Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversion Dams

2014 Annual Report
Phase 3: Roza and Cowiche Dams

Ann B. Grote, Mark C. Nelson, Cal Yonce, Ken Poczekaj, RD Nelle

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
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On the cover: A radio-tagged adult Pacific lamprey is released in the lower Yakima River. Photo credit Dave Herasimtschuk, USFWS / Freshwaters Illustrated.

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PASSAGE OF RADIO-TAGGED ADULT PACIFIC LAMPREY AT YAKIMA RIVER DIVERSION DAMS: 2014 ANNUAL REPORT

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Abstract- The Pacific lamprey *Entosphenus tridentatus* has declined across much of its range in the Pacific Northwest, including in the Yakima River. Several irrigation diversion dams may prevent or delay the upstream migration of adults in the Yakima River, but the total impact on migration and spawning is not known. This report details the third and final phase of a radio-telemetry study designed to determine residence times downstream of dams, passage timing and durations, passage efficiencies, and passage routes of Pacific lampreys at diversion dams on the Naches and Yakima rivers. Eighty-nine adult Pacific lampreys were implanted with radio transmitters and PIT tags and released downstream of Cowiche and Roza dams on September 12, 2013 and April 4, 2014. Overall, combined passage efficiency of all released lampreys was 79% at Cowiche Dam. However, seasonal passage efficiencies at Cowiche Dam were greater for study fish released in the fall (95%) than in the spring (59%). This result is consistent with observations from dams studied during Phase 2 (Sunnyside and Wapato Dams) where passage success was also higher for fall-release fish. In contrast, seasonal passage efficiencies were greater for spring-release lampreys at the dams studied during Phase 1 (Wanawish and Prosser dams) and this seasonal difference at neighboring dams may have implications for lampreys that naturally enter and migrate through the Yakima River. At Roza Dam, the overall combined passage efficiency was 0%. While 36 of 44 (82%) tagged lampreys that approached the dam entered the fish ladder, only 5 of 44 (11%) were detected above the ladder in the tunnel and fish facility. No tagged lampreys were detected passing the fish facility nor upstream of Roza Dam. These results indicate that both the fish ladder and the fish facility obstruct lamprey passage. Thus, as currently built and operated, Roza Dam is a barrier to adult Pacific lamprey migration. Techniques to improve passage at the dam for the short term are discussed. Additional study is needed to identify specific lamprey passage impediments and implement long term solutions at Roza Dam.

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Introduction

The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River Basin and many of its tributaries (Patten et al. 1970). Over the last two decades, Pacific lamprey populations have decreased throughout much of their native range (Close et al. 2002, Kostow 2002). This decline is evident in Yakima River, where recent adult Pacific lamprey returns have been minimal: between 2002 and 2014 adult passage counts at Prosser Dam ranged from 0 to 87 individuals per year (Columbia River DART 2015). Several factors including construction and operation of hydroelectric and diversion dams, river impoundment, water withdrawals, stream alteration, habitat degradation, elevated water temperatures, pollution, and ocean conditions have likely contributed to this decline (Luzier et al. 2011).

High-head hydroelectric dams in the main stem Columbia River cause major delays and difficulties for the upstream migration of Pacific lampreys. Telemetry studies of Pacific lamprey movements documented that less than 50% of tagged fish successfully passed upstream through fishways at main stem dams (Moser et al. 2002, Moser et al. 2002a, Johnson et al. 2009, Keefer et al. 2009). In addition, recent work from the Umatilla River indicates that smaller, diversion-type dams may also prove difficult for lampreys to pass (Jackson and Moser 2012). Several diversion dams in the Yakima River Basin may be impediments to adults migrating to suitable spawning areas. However, details on upstream migration, timing, spawning, and distribution of Pacific lamprey in the Yakima River are not well understood.

In 2011, we began a multi-year study investigating Pacific lamprey migration in the Yakima River basin. The objective of this radio telemetry study was to evaluate adult Pacific lamprey passage at Yakima River diversion dams, including approach timing, residence time downstream of dams, passage routes, efficiencies and duration, and migration rates between dams. Information from this study will help guide management recommendations for improving passage at the dams in the Yakima River.

Results from Phases 1 and 2 of this study showed that more than 93% of tagged lampreys moved upstream following release and actively attempted to pass dams. Dam passage efficiencies were lower at Wanawish and Prosser dams on the lower Yakima River, than at Sunnyside and Wapato dams located further upstream. Passage efficiencies also varied seasonally. At Wapato and Sunnyside dams passage efficiencies were higher in the fall; whereas at Wanawish and Prosser dams, passage efficiencies increased in the spring. Cumulative passage through multiple dams declined exponentially, and only 7% of tagged lampreys released below Wanawish succeeded in passing four sequential dams.

This annual report presents the results of Phase 3 of our study at Cowiche and Roza dams for the 2013 migratory year, from September 12, 2013 through November 30, 2014.

Background

Similar to summer steelhead *Oncorhynchus mykiss*, Pacific lamprey enter freshwater a year prior to spawning, migrate upstream to overwinter, and then access spawning tributaries or areas the following spring. Unlike many anadromous fishes, Pacific lampreys do not appear to home to their natal streams (Hatch and Whiteaker 2009, Spice et al. 2012), but instead may utilize the "suitable river strategy" in which returning adults are attracted to streams inhabited by larval lamprey or ammocoetes (Waldman et al. 2008). Recent genetic studies differ on whether Pacific lampreys are panmictic (Goodman et al. 2008, Docker 2010, Spice et al. 2012).

Adults typically return to the Columbia River from February to June (Kostow 2002) and begin to arrive at McNary Dam (67 kilometers downstream of the Yakima River confluence) in early June with the peak of migration in late July or early August (Columbia River DART 2015). During a migratory year, lampreys are not observed at Prosser Dam until mid to late August and only a few are counted through the fall. Most of the returning adults are observed the following spring with the majority counted during April and May (Columbia River DART 2015). However, radio telemetry studies conducted in tributaries such as the John Day River (Bayer et al. 2000), the Willamette River (Clemens et al. 2011), and the Methow River (Nelson et al. 2009) found that Pacific lamprey entered these spawning tributaries in late summer and completed about 85% of their migration to spawning areas before overwintering. Thus, it appears that migration timing in the Yakima River differs from other Columbia River tributaries.

This shift may be related to temperature differences between the Yakima and Columbia rivers. During July and August, temperatures in the lower Yakima River are on average almost 4 °C higher than in the Columbia River (mean 23.8 °C vs. 20.0 °C, 2002 to 2009 data- USBOR 2015; Columbia River DART 2015). This may create a thermal barrier that either encourages lampreys to migrate past the Yakima River and continue upstream in the Columbia River or discourages lampreys from entering the Yakima River until later in the fall after temperatures equilibrate. Elevated spring passage numbers at Prosser Dam suggest that lampreys may also be overwintering in the Columbia River and entering the Yakima River the following spring.

To evaluate seasonal effects on Yakima River lamprey migration, we designed our study to test passage at the dams during both the fall and spring. Accordingly, we tagged and released a portion of our study fish in the fall and held the others over winter before tagging and releasing them in the spring. This design was intended to mimic both the timing of the "natural" run and the condition of the lampreys during their migration in the Yakima River.

Methods

Study Area

The Yakima River flows for 344 km, from the headwaters at Keechelus Lake in the Cascade Mountains to the confluence with the Columbia River at river kilometer (rkm) 539, and drains an area of approximately 15,941 km^2 (Figure 1). Annual mean discharge at the Kiona Gage Station (rkm 48.1) is 3,479 ft^3/s (range 1,293 – 7,055 ft^3/s), with the highest daily mean discharge of 59,400 ft^3/s recorded on December 24, 1933 and the lowest daily mean discharge of 225 ft^3/s recorded on April 4, 1977 (USGS 2011). The main tributaries include Satus Creek, Toppenish Creek, Naches River, Taneum Creek, Teanaway River, and Cle Elum River.

A complex irrigation network, managed in large part by the U.S. Bureau of Reclamation (USBOR), makes the Yakima River Basin one of the most intensely irrigated areas in the United States. Six lakes and reservoirs, with a total active storage capacity of 1.07 million acre-feet, hold the spring and summer snowmelt in the mountains for delivery to irrigation districts between April and October (Fuhrer et al. 2004). Surface water diversions are equivalent to about 60% of the mean annual stream flow from the basin (Fuhrer et al. 2004). In spring, the stream flow reflects the quantity of water stored in the mountain snowpack, while during the dry summer months it reflects the quantity of water released from the basin's storage reservoirs. During summer, return flows from irrigated land account for 50 to 70% of the flow in the lower Yakima River (Fuhrer et al. 2004).

Irrigation water is distributed throughout the network via rivers, creeks, and man-made canals. Irrigation diversion dams include Wanawish, Prosser, Sunnyside, Wapato, Roza, Town, and Easton on the Yakima River and Cowiche and Wapatox on the Naches River (Figure 1).

Fixed Stations

Fixed radio telemetry stations were installed at five diversion dams and at the outfall of a power plant return flow canal (Figure 2). The standard layout at a diversion dam consisted of long-range aerial yagi-type antennas that monitored downstream of the dam, the face of the dam, and upstream of the dam. Underwater antennas monitored pools at the entrance, middle, and exit of each fishway. Hanging antennas were deployed above the waterline at the intersections of the fishways and dam face where flow conditions or debris loads would have damaged underwater equipment. Underwater and hanging antennas were constructed of coaxial cable with 100 mm of the inner wire bared at the end, and had a short (1 - 4 m) detection range. Aerial antennas were mounted on masts; underwater antennas were suspended on chains; and hanging antennas were zip-tied to rails and posts.

Data logging telemetry receivers, (Lotek SRX-400A, Lotek SRX-600), equipped with an antenna switching unit (Lotek ASP 8), were housed in a metal box at each station (Lotek Wireless, Newmarket, Ontario). When available, AC power was used to charge the external 12v battery that powered the receiver at each diversion station. Solar panels were used as a back-up power system and as the primary power source at stations without AC power.

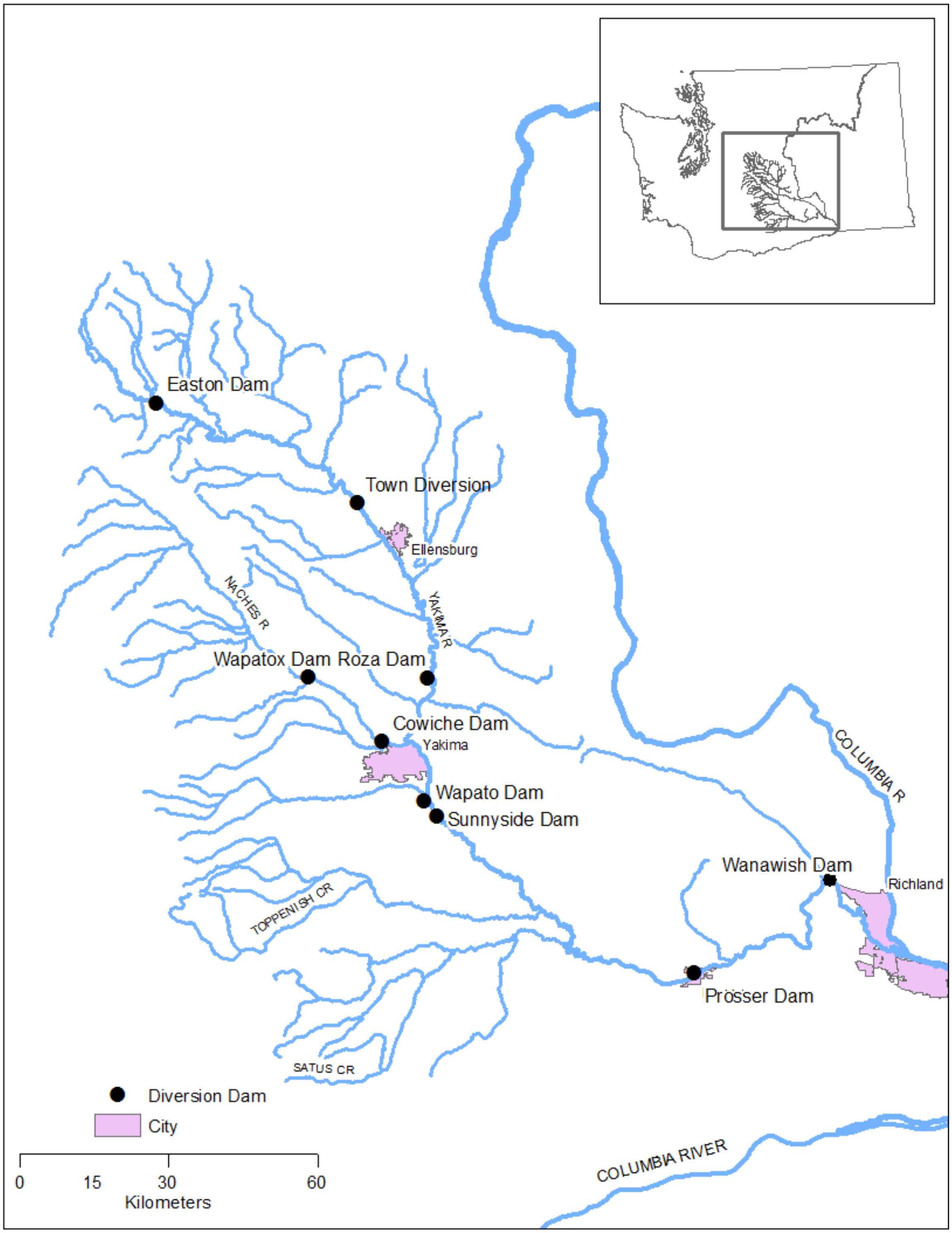

Figure 1. Map of the Yakima River watershed, showing the locations of the major diversion dams.

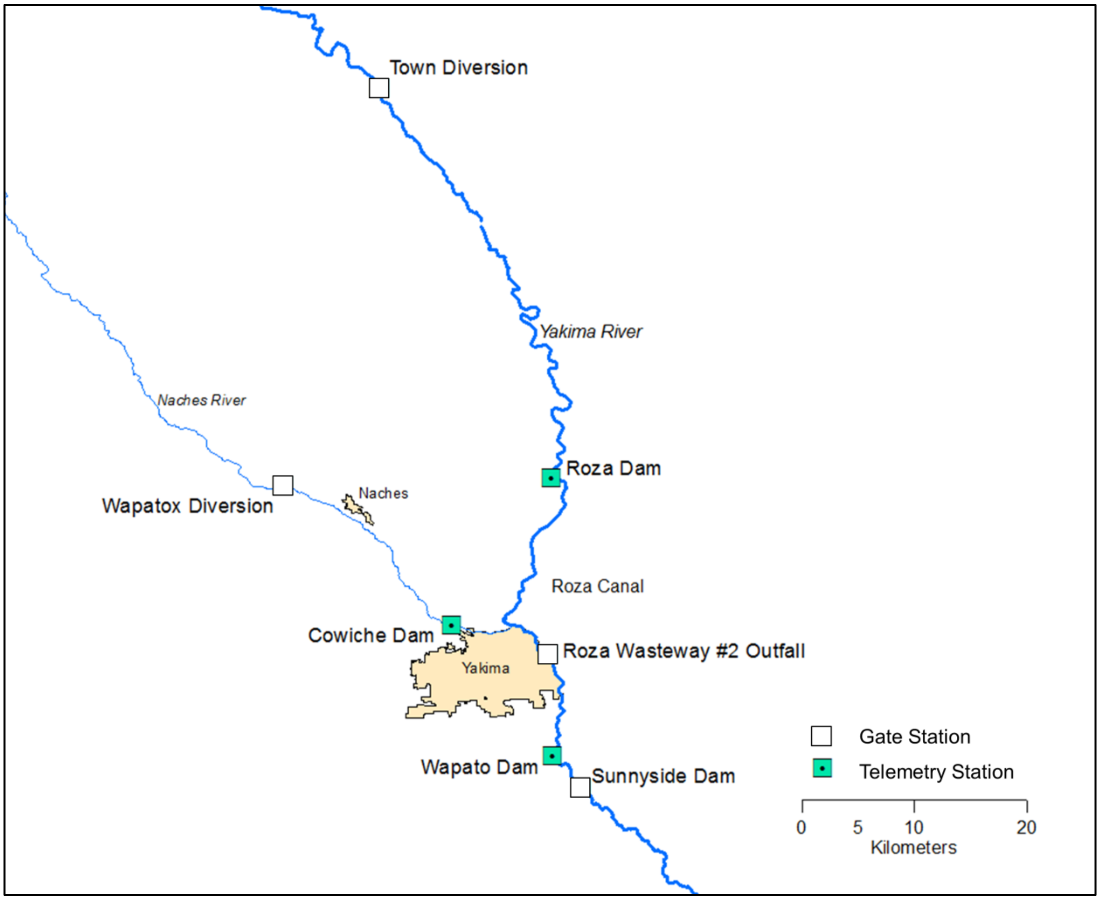

Figure 2. Map of the middle Yakima River basin showing the locations of fixed telemetry stations during 2013 and 2014.

The following illustrations of each dam and fishway were generated in Google SketchUp (version 8.016846) and are based on engineering drawings and construction blueprints obtained from the USBOR on aerial photos. These illustrations depict the general layout of the fishways and thus omit screening and operational details.

Roza Dam

Roza Dam (rkm 205) was built in 1939 and is operated by the USBOR. It is a concrete weir with two moveable roller gates. The dam stands 20.4 m tall and is 148 m in length (USBOR 2015). Water is diverted into the Roza Canal on the river right of the dam.

The Roza Dam fishway is comprised of several components, including a fishway entrance on river left, a pool and notched weir fish ladder on river left, and a tunnel passage connecting the ladder to the Roza adult fish monitoring facility (hereafter "fish facility") (Figure 3). A cross-dam gallery passage connects an entrance on river right with the fish ladder on the left.

Flows through the Roza Dam fish ladder are maintained at approximately 100 ft^3/s. An auxiliary water supply (AWS) moves water from the forebay down through diffuser grates at the bottom of the fishway (2nd and 3rd pools), in order to provide additional attractant flow at the fishway entrance. The forebay intake for the AWS is located at the downstream end of the tunnel, and flows bypass much of the fish ladder (Figure 4). The AWS was originally designed so that flows through the bottom diffuser grates could be adjusted or even shut off completely. However, parts of the system are currently inoperable, and flow adjustments are therefore limited (Josh Reynolds, USBOR, personal communication).

Four telemetry stations were deployed at Roza Dam. The river right station was equipped with three antennas, a downstream aerial, a hanger at the river right gallery entrance, and an underwater antenna located in the excess water return bay for the juvenile bypass system (Figure 3). The river left station was equipped with underwater antennas at the fishway entrance, the gallery junction at the base of the ladder, partway up the fish ladder (pool 7), near the ladder exit (pool 23), and with a downstream facing aerial antenna (Figure 4). The tunnel station was equipped with three underwater antennas: one at the tunnel entrance, one halfway up the tunnel passage, and one at the trash rack intake for the AWS (Figure 4).

The Roza fish facility station was initially equipped with two antennas: an underwater antenna located at the entrance to the fish facility, and an upstream aerial antenna monitoring the forebay. Antennas were added to this station mid-study to address modifications made at the fish facility. During Phase 2, we documented that the fish crowder in the Roza Dam fish facility holding tank was not effective at collecting lamprey so tagged lampreys that entered the fish facility did not access the slide of the fish sorter (Grote et al. 2014). The floor of the holding tank is slanted and lampreys are able to avoid the crowder by staying in the deep end of the tank or moving through diffuser grates on the tank bottom. In the fall of 2013, three Phase 3 study lampreys entered but did not pass the fish facility. In response, the USBOR and Yakama Nation modified the holding tank based on their observations of the behavior of the tagged lampreys. In November 2013 an exit hole (~ 10 cm in diameter) was drilled through the concrete wall in the southwest corner of the holding tank to allow lampreys to swim directly into the pool of the dam (Figure 5). Following the modification, two additional underwater antennas were installed to monitor the exit hole and the interior of the holding tank.

The Roza Dam fishway contains three Passive Integrated Transponder (PIT) antennas installed and maintained by the Pacific States Marine Fisheries Commission (Figure 4). These swim-through antennas are mounted in the notches of weirs 3, 4, and 5 in the fish ladder (Figure 6). Detection data from the Roza Dam PIT array were downloaded from the PTAGIS Database (PTAGIS 2015).

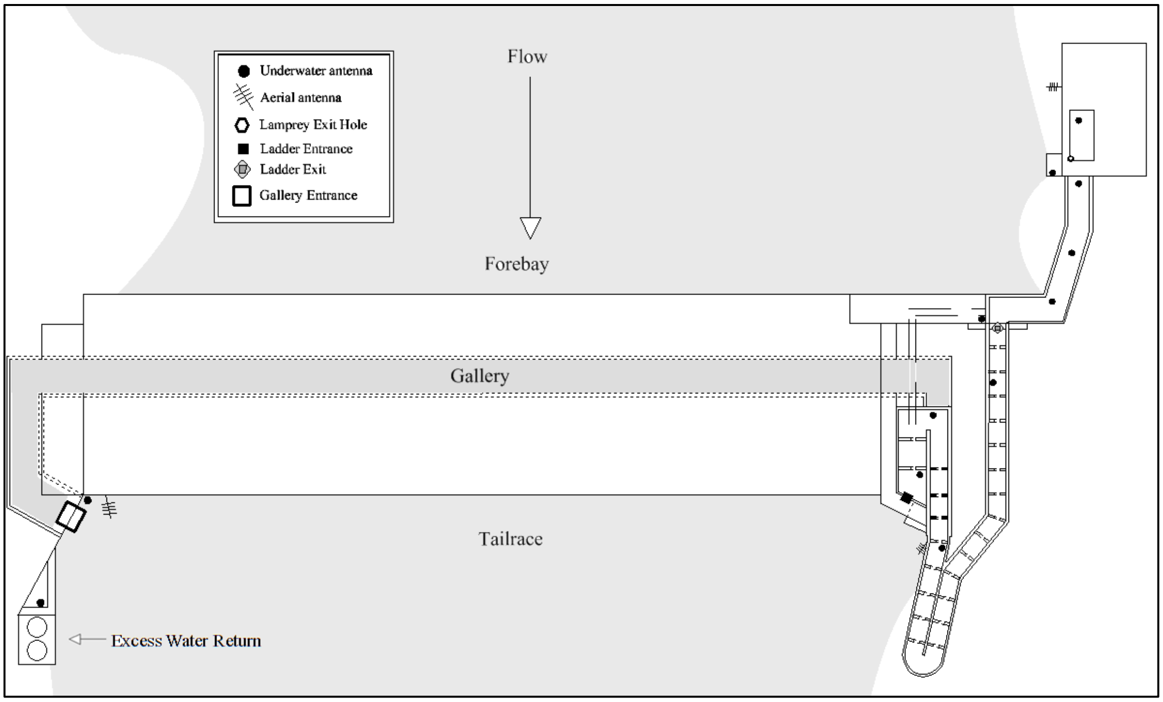

Figure 3. Locations of telemetry antennas at Roza Dam during 2013 and 2014.

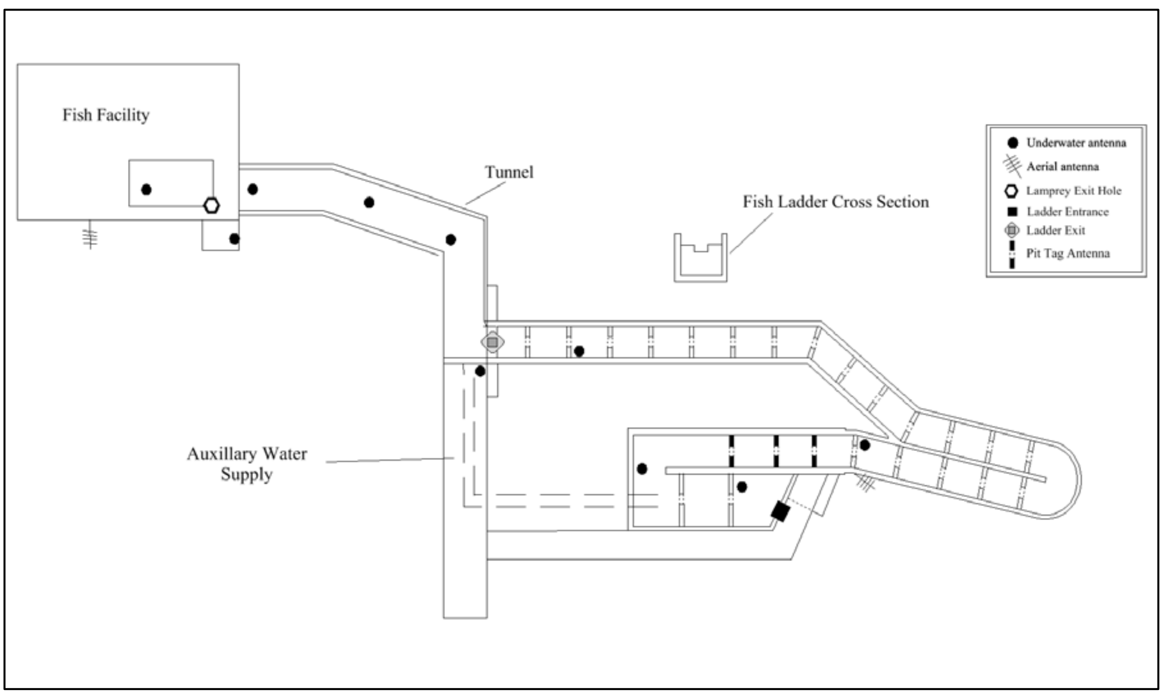

Figure 4. Detail of the Roza Dam fishway, radio telemetry and PIT antenna arrays during 2013 and 2014.

Figure 5. Exterior view of the lamprey exit hole in the Roza fish facility holding tank during the fall maintenance drawn down of the forebay. The perforated plate visible through the hole is part of the fish crowder.

Figure 6: The 3-weir PIT antenna system located in weirs 3, 4, and 5 of the Roza Dam fish ladder.

Cowiche Dam

Cowiche Dam on the Naches River (rkm 6) is a concrete gravity ogee weir. It is approximately 65 m in length, with a 1.5 m crest, a 6.4 m ogee spillway, and a 6.4 m apron (George and Prieto 1993). A fish ladder consisting of vertical slot pools is located on the river left of the dam. The left bank was equipped with three aerial antennas: one downstream, one across the face of the dam, and one upstream (Figure 7). Four underwater antennas monitored the fish ladder (entrance, mid-point, exit), and the corner where the dam face meets the fish ladder.

A diversion canal is located on the river right side of Cowiche Dam and removable flashboards can be installed on this side of the dam to manage diversion flows. The interior of the diversion canal is screened with a rotating drum and a bypass system returns fish to the middle of the river channel, 150 m downstream of the dam. Two aerial antennas (upstream and downstream) were deployed at Cowiche Dam right bank and a hanging antenna monitored the corner of the dam face (Figure 7). Two underwater antennas monitored the diversion canal water intake structure and the drum screen.

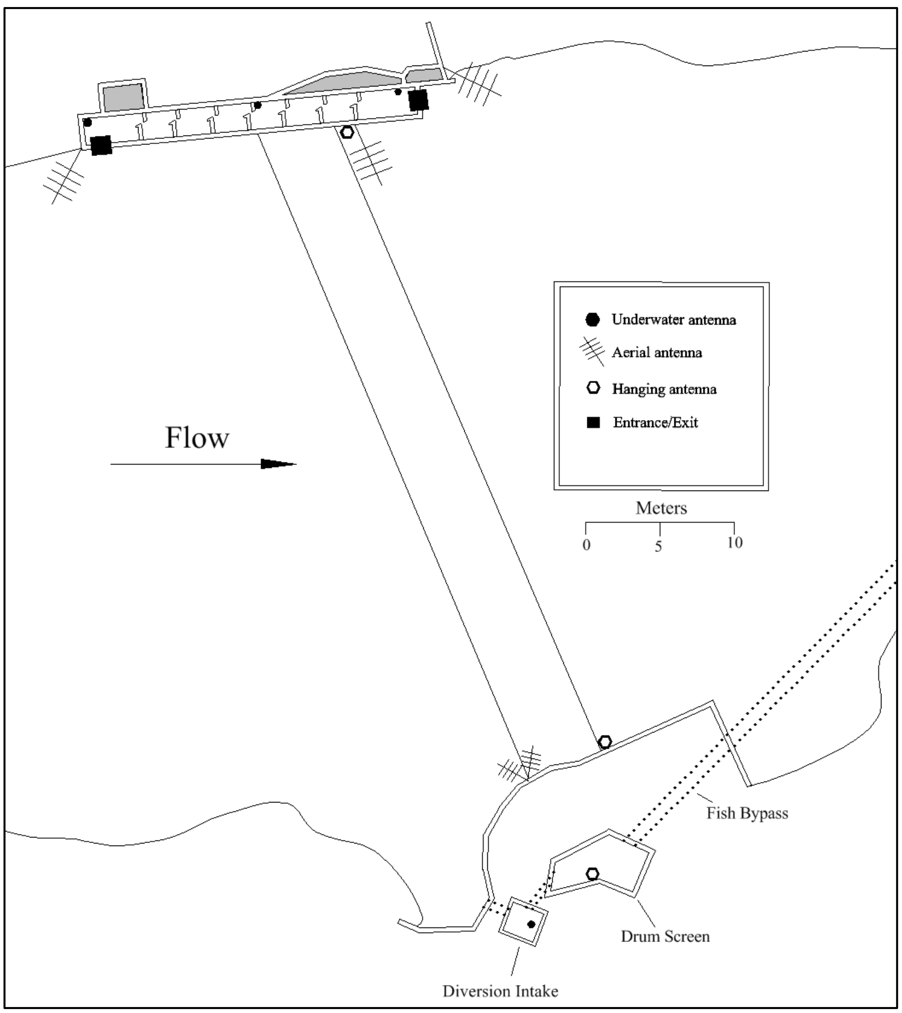

Figure 7. Locations of telemetry antennas at Cowiche Dam during 2013 and 2014.

Gate Stations
In addition to the telemetry systems deployed at study dams, simplified "gate" stations were set up at Wapatox Dam on the Naches River and Ellensburg Town Canal Diversion Dam, the Roza Wasteway #2 Canal (hereafter "Wasteway") Outfall, and Sunnyside Dam on the Yakima River (Figure 2). These gate stations were used to determine if tagged lampreys left the study area.

Wapatox Dam on the Naches River (rkm 17) is a concrete fixed-crest weir located upstream of the town of Naches, Washington. The Wapatox Dam fishway consists of three pools against the river left abutment (USBOR 2002). Wapatox Dam was equipped with two aerial antennas on river left, one facing downstream and the other facing upstream, and an AC powered receiver (Figure8).

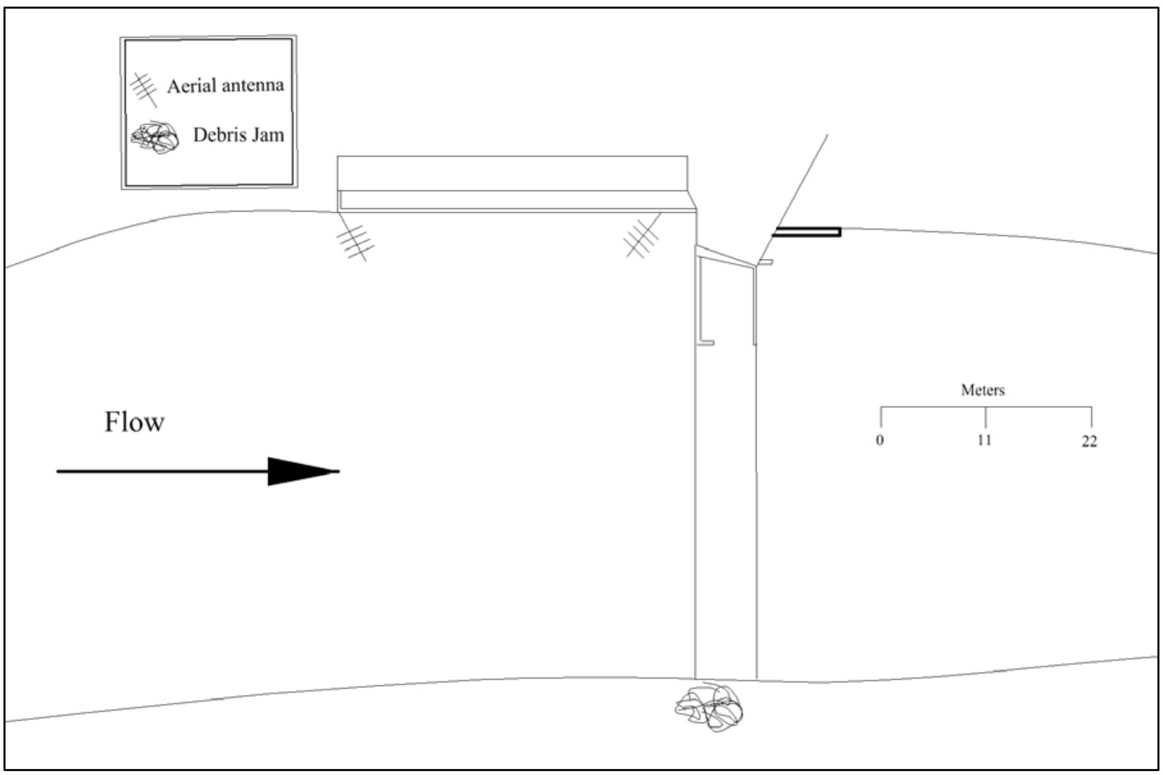

Figure 8. Locations of telemetry antennas at Wapatox Dam during 2013 and 2014.

Ellensburg Town Canal Diversion Dam on the upper Yakima River (rkm 259.5) is located upstream of Ellensburg, Washington. There is a baffle chute fish ladder on the river right side of the dam. The telemetry station at this site was deployed on river left, and consisted of a single downstream-facing antenna and an AC powered receiver (Figure 9).

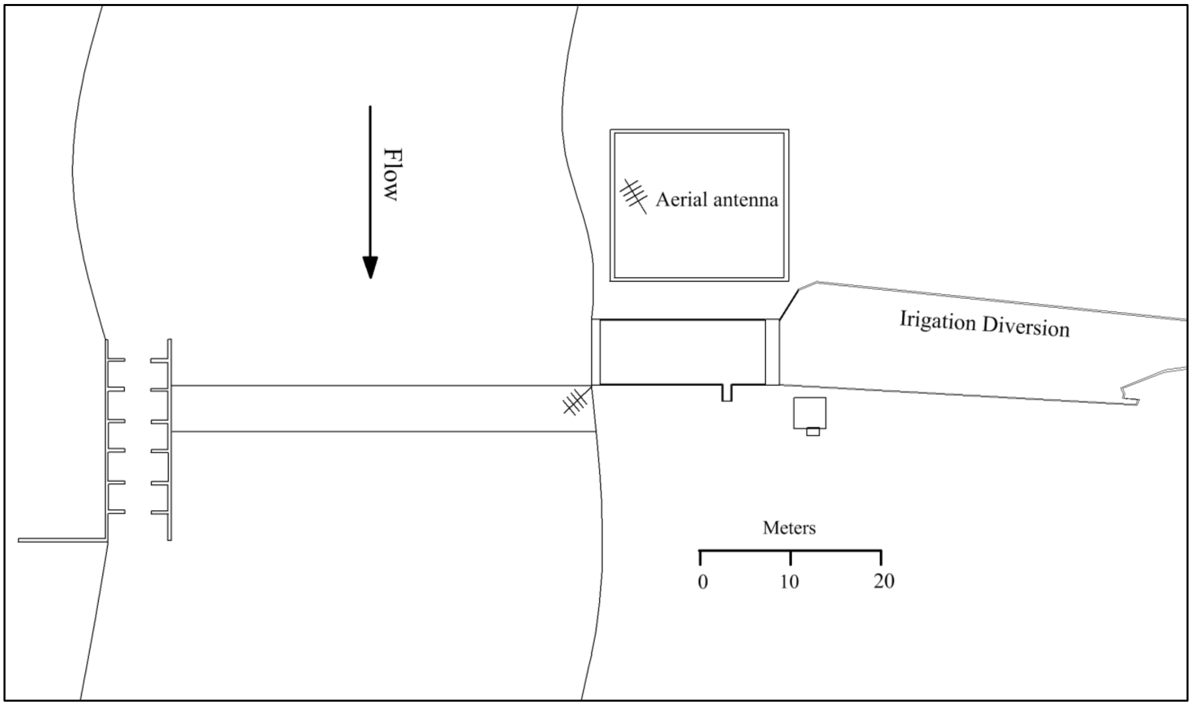

Figure 9. Locations of the telemetry station at Ellensburg Town Canal Diversion Dam during 2013 and 2014.

The Roza Wasetway #2 Canal returns water from the Roza Diversion Canal and Roza Power Plant to the main stem Yakima River at rkm 184. The Wasteway Outfall station consisted of a single aerial antenna facing upstream into the main stem Yakima River, and an AC-powered receiver. Both the Wapatox and Roza Wasteway Outfall telemetry sites were installed and operated in collaboration with the Yakama Nation Fisheries Program steelhead telemetry study. Detailed information on the Wasteway and telemetry site can be found in the Phase 2 Lamprey Telemetry Report (Grote et al. 2014).

Sunnyside Dam is a concrete ogee weir with an embankment wing and a diversion canal on the Yakima River (rkm 167). Fish passage facilities consist of three stair step vertical slot ladders, one on each bank and one near the center of the dam. This site was previously evaluated in Phase 2, and the same telemetry system was used in Phase 3: upstream and downstream-facing aerial antennas, along with multiple hanging antennas in each fish ladder, and hanging ladders in at the corners of the dam face (Grote et al. 2014).

Telemetry Data Analysis

For descriptive purposes, the definitions of *left* and *right* were referenced to the downstream river flow direction, and applied to the river banks as well as the island fishways at the dams. *First approach* was defined as the first detection recorded on any antenna at a fixed telemetry station. *Below dam residence* time was calculated as the elapsed time between the first downstream detection at the dam and either the first detection of entry into the fishway during a passage event, or the last detection before a fish moved downstream out of range of the receivers. *Fishway passage* was calculated as the elapsed time between the first fishway entrance detection and the last fishway exit detection during a passage event. *Dam passage efficiency* was defined as the number of lampreys that successfully passed the dam at least once divided by the number of lampreys that approached the dam (i.e., passage through a dam was only scored one time for each fish). *Above dam residence* was defined as the difference between the last fishway exit detection and the last upstream aerial antenna detection at the dam.

Metrics specific to the Roza Dam fishway were also calculated. *Roza fishway residence* time was calculated as the time elapsed between the first and last detections from within the Roza Dam fishway. Fishway residence time does not represent continuous residence within the Roza fishway. Tagged lampreys often spent extended periods near the fishway entrance antenna. However our instrumentation could not determine if detection gaps were individual ingress/egress events from the ladder, or whether the fish simply moved away from the antenna. Therefore, we calculated *Roza fishway incursions*: the minimum number of times that an individual lamprey was detected entering the Roza fishway. Discreet entrance events were defined as 1) the lamprey being detected within the ladder, and subsequently detected at another location, or 2) as a time gap in detections at the fishway entrance greater than 3 days.

Collection

Adult Pacific lampreys were supplied by the Yakama Nation Fisheries Program from lampreys collected at Bonneville Dam, the Dalles Dam, and John Day Dam on the lower Columbia River between June and August 2013. Fish were captured in funnel traps at the picketed leads of the fish counting stations on both sides of the dams. They were transported to the Yakama Nation Prosser Hatchery facility and held until tagging. Holding facilities consisted of flow-through metal stock tanks supplied with river and/or well water. Husbandry of the study lampreys was provided by the Yakama Nation Lamprey Team.

Radio Transmitter Implantation

Implantation surgeries took place in the spawning shed at the Yakama Nation Prosser Hatchery facility. The surgical procedure was modified from methods described in Moser et al. (2002) and Nelson et al. (2007). Tools and transmitters were chemically disinfected with Benz-All®. Each lamprey was anesthetized in a bath of 80 mg/l tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate to match the pH of the river water. After 8 to 10 minutes the fish was removed from the bath and total length (mm), interdorsal base length (mm), girth (mm), and weight (g) were measured and recorded. The lamprey was then placed on a cradle made from PVC pipe and the head and gills were immersed in a 15 L bath of 40 mg/l of buffered MS-222. Wet sponges were placed in the cradle to secure the lamprey from sliding out of the cradle. Using a number 12 curved blade scalpel, a 25 mm incision was made 1 cm lateral to the ventral midline with the posterior end of the incision stopping in line with the anterior end of the first dorsal fin. A catheter was inserted through the incision and out the body wall 4 cm posterior to the incision. The antenna was threaded through the catheter and the individually coded radio transmitter was inserted into the incision. Lotek NTC-6-2 transmitters (Lotek Wireless, New Market, Ontario, 9 x 30 mm, 4.3 g, 441 d battery life) were implanted in fall release lampreys, and Lotek NTC-4-2L transmitters (8 x 18 mm, 2.1 g, 162 d battery life) were implanted into spring release lampreys.

Lampreys were also tagged with 12 mm full duplex (FDX) PIT tags (Digital Angel, New London, Connecticut) inserted into the incision, posterior to the radio tag. The incision was then closed with 3 to 4 braided absorbable sutures tied with surgeon's knots in an interrupted pattern. Following tagging, the lamprey was placed in a recovery bucket containing aerated well water and transferred to the holding tanks. Lampreys were held a minimum of three weeks after tagging and before release. The fall release group was held in river water supplemented with well water to control for temperature. The spring release group was held overwinter on well-water and acclimated to a mixture of well and river water one week before release.

Release

Release dates were selected to mimic the seasonal Pacific lamprey movements in the Yakima River system. Release sites were located 0.6 km downstream of Roza Dam, and 1.2 km downstream of Cowiche Dam. Release sites were chosen based on their accessibility and proximity to each dam. Individual lampreys were allocated to a release treatment by arbitrarily removing them from the holding tank. Immediately prior to release, lampreys were scanned with radio and PIT antennas to confirm fish identity and tag functionality and retention.

Monitoring

Fixed telemetry stations operated continuously and were downloaded weekly. Test tags were activated during downloads to ensure the antennas and receivers were operating and recording properly. Foot and truck-based mobile tracking was conducted opportunistically to determine precise lamprey locations at the dams as well as approximate locations between the dams.

Last Known Detections

Last known detection locations were reported for each radio tag, but it is unclear if these last detections represent the final locations of study lampreys. Determining the type of the last known detection was beyond the scope of this study, but they may represent several scenarios including:

1) Tag retained: Indicates holding or possible spawning location of live lamprey.
2) Tag retained: Indicates location where transmitter battery failed, and lamprey movements continued but were not detected.
3) Tag retained: Indicates location of lamprey carcasses (mortality or predation).
4) Tag shed: Indicates location where transmitter was expelled, and lamprey movements continued but were not detected.

Discharge and Temperature

Stream discharge was obtained from the USBOR Pacific Northwest Region Hydromet website (USBOR 2015a). Average daily flow was queried for the Naches River station near Naches (NACW) and the Yakima River stations below Roza Dam (RBDW), and near Parker (PARW). Discharge is reported in cubic feet per second (ft^3/s).

Temperature loggers were deployed at Roza, Cowiche and Sunnyside dams, but software failures and vandalism resulted in data losses at each site. Hydromet average daily water temperature data from the same stations were used instead.

Statistics

Differences between the mean total length, weight, and interdorsal base length for the fall and spring release groups were assessed using 1-tailed t-tests. Differences in mean girth for the two release groups were evaluated using a non-parametric Mann-Whitney Rank Sum Test. All statistical comparisons were performed in SigmaPlot version 13.0 (Systat Software, San Jose, CA) using a 4-comparison Bonferroni-corrected alpha level of 0.0125.

Results

Tagging

Tagging and release occurred in the fall 2013 and the spring 2014.

For the fall releases, 45 adult Pacific lampreys were radio tagged during August 19-21, 2013 (Table 1). Weights ranged from 360 to 650 g and total lengths from 605 to 747 mm (Figure 10). Girths ranged from 104 to 131 mm (Figure 11) and interdorsal base length ranged from 19 to 42 mm (Figure 12).

For the spring releases, 44 lampreys were tagged on March 11-13, 2014 (Table 2). Weights ranged from 250 to 467g, and lengths ranged from 546 to 720 mm (Figure 10). Girths ranged between 92 and 117 mm (Figure 11), and interdorsal base lengths ranged from 16 to 40 mm (Figure 12).

Table 1. Morphometric data for radio-tagged adult Pacific lampreys released in the Yakima and Naches rivers on September 12, 2013. Release locations are denoted as: BCD (Below Cowiche Dam), BRD (Below Roza Dam).

Code	Total Length (mm)	Weight (g)	Girth (mm)	Interdorsal Base Length (mm)	Release Location
97	660	420	108	24	BCD
99	657	430	113	19	BCD
101	642	400	106	24	BCD
103	666	480	116	25	BCD
107	623	390	108	23	BCD
112	691	460	114	34	BCD
114	675	480	117	22	BCD
115	701	540	122	31	BCD
119	661	440	112	25	BCD
120	693	500	121	27	BCD
123	685	510	--	36	BCD
127	647	390	106	26	BCD
128	745	520	116	34	BCD
129	650	470	115	33	BCD
130	622	470	117	32	BCD
131	700	480	118	40	BCD
132	713	420	105	37	BCD
133	697	550	116	39	BCD
134	662	510	126	31	BCD
135	688	390	113	34	BCD
136	689	480	117	35	BCD
138	665	460	113	31	BCD
94	668	440	115	33	BRD
95	668	410	104	28	BRD
96	700	470	114	37	BRD
98	661	440	113	22	BRD
100	747	630	128	32	BRD
102	709	490	114	27	BRD
104	673	430	107	29	BRD
105	661	470	117	42	BRD
106	698	510	117	30	BRD
108	728	540	118	29	BRD
109	713	560	120	20	BRD
110	701	490	116	31	BRD
111	641	370	106	24	BRD
113	677	480	116	36	BRD
116	607	360	104	22	BRD
117	618	370	107	25	BRD
118	723	650	131	32	BRD
121	605	360	107	31	BRD
122	675	470	115	30	BRD
124	737	570	117	34	BRD
125	633	410	107	25	BRD
126	720	520	115	36	BRD
137	630	380	105	32	BRD

Table 2. Morphometric data for of radio-tagged adult Pacific lampreys released in the Yakima and Naches Rivers on April 4, 2014. Release locations are denoted as: BCD (Below Cowiche Dam), BRD (Below Roza Dam).

Code	Total Length (mm)	Weight (g)	Girth (mm)	Interdorsal Base Length (mm)	Release Location
142	630	360	103	35	BCD
143	628	358	100	35	BCD
144	605	382	108	23	BCD
147	636	405	107	31	BCD
148	553	277	97	21	BCD
149	642	349	98	27	BCD
150	590	383	105	30	BCD
151	557	250	95	31	BCD
152	572	293	95	28	BCD
161	631	378	104	40	BCD
162	666	401	105	32	BCD
163	572	294	97	16	BCD
171	623	350	103	40	BCD
173	590	349	105	30	BCD
174	606	339	100	24	BCD
175	580	356	102	31	BCD
177	666	362	100	31	BCD
178	720	467	110	37	BCD
181	610	365	104	28	BCD
182	592	370	111	18	BCD
183	602	361	104	27	BCD
185	568	292	97	29	BCD
139	590	363	103	36	BRD
140	555	332	100	23	BRD
141	661	419	107	40	BRD
145	600	338	103	35	BRD
146	665	460	109	37	BRD
153	645	450	115	29	BRD
154	546	302	98	17	BRD
155	664	406	104	38	BRD
156	662	458	117	35	BRD
157	616	396	106	27	BRD
158	628	338	98	27	BRD
159	590	297	95	25	BRD
160	609	313	97	26	BRD
164	575	374	110	25	BRD
165	604	330	101	27	BRD
166	630	355	100	31	BRD
168	654	383	104	33	BRD
169	590	279	92	25	BRD
172	585	302	98	22	BRD
176	551	271	95	22	BRD
179	647	404	110	30	BRD
184	582	297	95	30	BRD

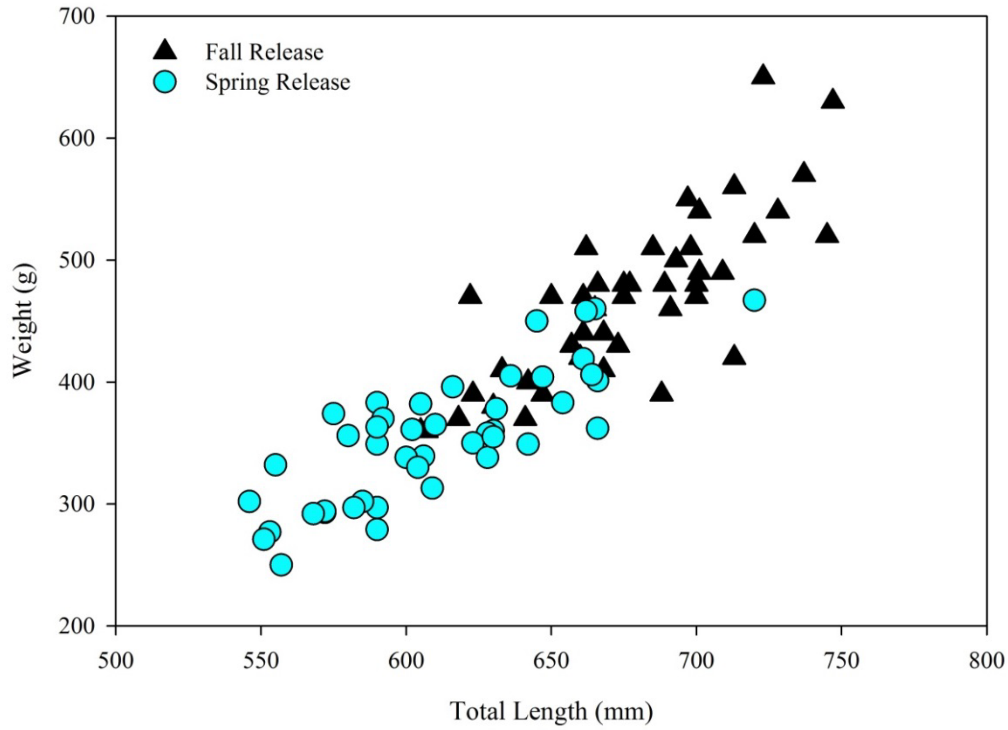

Figure 10. Weight versus total length of radio-tagged Pacific lampreys released into the Yakima and Naches rivers on September 12, 2013 and April 4, 2014.

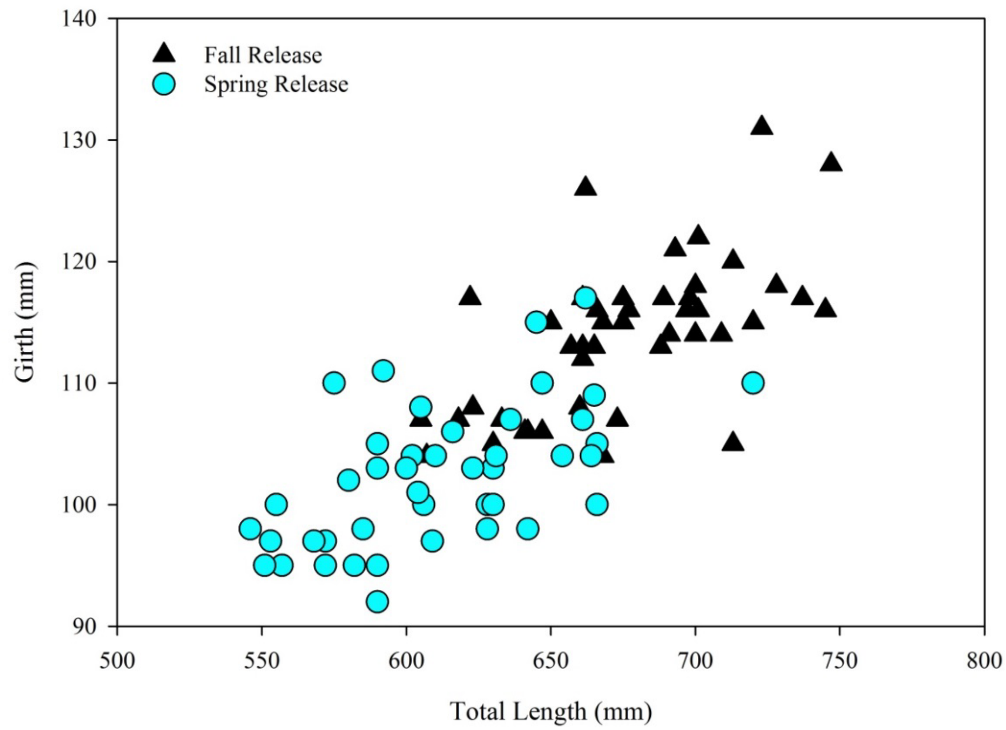

Figure 11. Girth versus total length of radio-tagged Pacific lampreys released into the Yakima River on September 12, 2013 and April 4, 2014.

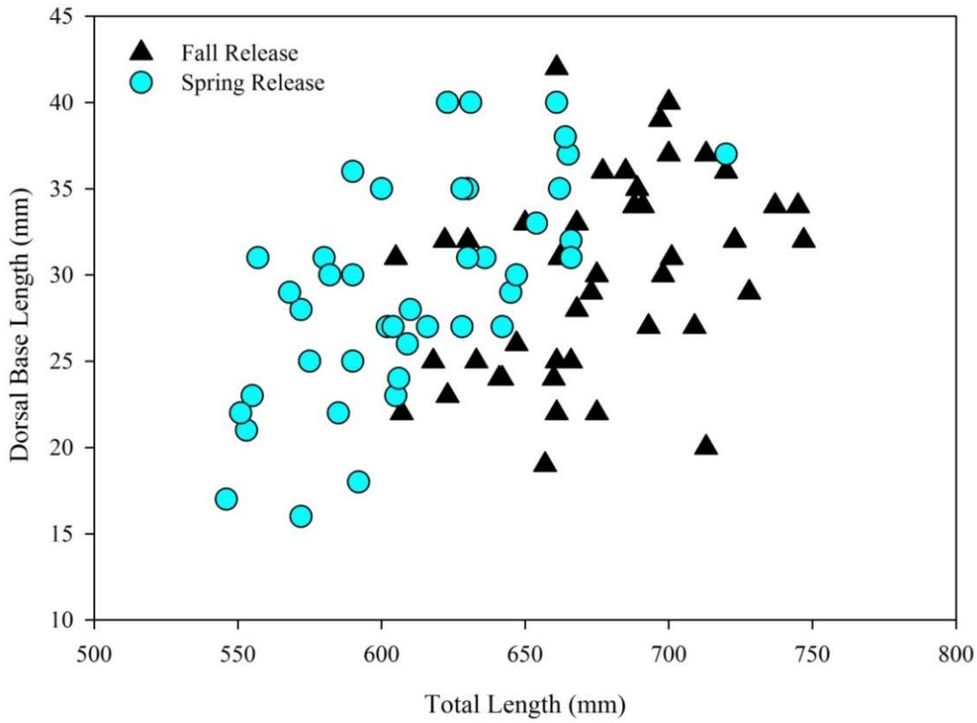

Figure 12. Interdorsal base length versus total length of radio-tagged Pacific lampreys released into the Yakima River on September 12, 2013 and April 4, 2014.

Mean lamprey weight, total length, and interdorsal base length were all significantly greater (p = <0.001) for the fall release group than the spring release group (Table 3). No significant difference in interdorsal base length (p = <0.26) was observed between releases.

Table 3: Summary of lamprey size measurements and probability values for radio-tagged Pacific lampreys released into the Yakima and Naches rivers on September 12, 2013 and April 4, 2014.

	Fall (n = 45)	Spring (n = 44)	*p*-value
Measurement	Mean (SD)	Mean (SD)	
Total Length (mm)	676 (36)	611 (39)	<0.001
Weight (g)	467 (67)	355 (52)	<0.001
Girth (mm)	114 (6)	102 (6)	<0.001
Interdorsal Base Length (mm)	30 (6)	29 (6)	0.261

Holding

One hundred percent of radio tags and 95.4% of PIT tags were retained at the time of release. No mortalities occurred during the holding period.

Release

Fall release- A total of 45 tagged lampreys were released on September 12, 2013. Twenty-three lampreys were released in the Yakima River downstream of Roza Dam (Figure 13). Twenty-two lampreys were released in the Naches River downstream of Cowiche Dam (Figure 14).

Spring release- A total of 44 Pacific lampreys were released on April 4, 2014. Twenty-two tagged study lampreys were released downstream of Roza Dam (Figure 13), and twenty-two lampreys were released downstream of Cowiche Dam (Figure 14).

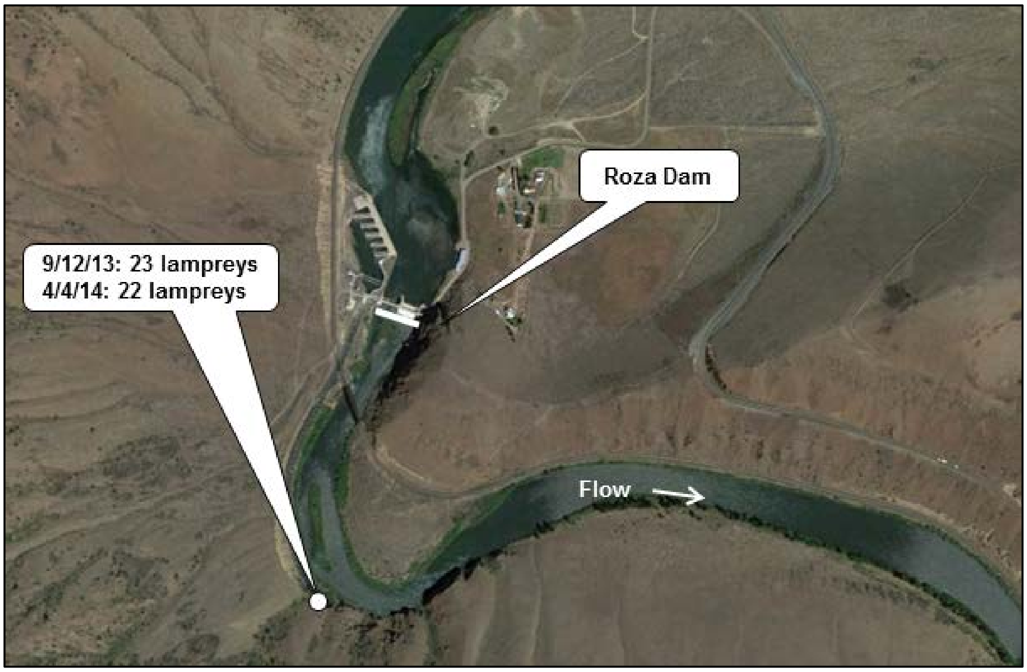

Figure 13. Release location of radio-tagged adult Pacific lampreys downstream of Roza Dam on September 12, 2013 and April 4, 2014.

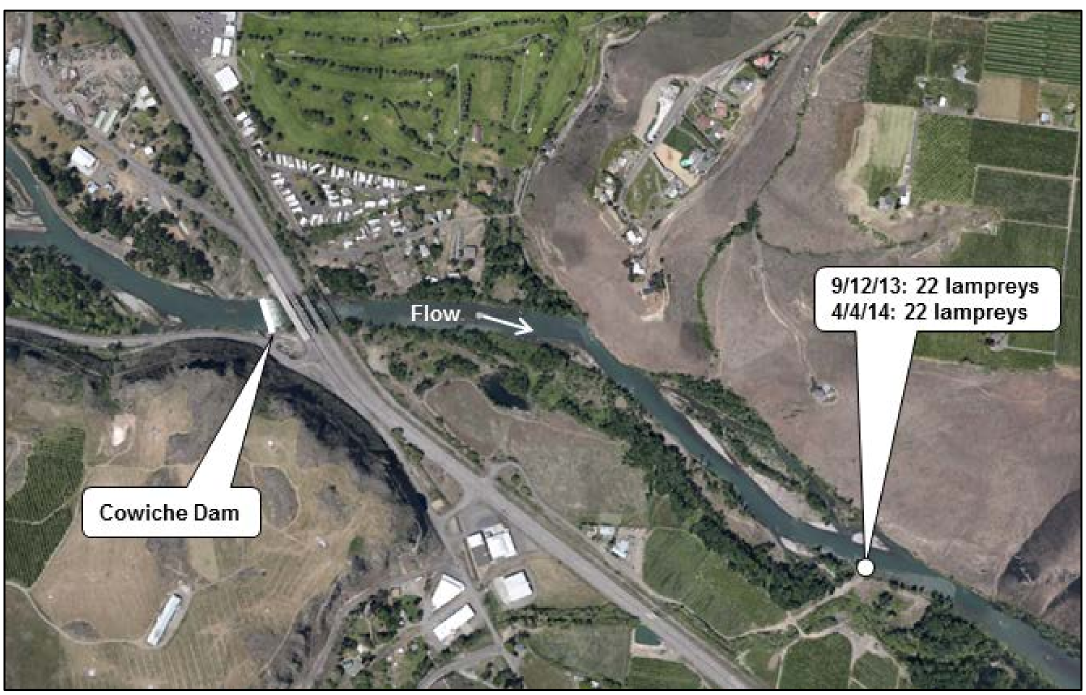

Figure 14. Release location of radio-tagged adult Pacific lampreys downstream of Cowiche Dam on September 12, 2013 and April 4, 2014.

Movements
Overall, eighty-three of eighty-nine (93%) lampreys moved upstream from their release sites. Four moved downstream, one moved immediately into Cowiche Creek, and one was not detected after release. The movements of radio-tagged lampreys at each dam are described in the following sections.

Cowiche Dam
First approach of fall release- Twenty-one of twenty-two (95%) tagged lampreys released downstream of Cowiche ultimately moved upstream from the release site and approached the dam. The majority of the fall release group (n = 17) approached the dam within 16 hours of release (Table 4). Two fall release lampreys approached the dam within 69 hours of release, and one lamprey overwintered downstream of the release site and did not approach until the following spring. Code 134 did not approach the dam, but instead moved downstream into the main stem Yakima River.

First approach of spring release- Seventeen of twenty-two (73%) lampreys released below Cowiche Dam moved upstream to approach the dam. First approach timing for the spring treatment group was later and more variable than for the fall treatment group, as only two tagged lampreys approached the dam within 16 hours of release (Table 4). The other lampreys approached the dam between 2 and 43 days after release.

Below dam residence-
Below dam residence time ranged from 18.7 minutes to 85 days (Table 4). Fish that successfully passed the dam exhibited shorter residences than those that did not (Table 5). Lampreys that passed Cowiche Dam in the fall exhibited shorter residence times that those that passed in the spring (Table 5). No tagged lampreys overwintered within detection range of Cowiche Dam.

Table 4. Cowiche Dam approach and residence data: first and last detection dates and below dam residence times (Days) of adult radio-tagged Pacific lampreys released in fall 2013 and spring 2014.

Code	1st Detection Date	Last Detection Date	Days	Pass Dam?
123	09/12/13 14:17	09/12/13 16:32	0.09	Yes
130	09/12/13 14:21	09/12/13 14:43	0.01	Yes
135	09/12/13 14:35	09/12/13 15:57	0.06	Yes
107	09/12/13 14:46	09/12/13 15:20	0.02	Yes
99	09/12/13 14:56	Unknown	--	Yes
115	09/12/13 15:35	09/12/13 15:56	0.01	Yes
129	09/12/13 16:02	09/12/13 16:45	0.03	Yes
103	09/12/13 17:31	09/12/13 18:40	0.05	Yes
97	09/12/13 18:04	09/12/13 19:01	0.04	Yes
127	09/12/13 20:23	09/12/13 21:38	0.05	Yes
101	09/12/13 22:21	09/12/13 23:26	0.05	Yes
132	09/12/13 22:36	09/12/13 23:52	0.05	Yes
133	09/12/13 22:44	09/12/13 23:11	0.02	Yes
136	09/12/13 23:07	09/12/13 23:30	0.02	Yes
114	09/12/13 23:19	09/12/13 23:38	0.01	Yes
112	09/12/13 23:23	09/13/13 00:02	0.03	Yes
128	09/12/13 23:41	09/13/13 00:00	0.01	Yes
138	09/12/13 23:42	09/13/13 00:38	0.04	Yes
119	09/13/13 21:32	09/13/13 21:53	0.01	Yes
120	09/15/13 06:46	09/15/13 07:22	0.03	Yes
171	04/04/14 21:49	05/12/14 20:57	37.96	No
173	04/05/14 02:27	05/12/14 21:35	37.80	No
185	04/06/14 23:20	04/10/14 10:39	3.47	No
161	04/07/14 01:35	04/22/14 22:15	15.86	Yes
147	04/08/14 19:15	04/08/14 22:25	0.13	Yes
182	04/09/14 06:06	04/25/14 01:32	15.81	No
148	04/09/14 11:29	04/29/14 20:55	20.39	Yes
151	04/09/14 20:54	06/04/14 21:33	56.03	No
152	04/20/14 17:44	05/23/14 02:25	32.36	No
143	04/21/14 01:44	05/01/14 22:04	10.85	Yes
177	04/21/14 08:34	04/21/14 23:48	0.63	Yes
178	04/29/14 23:25	05/02/14 21:13	2.91	Yes
142	04/29/14 23:51	05/01/14 21:01	1.88	Yes
181	05/02/14 19:55	05/02/14 20:41	0.03	Yes
174	05/02/14 20:16	05/27/14 23:09	25.12	No
149	05/02/14 22:37	05/14/14 00:46	11.09	Yes
131	05/16/14 01:09	08/09/14 02:46	85.07	No
162	05/16/14 21:57	05/22/14 00:02	5.09	Yes

Table 5. Summary of below dam residence times for radio-tagged Pacific lampreys released below Cowiche Dam in fall 2013 and spring 2014.

Release Group	Passage success	*n*	Duration (days)	Mean (days)	Median (days)	SD (days)
Fall	Yes	20	0.01 – 0.09	0.03	0.03	0.02
	No	1	85.07	85.07	85.07	--
Spring	Yes	10	0.03 – 20.39	6.89	4.00	7.24
	No	7	3.47 – 56.03	29.79	32.36	17.01

Dam passage efficiency and fishway passage- Thirty-eight tagged lampreys approached Cowiche Dam, and thirty of these successfully passed upstream, for an overall dam passage efficiency of 79% (Table 6). Twenty-one fall-release lampreys approached the dam, and twenty of these passed (95%). All of the fall release lampreys that passed Cowiche Dam did so within three days of release; most (n = 17) passed within 24 hours. Only one fall-release fish approached the dam and did not pass; however, this lamprey (code 131) overwintered below the release site and did not approach the dam or enter the fishway until May 2015.

Both approach numbers and dam passage efficiency decreased for the spring release. Seventeen spring release fish approached the dam. All 17 entered the fishway, and 10 passed (59%). Spring-release lampreys did not initiate passage as rapidly as the fall-release fish; successful passage events began on April 10 (6 days after release), and continued through early June, 2014.

All lampreys that passed Cowiche Dam approached and entered the river left fish ladder, and 29 of 30 fish used the ladder to pass the dam. One lamprey (Code 99) was detected repeatedly at the ladder entrance antenna, but never at the mid-ladder or exit antennas. This lamprey passed the dam and was later detected upstream. It is possible that it used the ladder and was undetected at the upper antennas. Alternatively, it may have passed via an unknown route on the dam face, as had been previously documented in our evaluations of Wanawish, Sunnyside, and Wapato Dams (Grote et al. 2014).

Passage events at Cowiche Dam were generally short, with the exception of three fish that spent more than 21 hours in the ladder (Table 6). Mean passage duration was shorter for passage events that occurred in the fall (mean = 2.2 hr, SD = 4.8) than in the spring (mean = 9.45 hr, SD = 13.9). Passage occurred primarily in the afternoon or at night, as 80% of successful passage events were initiated between 16:00 and 04:00 (Table 6).

Table 6. Cowiche Dam passage data: passage routes, dates of entry, exit, and total time in fish ladder, and daily mean water temperature for Pacific lamprey passage events from September 2013 to November 2014.

Code	Release Site/Period	Passage Route	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
130	BCD/Fall	L. Ladder	09/12/13 14:43	09/12/13 15:26	0.72	16.6
107	BCD/Fall	L. Ladder	09/12/13 15:20	09/12/13 15:30	0.16	16.6
99	BCD/Fall	Unknown	--	--	--	16.6
115	BCD/Fall	L. Ladder	09/12/13 15:56	09/12/13 16:11	0.25	16.6
135	BCD/Fall	L. Ladder	09/12/13 15:57	09/12/13 16:18	0.35	16.6
123	BCD/Fall	L. Ladder	09/12/13 16:32	09/12/13 16:56	0.40	16.6
129	BCD/Fall	L. Ladder	09/12/13 16:45	09/12/13 17:02	0.28	16.6
103	BCD/Fall	L. Ladder	09/12/13 18:40	09/12/13 19:39	0.99	16.6
97	BCD/Fall	L. Ladder	09/12/13 19:01	09/12/13 19:31	0.48	16.6
127	BCD/Fall	L. Ladder	09/12/13 21:38	09/12/13 23:54	2.25	16.6
133	BCD/Fall	L. Ladder	09/12/13 23:11	09/12/13 23:35	0.39	16.6
101	BCD/Fall	L. Ladder	09/12/13 23:26	09/13/13 01:55	2.49	16.6
136	BCD/Fall	L. Ladder	09/12/13 23:30	09/13/13 03:05	3.57	16.6
114	BCD/Fall	L. Ladder	09/12/13 23:38	09/12/13 23:50	0.20	16.6
132	BCD/Fall	L. Ladder	09/12/13 23:52	09/13/13 04:38	4.76	16.6
128	BCD/Fall	L. Ladder	09/13/13 00:00	09/13/13 00:18	0.30	16.9
112	BCD/Fall	L. Ladder	09/13/13 00:02	09/13/13 00:56	0.90	16.9
138	BCD/Fall	L. Ladder	09/13/13 00:38	09/13/13 21:52	21.24	16.9
119	BCD/Fall	L. Ladder	09/13/13 21:53	09/13/13 22:20	0.45	16.9
120	BCD/Fall	L. Ladder	09/15/13 07:22	09/15/13 08:11	0.82	17.2
147	BCD/Spring	L. Ladder	04/08/14 22:25	04/10/14 14:22	39.96	6.6
177	BCD/Spring	L. Ladder	04/21/14 23:48	04/22/14 10:16	10.47	6.6
161	BCD/Spring	L. Ladder	04/22/14 22:15	04/23/14 00:45	2.50	7.4
148	BCD/Spring	L. Ladder	04/29/14 20:55	05/01/14 02:46	29.86	7.7
142	BCD/Spring	L. Ladder	05/01/14 21:01	05/01/14 22:11	1.16	8.7
143	BCD/Spring	L. Ladder	05/01/14 22:04	05/01/14 23:14	1.17	8.7
181	BCD/Spring	L. Ladder	05/02/14 20:41	05/03/14 01:13	4.53	8.8
178	BCD/Spring	L. Ladder	05/02/14 21:13	05/02/14 22:41	1.47	8.8
149	BCD/Spring	L. Ladder	05/14/14 00:46	05/14/14 03:05	2.33	9.8
162	BCD/Spring	L. Ladder	05/22/14 00:02	05/22/14 01:08	1.10	10.3

Fewer successful passage attempts were made in the spring than in the fall at Cowiche Dam. Only one fall release fish did not pass after entering the ladder; this failed passage attempt occurred during the spring in May 2014. For the spring release treatment, six lampreys entered the ladder but did not pass the dam. Three of these approached the ladder exit, but were immediately detected moving back downstream in the ladder.

Discharge- The majority of passage events occurred during periods of increasing discharge (Figure 15). Fall passage events occurred at flows between 1,994 ft^3/s and 2,145 ft^3/s. Spring passage events occurred over a wider range of high flows between 3,219 ft^3/s and 4,169 ft^3/s.

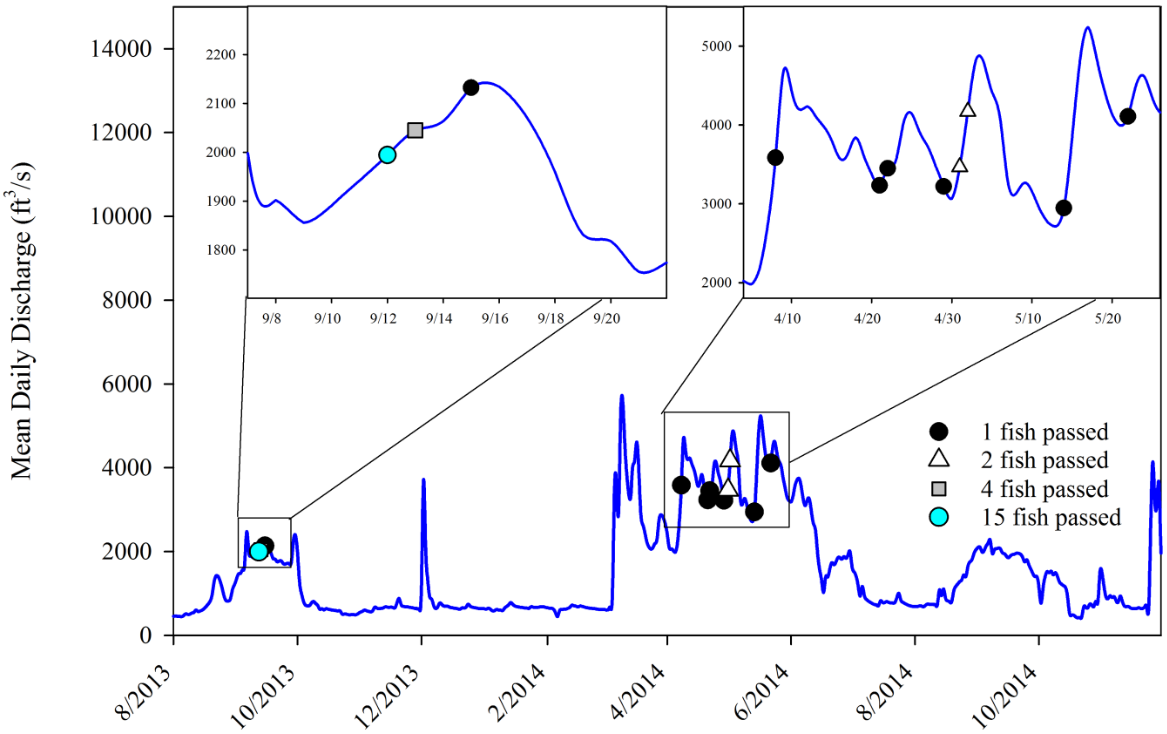

Figure 15. Mean daily discharge and passage timing of radio-tagged lampreys at Cowiche Dam on the Naches River, August 2013 through November 2014.

Temperature- Mean daily water temperatures in the Naches River varied from 0 to 19 °C. Lamprey passage occurred when mean daily temperatures ranged from 6.6 to 17.2 °C, with fall passage events occurring at warmer temperatures than spring passage events (Figure 16). In the fall, mean daily water temperatures declined rapidly after the last lamprey passed on September 15, 2013. During this time, lamprey movements became less frequent before ceasing all together over the winter. In the spring, passage events resumed when temperatures increased to greater than 6.6 °C. Passage events occurred during increasing temperatures or at temperature inflections when temperatures were transitioning from increasing to decreasing.

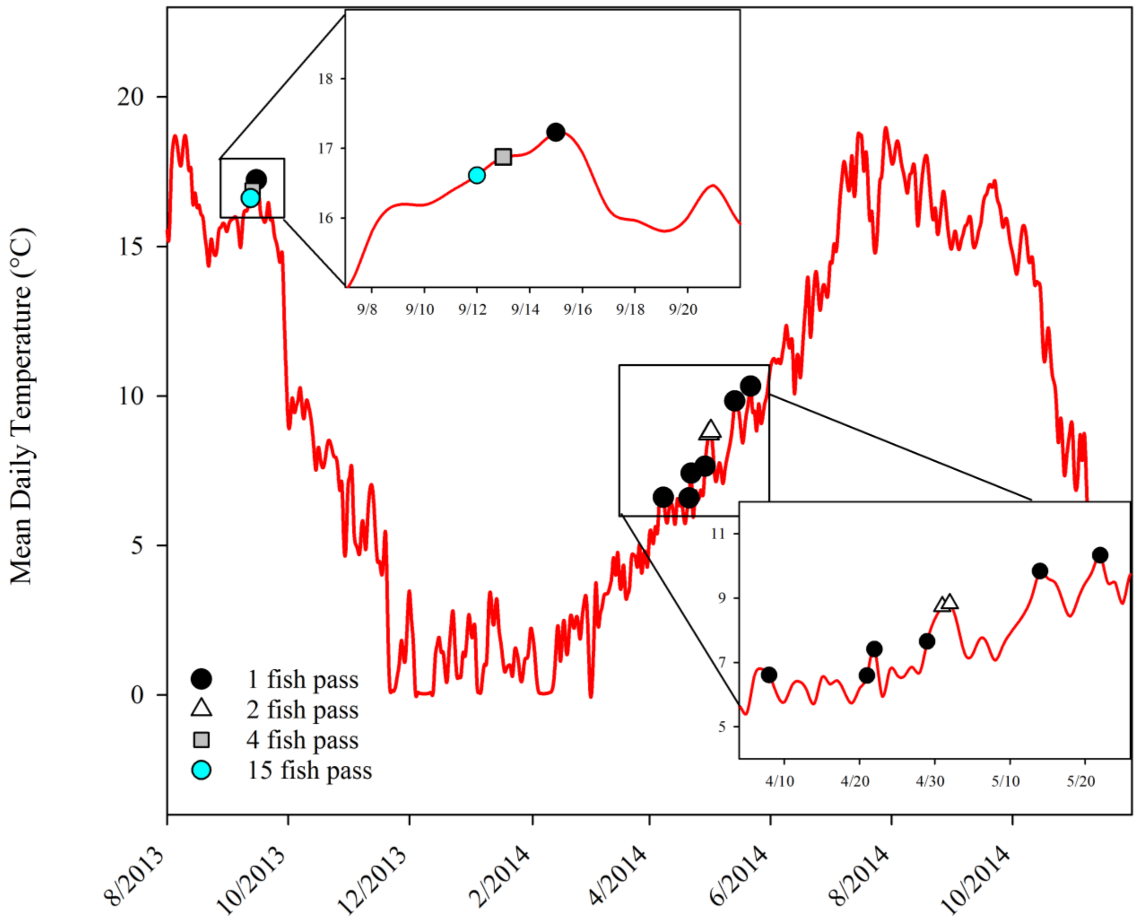

Figure 16. Mean daily water temperatures and passage timing of radio-tagged lampreys at Cowiche Dam on the Naches River, August 2013 through November 2014.

Above dam residence- All of the study lampreys that passed Cowiche dam moved rapidly upstream. Twenty-eight lampreys left the upstream detection zone less than 1.5 hours after exiting the fishways, and the remaining two lampreys moved upstream within twenty five hours of exiting.

Cowiche Diversion Canal- Eight tagged lampreys were detected at the river right side of the dam. No fish passed the right side of the dam and none were detected in the diversion canal intake or screening structures.

Roza Dam

First approach of fall release- On September 12, 2013, 23 tagged lampreys were released downstream of Roza Dam and all eventually approached the dam (Table 7). The majority began moving upstream almost immediately, as 17 lampreys were first detected approaching the dam within 14 hours of release. Three lampreys approached Roza Dam over the next three days. Two fall release lampreys overwintered downstream of the release site and waited until the following spring (May and June 2014) to approach the dam. One of these (Code 109) was the last of either the fall or spring release to approach the dam.

First approach of spring release- On April 4, 2014, 22 tagged lampreys were released downstream of Roza Dam and 21 were eventually detected approaching the dam (Table 7). Five spring release lampreys first approached the dam within twelve hours of release and six approached over the next four and a half days. The other 11 lampreys first approached the dam over the next five weeks.

Only one lamprey didn't approach the dam. Code 139 was mobile tracked 14 times between April 15, 2014 and August 29, 2014, and the detections occurred within the general area of the release site. Although there did appear to be local (~150 m) movements between detections, it may be that this was either a mortality or an expulsion.

Below dam residence- Below dam residence was longer and more variable for the fall than the spring treatment group (Table 8). This result is expected given the longer battery life of the fall-release tags.

Table 7. Roza Dam approach and residence data: first and last detection dates and below dam residence times (days) of adult radio-tagged Pacific lampreys released in fall 2013 and spring 2014.

Code	1st Detection Date	Last Detection Date	Below Dam Residence Days	Pass Dam?
102	09/12/13 20:19	08/17/14 18:17	338.92	No
98	09/12/13 20:24	09/17/14 08:43	369.51	No
110	09/12/13 20:50	08/13/14 15:32	334.78	No
113	09/12/13 20:52	08/24/14 03:54	345.29	No
137	09/12/13 21:00	05/06/14 14:06	235.71	No
111	09/12/13 21:09	09/22/13 18:39	9.90	No
95	09/12/13 21:23	06/24/14 21:57	285.02	No
121	09/12/13 21:24	05/15/14 22:46	245.06	No
96	09/12/13 21:34	05/20/14 08:37	249.46	No
104	09/12/13 21:36	10/16/14 09:14	398.48	No
117	09/12/13 21:44	08/20/14 08:19	341.44	No
94	09/12/13 22:03	06/11/14 00:53	271.12	No
122	09/12/13 22:19	08/17/14 00:21	338.08	No
105	09/12/13 22:26	06/04/14 22:17	264.99	No
125	09/12/13 22:29	08/09/14 23:21	331.04	No
106	09/12/13 22:38	05/23/14 09:38	252.46	No
100	09/13/13 02:10	05/25/14 22:00	254.83	No
126	09/13/13 21:15	09/26/14 23:16	378.08	No
108	09/14/13 00:43	05/06/14 01:44	234.04	No

Table 7 continued on next page.

Table 7. Continued.

Code	1st Detection Date	Last Detection Date	Below Dam Residence Days	Pass Dam?
118	09/15/13 20:38	10/13/14 01:38	392.21	No
116	03/23/14 21:34	06/04/14 02:06	72.19	No
160	04/04/14 21:09	07/22/14 21:15	109.00	No
157	04/04/14 21:30	06/05/14 17:03	61.81	No
146	04/04/14 22:15	08/25/14 22:41	143.02	No
156	04/04/14 22:27	08/11/14 19:11	128.86	No
141	04/04/14 23:48	07/08/14 09:17	94.40	No
153	04/08/14 21:13	05/19/14 02:48	40.23	No
172	04/09/14 21:38	06/04/14 10:03	55.52	No
154	04/09/14 22:06	06/06/14 15:34	57.73	No
164	04/09/14 22:09	05/25/14 14:47	45.69	No
165	04/09/14 22:14	04/18/14 21:19	8.96	No
169	04/09/14 22:19	05/05/14 07:19	25.37	No
158	04/17/14 01:00	09/03/14 00:44	138.99	No
168	04/29/14 22:02	05/23/14 23:06	24.04	No
184	04/29/14 22:05	05/30/14 18:07	30.83	No
140	04/29/14 22:28	05/12/14 11:05	12.53	No
145	04/30/14 21:37	05/27/14 23:14	27.07	No
155	05/01/14 21:23	05/12/14 20:56	10.98	No
159	05/03/14 22:33	05/15/14 13:35	11.63	No
124	05/14/14 02:45	09/26/14 17:20	135.61	No
176	05/16/14 21:42	08/28/14 04:28	103.28	No
166	05/16/14 21:58	08/27/14 06:13	102.34	No
179	05/16/14 23:33	08/27/14 23:09	102.98	No
109	06/19/14 20:13	08/03/14 17:43	44.90	No

Table 8. Summary of below dam residence times for radio-tagged Pacific lampreys released downstream of Roza Dam in fall 2013 and spring 2014.

Release Group	Passage success	*n*	Duration (days)	Mean (days)	Median (days)	SD (days)
Fall	Yes	0	--	--	--	--
	No	23	9.90 - 398.48	266.22	271.12	108.84
Spring	Yes	0	--	--	--	--
	No	21	8.96 - 143.02	63.58	55.52	45.47

Dam passage efficiency- None of the lampreys that approached Roza Dam successfully passed the dam (Table 7). Of the 44 tagged lampreys that approached, 36 entered the fish ladder but only 5 were detected moving into the tunnel and the fish facility (Table 9). No tagged lampreys passed through fish facility, and the five that entered reversed course and were later detected downstream in the ladder or below the dam. More lampreys entered the lower components of the fishway (up to the PIT array) than entered the upper sections, including the tunnel and fish facility (Table 9).

Table 9. Numbers of radio-tagged lamprey detected at components of the Roza Dam Fishway.

	Number of Lampreys Moving Through the Roza Fishway				
Release Group	**Approach Dam**	**Enter Ladder**	**Enter PIT Array**	**Enter Tunnel**	**Enter Fish Facility**
Fall	23	18	13	5	5
Spring	21	18	15	0	0
Totals	**44**	**36**	**28**	**5**	**5**

Fishway Residence Time and Incursions- Fishway residence times were longer and more variable for fall treatment lampreys than for spring treatment lampreys (Tables 10 and 11). The average number of fishway incursions was greater for the spring release (mean = 3.0, SD = 2.1) than the fall release (mean = 1.9, SD = 1.1). Incursions occurred in the fall 2013 (n =11), spring 2014 (n = 69), and summer 2014 (n = 9). Lampreys appeared more likely to enter the fishway in the afternoon or at night, as 86% of first detections in the Roza Ladder occurred between 16:00 and 04:00 (Table 10).

Table 10. Roza Dam fishway residence data: first and last ladder detection dates, fishway residence times (days), and the number of incursions made into the ladder by adult radio-tagged Pacific lampreys released in fall 2013 through summer 2014.

Code	Release Site/Period	First Ladder Detection	Last Ladder Detection	Fishway Residence Days	Number of Incursions
98	BRD/Fall	09/12/13 21:14	06/04/14 22:13	265.0	4
122	BRD/Fall	09/12/13 22:34	10/14/13 07:21	31.4	1
106	BRD/Fall	09/12/13 23:28	05/21/14 16:47	250.7	3
111	BRD/Fall	09/13/13 04:33	09/22/13 18:27	9.6	2
102	BRD/Fall	09/13/13 21:07	09/20/13 05:40	6.4	1
96	BRD/Fall	09/14/13 21:46	10/15/13 19:14	30.9	1
126 [a]	BRD/Fall	09/15/13 23:03	09/26/14 23:16	376.0	2
110	BRD/Fall	09/16/13 21:37	05/16/14 22:35	242.0	2
113	BRD/Fall	09/18/13 21:10	09/21/13 05:23	2.3	1
117	BRD/Fall	10/10/13 00:05	05/25/14 03:13	227.1	3

Table 10 continued on next page.

Table 10 Continued.

Code	Release Site/Period	First Ladder Detection	Last Ladder Detection	Fishway Residence Days	Number of Incursions
116	BRD/Fall	03/23/14 22:14	04/09/14 02:08	16.2	2
141	BRD/Spring	04/05/14 02:07	07/06/14 00:16	91.9	4
146	BRD/Spring	04/05/14 03:06	07/09/14 23:55	95.9	4
157	BRD/Spring	04/05/14 13:59	06/04/14 01:01	59.5	3
105	BRD/Fall	04/07/14 00:11	05/17/14 00:35	40.0	3
95	BRD/Fall	04/09/14 20:36	04/10/14 02:47	0.3	1
160	BRD/Spring	04/09/14 21:08	07/22/14 21:14	104.0	3
164	BRD/Spring	04/12/14 10:39	04/14/14 10:33	2.0	1
165	BRD/Spring	04/13/14 02:35	04/15/14 04:29	2.1	1
172	BRD/Spring	04/23/14 00:06	05/24/14 19:42	31.8	3
184	BRD/Spring	05/01/14 23:05	05/26/14 23:11	25.0	7
158	BRD/Spring	05/02/14 22:16	06/10/14 00:44	38.1	5
155	BRD/Spring	05/03/14 11:24	05/11/14 17:15	8.2	2
140	BRD/Spring	05/03/14 18:16	05/11/14 10:36	7.7	1
169	BRD/Spring	05/03/14 21:12	05/05/14 07:19	1.4	1
168	BRD/Spring	05/04/14 01:40	05/22/14 23:57	18.9	4
145	BRD/Spring	05/04/14 21:50	05/27/14 23:07	23.1	3
100	BRD/Fall	05/13/14 03:53	05/13/14 21:08	0.7	1
124	BRD/Fall	05/16/14 21:13	08/08/14 21:20	84.0	4
118	BRD/Fall	05/16/14 21:33	06/28/14 03:14	42.2	2
153	BRD/Spring	05/17/14 11:10	05/17/14 14:05	0.1	1
179	BRD/Spring	05/17/14 21:47	05/17/14 22:36	0.0	1
176	BRD/Spring	05/21/14 21:42	08/16/14 14:54	86.7	8
125	BRD/Fall	06/06/14 21:52	06/06/14 21:58	0.0	1
109	BRD/Fall	06/19/14 22:53	06/20/14 06:25	0.3	1
166	BRD/Spring	07/01/14 22:20	08/12/14 08:36	41.4	2

[a] Last detected in ladder in PIT array: lamprey may have died in the ladder.

Table 11. Summary of Roza Dam fishway residence times for radio-tagged Pacific lampreys released downstream of Roza Dam in fall 2013 and spring 2014.

Release Group	n	Duration (days)	Mean (days)	Median (days)	SD (days)
Roza/Fall	18	0.00 - 376.01	90.29	31.13	121.44
Roza/Spring	18	0.03 - 104.00	35.44	24.03	36.57

Roza Dam Fish Facility- Five tagged lampreys (Codes 96, 106, 111, 122, 124) moved through the fish ladder and the tunnel and entered the fish facility (Table 9). All five were from the fall release treatment. Four of the five ascended the ladder rapidly and were first detected entering the facility within 2.5 days of release.

Code 124 was the only tagged lamprey to enter the fish facility after the lamprey exit hole was installed in November 2013. Code 124 overwintered downstream before approaching the dam and entering the fishway on May 14, 2014. From May through August 2014, this lamprey moved in and out of the fishway at least four times and was finally detected entering the fish facility on August 5, 2014, nearly 11 months after it was released. Code 124 made at least seven distinct incursions into the fish facility, where it spent a total of 2.7 days. Code 124 did not use the lamprey exit hole in the tank and was detected leaving the fish facility moving downstream through the tunnel.

Roza Dam Auxiliary Flow & Ladder Bypass- While moving downstream through the tunnel, Code 124 may have been entrained in the auxiliary water supply (see Figure 4). No other lampreys appeared to have gone through the AWS.

Roza Fish Ladder PIT Detections- Twenty-eight of the thirty-six tagged lampreys (78 %) that entered the fishway were detected in the PIT array, where they generated 176,734 detections (Table 12). Five lampreys (Codes 172, 140, 158, 106, and 160) generated 58% of all PIT detections. Total daily counts of PIT detections ranged from 2 – 15,955 and were highly variable (mean = 2295, SD = 3,147). On four days (May 3, 4, 16, and 17) the total daily counts of PIT detections in the ladder exceeded 10,000 records. Most lampreys were logged at all three of the weirs, but 14% were only detected at the downstream weir, indicating that some study fish did not pass the entire PIT array.

Detection histories indicate that study lampreys moved rapidly between PIT antenna weirs, with transitions times of only seconds or minutes. Transitions made while fish were moving up the ladder were shorter than those made while moving down. For upstream movements, the time elapsed while fish were stationary at antennas often exceeded transition times between antennas. Lampreys were present at a single antenna for many minutes before moving rapidly up to the next detection location.

Table 12. Summary of PIT detections from tagged Pacific lampreys in the Roza Dam fish ladder.

Code	n of PIT detections at:			
	Downstream Antenna (#3)	Middle Antenna (#2)	Upstream Antenna (#1)	Total
68	5	0	0	5
110	22	15	4	41
153	62	0	0	62
113	27	153	25	205
111	239	412	27	678
126	302	68	459	829
105	861	0	0	861
184	206	255	606	1,067
102	1,036	34	7	1,077
109	148	44	955	1,147
166	340	196	1,165	1,701
96	1,210	1,673	12	2,895
155	2,130	1,056	210	3,396
117	1,162	1,360	1,369	3,891
141	484	814	2,609	3,907
122	2,731	1,578	17	4,326
124	1,357	2,480	1,440	5,277
98	1,526	2,278	2,640	6,444
157	2,493	1,945	2,008	6,446
169	1,856	1,003	3,689	6,548
176	1,077	2,212	3,429	6,718
146	1,363	2,217	4,390	7,970
145	2,427	2,468	3,281	8,176
172	4,667	3,728	1,296	9,691
140	9,980	0	0	9,980
158	3,849	3,818	4,251	11,918
106	3,848	3,662	4,963	12,473
160	16,594	15,763	26,648	59,005

Roza Dam Right and Gallery- Ninety-eight percent of study lampreys that approached the dam were detected at the gallery entrance at Roza right. Detection histories at both sides of the dam suggest that lampreys may have moved through the gallery to both enter and exit the fishway. However, the interior of the gallery was not monitored as a part of this study and such use could not be verified by telemetry detections.

Discharge- Tagged lampreys first entered the Roza fishway at a variety of discharge levels (Figure 17). Those entering in the fall did so at relatively low flows between 580 ft^3/s and 828 ft^3/s. Lampreys entering in the spring and summer did so at more variable flows between 889 ft^3/s and 2960 ft^3/s. Initial entrance in the fall tended to occur when the hydrograph was increasing (Figure 17). Spring and summer initial entrance was observed over a range of discharge conditions (Figure 17).

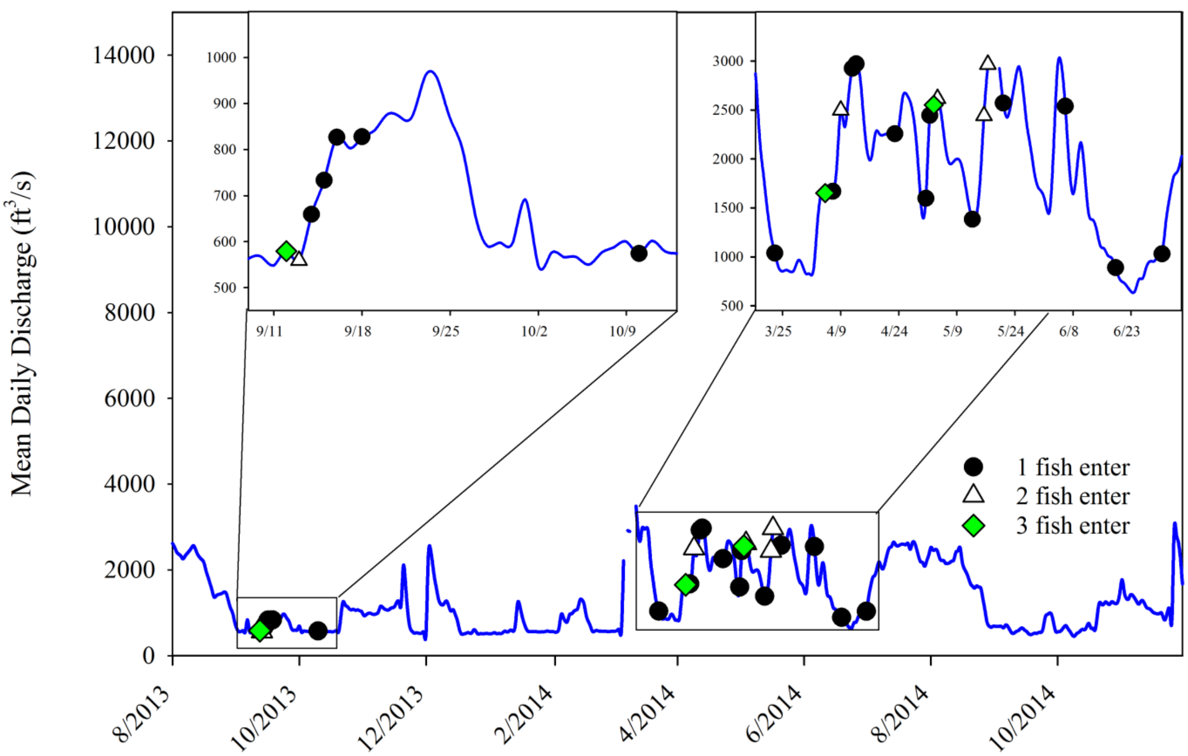

Figure 17. Mean daily discharge and timing of first entrance into the fishway for radio-tagged lampreys at Roza Dam from August 2013 through November 2014.

Temperature- Mean daily water temperatures between 0.3 and 20.4 °C were recorded by the BOR Hydromet station at Roza Dam. Tagged lampreys first entered the fishway at temperatures ranging from 11.1 to 20.4 °C in the fall and 7.4 to 15.4 °C in the spring and summer (Figure 18).

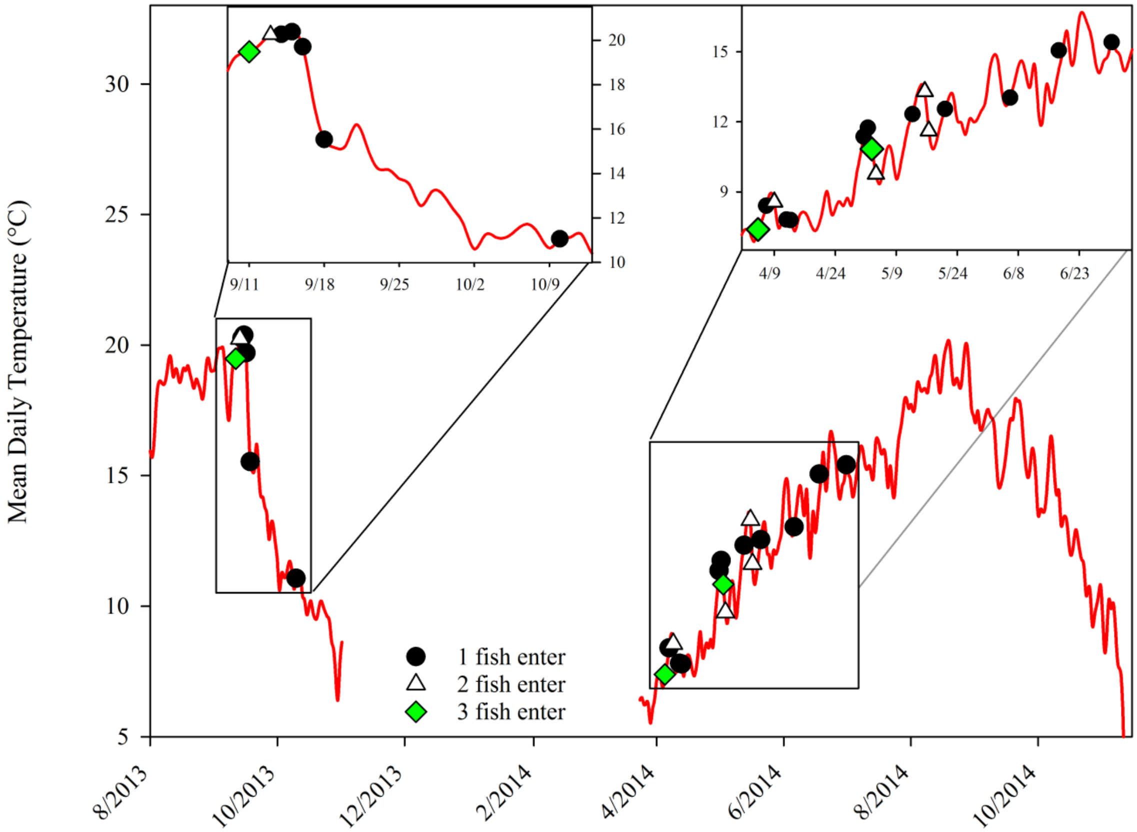

Figure 18. Mean daily water temperatures and timing of first entrance into the fishway for radio-tagged lampreys at Roza Dam from August 2013 through November 2014. Roza temperature data are not available from November 2, 2013 – March 23, 2014.

Roza Wasteway #2 Canal

One lamprey (Code 134) initially moved downstream from the release site on the Naches River and migrated into the main stem Yakima River. Code 134 continued to move downstream until it entered the Roza Wasteway #2 canal (rkm 184) by October 10, 2013 and overwintered there. While overwintering, it was detected at several different locations in the Wasteway, including the tailrace pool below the power station and the calm water immediately inside the screened Wasteway Outfall. Code 134 was last detected in the Wasteway on May 4, 2014, when it migrated upstream in the main stem Yakima River and was detected at Roza Dam on May 14, 2014.

Wapatox Dam

The telemetry station at Wapatox Dam was operated from November 20, 2013 to May 5, 2014. Tagged lampreys were present at this site before the station was deployed and after it was removed. Wapatox passage was therefore evaluated using radio detections combined with mobile tracking detections (Table 13). Of the 22 tagged lampreys known to approach Wapatox Dam, 14 successfully passed, resulting in an overall dam passage efficiency of 63.6%. Passage efficiencies were similar for the fall release fish (64.7%) and spring release fish (60.0 %), but the sample sizes are small. Seventeen of twenty-five

(77.2 %) lampreys that approached Wapatox Dam were from the fall release group. Three fall release lampreys (Codes 101, 123, and 136) overwintered below the dam within range of the radio antenna and moved downstream the following spring.

Table 13. Wapatox Dam approach and passage summary for radio-tagged adult Pacific lampreys, September 2013 through November 2014.

Fish ID	Release Site	First Wapatox Detection	Pass?
123	BCD/Fall	09/18/13 11:00	No
101	BCD/Fall	09/25/13 14:25	No
133	BCD/Fall	11/20/13 21:00	No
112	BCD/Fall	05/01/14 01:53	Yes
161	BCD/Spring	05/17/14 02:26	Yes
99	BCD/Fall	Unknown	Yes
103	BCD/Fall	Unknown	Yes
107	BCD/Fall	Unknown	Yes
114	BCD/Fall	Unknown	Yes
115	BCD/Fall	Unknown	Yes
119	BCD/Fall	Unknown	Yes
120	BCD/Fall	Unknown	No
127	BCD/Fall	Unknown	Yes
129	BCD/Fall	Unknown	Yes
132	BCD/Fall	Unknown	Yes
135	BCD/Fall	Unknown	No
136	BCD/Fall	Unknown	No
138	BCD/Fall	Unknown	Yes
143	BCD/Spring	Unknown	No
177	BCD/Spring	Unknown	Yes
178	BCD/Spring	Unknown	Yes
181	BCD/Spring	Unknown	No

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On September 18, 2013, Code 135 was recovered from the river left bank at Wapatox Dam. The tag was found on the riprap next to a fresh otter midden, and the antenna showed tooth marks and signs of being chewed. No other depredated tags were recovered at this site, but otters were observed at the dam on a regular basis.

Ellensburg Town Canal Diversion Dam
No radio-tagged lampreys passed Roza Dam; thus none were detected approaching Ellensburg Town Canal Diversion Dam.

Uppermost Detections

Uppermost detection locations for study lampreys released below Cowiche Dam ranged from the release site (rkm 4.6) to Cliffdell (rkm 57) (Figure 19). Most mobile tracking surveys focused on the main stem Naches River, but the uppermost detections for three lampreys occurred in tributaries. The highest upstream locations for Codes 183 and 175 were in Cowiche Creek (see *Last Known Detections* below). Code 138 passed Cowiche and Wapatox Dams before overwintering in the Tieton River at rkm 4.

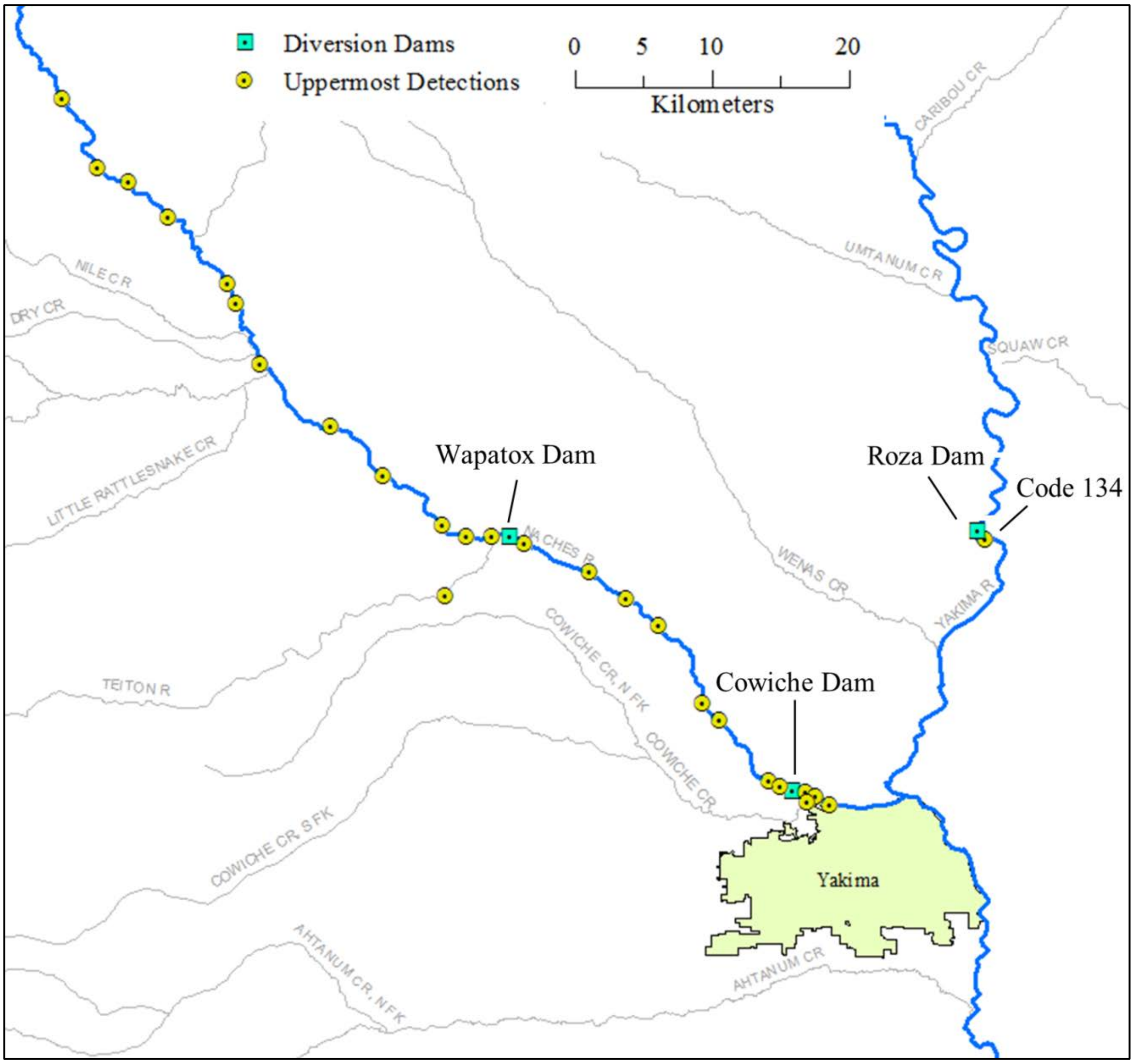

Figure 19. Uppermost detection locations of radio-tagged Pacific lampreys released below Cowiche Dam from September 2013 to November 2014. Note that Code 134 moved downstream out of the Naches River, and eventually approached Roza Dam in the Yakima River system.

Two study lampreys migrated downstream out of their release rivers and up into a different system. Code 134 moved downstream from release below Cowiche Dam, traveled through the main stem Yakima River into the Roza Wasteway, and eventually migrated upstream to Roza Dam. Code 159 was released below Roza Dam, which it initially approached before moving downstream to enter the Naches River system, where it was detected downstream of Cowiche Creek.

Last Known Detections

Fifty-seven lampreys were last detected in the Yakima River and thirty-two were in the Naches River system (Table 14). Most of the study lampreys released below Roza Dam were last detected in the reach below the dam. Most of the study lampreys released below Cowiche Dam were last detected in the reach above the dam.

Two lampreys were last detected near Cowiche Creek. Code 183 was located in a pool immediately upstream of a small flashboard diversion dam located at one of the Cowiche Creek irrigation return flow channels (Figure 20). This tag remained at the same location in a small pool for over 7 weeks. Code 175 was located in a dense blackberry thicket next to the creek and was likely depredated.

Table 14. Summary of last known detection locations (dam or reach) of radio-tagged Pacific lampreys released in Yakima River during fall 2013 and spring 2014.

Reach	Number final detections
Between Sunnyside and Wapato dam	9
Between Wapato Dam and Roza Wasteway #2 Outfall	4
Between Roza Wasteway Outfall and Roza Dam	40
In Roza Dam fishway	4
Between the Naches confluence and Cowiche Dam	9
In Cowiche Creek	2
Between Cowiche Dam and Wapatox Diversion Dam	12
Above Wapatox Diversion Dam	9

The majority of tagged lampreys released in the Naches River moved downstream after reaching their uppermost point in the river. Fifty-five percent of the Cowiche release lampreys moved more than 2.4 rkm downstream from their uppermost detection. Eighteen percent were detected moving downstream to Sunnyside Dam, 23 rkm from the release site.

Code 182 from the Cowiche releases was last detected in the Wapato Diversion Canal on June 20, 2014. This lamprey was entrained in the canal while migrating downstream. Without additional detections, it is unclear if Code 182 remained in the canal or returned to the main stem Yakima River.

Figure 20. Mobile tracking at a small flashboard dam near the mouth of the Cowiche Creek. Code 183 was last detected immediately upstream of this dam under the overhanging bushes.

Discussion

Monitoring and evaluating the status of lampreys and the effects of human actions on depressed populations presents several challenges. The numbers of adult Pacific lamprey migrating to spawn in the Yakima River have remained low since counts began at Prosser Dam in 2002, with annual counts of only double digits. This scarcity precluded capturing and tagging Yakima River lampreys during our study; so instead, adults collected by the Yakama Nation Fisheries Program at lower Columbia River dams were used as a surrogate. Our study design therefore required several assumptions, including that the study lampreys behaved similar to those that naturally entered the Yakima River; that radio tags did not significantly affect the migration of the study animals; and that the telemetry data and its interpretation reflected natural behavior of lampreys at the dams.

As in Phases 1 and 2, nearly all Phase 3 tagged lampreys moved upstream (93%) and attempted to pass the diversions, indicating that study lampreys were motivated to migrate upstream despite being translocated from the lower Columbia River (Johnsen et al. 2013, Grote et al. 2014). Most of the lampreys were persistent in their attempts, successful or otherwise, to pass the dams, suggesting relatively minimal effects of the tags or the tagging procedure. However, the sample sizes at each dam are small and interpretation of the results requires some caution. Pacific lampreys are complex animals and individuals can exhibit a variety of behaviors depending on the time of year and their physiological condition (Moser et al. 2013). Thus, it can be difficult to determine the ultimate factors that may impact their particular movements during migration. Because Pacific lamprey risk extirpation in much of the watershed, it has been a priority to provide information quickly in order to begin improvements at dams in the Yakima River. Our study produced a large quantity of raw telemetry data, and interpretation and analysis is ongoing. Therefore, the results presented to date in our annual reports are provisional and subject to change in the final report to be issued at the end of the project.

Passage Efficiencies

Cowiche Dam

Passage efficiencies at Cowiche Dam were consistent with other Yakima River diversion dams. Overall passage efficiencies at Cowiche Dam (79%) were similar to Wapato Dam (82%) and Sunnyside Dam (68%) (Grote et al. 2014), but greater than Prosser Dam (48%) and Wanawish Dam (62%) (Johnsen et al. 2013). Seasonal passage metrics at Cowiche Dam also appeared similar to those at the two downstream neighboring dams. Passage efficiencies were higher for lampreys released in the fall at Cowiche Dam (fall: 95%, spring: 59%), Wapato Dam (fall: 95%, spring: 45%), and Sunnyside Dam (fall: 96%, spring: 33%) (Grote et al. 2014). This contrasts with the two lowest downstream Yakima River dams where passage efficiencies were higher for fish released in the spring at Wanawish Dam (fall: 53%, spring: 71%) or similar between treatment groups at Prosser Dam (fall: 50%, spring: 45%) (Johnsen et al. 2013).

The difference in seasonal passage timing between the lower river dams (Wanawish and Prosser) and the middle river dams (Sunnyside, Wapato, and Cowiche) may be problematic for migrating lampreys. Increased passage success for fall-release fish suggests that there is a seasonal advantage (possibly environmental, physiological, or both) that facilitates passage of the middle river dams in the fall. However, with reduced fall passage success at the lower dams, adult lampreys may be delayed below Prosser and Wanawish dams and overwinter until passage conditions at those facilities improve. In this case, the majority of lampreys may miss the fall window of opportunity at the middle dams, and may have to attempt to pass them under less than optimal conditions the following spring.

The lower passage efficiency for the spring release at Cowiche Dam may have a basis in the operation and maintenance of the ladder. Of the 17 spring-release lampreys that approached the dam and entered the fishway, 10 passed and 7 did not. Of the seven that did not pass, five were detected at either the ladder midpoint or exit antennas before they reversed course and moved back downstream through the ladder. We did not usually examine whether the ladder was obstructed during our weekly visits and there may have been conditions that prevented tagged lampreys from passing. High flows periodically deposit gravel and other material into the fishway exit and upper end of the ladder (Patrick Monk, USFWS, personal communication.) which could have deterred lamprey from exiting the ladder. Alternatively, high flows at this site may be a hydraulic barrier at the ladder exit, as flows during the spring passage events were roughly double those when lampreys passed the previous fall. More frequent ladder maintenance or installation of flow deflectors (Grote et al. 2014) may improve lamprey passage at Cowiche Dam.

Roza Dam

At the other diversion dams we monitored in the Yakima River system, the fishways are relatively simple vertical slot ladders and tagged lampreys that successfully passed generally did so within a few hours after entering the ladder (Johnsen et al. 2013, Grote et al. 2014). In contrast, Roza Dam is much higher and the fishway is a pool and overflow weir design that is long, complex, and composed of several discreet components that may present different sets of challenges. Despite a 98% approach efficiency, no tagged lampreys passed Roza Dam and the fish facility. Although evaluating specific impediments in the Roza fishway was beyond the scope of this study, several details revealed by telemetry and PIT tags bear discussion.

Only 5 of 36 (14%) of Phase 3 lampreys that entered the Roza Dam fishway ultimately entered the fish facility. This result is lower than in Phase 2, when 6 of 9 (67%) tagged lampreys that entered the ladder were detected at the fish facility (Grote et al. 2014). The reduction in ladder passage efficiency could be the result of small sample sizes or flow conditions that were less conducive to lamprey passage during Phase 3. Another possibility is that the lampreys that approached Roza in Phase 2 were a subset of the run that was highly “motivated” to pass (Kirk 2015). For instance, all of the Phase 2 fish had passed both Sunnyside and Wapato dams (n = 7) or Wapato Dam (n = 4) before approaching Roza. Previous experience passing the downstream dams may have increased the likelihood of lampreys navigating additional structures, either because of learned behavior or because they exhibited a rapid migration “temperament” (Moser et al. 2013). In contrast, the fish that approached Roza Dam in Phase 3 were naïve to passage at diversion dams and likely exhibited a variety of migration temperaments.

In either case, the proportion of Phase 3 lampreys that entered the tunnel and fish facility was low, suggesting that the ladder section is at least partially responsible for the lack of adult passage at Roza Dam. This result is not surprising, given that the pool and weir ladder was designed for salmonids and does not accommodate lamprey behavior, morphology, and swimming style (Mesa et al. 2003, Keefer et al. 2010, 2011). Potential issues in the ladder may include high water velocities in the notched overflow weirs, confused hydraulics in both turnpools (see Figure 4), poor attachment surfaces on pitted concrete, the high number of pools and weirs in the fishway (25), and the auxiliary water supply diffuser grates in the bottom ladder pools. Additional studies are needed in the Roza Dam ladder to identify specific lamprey passage impediments and implement improvements.

All lampreys (from both Phase 2 and 3) that negotiated the ladder and entered the Roza Dam fish facility did so in the late summer or early fall and all were from the fall releases. This result is consistent with our observations at other middle Yakima River dams, where successful passage is more likely in the fall than in the spring. While the causal mechanism behind this seasonal difference remains unclear, an additional confounding factor may have affected spring passage efficiencies at Roza Dam. During the spring of 2013 and 2014, a juvenile salmon survival study required several periods of streamflow manipulations through the Roza Dam control structures (Toby Kock, USGS, personal communication) and the variable discharges may have affected the spring passage efficiencies of our tagged lampreys.

One approach to improving lamprey passage at Roza Dam could be to reduce water velocities in the ladder. Lampreys are relatively poor swimmers compared with Pacific salmonids, and studies at hydroelectric facilities suggest that velocity barriers can impede lamprey movements through fishways that have been designed for other species (Moser et al. 2002a, Keefer et al. 2011). At Bonneville Dam, reducing water velocities in the pool and weir fishway significantly improved ladder entrance efficiencies for adult Pacific lampreys (Johnson et al. 2012). Reducing flows to lamprey friendly levels (~0.87 – 1.0 m/s) may also help lampreys negotiate extended high-velocity zones in fishways (Mesa et al. 2003, Kirk et al. 2015). A benefit of this approach is that flows can be reduced at night, when lamprey are most active in the ladder, and return to standard levels during the day, thereby limiting impacts to listed salmonids and other species that pass during daylight hours. Velocity reductions could also be limited to the times of year (spring and fall) when adult lampreys are most likely to attempt to pass Roza Dam.

The feasibility of this approach may depend on whether flow reductions can be implemented within standard fishway operating procedures. At Roza Dam, functional issues with the auxiliary water supply complicate the manipulation of flows at the base of the ladder and may require repairs. Water velocities could be reduced by limiting flows from the top of the Roza fish ladder, but this method requires further development. Finally, while flow reductions may be a viable option at the Roza Dam pool and weir ladder, this approach would not be feasible at other Yakima River diversion dams with vertical slot ladders. Water velocities through vertical slots are set by slot width and pool dimensions, and thus cannot be easily manipulated.

Beyond the ladder, upstream egress from the Roza Dam fish facility is problematic as the crowder configuration and fish handling operations are not designed to pass lampreys. To address this issue, the Yakama Nation Fisheries Program and BOR drilled a lamprey-specific exit hole in the wall of the fish facility holding tank to allow lampreys to directly access the forebay of the dam. Only one radio-tagged lamprey entered the fish facility after the hole was drilled, and that lamprey did not use the exit. Passage through the exit may be restricted because the hole is only accessible when the crowder is extended away from the tank wall, and lampreys therefore have limited time to locate and use the exit. Further monitoring and evaluation is needed to assess if the exit will pass lampreys.

The majority of our analysis focused on the fishway on river left at Roza Dam, but study fish explored both sides of the dam, and 98% of the lampreys that approached were also detected at the river right gallery entrance. Extensive use of this area may make the right side of Roza Dam a suitable location for a Bonneville Dam-style Lamprey Passage System (Figure 21) (Moser et al. 2006, Moser et al. 2011). Although more complex than the simple systems proposed for the downstream Yakima River dams, the advantages of this type of system include: 1) allowing lampreys to move directly into the forebay, and 2) minimizing alterations (and associated permitting and review) to the existing fish passage system on the left bank.

Figure 21. Photograph of a Lamprey Passage System at Bonneville Dam where lampreys ascend through a series of ramps and rest boxes. Image Credit: Jamie Francis, The Oregonian.

Wapatox Dam

Incidental detection data from Wapatox Dam were used to estimate an overall passage efficiency for the site (63.6%), but this estimate is not directly comparable to those from study dams where data collection was standardized. Wapatox was not a study dam and the telemetry station was operated as a gate station with only two aerial antennas. No study lampreys were released directly below Wapatox, and all lampreys that approached this dam had previously passed Cowiche Dam. The Wapatox telemetry station was not deployed for much of Phase 3, and tagged lampreys both approached and passed the dam at times when the station was not operational. So while the passage efficiency we report here represents an initial estimate for Wapatox Dam, additional studies would be required to develop a more accurate and robust estimate.

Although we did not evaluate specific passage routes as a part of the study, we did identify potential routes that could be investigated in the future. On the river left side of the Wapatox Dam there is a debris slot that two tagged lampreys entered (Figure 22).

There is also a pool-and-weir fishway on the river left dam apron, although this structure becomes submerged at higher flows. On the river right side of the dam, there is a cobble bar and debris jam that may modify hydraulics and allow lamprey to pass at higher flows (Figure 23).

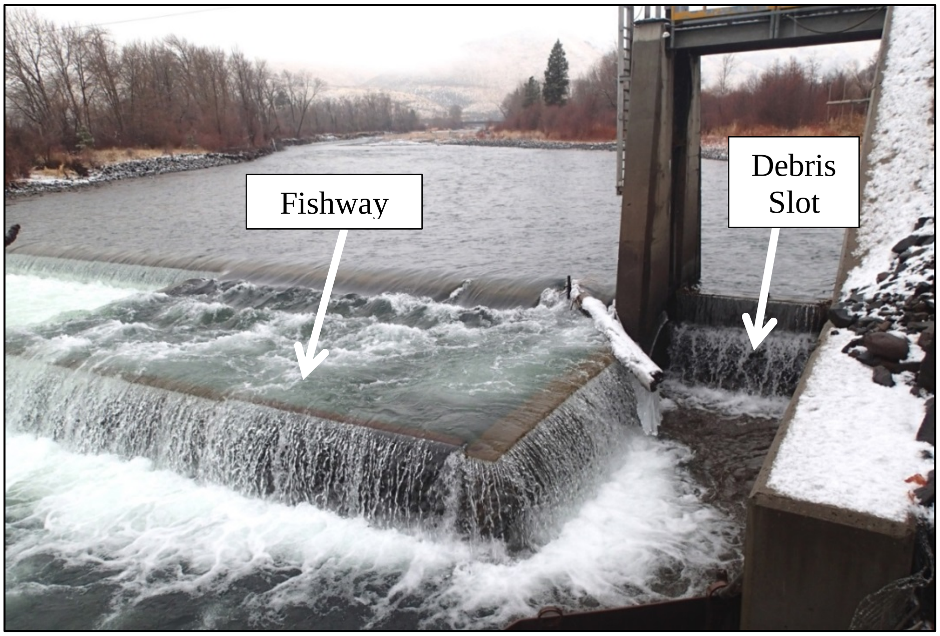

Figure 22. Photograph of the river left side of Wapatox Dam. Mobile tracking surveys detected two study lampreys in the debris slot. The raised pools of the fishway are also visible, although these become inundated at higher flows.

Figure 23. Photograph of the cobble bar and debris jam on the river right bank of Wapatox Dam.

Tributary Use

Information is lacking on the distribution of adult Pacific lampreys in Yakima River tributaries. Our results from Phases 1 and 2 indicate that while tagged adults did not enter lower river tributaries (Toppenish, Satus, and Ahtanum creeks), they frequently entered larger streams upriver (Naches River, Roza Wasteway (Johnsen et al. 2013, Grote et al. 2014). Tributaries used by tagged lampreys in Phase 3 included both small streams (Cowiche Creek) and larger waterways (Tieton River, Roza Wasteway).

Although the number of lampreys detected in tributaries was small (n = 5), it is probably an underestimate. Three lampreys were detected near the confluence of the Naches River and Rattlesnake Creek, but their exact locations could not be verified, and they were assumed to be in the main stem river. Seven lampreys were last detected migrating upstream of Cowiche Dam months before their transmitter batteries were due to expire. It is possible that these fish may have moved into streams that were not monitored (Nile Creek, Dry Creek, Gold Creek, Wenas Creek) and this use would not have been detected by our mobile tracking surveys. Alternatively, they may have moved rapidly through the areas of tributaries that were monitored and been missed by the weekly surveys.

Cowiche Creek

The lower reach of Cowiche Creek is diverted into a series of interconnected channels, some of which return water to the river and others that divert water to irrigation ditches. There are two unscreened outflows into the Naches River and a main irrigation canal that is screened approximately 400 meters downstream of the intake. Three tagged lampreys entered lower Cowiche Creek within a month of release, and two became stationary shortly thereafter. These fish may have become entrained or been depredated in the channel network which is shallow and lacks large complex substrate or refugia. The third lamprey exited Cowiche Creek by mid-May, and eventually migrated downstream into the main stem Yakima River.

Roza Wasteway #2

One tagged lamprey moved downstream and overwintered in Roza Wasteway. It eventually exited the Wasteway and resumed upstream migration in the Yakima River to Roza Dam. Use of the Wasteway was documented extensively in Phase 2 of this study, when twenty-four tagged lampreys entered the Wasteway (Grote et al. 2014). Seven of these fish were never detected leaving the canal and were assumed to be mortalities. The Wasteway is clearly attractive to adult Pacific lampreys, and managers may wish to take advantage of this behavior to monitor adult migrants or trap lamprey broodstock for artificial production programs. Alternatively, if managers decide that Pacific lamprey should be excluded from the Wasteway, the existing screening will need to be modified. Grating with bar spacing of 1.9 cm or less would be required to effectively exclude adult Pacific lampreys (Moser et al. 2008).

Data Management and Study Design

Many radio-telemetry passage studies, especially those focusing on juvenile salmonid outmigration, detect study fish only briefly as they approach and pass dams. In contrast, our study lampreys resided at dams for up to 11 months. As a result, our Phase 3 telemetry systems generated over 1.78 million detection events. The majority of these events (71%) occurred at Roza Dam, where lampreys were unable to pass and therefore remained within detection range for extended periods of time.

This volume of data exceeded the storage capacity and file size limitation of the Phase 1 and 2 database. In order to manage the Phase 3 data, we designed and build a new MS Access database in collaboration with the USFWS Columbia River Fisheries Program. The new design allows direct importation of raw data files in a variety of formats. Automating the import routines drastically reduced the amount of staff time required to manage the database, along with eliminating transcription errors from data manipulation. Another advantage is improved database functionality with the ability to produce detailed detection histories for each fish. Future telemetry evaluations of upstream passage of Pacific lamprey would benefit from detailed planning for data management and storage requirements.

Future studies may also benefit from reducing detections that are redundant or offer little new information from stationary tags. Motion sensor tags would be ideal for this application, provided that they have sufficient battery life. One practical option is to reduce the burst rate interval for the radio transmitters from 6 seconds to 8 seconds. The risk of increasing the burst interval is the potential loss of detections when lampreys move quickly. This risk could be addressed by doubling the number of antennas deployed at critical or high velocity locations. Doubling the receivers at the highest and lowest stations could also be used to generate passage and detection probabilities for these reaches in a mark-recapture framework. Station redundancy in the final reach is necessary to estimate independent detection and survival probabilities (as opposed to a single joint probability of both) in many mark-recapture models.

PIT Tag Use in Lamprey Passage Studies

Our study lampreys were tagged with both FDX PIT tags and radio transmitters for the first time in Phase 3. Twenty-eight lampreys were detected a total 176,734 times at the three PIT antennas at weirs 3, 4, and 5 in the Roza Dam fish ladder. PIT data collected at the weirs were valuable for validating radio detections, identifying false positive records, and inferring the directionality of lamprey movements in the fish ladder.

However, using PIT tags did pose several problems. First, the radio telemetry and PIT systems were not time-synced, which made it difficult to interpret the detection histories produced by both tag types. Future studies using both systems should include methods to initialize and maintain time standardization between platforms. Second, timestamps showed that study lampreys were present at PIT antennas in the Roza ladder for extended periods. The presence of stationary tags within the read-range of PIT antennas may cause tag “collisions” resulting in reduced detection probabilities for other PIT-tagged fish passing through fishways. An analysis conducted by PTAGIS staff at our behest indicated that overall salmonid detection efficiencies at Roza Dam were not negatively impacted by the presence of PIT tagged lampreys (Nicole Tancreto, PSMFC, personal communication).

In the case of the Roza Dam ladder, it is possible that the PIT antennas were an attractive attachment site for lamprey. Much of the concrete in the ladder is eroded with uneven and exposed aggregate surfaces (Figure 24). Pacific lampreys may preferentially attach to the smooth PIT antenna plates while attempting to negotiate high water velocities in the weir notches.

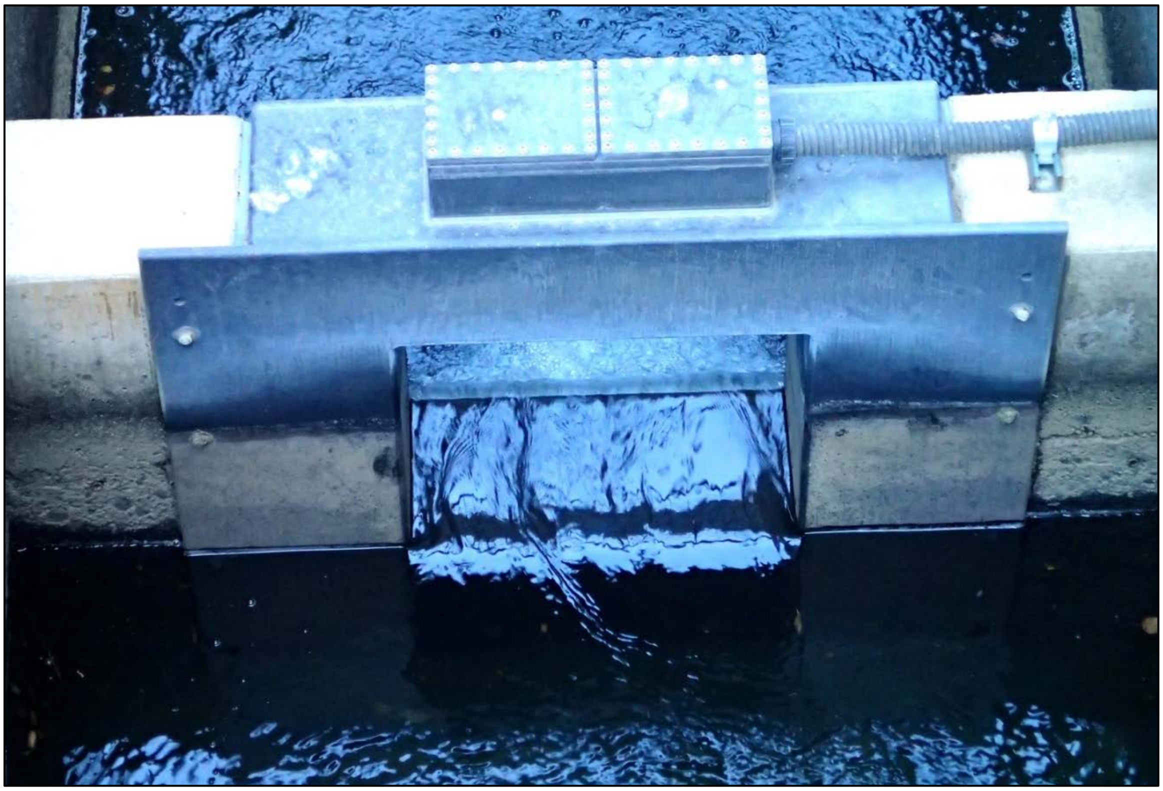

Figure 24. Detail photograph of the middle PIT antenna in a notched weir in the Roza Dam Fish Ladder. The antenna plate surface is smooth, and may provide a better lamprey attachment surface than the eroded concrete of the weir.

Although the PTAGIS Steering Committee has approved the use of FDX PIT tags to mark adult lamprey, caution should be exercised when deciding where and when to release PIT-tagged lamprey. Adults may reside for months at dams or other migratory obstacles, where their swimming style may lead them to attach to and potentially overload PIT antenna systems. Study locations with redundant fish counting systems (i.e. multiple PIT antennas, fish traps, counting stations, handling facilities, etc.) or without other PIT-tagged species would seem best-suited for use of PIT tags in lampreys, as these conditions would limit the risk of reduced detection efficiencies.

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