tailrace; 12) Miller Island; 13) Deschutes R. mouth; 14) John Day River.

Table 1. Locations JSATS receivers were deployed by University of Idaho (UI) in 2013. River mile kilometer (RKM) zero = mouth of Columbia River.

Agency	River	Location	RKM
UI	Columbia	Dodson, OR	225.6
UI	Columbia	Skamania, WA	225.7
UI	Columbia	Bonneville Dam tailrace	233.0
UI	Columbia	Cascade Locks, OR	240.2
UI	Columbia	Stevenson, WA	243.0
UI	Columbia	White Salmon River, WA shore	270.4
UI	Columbia	White Salmon River, mid-river, WA shore	270.4
UI	Columbia	White Salmon River, mid-river	270.4
UI	Columbia	White Salmon River, mid-river, OR shore	270.3
UI	Columbia	White Salmon River, OR shore	270.0
UI	Columbia	White Salmon River, mouth	271.4
UI	Columbia	Hood River, mouth	272.4
UI	Columbia	Hood River, WA shore	273.0
UI	Columbia	Hood River, mid-river, WA shore	273.0
UI	Columbia	Hood River, mid-river, OR shore	273.0
UI	Columbia	Hood River, OR shore	273.0
UI	Columbia	Klickitat River, ~300m upstream from mouth	290.6
UI	Columbia	Lyle, upstream of Klickitat R. mouth WA shore	292.7
UI	Columbia	Lyle, upstream of Klickitat R. mouth mid-river	292.7
UI	Columbia	Lyle, upstream of Klickitat R. mouth OR shore	292.7
UI	Columbia	The Dalles Dam tailrace, WA shore	304.9
UI	Columbia	The Dalles Dam tailrace, mid-river	304.9
UI	Columbia	The Dalles Dam tailrace, OR shore	304.9
UI	Columbia	Miller Island downstream, WA shore	325.9
UI	Columbia	Miller Island downstream, mid-river	326.0
UI	Columbia	Miller Island downstream, OR shore	326.0
UI	Columbia	Deschutes River, mouth	328.2
UI	Columbia	Miller Island upstream, WA shore	333.6
UI	Columbia	Miller Island upstream, mid-river	333.6
UI	Columbia	Miller Island upstream, OR shore	333.7
UI	Columbia	John Day River, ~1200 m upstream from mouth	352.0

Data downloading and processing

Data were loaded into a database maintained at the University of Idaho. Autonomous nodes were downloaded monthly by transferring data to a portable computer. Clocks on all receivers and readers were synchronized to assure comparability between data collected at different sites. Records were screened to remove obvious error (noise) records and detections that occurred before fish were released. Records were inspected for accuracy, and assigned codes summarizing the movements of tagged fish.

Data analysis

Lamprey travel times (d) and migration rates (km/d) were calculated from the last record at a receiver site to the first record at upstream receiver sites. We estimated detection efficiency for each receiver site as the proportion of adults that were detected at the location of those known to have passed the location based on detections at upstream JSATS and HD-PIT detection sites. Detection on individual JSATS receivers required assumptions about valid versus invalid ("noise") records. Valid detections were defined as those with three detections at any receiver within a 15 min time block within a plausible spatial range. Coded data were used to estimate several passage metrics, including travel times, migration rates, and residence times. We estimated residence times at receiver sites and described the final locations of individual fish using both JSATS and HD-PIT detection records. We tested for associations between lamprey migration rate and tag date, water temperature, and body length using univariate linear regression. We compared the passage frequencies of JSATS and HD-PIT tagged adults at Bonneville, The Dalles, John Day and McNary Dams to test whether there was evidence of a greater tag burden in the JSATS-tagged adults (i.e., adults were double tagged with JSATS + HD-PIT or HD-PIT only) using the multiple logistic regression model

Passed (yes, no) = tag type (HD only, JSATS+HD) + tag date + length + tag type*length

Travel time, migration rate, detection efficiency, diel behavior, and residence time analyses were based on data collected from June 2013 through October 2013. Final fates and distributions were determined from JSATS and HD-PIT records in fall 2013 (i.e., potential lamprey detections in spring 2014 had not occurred or been incorporated into the database).

Results

Lamprey tagging and release

The total number of adult lamprey recorded at Bonneville Dam in 2013 was 91,160 (N. Zorich, *personal communication*). The double-tagged sample of 400 lampreys represented 0.44% of the total count at Bonneville Dam. Due to contractual issues we did not receive transmitters until late June and the first portion of the lamprey run was not sampled. Once tagging began, the sample was in approximate proportion to the run (Figure 2). Fish were released into the Bonneville tailrace at Hamilton Island (n = 102), Tanner Creek (n = 95), Bonneville Reservoir at Stevenson (n = 98) and Cascade Locks (n = 105).

Size metrics were similar between JSATS-tagged fish and fish that were HD-PIT-tagged only in 2013 (Table 2).

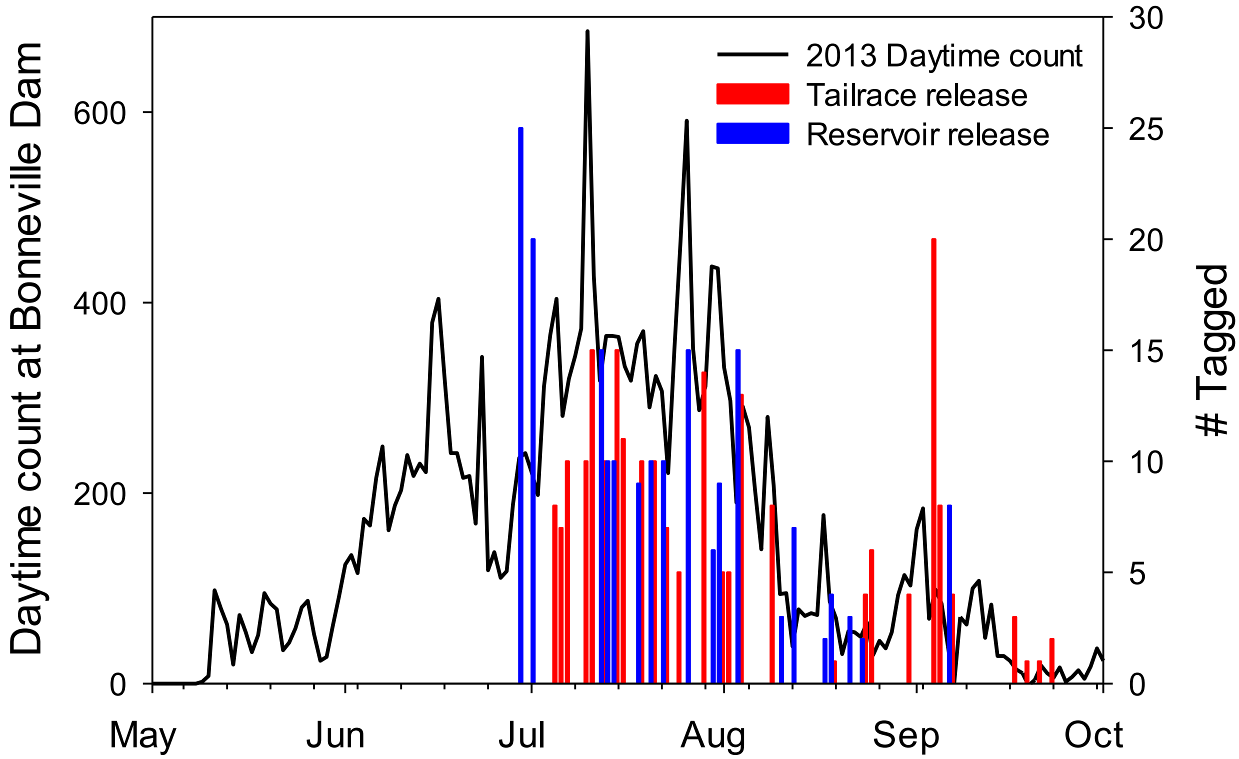

Figure 2. Distribution of JSATS-tagged Pacific lamprey and daily daytime count at Bonneville Dam, 2013.

Table 2. Length, weight, and girth of adult Pacific lamprey double tagged with HD-PIT and JSAT transmitters at Bonneville Dam in 2013. For comparison, data from lampreys that were tagged only with HD-PIT tags in 2013 are shown; details for the HD-PIT sample are reported in Keefer et al. (*in prep*).

	Length (cm)			Girth (cm)			Weight (g)		
Study group	*n*	Mean	*sd*	*n*	Mean	*sd*	*n*	Mean	*sd*
Tailrace release	197	64.3	4.1	197	10.6	0.8	197	423.4	77.4
Reservoir release	203	65.4	4.4	203	10.8	1.0	195	442.3	94.8
All releases	400	64.8	4.3	400	10.7	0.9	392	432.8	86.9
HD PIT only	941	65.0	4.4	942	10.8	0.9	943	443.7	93.2

Telemetry monitoring

JSATS telemetry monitoring at nearly all sites remained in place through October of 2013. The Deschutes River mouth site was removed in late September by the Wasco County Sheriff's

Department due to frequent calls from concerned anglers and was not redeployed. All sites had nearly continuous coverage, with short (<1 h) periods of no coverage for receiver maintenance (Figure 3).

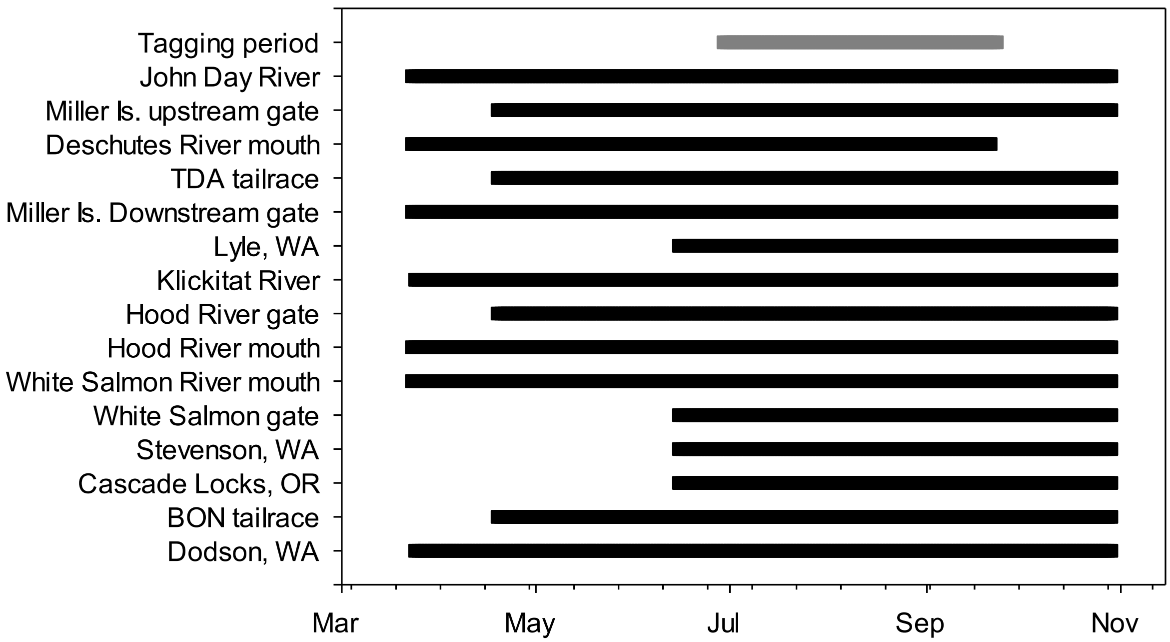

Figure 3. Autonomous node deployment schedule by site, March 2013 through October 2013.

Detection efficiencies differed little by location. Of the 400 lamprey released, 395 (99%) were detected on at least one autonomous node receiver. The five undetected tagged lamprey had been released at Hamilton Island or Tanner Creek, where we did not have a release site receiver deployed. Detection efficiency at Dodson, WA could not be estimated because of a lack of detections sites downstream and consequently it remains unknown if the five lamprey moved downstream of the tailrace undetected. Detection efficiency of reservoir-released fish was 98% at the receiver near the Cascade Locks Marina release site, and 99% at the receiver near the Stevenson release site. Among the other receiver gates, detection efficiencies ranged from 94% at the Bonneville Dam tailrace receiver to 98% at the Miller Island upstream receivers (Figure 4).

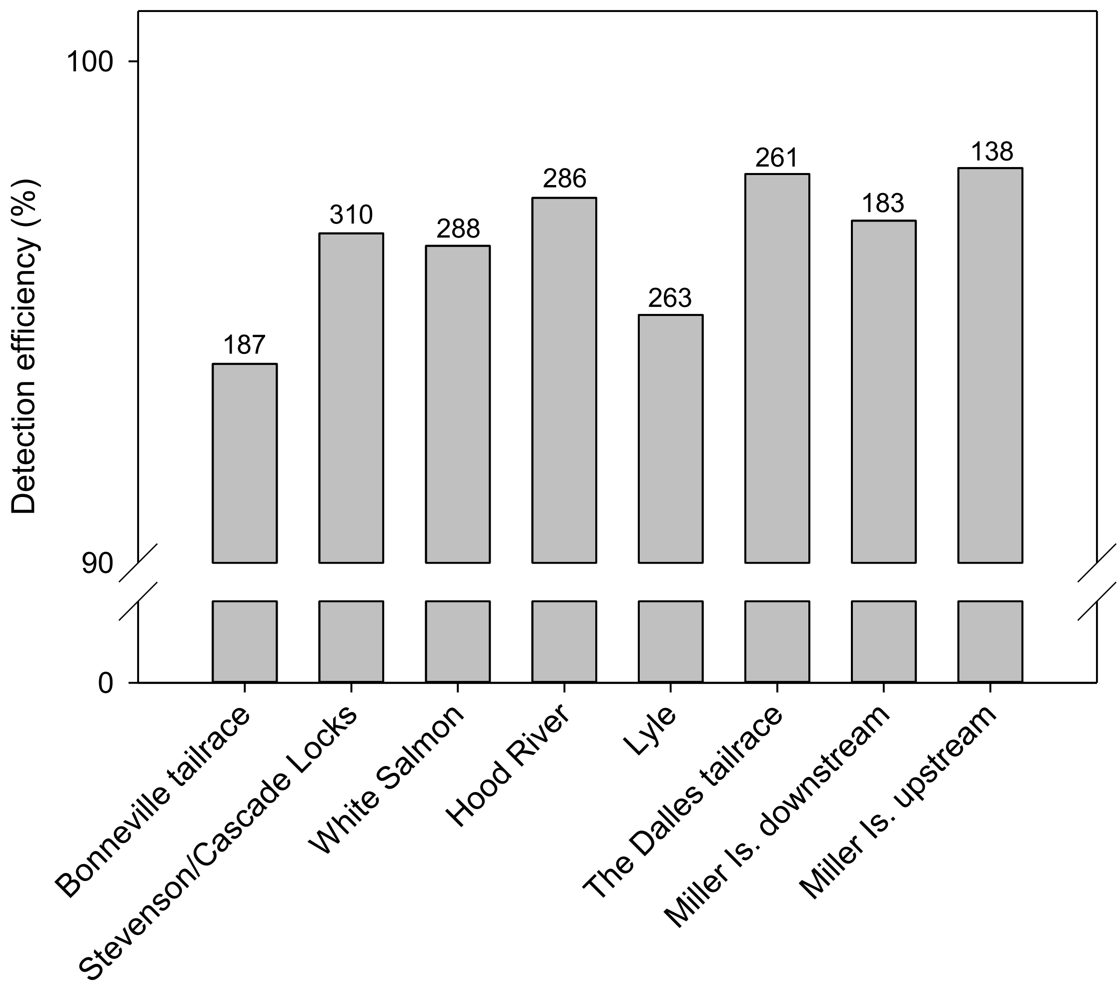

Figure 4. Detection efficiencies of JSATS receivers, by gate, for all tagged Pacific lamprey. Sample sizes detected upstream are shown above each bar.

Most (84%) of the adults detected in the Bonneville Reservoir were later detected at upper reservoir sites for both release groups (Figure 5). The proportion of adults detected at upstream sites differed among release locations because many lamprey released to the tailrace did not pass Bonneville Dam (Figure 5). The distribution of adults upstream of Bonneville Dam was similar between those released to the tailrace that passed Bonneville Dam and those released in Bonneville Reservoir (Figure 5).

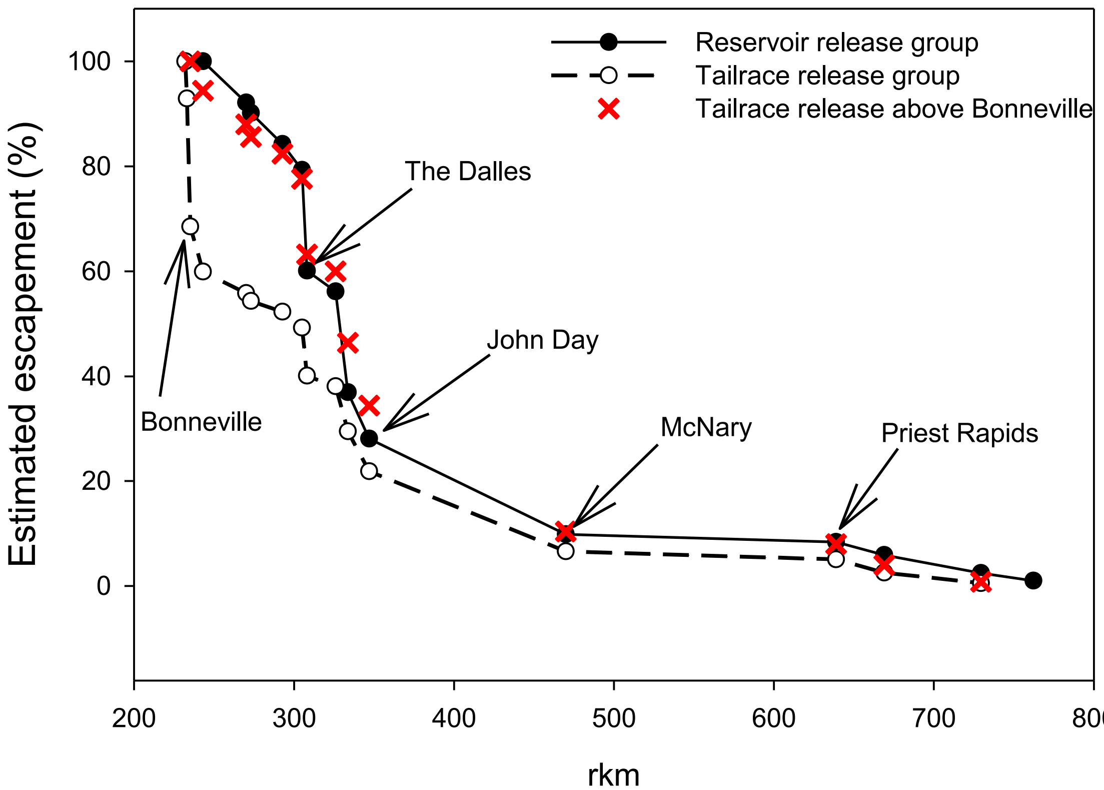

Figure 5. Percentage of JSATS tagged Pacific lamprey detected at Bonneville Reservoir and upriver receiver gates, by release group. The 'Tailrace release above Bonneville' group refers to those fish that were released to the tailrace and passed the dam.

Diel activity

Tagged lampreys moved upstream during day and night, but patterns differed among sites. First and last detections at the Hood River gate showed considerable movement during mid-day, regardless of release group. In contrast, first and last detections for both release groups at other reservoir gates occurred primarily at night and in early morning (Figure 6).

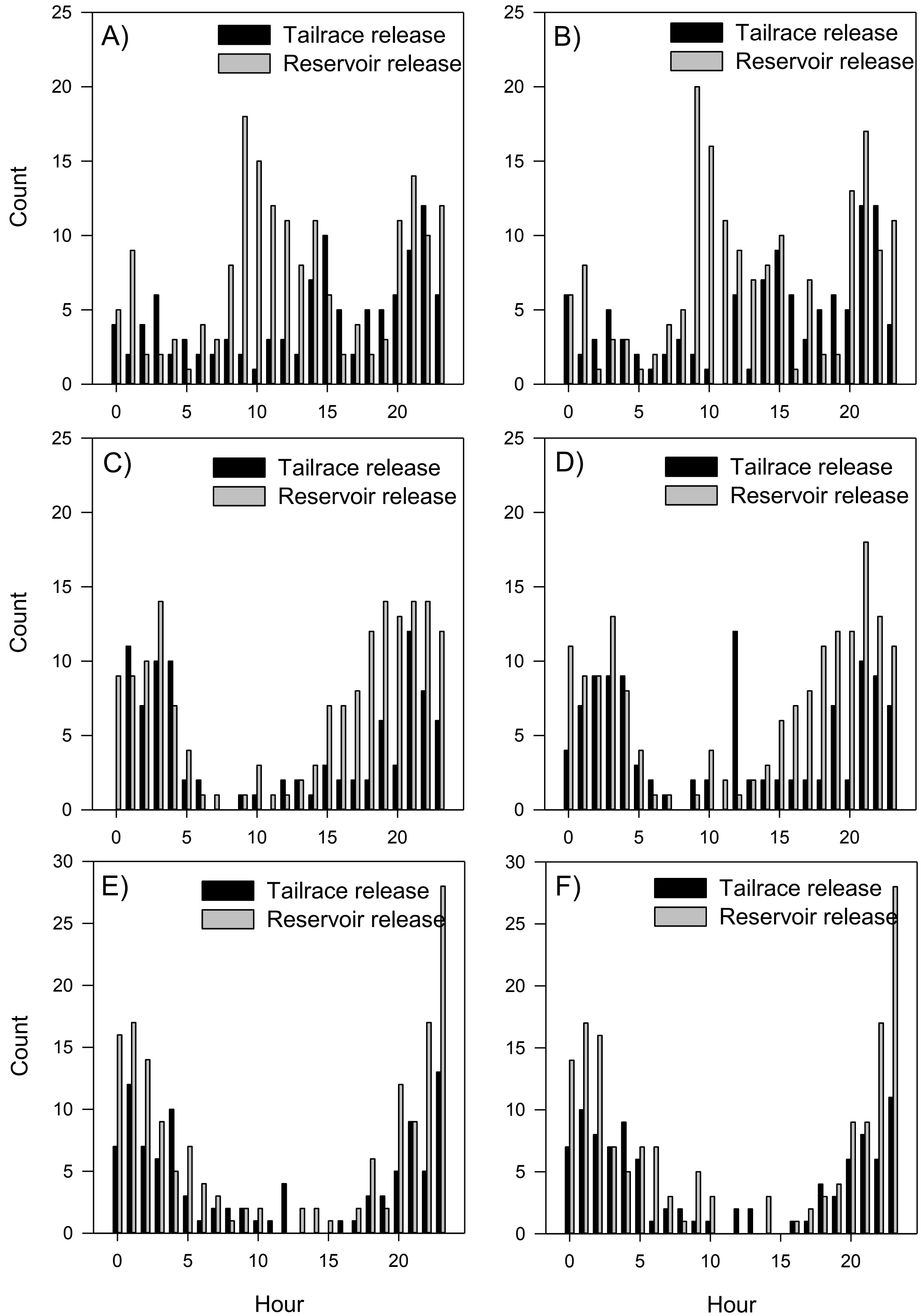

Figure 6. Distribution of first (left panels) and last (right panels) detections by hour for JSATS-tagged Pacific lamprey on receivers at the Hood River (A and B), Lyle (C and D), and The Dalles Dam tailrace (E and F) sites (Washington and Oregon shores, combined).

Travel times and migration rates

Tagged lamprey released downstream from Bonneville Dam passed the dam slowly, but then migrated rapidly through all reservoir reaches (Figure 7 and Table 3). Similarly, reservoir-released lamprey moved quickly through the reservoir reaches. Median migration rates for tailrace-released fish were 26.5-62.0 km/d through the Reservoir reaches versus 0.5 km/d from release past Bonneville Dam (Figure 7 and Table 3). Median Reservoir rates for reservoir-released samples were 46.8-61.1 km/d.

Analyses using univariate linear regression found no correlation between migration rate through the reservoir reach with the largest sample size (White Salmon to Hood River) and release date (n = 233, $r^2 < 0.001$, $P = 0.65$), or water temperature (n = 233, $r^2 < 0.001$, $P = 0.91$) (Figure 8). We found a weak, but significant correlation between migration rate and lamprey fork length (n = 233, $r^2 = 0.023$, $P = 0.022$) (Figure 8).

Table 3. Travel times (d) and migration rates (km/d) of JSATS-tagged adult Pacific lamprey released in the Bonneville Dam tailrace (top) and Bonneville Reservoir (bottom), 2013.

		Travel time (d)			Migration rate (km/d)		
Reach	*n*	Mean	Median	Range	Mean	Median	Range
Tailrace-released fish							
Release – BON ladder top	81	13.3	5.4	0.3-67.1	1.1	0.5	0.04-10.8
BON ladder top – White Salmon	69	2.8	1.3	0.5-42.2	28.2	26.5	0.8-71.7
White Salmon – Hood River	105	0.1	0.1	0.03-1.0	57	59	2.9-93.5
Hood River – Lyle	94	0.5	0.3	0.2-2.1	53.1	62	9.3-92.2
Lyle – TDA Tailrace	81	0.4	0.2	0.1-1.9	46	53.5	6.5-87.2
Reservoir-released fish							
Release – White Salmon	181	1.2	0.6	0.4-22.1	44.7	46.8	1.4-86.2
White Salmon – Hood River	174	0.3	0.1	0.03-33.8	54	58.8	0.1-94.6
Hood River – Lyle	161	0.6	0.3	0.2-6.1	54.9	61.1	3.2-92.4
Lyle – TDA tailrace	152	0.7	0.2	0.1-24.9	49	57.6	0.5-86.0

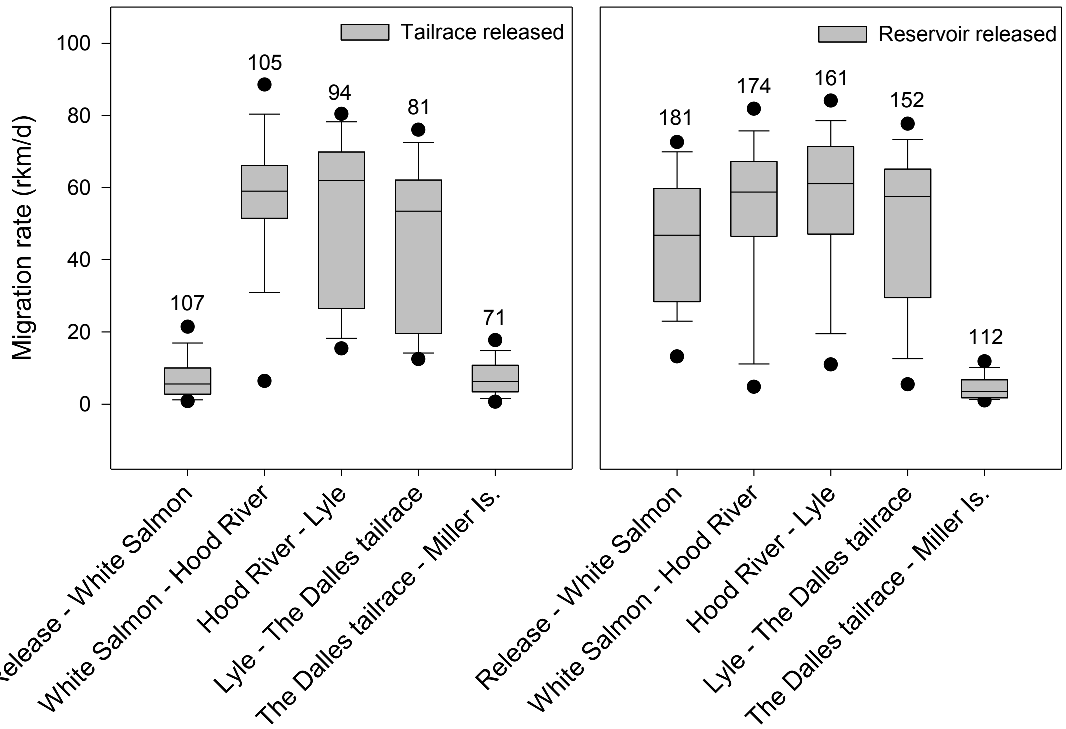

Figure 7. Migration rates (km/d) by reach for JSATS-tagged Pacific lamprey released into the Bonneville Dam tailrace (left) or Bonneville Reservoir (right). Sample sizes are shown above each bar. Box plots show 5th, 25th, 50th, 75th and 95th percentiles.

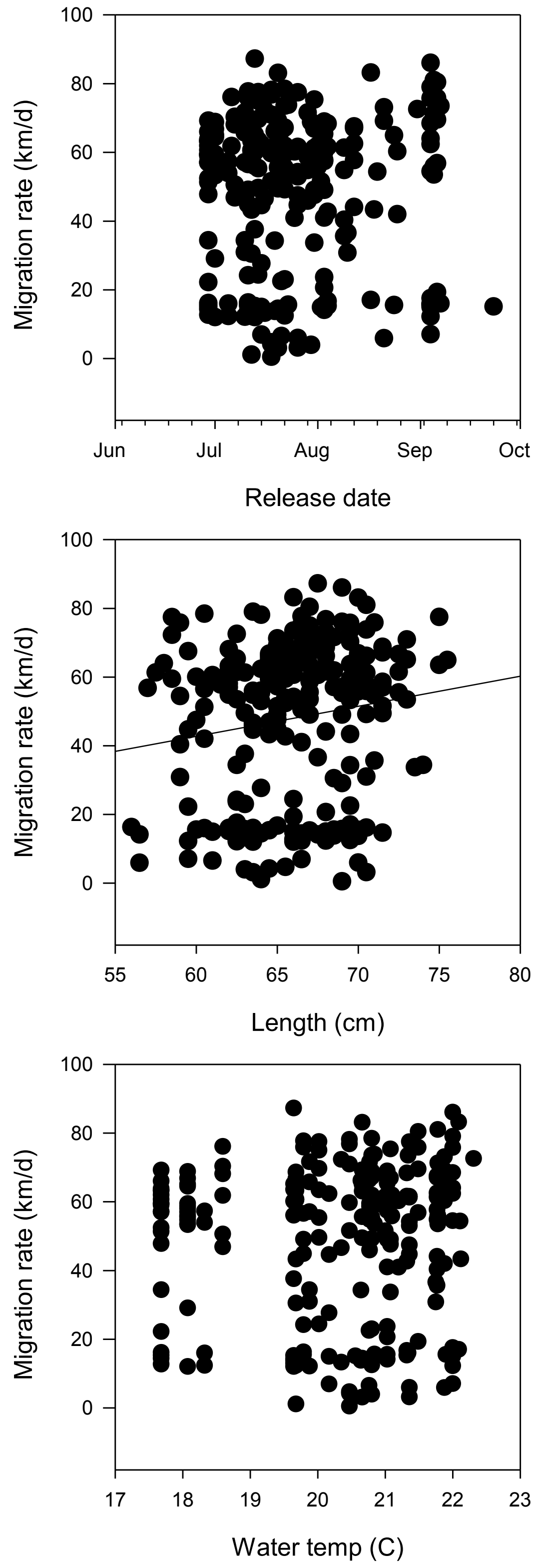

Figure 8. Relationships between migration rate (White Salmon River-Hood River reach) and water temperature at release (top), fork length (middle), and release date (bottom) for adult Pacific lamprey tagged in 2013 (both release groups combined).

Residence times

We examined residence time within the detection range of individual autonomous nodes as a secondary measure of migration rate. Lamprey were present near the Cascade Locks release site for the longest period, but were present at other sites for twenty minutes or less in nearly all cases (Figure 9). Median residence time at the Cascade Locks and Stevenson release site receivers was 0.2 h (*mean* = 0.8 h; *range* = 0.03 – 6.5 h) and 0.2 h (*mean* = 0.4 h; *range* = 0.01 – 3.6 h), respectively (Figure 9). Median residence times at other Bonneville Reservoir receivers ranged from 0.14 h at the Lyle site to 0.24 h at the The Dalles tailrace site (Figure 9). Median residence times at Miller Island receivers were 0.21 h at both the downstream and upstream sites (Figure 9).

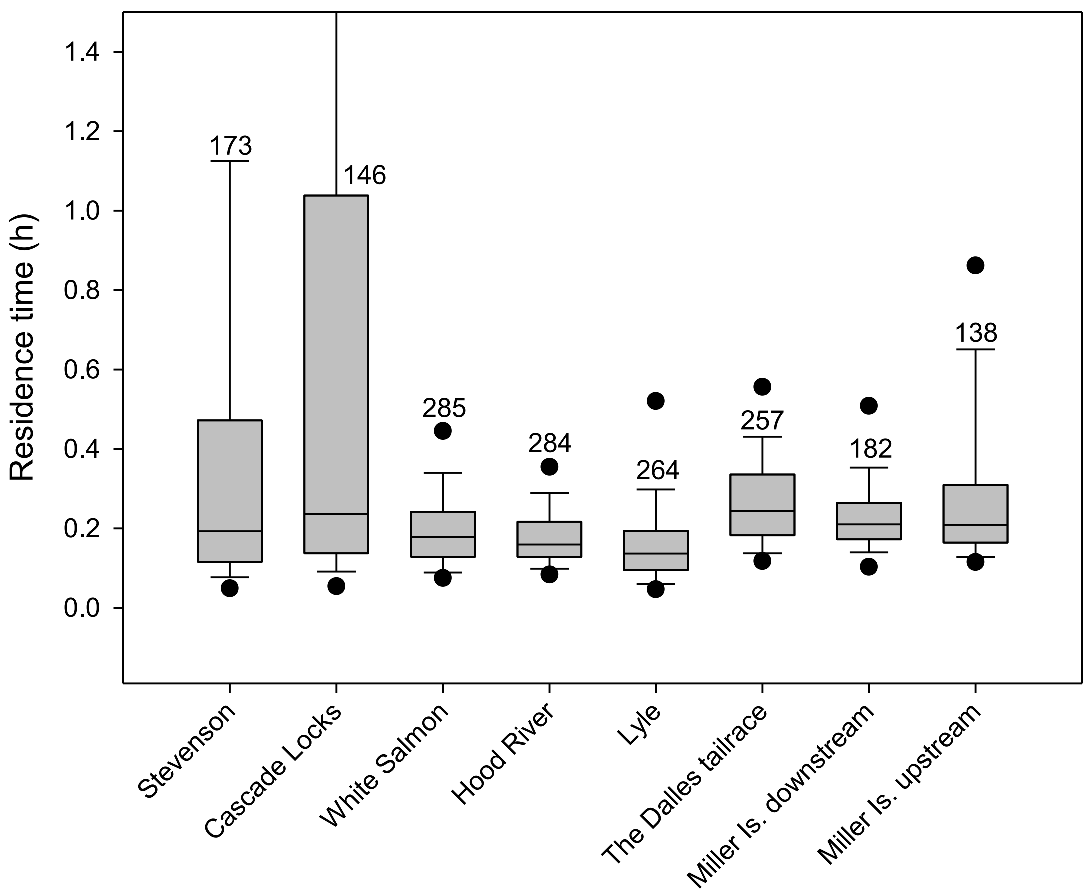

Figure 9. Residence times for JSATS-tagged Pacific lamprey on receivers in Bonneville Reservoir. Four outliers omitted for clarity. Sample sizes are shown above each bar. Box plots show 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles.

Final distribution and escapement

The probability of passing Bonneville, The Dalles, John Day, or McNary dams based on PIT tag detections did not differ ($P > 0.10$, χ^2 test) between adult lampreys double-tagged with JSATS + HD-PIT tags versus adults tagged with only an HD-PIT tag in 2013 (Table 4). Analyses using logistic regression also suggested that tag type was not a significant factor in the probability of dam passage at lower Columbia River dams when statistically controlling for the effects of body size and date of tagging. Body length was significant at Bonneville ($\chi^2 = 27.12$, $P = 0.0001$), The Dalles ($\chi^2 = 37.14$, $P = 0.0001$), and McNary dams ($\chi^2 = 4.99$, $P = 0.03$), with larger fish more likely to pass. Lamprey that successfully passed these dams were 1.9 cm longer, on average, than those that did not pass. Tag date was significant only at The Dalles ($\chi^2 = 7.51$, $P = 0.006$) and John Day dams ($\chi^2 = 5.32$, $P = 0.02$). Lamprey that successfully passed these dams were tagged 6.5 days earlier, on average, than those that did not pass. We note that the HD-PIT proportions reported include only lamprey released during the JSATS sampling period (29 June and 23 September; i.e., early-run HD-PIT only fish were excluded) and thus differ from those reported elsewhere (Keefer et al., in prep).

Table 4. Results of Pearson's chi-square tests of upstream dam passage proportions between JSATS (n = 197) and HD-PIT (n = 588) tagged Pacific lamprey released in the Bonneville Dam tailrace between 29 June and 23 September.

	HD-PIT		JSATS			
	n	%	*n*	%	*Chi-square*	*P*
% past Bonneville	364	61.9	125	63.5	0.15	0.699
% past The Dalles	197	33.5	76	38.6	1.68	0.195
% past John Day	122	20.7	36	18.3	0.56	0.454
% past McNary	54	9.2	13	6.6	1.26	0.262

Once above Bonneville Dam, both release groups showed similar patterns in reach escapement, particularly when passing dams (Figure 5, Table 5). The tailrace-release group had a distribution pattern similar to reservoir-released fish within Bonneville Reservoir. One hundred and ten tailrace-released fish (55.8%) were detected on the White Salmon gate or above. One hundred and three fish (52.3%) were detected at the Lyle, WA receivers, and ninety-seven tagged lampreys (49.2%) were detected on or above The Dalles Dam tailrace receivers. Seventy-nine fish (40.1%) were detected on top of the ladder HD-PIT antennas at The Dalles Dam and seventy-five (38.1%) at the Miller Island downstream gate; fifty-eight fish (29.4%) were subsequently detected at the Miller Island upstream gate, forty-three (21.8%) continued to John Day Dam and thirteen fish (6.6%) were detected passing McNary Dam. No tailrace-released tagged lampreys were detected entering the Snake River. Ten fish (5.1%) were detected in the mid-Columbia River at Priest Rapids Dam. Five fish (2.5%) were detected at Wanapum Dam, and a single lamprey was detected passing Rock Island Dam.

Over half (n = 122, 60.1%) of the 203 reservoir-released fish were detected at or above The Dalles Dam (Figure 5, Table 5). Nearly all of the reservoir-released fish were detected as far upstream as the White Salmon gate (n = 187, 92.1%) and the majority were detected as far as The Dalles Dam tailrace (n = 161, 79.3%). One hundred and fourteen fish (56.2%) were detected as far as the Miller Island downstream gate, and seventy-five (36.9%) were detected at the gate upstream of Miller Island. Fifty-seven fish (28.1%) were detected on HD-PIT antennas at John Day Dam or upstream, and twenty fish (9.9%) were detected as far as McNary Dam. Seventeen lamprey (8.4%) were detected passing Priest Rapids Dam, twelve fish (5.9%) were detected at Wanapum Dam, five fish (2.5%) were detected passing Rock Island Dam, and two fish (1.0%) was detected passing Rocky Reach Dam. One reservoir-released lamprey was detected entering the Snake River at Ice Harbor Dam.

Last detections of lamprey from JSATS and HD-PIT antennas were used to estimate the final distribution of lamprey (Table 6) for tailrace- and reservoir-released groups. At the broadest scale, the 197 tailrace-released lamprey were classified as: passing Bonneville Dam (*n* = 125, 63.5%); exiting the Bonneville Dam tailrace downstream (*n* = 9, 4.6%); last detected in the Bonneville tailrace (*n* = 58, 29.4%); or undetected (*n* = 5, 2.5%). Forty-two tailrace-released lamprey (21.3%) were last detected in the Bonneville Reservoir with unknown final fate. Twenty-three tailrace-released lamprey had last detections in or at the mouths of tributaries (11.7% of total, 18.4% of 125 entering the reservoir). Tailrace-released fish were last detected on JSATS receivers within the John Day River (*n* = 6, 3.1%) and at the mouth of the Deschutes River (*n* = 9, 4.6%). Tailrace-released fish were also last detected on HD-PIT antennas located within Hood River (*n* = 2, 1.0%), Fifteenmile Creek (*n* = 1, 0.5%), and the Deschutes River (*n* = 5, 2.5%) (Table 6).

Reservoir-released lamprey were classified as passing The Dalles Dam (*n* = 81, 39.9%), entering a tributary (*n* = 41, 20.2%), falling back over Bonneville Dam (*n* = 4, 2.0%), or last detected in the reservoir with unknown final fate (*n* = 77, 37.9%). Forty-one reservoir-released lampreys (20.2%) were last detected at the mouths or within tributaries. Tagged lamprey were last detected on JSATS receivers at the mouths of Hood River (*n* = 2, 1.0%) and Deschutes River (*n* = 16, 7.9%), and within the Klickitat River (*n* = 1, 0.5%) and John Day River (*n* = 10, 4.9%). Lamprey were also last detected on HD-PIT antennas in Fifteenmile Creek (*n* = 2, 1.0%), and the Deschutes River (*n* = 10, 4.9%) (Table 6).

Table 5. Reach escapement estimates for JSATS-tagged Pacific lamprey in the tailrace and reservoir release groups.

Tailrace release (*n* = 197)			**Reservoir release (*n* = 203)**		
Reach	***n***	**%**	**Reach**	***n***	**%**
Release to Bonneville Dam tailrace	183	92.9			
Release to Bonneville Dam	135	68.5			
Release to Bonneville forebay	125	63.5			
Release to White Salmon River gate	110	55.8	Release to White Salmon River gate	187	92.1
Release to White Salmon River mouth	--	--	Release to White Salmon River mouth	--	--
Release to Hood River mouth	2	1.0	Release to Hood River mouth	2	1.0
Release to Hood River gate	107	54.3	Release to Hood River gate	183	90.2
Release to Klickitat River	--	--	Release to Klickitat River	1	0.5
Release to Lyle, WA	103	52.3	Release to Lyle, WA	171	84.2
Release to The Dalles Dam tailrace	97	49.2	Release to The Dalles Dam tailrace	161	79.3
Release to Fifteenmile Creek	1	0.5	Release to Fifteenmile Creek	2	1.0
Release to The Dalles Dam	79	40.1	Release to The Dalles Dam	122	60.1
Release to The Dalles Dam top of the ladder HD-PIT antennas	76	38.6	Release to The Dalles Dam top of the ladder HD-PIT antennas	117	57.6
Release to downstream of Miller Island	75	38.1	Release to downstream of Miller Island	114	56.2
Release to Deschutes River mouth	14	7.1	Release to Deschutes River mouth	26	12.8
Release to upstream of Miller Island	58	29.4	Release to upstream of Miller Island	75	36.9
Release to John Day Dam	43	21.8	Release to John Day Dam	57	28.1
Release to John Day River	6	3.0	Release to John Day River	10	4.9
Release to McNary Dam	13	6.6	Release to McNary Dam	20	9.9
Release to Ice Harbor Dam	--	--	Release to Ice Harbor Dam	1	0.5
Release to Lower Monumental Dam	--	--	Release to Lower Monumental Dam	--	--
Release to Little Goose Dam	--	--	Release to Little Goose Dam	--	--
Release to Priest Rapids Dam	10	5.1	Release to Priest Rapids Dam	17	8.4
Release to Wanapum Dam	5	2.5	Release to Wanapum Dam	12	5.9
Release to Lower Granite Dam	--	--	Release to Lower Granite Dam	--	--
Release to Rock Island Dam	1	0.5	Release to Rock Island Dam	5	2.5
Release to Rocky Reach Dam	--	--	Release to Rocky Reach Dam	2	1.0

Table 6. Last recorded locations for JSATS-tagged Pacific lamprey in the tailrace and reservoir release groups.

	Tailrace release (n = 197)		Reservoir release (n = 203)	
Last recorded location	***n***	**%**	***n***	**%**
No record after release	5	2.5		
Dodson/Skamania	9	4.6	1	0.5
Bonneville Dam tailrace	48	24.4	3	1.5
Bonneville Dam - Cascades Is. AWS	1	0.5		
Bonneville Dam - lamprey rest boxes	5	2.5		
Bonneville Dam - WA ladder	4	2.0		
Bonneville Dam - WA ladder exit	3	1.5		
Bonneville Dam - Bradford LPS	4	2.0		
Cascade Locks	2	1.0	5	2.5
Stevenson	6	3.0	7	3.4
White Salmon	1	0.5	2	1.0
Hood River mouth			2	1.0
Hood River (HD-PIT)	2	1.0		
Hood River	4	2.0	11	5.4
Klickitat River			1	0.5
Lyle	6	3.0	10	4.9
The Dalles Dam tailrace	17	8.6	37	18.2
Fifteenmile Creek (HD-PIT)	1	0.5	2	1.0
At The Dalles Dam	3	1.5	5	2.5
The Dalles Dam ladder exits	1	0.5	3	1.5
Miller Island downstream	4	2.0	17	8.4
Deschutes River mouth	9	4.6	16	7.9
Deschutes River mouth (HD-PIT)	4	2.0	6	3.0
Sherars Falls (Deschutes-HD-PIT)			3	1.5
Warm Springs R. (Deschutes-HD-PIT)	1	0.5	1	0.5
Miller Island upstream	15	7.6	18	8.9
At John day Dam	6	3.0	8	3.9
John Day Dam ladder exits	16	8.1	16	7.9
John Day River	6	3.0	10	4.9
At McNary Dam	1	0.5	1	0.5
McNary Dam ladder exits	2	1.0		
Ice Harbor Dam			1	0.5
Priest Rapids Dam	5	2.5	5	2.5
Wanapum Dam	4	2.0	7	3.4
Rock Island Dam	1	0.5	3	1.5
Rocky Reach Dam			2	1.0

Discussion

Overall, results of the 2013 telemetry study to date have been generally consistent with previous results. We found no evidence that double tagging with JSATS and HD-PIT tags had additional tagging effects compared to tagging with only HD-PIT tags, in contrast to previous evidence of tagging effects associated with radio-tagging. Passage rates of JSATS-tagged adults in 2013 at Bonneville Dam were among the highest recorded for any tagged group, though direct comparison to prior years was compromised by late sample. Similar to prior years, most adults moved quickly through the lower Bonneville Reservoir, with evidence of tributary entry, and most lampreys with unaccounted for fates at the end of 2013 were distributed in the upper reservoir and tailrace of The Dalles Dam. Monitoring during spring 2014 will provide potential additional detections. Below we discuss the potential mechanisms generating the observed distribution patterns and potential ways of refining fate determinations in the Bonneville Reservoir and The Dalles Dam tailrace. A forthcoming report (early fall 2014) will provide refined summaries including detections in spring 2014 and a multi-year summary of JSATS results across the four tagging years (2010-2013).

Dam passage rates were similar to those of PIT-tagged only fish, and we found no evidence of any tagging effects associated with use of the JSATS transmitters. Detection efficiencies were higher at reservoir and tailrace gates in 2013 than in previous years, likely due to the deployment of additional receivers at most sites.

Travel times and migration rates

JSATS monitoring provided the opportunity to estimate migration rates of lamprey within the reservoir without the influence of dam passage time (a complicating factor for HD-PIT only samples). The majority of tagged lamprey migrated quickly through Bonneville Reservoir and entered The Dalles Dam tailrace. Within-reservoir travel times and migration rates varied greatly among individual lamprey, but were rapid compared to passage past dams. Medians rates were similar to those observed in the 2010, 2011, and 2012 JSATS studies (Naughton et al. 2011; Noyes et al. 2012; Noyes et al. 2013). There was no significant association between migration rate in reservoir reaches with water temperature and release date, although we note that the JSATS tagging effort started in late June and the sample was biased towards the latter part of the run.

Distribution and fate

A key finding of this study is the observation that the majority (83.5%) of adults that entered or were released to Bonneville Reservoir rapidly and successfully passed ~80% the length of the reservoir and were detected at the Lyle gate, approximately 16 rkm downstream from The Dalles Dam. The high percentages of JSATS-tagged fish that reach upper Bonneville Reservoir sites suggest that migration conditions and factors such as predation and prespawn mortality did not strongly contribute to the overall unaccounted-for fates in the downstream two-thirds of Bonneville Reservoir during the summer and fall migration as observed in past studies, and that few fish were overwintering in the downstream two-thirds of Bonneville Reservoir. Potential fates for this group given passage to the upper reservoir in fall include: 1) lamprey were overwintering in The Dalles Dam tailrace and resuming upstream migration in the spring; 2) lamprey were overwintering in The Dalles Dam tailrace and returning (undetected) to downstream spawning tributaries in the spring; 3) lamprey were spawning in The Dalles Dam tailrace in the spring; 4) adults with final records at Lyle and The Dalles Dam tailrace were prespawn mortalities or predation mortalities. Previous HD-PIT studies show that a small proportion of the fish resumed upstream movement in the main stem and were detected passing dams in the spring following tagging (e.g., <3% of tagged sample; Keefer et al. 2012). Fixed receiver sites will be deployed in the Bonneville Dam tailrace, Bonneville Reservoir, and at tributary sites in the spring of 2014 to monitor movement of tagged lamprey that were unaccounted for at the end of monitoring in fall 2013. Previous JSATS studies have found that as much as 12% of unaccounted-for lamprey may enter tributaries in the spring following tagging (Noyes et al. 2013).

Determining the final distribution of lamprey with last records in FCRPS reservoirs was a primary biological objective of this study. Distributions of tagged fish in both release groups were similar to distributions seen in previous years. The distribution patterns reported in previous years were mostly determined from detections on radio and HD-PIT antennas located at dams, and only showed if a tagged fish approached, entered, exited, or passed a dam, or entered a tributary in the fall for radio-tagged adults. Generally, of the tagged fish observed to successfully migrate past a given dam in past studies about half were not detected at upstream dams (e.g., Keefer 2009a, d). Little is known from past studies of the final fates of the lampreys last detected in Bonneville Reservoir, though past radiotelemetry studies indicate that relatively few moved into tributaries to Bonneville Reservoir in the fall or early winter (prior to the expiration of radio tag battery life; e.g., Moser et al. 2002; Keefer et al. 2010).

Monitoring in and at the mouths of the Hood, White Salmon, Klickitat, Deschutes, and John Day Rivers (JSATS) and in Fifteenmile Creek (HD-PIT) revealed that sixty-three of the JSATS adults (15.8%) entered one of these tributaries in 2013. Radiotelemetry studies in 2008 and 2010 detected 3.5% and 9.9%, respectively, of tagged fish entering monitored tributaries. Tributary entry was higher among reservoir-released fish (20.2%) than tailrace-released fish (11.7%). Past JSATS and radiotelemetry studies suggest movements into the Klickitat River and Fifteenmile Creek are more common than into other tributaries during late summer and fall (Keefer et al. 2010; Noyes et al. 2013). However, results from 2013 show the majority of tributary entries by tagged fish were into the John Day and Deschutes rivers, with few fish entering the Klickitat River or Fifteenmile Creek. This pattern may result – in part – from the delayed start of our JSATS tagging effort, rather than a change in lamprey behavior. For example, early-arriving HD-PIT lamprey were more likely to enter Bonneville tributaries in the 2012 HD-PIT study compared to those that entered the John Day River; the year-to-year consistency of such patterns is unknown. Alternatively, interannual variation in environmental conditions may have altered the relative attractiveness and entry rate to the different tributaries.

The current JSATS receiver configuration is not ideal for use in smaller tributaries due to insufficient water depth and high levels of noise. Consequently, many tributaries to Bonneville Reservoir are unmonitored or only monitored at their mouths (e.g. the White Salmon River). As a result, tributary entry must be inferred based on final detections on tributary mouth receivers, or, for unmonitored tributaries, may be estimated from observed rates at monitored tributaries. Based on observed entrance rates at monitored tributaries, it is possible that between 0.25% and 10% of unaccounted for lamprey may enter each unmonitored tributary.

A substantial proportion of adult lamprey were last detected in tailraces. However, dam operations and safety concerns make it difficult to monitor lamprey in the powerhouse channels and spillways of the Bonneville and The Dalles dam tailraces, where many tagged lamprey were last detected entering. Modified JSATS receivers that could be deployed in shallow tributaries or from shore in noisy or hard to access areas (e.g. near fishways entrances or in Boat Restriction Zones in dam tailraces and forebays) could help refine the final fates and distributions of unaccounted for lamprey. In particular, the recent development of 3-D JSATS receiver arrays could be used to refine behavior and distribution of lamprey in tailraces with respect to environmental conditions and the distribution of potential predators such as white sturgeon and marine mammals. Such monitoring could also provide information on the behaviors of lamprey as they approach the face of the dam that could inform the design of alternative lamprey entrances.

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