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Columbia River Fish and Wildlife Conservation Office

Monitoring the Entrainment of Juvenile Pacific Lamprey at Irrigation Canals of the Umatilla River

2022 Annual Report

William Simpson

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On the cover: *Feed Diversion Dam during standard river discharge (above) and during a flooding event (dam obscured) in 2020 (below). Picture by William Simpson.*

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Disclaimers

Monitoring the Entrainment of Juvenile Pacific Lamprey at Irrigation Canals of the Umatilla River
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Abstract – Outmigrating juvenile Pacific Lamprey are inadvertently diverted from rivers and streams into irrigation diversions common to the arid interior of the Columbia River basin (entrainment), where fish can be trapped and killed. Lamprey may be particularly susceptible to entrainment and harm because fish screens associated with these structures were originally designed to rescue juvenile salmonids from canals, not lamprey that are morphologically and behaviorally different from salmonids. As a result, the entrainment of lamprey into intermittently operating irrigation canals where fish may interact with screen infrastructure is seen as a potential factor that limits lamprey in some environments. Entrainment of PIT (Passive Integrated Transponder)-tagged juvenile Pacific Lamprey was primarily monitored at Feed Diversion Canal on the Umatilla River using stationary and mobile PIT tag arrays to determine what factors (river flow, fish size) influence entrainment, and if fish leave the canal unharmed through rotary drum screen and bypass infrastructure common to the Columbia River basin. A large proportion of PIT-tagged juvenile Pacific Lamprey released upstream of the canal headgate was estimated as entrained into the canal in 2020 (54%, CI95 39–78%), but no fish were released in 2022 and no fish tagged in previous years were detected at the fixed array within the canal in 2022. No juvenile Pacific Lamprey were detected as stranded or killed within the irrigation canal during mobile PIT tag detection surveys. Mobile PIT detection surveys were highly efficient at detecting PIT tags seeded within

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the canal during water diversion and after dewatering, suggesting significant numbers of PIT tags liberated from dead juvenile lamprey would be detected by these surveys. Few PIT-tagged lamprey were redetected downstream in the Umatilla and Columbia Rivers after their entrainment, obscuring the fate of these fish. However, the newly installed PIT antenna at the bypass outfall detected most entrained salmonids in 2022, suggesting that the bypass of entrained juvenile lamprey may be well documented in future years. The number of fish detected as entrained inside of Feed Diversion Canal in previous years was negatively related to Umatilla River flows at their time of release upstream of the canal, and this lamprey entrainment did not appear to be size selective based on the size distributions of detected and undetected fish. Continued annual monitoring of lamprey entrainment may provide information managers can use to evaluate how river flows may be used to avoid short windows of potential entrainment during the outmigration of juvenile Pacific Lamprey and how successful entrained juvenile lamprey are at using screen and bypass infrastructure originally made to rescue salmonids from irrigation canals.

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Introduction

Irrigation diversions are common within the arid interior of the Columbia River basin and can inadvertently trap fish. Juvenile Pacific Lamprey (*Entosphenus tridentatus*) are poor swimmers relative to juvenile salmonids (Dauble et al. 2006; Muller et al. 2006), and as a result, they may be particularly susceptible to diversion from rivers and streams into irrigation canals (entrainment) during their rearing and downstream migration (Moser et al. 2015). Rotary drum fish screens commonly found at irrigation canals in the Columbia River basin are generally designed to exclude juvenile salmonids from canals (McMichael et al. 2004), not juvenile lamprey. Once entrained, escaping from screened irrigation canals may be more difficult for juvenile lamprey than for salmonids due to differences in body size, body shape, swim performance, and behavior (Moser et al. 2015). Because of this uncertainty, the Bureau of Reclamation (Reclamation) wants to identify techniques to reduce entrainment, trapping, and mortality of lamprey at many of their diversion structures in the mid-Columbia River basin. This requires quantifying the aggregate loss of juvenile lamprey entrained into irrigation canals and how many fish pass the canal intakes unimpeded. To this end, Reclamation and their cooperators are conducting a collaborative research and monitoring effort in the Umatilla River basin that focuses on tracking lamprey implanted with PIT tags (Passive Integrated Transponders) as they move through the river network and encounter irrigation canals (Reclamation 2016). Long-standing PIT tag interrogation systems (PIT arrays) within irrigation canals originally designed to monitor steelhead entrainment will allow Reclamation to quantify the entrainment of juvenile lamprey, and recently installed PIT arrays in the Umatilla River can redetect entrained fish after they use screening and bypass infrastructure. Reclamation enlisted the Columbia River Fish and Wildlife Conservation Office to install and report on the maintenance, operations, and detections of PIT arrays in irrigation canals and their adjacent river arrays (Reclamation agreement # R20PG00060 and FWS# 4837-1374). The detections of lamprey at PIT arrays near Feed Diversion Dam, Maxwell Diversion Dam, and Three Mile Falls Diversion Dam (TMF) of the Umatilla River are indicative of the canal entrainment or the screening and bypass of juvenile lamprey. Therefore, the data gathered for this project were used to examine 1) how river discharge is related to the proportion of juvenile Pacific Lamprey entrained from groups of fish released upstream of the Feed Diversion Canal headgate, 2) how the entrainment timing of volitionally outmigrating juvenile lamprey relates to the timing of juvenile lamprey release groups, 3) if canal entrainment of juvenile Pacific Lamprey is size selective, 4) direct and indirect evidence of juvenile lamprey dying or becoming stranded within the irrigation canals, and 5) the proportion of juvenile lamprey documented inside the canals that successfully use the screening and bypass infrastructure to return to the river.

Study Sites

The Feed Diversion Dam and Canal is a Reclamation diversion structure located on the Umatilla River 2.4 km southeast of Echo, Oregon (Figure 1). The dam is constructed of concrete and rock and employs a timber weir with an embankment wing that raises the water level in the Umatilla River by 1.2 m. This furnishes surface water to a canal that extends to the Cold Springs Reservoir. Feed Diversion Canal has a maximum diversion capability of 6.2 m^3/sec (219 CFS). Water velocity testing at the rotary drum screen of Feed Diversion Canal was conducted shortly after its construction in 1994. Testing indicated the screen usually met 1994 NOAA criteria for salmonid smolts when canal discharge was 5.6 m^3/sec (ratio of sweep to approach velocity in front of the screen was two or more 91% of the time, and the approach velocity was usually ≤ 0.18 m/s; Cameron et al. 1997). The Feed Diversion Dam has an adult ladder and a slot in the dam structure to assist adult salmonids with upstream passage. A lamprey passage system is attached to the adult ladder to assist adult lamprey with upstream dam passage. During the 2022 water year, the headgate supplying water to Feed Diversion Canal opened intermittently beginning on January 10th 2022 (Table 1). The canal headgate operates while juvenile Pacific Lamprey are known to move downstream. On April 6th 2022 the canal was dewatered, essentially draining the water within the canal down to maintenance levels. Under maintenance conditions the headgate is left slightly open, only allowing enough water into the canal to keep its substrate wet between the headgate and the fish screen with the goal of allowing any

Table 1. First and last dates of operation for Feed Diversion Canal by water year. Canal operation within these dates can be intermittent.

Water year	First Date		Last Date	Mean Daily Diversion Rate ($m^3/s \pm 2SE$)
2017	1/23/2017	–	5/12/2017	5.0 (± 0.2)
2018	11/29/2017	–	4/3/2018	5.5 (± 0.2)
2019	12/19/2018	–	4/29/2019	4.9 (± 0.3)
2020	1/22/2020	–	3/20/2020	5.2 (± 0.4)
2021	12/21/2020	–	4/2/2021	4.8 (± 0.3)
2022	1/10/2022	–	4/6/2022	5.0 (± 0.4)

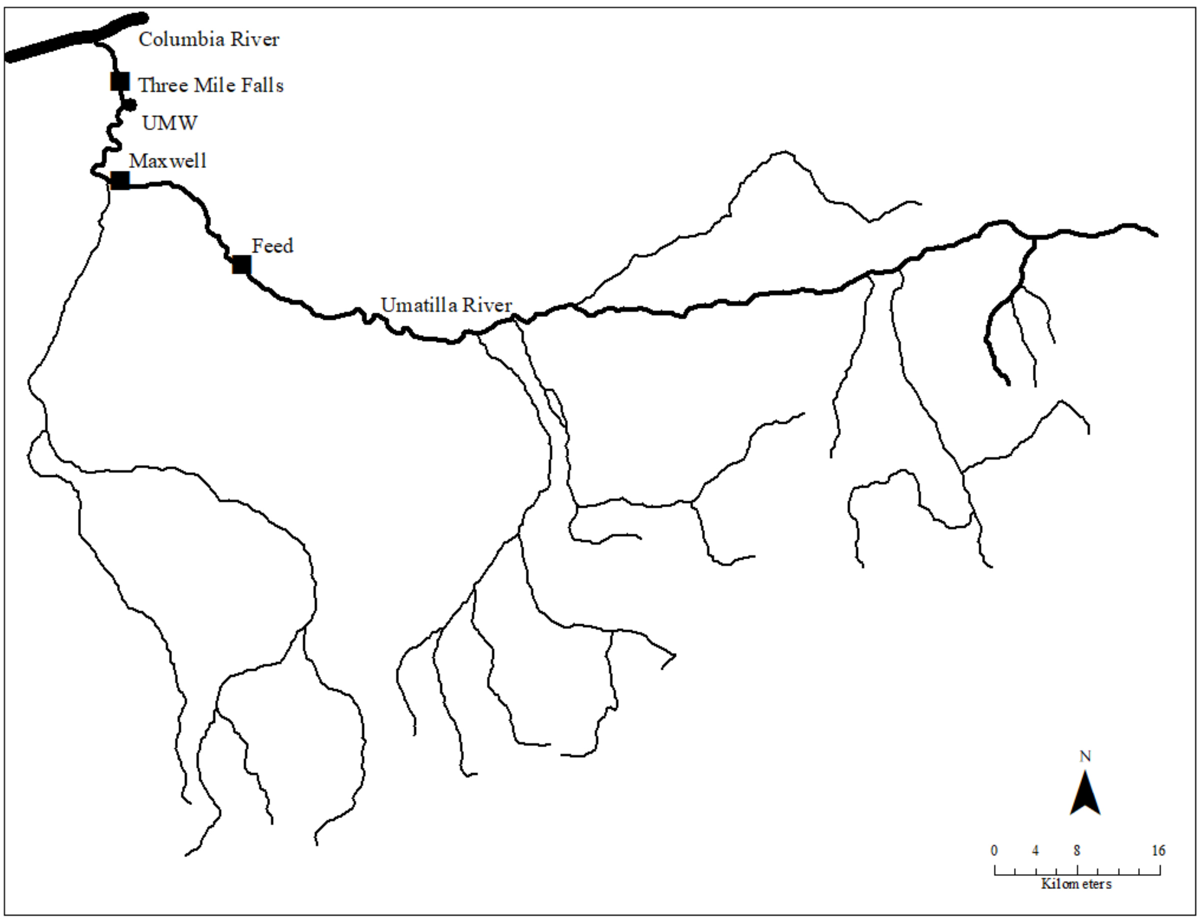

Figure 1. A map of the Umatilla River basin. Squares represent Bureau of Reclamation diversion dams and the diversion points of their associated canals. The circle marks the currently operating mainstem array site.

fish remaining within the canal to escape through the bypass system. The remaining patchwork of dry and pooled areas in the canal continue to dry out over the summer due to evaporation and vegetation growth within the canal.

Feed Diversion Canal has fixed antenna arrays in a pass-through orientation at upstream (Figure 2A) and downstream sites (Figure 2B) within the canal to detect PIT-tagged fish while they are entering and exiting the canal (Figure 3). The upstream and downstream antenna arrays are comprised of multiple (N = 6 and N = 5, respectively) individual antennas. Antennas in the upstream headgate array have a double loop design that performs better than a single loop design in the high electromagnetic interference (noise) environment surrounding the Feed Diversion Canal headgate. Due to water turbulence, velocity, and canal maintenance, PIT-tag antenna arrays were positioned 15 m downstream from the Feed Diversion Dam's headgate and 15 m upstream from the fish drum-screen structure. Finally, in late 2020 an additional array consisting of a single antenna was installed on the face of the Feed Diversion bypass outfall into the Umatilla River (Figure 4). PIT detection data are available for this site on the PTAGIS regional database (site code FDC; PSMFC 2021).

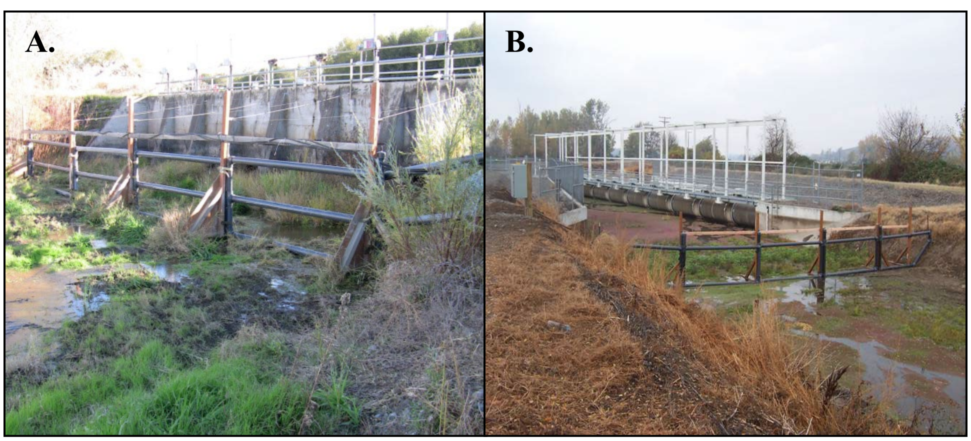

Figure 2. PIT arrays within Feed Diversion Canal. (A) Upstream PIT antenna array and the headgate. Instream posts and cables provide antenna support. The two parallel inductive loops of these antennas more evenly distribute the magnetic field genera generated by the antenna. As a result, the read range of PIT tags can be increased at sites that have high noise. (B) Downstream PIT antenna array upstream of the fish screening structure at Feed Diversion Canal.

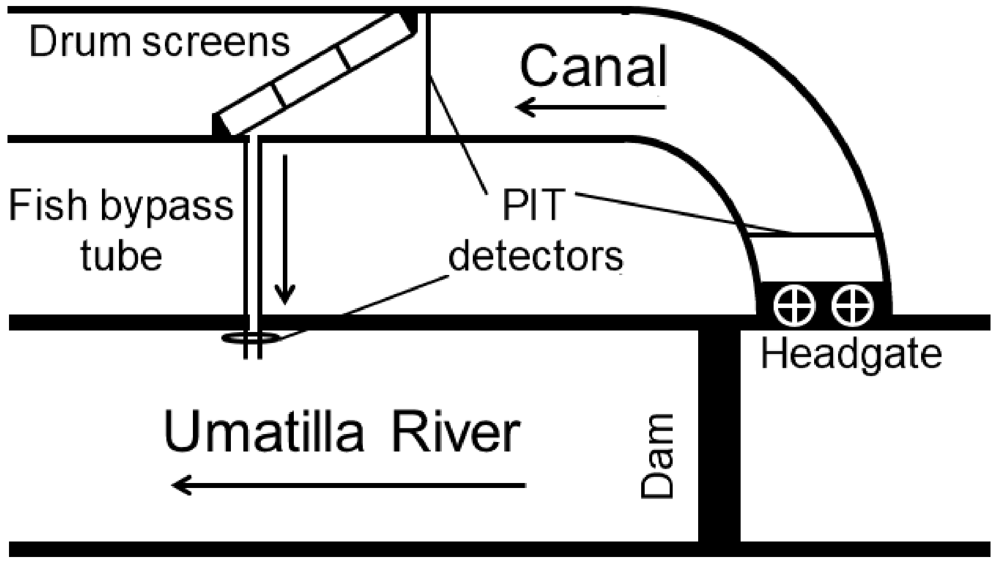

Figure 3. Diagram of Feed Diversion Dam. The diagram illustrates the headgate, screen, and bypass infrastructure of Feed Canal, and PIT detector arrays associated with those structures (modified from Simpson 2018).

Figure 4. Fixed PIT antenna at the bypass outfall of the Feed Diversion Canal.

Two other Reclamation diversion structures on the Umatilla River that contain PIT tag detection infrastructure include Maxwell Diversion Dam and Canal and Three Mile Falls Dam/West Extension Irrigation District Canal. Maxwell does not divert water when PIT-tagged juvenile lamprey are released on the Umatilla River (January and February). Similarly, no water has been diverted in January and February at Three Mile Falls Dam since 2017. However, any PIT-tagged juvenile Pacific Lamprey that remains in the Umatilla after their release may have an opportunity to become entrained when annual canal operations begin in the spring.

Two PIT tag arrays have operated in the mainstem Umatilla River downstream of Feed Diversion Canal. These PIT tag arrays were placed in the Umatilla River to quantify juvenile lamprey that encounter diversion dams but do not become entrained and to detect downstream migrating fish after entrainment and successful bypass. The upstream mainstem array was located 45 m downstream of Feed Diversion Dam on the Umatilla River. All antennas from this stream spanning array were removed or buried in April 2019 due to flooding and have not been replaced (site code UMF; PSMFC 2021). The second downstream mainstem array is currently located adjacent to the Hermiston Recycled Water Facility owned by the City of Hermiston, which is 2.4 rkm upstream of TMF (Figures 1 and 5). This is the furthest downstream site on the Umatilla River known to have rock substrate suitable for the anchoring of antennas. The PIT array is made of a single row of up to four 6 × 1 m antennas, which covers more than the wetted width of the river at base flow (Figure 6). All four antennas are anchored in a pass over orientation to minimize damage by impacts from large wood and other debris. CANbus antenna cables are anchored between 0.7 and 1 m downstream of the antennas at this site. A battery switcher was installed to power the array in October of 2020 based on 2019 testing that suggest it may mitigate noise at the site. The PIT detection data for this site is available on the PTAGIS regional database (site code UMW; PSMFC 2021).

Figure 5. Interrogation site adjacent to the Hermiston Recycled Water Facility (UMW). The red rectangle on the aerial photograph indicates the location of the PIT array. The river flow is from the bottom to the top of the picture.

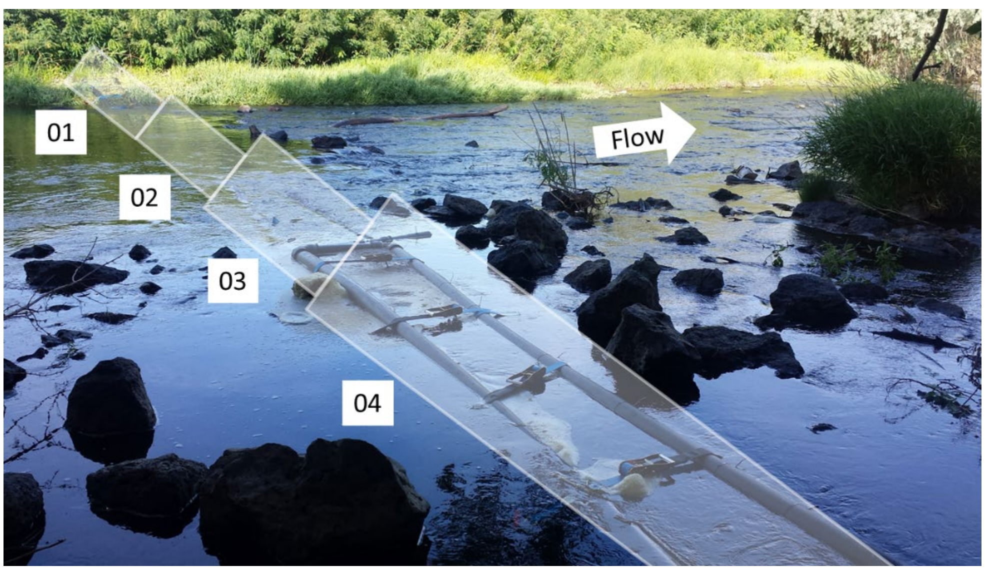

Figure 6. Umatilla River PIT array adjacent to the Hermiston Recycled Water Facility (UMW). The four individual antennas are numbered on the photograph.

PIT array Maintenance and Operations

The screen and headgate array within Feed Diversion Canal operated the entire time the canal was diverting water. The antenna at the bypass of Feed Diversion Canal was not operational between January 29th 12:37 and February 4th 11:07. The only PIT antenna operating for the UMW array in 2022 until August was antenna 3 (Table 2). Between August 1st 2022 10:18 and August 10th 2022 12:52 UMW was turned off for repairs. At this time antennas 3 and 4 were replaced with new antennas and the antenna previously in antenna 3's location was moved to antenna 1. Antenna 2 stopped operating due to damage in a previous year and it has not been replaced. The UMW array detected 269 salmonids in 2022 (Appendix A).

Table 2. The number of days (% days) each antenna in the UMW array operated in 2022.

Antenna	1	2	3	4
Days operated (%)	144 (39%)	0 (0%)	356 (98%)	144 (39%)

Methods

PIT-tagged Juvenile Lamprey.- Confederated Tribes of the Umatilla Indian Reservation (CTUIR) personnel have run a variety of screw traps on the Umatilla River between autumn and spring annually. This trapping indicates that the movement of outmigrating juvenile lamprey peaks during high river flows, including flooding or rain-on-snow events. CTUIR and its partners used a screw trap located approximately 2.8 rkm upstream of the river mouth to capture and tag juvenile Pacific Lamprey associated with these types of events on the Umatilla River in early 2017 and 2019 to 2020. Captured juvenile Pacific Lamprey were implanted with 8-mm FDX PIT tags and released in groups into the Umatilla River approximately 0.8 rkm upstream of the Feed Diversion Canal (FDC). The screw trap was not operated in 2021 and 2022; therefore, no release groups were placed upstream of Feed Diversion Canal (Table 3). CTUIR personnel have also intermittently used electrofishing in the Umatilla River and Meacham Creek upstream of Feed Diversion Canal to capture and tag larval and juvenile Pacific Lamprey with 8-mm and 10-mm FDX PIT tags, after which these fish were released near their capture location. From late 2020 through early 2022 no lamprey were captured, tagged, or released upstream of the canal via electrofishing (Table 3). Since 2017 we have monitored fish detection at antenna arrays within Feed Diversion Canal, in the Umatilla River, and downstream in the Columbia River to estimate what percentage of juvenile Pacific Lamprey releases become entrained into the canal, how water conditions are related to entrainment, to monitor the size distribution of entrained individuals, and to document individuals that escaped the canal. Steelhead and Chinook Salmon PIT detections were examined to confirm the satisfactory operation of the canal and bypass fixed arrays in years when few or no larval Pacific Lamprey were detected.

Table 3. The number of PIT-tagged Pacific Lamprey released annually by CTUIR personnel for detection. Juvenile Pacific Lamprey were captured in screw traps, tagged, and released in groups upstream of the Feed Diversion Canal (release groups). Both larval and juvenile Pacific Lamprey were also captured by electrofishing and released in place (volitional).

Water year	Release type	Release groups (N)	Juvenile Pacific Lamprey (N)	Release date(s)
2017	Release group(s)	3	309	2/8/2017 – 2/9/2017
2017	Volitional	N/A	0	N/A
2018	Release group(s)	0	0	N/A
2018	Volitional	N/A	0	N/A
2019	Release group(s)	1	498	1/24/2019
2019	Volitional	N/A	536	10/10/2018 – 11/15/2018
2020	Release group(s)	4	1478	1/26/2020 – 1/28/2020
2020	Volitional	N/A	0	N/A
2021	Release group(s)	0	0	N/A
2021	Volitional	N/A	0	N/A
2022	Release group(s)	0	0	N/A
2022	Volitional	N/A	0	N/A

Planting PIT Tags in Feed Diversion Canal for Mobile Canal Surveys.- When PIT-tagged fish die in irrigation canals, including juvenile Pacific Lamprey, some of these fish presumably decompose and shed their PIT tag within the canal. PIT tags that are no longer associated with a living fish counterpart due to shedding or mortality are often called “ghost tags” (Bond et al. 2019; Stout et al. 2019). We conducted canal surveys annually between 2018 and 2022 with portable PIT-tag detection systems to find ghost tags associated with dead juvenile Pacific Lamprey and we estimated the detection efficiency of these efforts by seeding the canal with a known number of PIT tags before each survey. The length of the unscreened portion of the canal (between the headgate and the bypass adjacent to the fish screen) is approximately 212 meters long (Cameron et al. 1997). The canal was seeded by standing on the bank of the canal and tossing one PIT tag perpendicularly into the canal approximately every 12 to 13 m of the canal’s length between the headgate PIT array and the canal screen. The model and length of PIT tags differed by seeding year (2018,2019,2021: TXP148511B-8.5mm; 2022: Mini HPT8-8.4mm and Mini HPT10-10.3mm). The placement of the first tag was determined by a random start. Between 22 and 15 tags were seeded at least once annually while the canal was still diverting water, and again after the canal stopped diverting water (Table 4). Work restrictions due to COVID-19 did not allow for seeding the canal with PIT tags in 2020. The timing of annual tag seeding during water diversion ranged from 7 to 52 days before canal drainage. Most of the canal’s bottom is paved with large, roughly flat rocks, on top of which rests shallow and patchily distributed sediment. Just upstream of the fish screen the canal bottom consists of a flat concrete apron. Little sediment rests upon this apron after dewatering of the canal, and the apron begins 143.5 meters downstream from the canal headgate. Detection efficiencies for seeded tags were examined based on canal operations, the timing of tag seeding, distance of tag seeding from the headgate, and the type of canal bottom substrate the tag was seeded over. This information was used to better understand if juvenile Pacific Lamprey that are stranded or die in the canal and leave ghost tags are likely to be detected during canal PIT tag surveys.

Table 4. The number of PIT tags seeded within the unscreened portion of Feed Diversion Canal. Various size and models of tag were seeded, and seeded tags were exposed to the operating canal for different durations and after the canal had been drained of water.

Seeding Date	Tag size/Model	Diverted water exposure (d)	Canal status	Tags seeded (N)
3/27/2018	8.9mm TXP148511B	7	diverting	15
4/30/2018	8.9mm TXP148511B	0	drained	15
3/8/2019	8.9mm TXP148511B	52	diverting	15
5/15/2019	8.9mm TXP148511B	0	drained	15
3/17/2021	8.9mm TXP148511B	16	diverting	15
4/21/2021	8.9mm TXP148511B	0	drained	15
3/24/2022	10.3mm Mini HPT10	51	diverting	11
3/24/2022	8.4mm Mini HPT8	51	diverting	11
3/24/2022	10.3mm Mini HPT10	13	diverting	11
3/24/2022	8.4mm Mini HPT8	13	diverting	11
4/21/2022	10.3mm Mini HPT10	0	drained	11
4/21/2022	8.4mm Mini HPT8	0	drained	11

PIT Tag Survey within Feed Diversion Canal.- Surveys at Feed Diversion Canal for planted PIT tags and PIT tags associated with stranded or dead juvenile lamprey were conducted after annual water diversion activities ceased and the canal was dewatered in 2018 (April 30th), 2019 (May 15th), 2021 (April 22nd), and 2022 (April 21st). A survey for PIT tags within Feed Diversion Canal was conducted in 2018 for PIT-tagged lamprey entrained in 2017 because PIT tags associated with entrainment are often detected within canals for multiple years (Simpson 2018). Feed Canal was not seeded with PIT tags in 2020 and no canal surveys were conducted that year. No release groups of PIT-tagged juvenile lampreys were placed upstream of Feed Diversion Canal in 2022. Canal surveys were simultaneously conducted by two people, both equipped with a portable PIT-tag detection system (PITpack; Hill et al. 2006). Both PITpacks were constructed from an IS1001-ACN PIT tag reader (Biomark), a Windows-based tablet for user interface, a lithium-ion battery, and a detection wand made of wire loop and PVC

(Figure 7). Starting at the canal headgate, the biologists scanned all areas where PIT tags from trapped or stranded fish were likely to be located and proceeded slowly in a downstream direction until the fish screens were reached. Biologists also scanned piles of fine sediment located just downstream of the fish screens for PIT tags associated with lamprey.

Figure 7. An IS1001ACN-based mobile PITpack reader system. (A) The PITpack reader is comprised of a waterproof Pelican case, a Windows-based tablet mounted in a harness, a detection alarm, and a lithium-ion battery. (B) Scanning a drained Feed Diversion Canal

Results

Detection of Entrained Juvenile Lamprey Using Fixed PIT Arrays within Feed Canal.- One PIT-tagged juvenile lamprey released in the Umatilla River was detected at the bypass array of Feed Diversion Canal in 2022. This fish was collected by electrofishing and was tagged and released at Meacham Creek on November 15^{th} 2018. Since the fish was not detected on arrays inside of the canal there is no evidence that it entered the canal. Canal detections of juvenile lamprey in previous years and their travel time through the canal are detailed in Tables 5 and 6. The proportion of released juvenile lamprey that were entrained in previous years and the size distribution of those fish are shown in Figures 8 and 9.

During the 2022 water year substantial numbers of Chinook Salmon (N = 986) and steelhead (N = 34) were detected either within the canal or at the bypass outfall PIT array (summarized in Appendix B). Many of these fish were detected within the canal (headgate and screen array, $N_{Chinook}$ = 749, $N_{steelhead}$ = 15), and the majority were detected at the bypass outfall ($N_{Chinook}$ = 949, $N_{steelhead}$ = 32). The detection efficiency of the newly installed bypass outfall array appeared to be high for fish tagged with 12-mm PIT tags (Chinook and steelhead) since the highest number of unique fish detections occurred at the bypass outfall, and 100 of 104 fish (96%) detected both within the canal and downstream of the canal were also detected at the bypass outfall.

Pacific Lamprey detections at irrigation canals in the Umatilla River basin are largely limited to Feed Diversion Canal. One juvenile Pacific Lamprey released in 2020 was detected at the bypass of the West Extension Diversion Canal (at Three Mile Falls Dam) on April 19th 2020. No lamprey has been detected at Maxwell Diversion Canal.

Table 5. The annual detection of PIT-tagged juvenile Pacific Lamprey released in groups upstream of the Feed Diversion Canal. Included are the total number of unique detections of juvenile Pacific Lamprey (total documented entrainment) in the canal and the percentage of released fish that represents (minimum percent of fish entrained), the number of unique fish detected at each antenna array (headgate and screen), the detection efficiency of the headgate array, the number of fish entrained from expanding the unique headgate detections by the detection efficiency of the headgate array and the percentage of released fish that represents, and the number and percentage of fish detected as entrained that were later detected downstream after escaping the canal.

Water year	Canal detections (N, %)	Headgate detections (N)	Detection efficiency (%, 95CI)	Headgate expanded lamprey entrainment (N, 95CI, %)	Screen detections (N)	Downstream detections (N, %)
2017	34, 11%	28	N/A	N/A	6	3, 9%
2018	N/A	N/A	N/A	N/A	N/A	N/A
2019	11, 2.2%	7	N/A	N/A	5	0, 0%
2020	260, 18%	162	20.3, 14.1–28.4	799, 571–1149, 54%	123	50, 19%
2021	N/A	N/A	N/A	N/A	N/A	N/A
2022	N/A	N/A	N/A	N/A	N/A	N/A

Table 6. The time to detection for PIT-tagged juvenile Pacific Lamprey from their release in groups upstream of the Feed Diversion Canal. Also included is the travel time between the headgate and screen antenna arrays (units in minutes unless otherwise noted as days [d]).

Water year	Time to headgate (median, range)	Time to screen (median, range)	Travel time (median, range)
2017	265, 15–1.4d	200, 111–42d	N/A
2018	N/A	N/A	N/A
2019	6, 4–25	15, 12–31	7, N/A
2020	604, 22–8.8d	618, 19–1.6d	4, 3–5
2021	N/A	N/A	N/A
2022	N/A	N/A	N/A

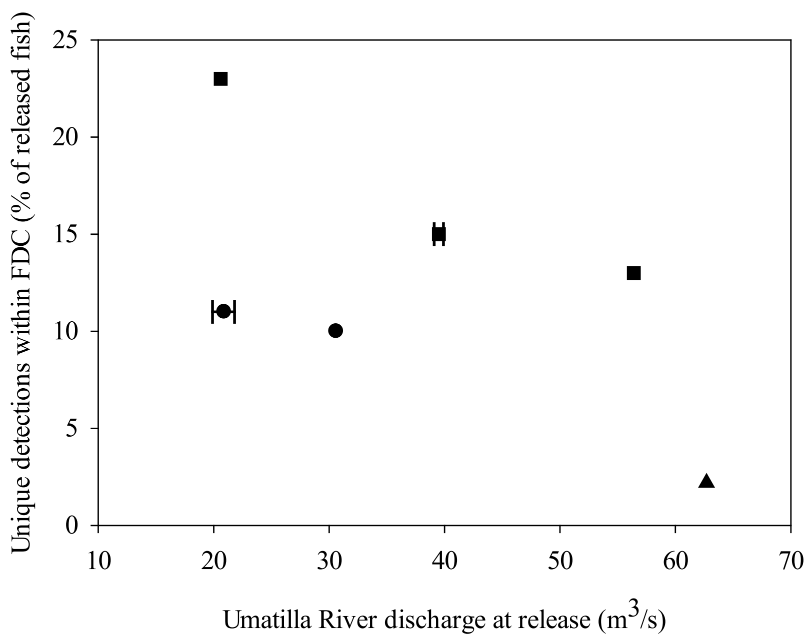

Figure 8. Relation between Umatilla River discharge and lamprey detected in Feed Diversion Canal. Discharge (m3/sec) was measured adjacent to Feed Diversion Canal (UMUO gage) during lamprey releases. The percentage of released juvenile lamprey detected as entrained is shown for 2017 (●), 2018 (▲), and 2020 (■). Detections are unexpanded and represent the minimum number of fish entrained. When multiple releases occurred in a single day (see Table 3) release groups were pooled by day and the range of discharge at the releases are depicted using horizontal bars.

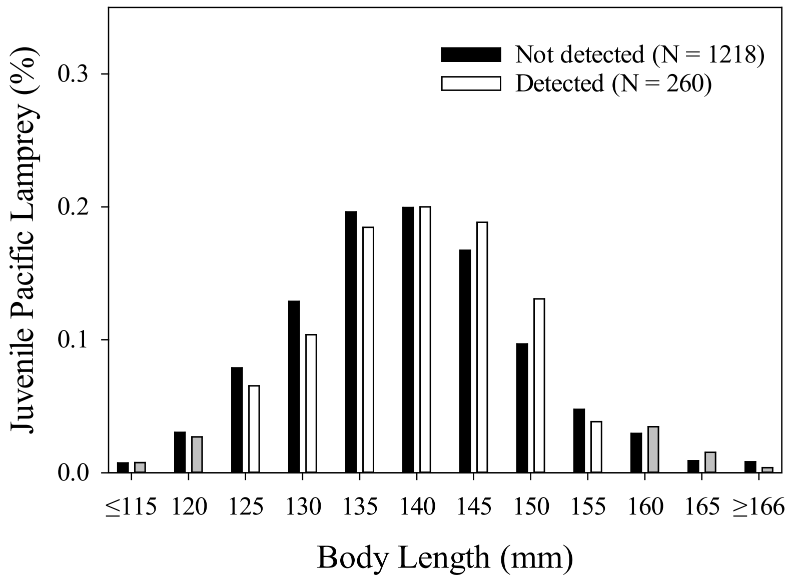

Figure 9. The size distribution at tagging of juvenile Pacific Lamprey by FDC detection in 2020. Distributions are compared between fish that were detected (entrained) shortly after their release, and those lamprey that were not detected as entrained into Feed Diversion Canal.

Mobile PIT Tag Surveys for Stranded Juvenile Lamprey within Feed Diversion Canal.- The canal was seeded with tags before surveys were conducted to estimate the efficiency of the mobile PIT tag detectors and if any PIT tags released from dead lamprey were likely to move through the canal. The detection efficiency of mobile surveys for PIT tags during the same year they were seeded within the canal were 63% in 2018 (n_{2018} = 19), 43% in 2019 (n_{2019} = 13), 90% in 2021 (n_{2021} = 27), and 82% in 2022 (n_{2022} = 54). The same year detection efficiency of these surveys were consistently higher for PIT tags seeded after the canal was dewatered (n_{2018} = 11, 73%; n_{2019} = 8, 50%; n_{2021} = 14, 93%; n_{2022} = 19, 86%) compared to tags that were seeded while the canal was diverting water (n_{2018} = 8, 53%; n_{2019} = 5, 33%; n_{2021} = 13, 87%; n_{2022} = 35, 80%). In total, 72% of tags were detected in the year they were first seeded (n = 113), 10% of tags were first detected a year or more after they were first seeded (n = 15), 10% of tags were never detected despite having the opportunity to be detected in surveys of subsequent years (n = 16), and 8% of tags were not detected without the opportunity to be detected in subsequent surveys (n = 12).

We also examined if the detection of seeded tags in any of the four survey years are related to if the canal was diverting water at the time of seeding, the canal substrate upon which the tag was seeded (rock pavers/concrete apron), PIT tag size and model, and the number of days water was diverted in the two months after the tag was seeded. The linear distance between where PIT tags were seeded and the canal headgate is a measure of tag distribution within the canal and the substrate over which the tag was seeded (Figure 10). Over multiple annual surveys there was no significant difference in the proportion of seeded tags detected based on canal operations (diverting/not diverting) during seeding or the canal substrate over which the tag was seeded (Fishers Exact Test $P > 0.05$). Tags seeded on the canal apron during water diversion were detected 67% of the time (n = 20), but tags seeded on the apron while the canal was dewatered were detected at similar percentages (86%, n = 19) as tags seeded upstream of the apron both during (83%, n = 49) and after (89%, n = 40) water diversion. A greater proportion of the Mini HPT10 pit tags were detected (93%, n = 30) over multiple annual surveys compared to the TXP148511B 8.9mm tags (82%, n = 74) and the Mini HPT 8 PIT tags (73%, n = 24), but these differences were not significant either (Fishers Exact Test $P > 0.05$). For tags seeded during water diversion, a smaller percentage of tags were detected when tags were placed in the canal 51-52 days before dewatering (65%, n = 24), compared to when tags were seeded within 16 days of dewatering (87%, n = 45; Fishers Exact Test $P \leq 0.05$). In 2022, 2 PIT tags that were previously seeded on the concrete apron just upstream of the bypass tube were detected at the bypass array, indicating they had passed through the bypass structure and tube. One tag was seeded in 2022 while water was being diverted through the canal and the other was seeded in 2021 after the canal had been dewatered. Seeded PIT tags were not detected crossing the fixed screen array upstream of the apron between 2018 and 2022. We did not detect any PIT tags associated with the 2017, 2019, or 2020 release of tagged lamprey upstream of Feed Diversion Canal screen during mobile antenna surveys conducted after canal dewatering.

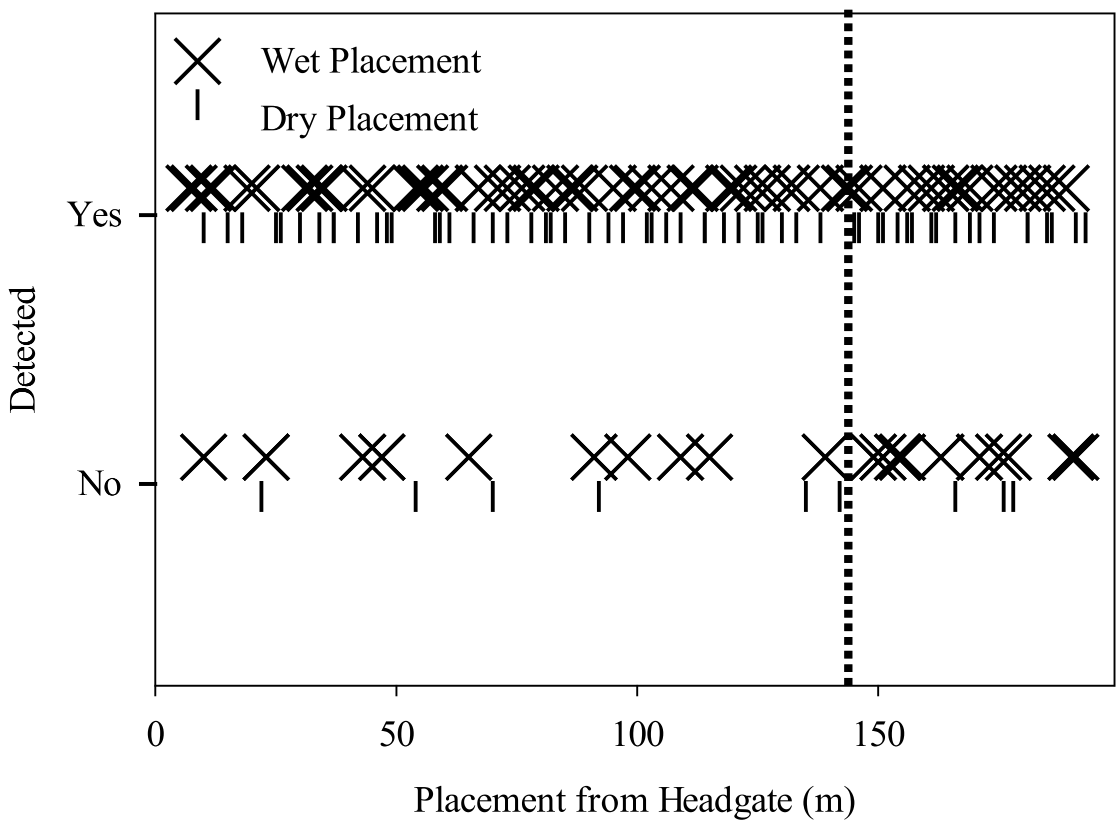

Figure 10. The detection of seeded PIT tags based on tag placement within Feed Diversion Canal. PIT tags were seeded while the canal was diverting water (wet placement) or after the canal was dewatered ('dry' placement) and at various distances from the Feed Canal headgate that correspond with different canal bottom substrates (rock pavers vs concrete apron, divided by the vertical dotted line at 143.5 m). Tag seeding and mobile antenna surveys for tag detection were conducted over four years (2018, 2019, 2021, 2022). Some tags were detected in surveys conducted after the year of their seeding.

Discussion

The entrainment of lamprey into intermittently operating irrigation diversions and their subsequent interaction with salmonid centric screen infrastructure is seen as a threat to lamprey and one of many potential factors limiting lamprey in freshwater environments of the Columbia River basin. Fish screening and the operation of screens is a fish conservation action common to the Pacific Northwest of the United States, yet the effectiveness of these actions is rarely evaluated in terms of the number of fish affected or how these structures affect fish populations (Moyle and Israel 2005). Developing a better understanding of factors that influence lamprey entrainment and screen effectiveness is thought to be an important component of lamprey conservation (Luzier et al. 2011; Clemens et al. 2017; Clemens et al. 2020).

One potentially effective method of addressing the trapping or stranding of juvenile Pacific Lamprey within irrigation canals is to prevent their diversion from rivers and streams into canals (entrainment). Canals with headgates that angle more perpendicularly to a river thalweg and face river flow directly are associated with greater larval lamprey entrainment than canals with headgates that divert water at a more parallel angle to the river thalweg and face river flow obliquely (Lampman and Beals 2019). Canals with a relatively large capacity to divert water tend to remove a greater proportion of discharge from streams and rivers, which is often related to more fish entrainment (Walters et al. 2012). Determining how multiple factors influence the entrainment risk of various life stages of lamprey is important since opportunities to change irrigation canal operations (diversion timing, average rate, or volume) can be limited. Methods to minimize Pacific Lamprey entrainment may be developed using information on how the diversion of these fish are related to biotic factors (e.g., fish size and age), abiotic factors (e.g., stream flow and temperature), and the interaction of these factors (e.g., fish physiology and behavior).

How river flows relate to the canal entrainment of juvenile Pacific Lamprey remains unclear. The outmigration of juvenile Pacific Lamprey is more variable and temporally dispersed compared to outmigration of juvenile salmonids with most individuals leaving during high spikes in river flows and rain events (Goodman et al. 2015). Similarly the initiation of outmigration in juvenile River and Sea Lamprey of Europe is related to low water temperatures, high stream discharges, and turbidity during the appropriate seasons (largely in winter and spring), and is often multimodal with peaks in both winter and spring (Baer et al. 2018). As a result, many outmigrating juvenile lamprey may encounter diversions during higher flow conditions when they may be less likely to become entrained. Peaks in migration may also provide a window to minimize entrainment through short reductions or suspensions of water diversion.

Exactly when these windows occur might be difficult to predict for juvenile Pacific Lamprey (Moser et al. 2015), but discharge spikes in January and February may have potential for mitigation (Baer et al. 2018).

Factors that influence juvenile lamprey entrainment were examined in this study by observing patterns in PIT tag detection after their release. Although river flows during lamprey entrainment events were within the range observed for the entrainment of spring-emigrating juvenile steelhead (Simpson and Peterson 2016), the proportion of emigrating juvenile Pacific Lamprey entrained after their release upstream of the Feed Canal headgate was greater than the known range of annual entrainment rates exhibited by outmigrating juvenile hatchery steelhead at Umatilla River canals (0–32%, Simpson and Peterson 2016) after accounting for the detection efficiency of the antenna arrays. This may be expected since juvenile Pacific Lamprey are weaker swimmers than juvenile steelhead. Also, since lamprey are thought to be more bottom oriented during outmigration due to their lack of a swim bladder, headgate structures that typically open from the bottom of streams could leave lamprey more vulnerable to entrainment. However, caution should be used when comparing entrainment between steelhead and lamprey since most steelhead entrainment on the Umatilla River occurred at Maxwell and West Extension Diversion Canals where canal-specific characteristics could drive differences in the percent of fish entrained (e.g., headgate orientation and location; Simpson and Ostrand 2012), as could the differences in mortality experienced between the various release and entrainment sites used in these studies. Unfortunately, a useful expanded estimate of entrainment was only generated at Feed Diversion Canal in 2020. This year three entrained PIT tags were detected associated with Pacific Lamprey tagged as larvae during the 2019 water year. These detections occurred in close temporal proximity to detections from the 2020 release groups, suggesting that these volitionally-entrained fish may be juvenile lamprey. If so, this would support the findings of other studies that the majority of juvenile lamprey migrate during high flow events, and the timing of group releases likely represent the experience of volitionally migrating juvenile lamprey. In general, detections of entrained lamprey appear to be negatively related to river discharge at release, suggesting that when lamprey encounter diversion headgates they are less likely to be entrained under high flow conditions. The rate of water diversion into Feed Canal is fairly consistent, so when the Umatilla River is experiencing higher flows, a relatively smaller proportion of the river is often diverted into the canal. A better understanding of the relation between river flow and entrainment could be achieved by continuing the comparison of flow to the total number (expanded) of fish entrained, and by obtaining a finer scale understanding of how environmental conditions relate to when volitionally migrating fish encounter irrigation diversions. The entrainment of juvenile Pacific Lamprey did not appear size selective across the lengths of released PIT-tagged juvenile lamprey and at river discharges experienced after their release (22–62 m^3/sec). In this analysis, undetected juvenile lamprey were assumed not to be entrained, but poor detection efficiency within the canal makes it likely that some undetected fish were actually entrained.

Another potential method to prevent the stranding and trapping of juvenile Pacific Lamprey in canals is the use of fish screens designed to return (bypass) fish back into the river after their entrainment. Like much of the Pacific Northwest, the fish screen and bypass infrastructure that lampreys encounter in the Umatilla River basin are designed to return juvenile salmonids to their river of origin. The interstitial spaces in these fish screens can be too large to successfully bypass small and narrow lamprey, allowing them to pass through screens instead of being diverted back into the river. In fact, the distribution of small larval lamprey within irrigation canals appears to be more related to the location of deposited fine sediment than the location of fish screens (Lampman and Beals 2019). However, a vertical traveling screen (2.0 m wide channel) was proven very effective at bypassing larger juvenile Pacific Lamprey released directly upstream due to the small pore size of the screen relative to body size of the lamprey (100%, Goodman et al. 2017). Few fish screens are evaluated for lamprey exclusion and bypass, so little is known about how the size and configuration of these fish screens affect bypass success for lamprey. Furthermore, juvenile lamprey may not hold in fine sediment upstream of fish screens the same way larval lamprey often do. For example, bypass detections of PIT-tagged juvenile Pacific Lamprey can be more common when fish are released just upstream of the rotary drum screens (82%, Lampman and Beals 2019), compared to when they are released near the headgate in an irrigation canal (3–

19%). This illustrates that little is understood about the fate (i.e., killed pre-bypass, bypassed, removed from the population by passing through the fish screen, stranded upon canal dewatering while holding in sediment) of individual juvenile lamprey once they enter irrigation canals that have fish screens installed downstream of their point of diversion.

The detection efficiency of PIT-tagged lamprey at the fixed arrays within Feed Diversion Canal was likely low. Few entrained juvenile lamprey were detected at both fixed arrays within the canal over all three years of monitoring release groups, which can be indicative of poor detection of 8-mm and 10-mm PIT tags at both arrays within the canal. Only 20% of entrained juvenile lamprey were detected at the headgate array, based on results from the only year we could estimate detection efficiency (2020). Many entrained salmonids with larger 12-mm PIT tags were detected at the fixed arrays within Feed Diversion Canal in 2022 (Appendix B). The annual detection efficiencies observed for juvenile steelhead with 12-mm PIT tags at the fixed Feed Canal arrays was relatively high (2016; headgate = 44%, screen = 80%). Presumably this poorer detection efficiency is driven by the smaller sized tags used for implantation in juvenile lamprey. However, other differences between salmonids and lamprey could also contribute to differences in detection efficiencies, such as their position in the water column, the orientation of their body (and PIT tag) while they move downstream, or how long lamprey remain in the detection field of the antenna.

Most of the 8 to 10-mm PIT tags seeded within the canal were detected at least once during our four mobile surveys (82%), and there was little evidence of any movement of seeded tags in the canal. No seeded tags were detected at the fixed array upstream of the screen or in sediment piles just downstream of the drum screen, and only 2 of 38 (5%) PIT tags seeded on the concrete apron were detected as passing through the bypass pipe to the outfall. Any PIT tags liberated from dead lamprey were likely available for detection by mobile surveys barring their mechanical destruction. Since the two tags detected at the bypass outfall in 2022 were seeded in the canal just upstream of the bypass tube, PIT tagged lamprey that die near the bypass screen could appear as live fish returning to the river.

Canal entrainment of juvenile Pacific Lamprey from the release groups occurred before the bypass outfall antenna was installed. Few canal-entrained juvenile Pacific Lamprey were documented returning to the Umatilla River through screen and bypass infrastructure via redetection at mainstem Umatilla and Columbia River arrays (19%), so the ultimate fate of most entrained fish is unknown. Confirmed escapees detected downstream were rarely observed at multiple locations, suggesting a poor ability to redetect tagged lamprey downstream. No PIT tags associated with lamprey were detected during mobile surveys within the canal despite their high detection efficiencies (33–93%), and previous electrofishing surveys by the Bureau of Reclamation have found no juvenile lamprey upstream of the fish screen (Sutphin et al. 2012; Sutphin et al. 2013). As a result, it is unlikely that most entrained juvenile Pacific Lamprey from the release groups held in sediment upstream of the canal screen, but instead were bypassed into the Umatilla River after which they were never redetected. Although it is possible some of these PIT tagged juvenile lamprey passed through the drum screen, other studies have shown that few lamprey greater than 100 mm (e.g., juveniles) pass through drum screens (Lampman and Beals 2019), and the Bureau of Reclamation also found no juvenile lamprey downstream of the screens during the same electrofishing surveys at Feed Diversion Canal. Based on bypass detections of juvenile steelhead and Chinook Salmon between 2021 and 2022, the new fixed antenna on the bypass outfall of Feed Canal should improve the ability to detect tags associated with any future juvenile lamprey release groups leaving the canal. Such improvements should allow the direct documentation of juvenile lamprey that return to the Umatilla River and allow comparisons of lamprey bypass at Feed Diversion Canal with lamprey encountering other types of bypass infrastructure (e.g., louvers and vertical traveling screens; Goodman et al. 2017) and entrained juvenile salmonids.

Additional Actions in 2023

Next year we plan to assess if we can detect deceased larval Pacific Lamprey that have been PIT tagged and released into the canal near the drum screen. Our goal is to understand if fish that die in the canal and move downstream prior to decomposition are detectable within the canal or at the bypass.

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APPENDIX A: PIT-tagged Fish Detected at the mainstem Umatilla River array UMW in 2022

Fish species/run	Capture/tagging site	Release site	Dates released	Dates detected	Unique fish (N)
Pacific Lamprey	Meacham Creek	Meacham Creek	11/15/2018	1/8/2022	1
Steelhead/Summer	Birch Creek	Birch Creek	2/21/2022 – 5/22/2022	4/20/2022 – 11/11/2022	8
Steelhead/Summer	Irrigon Hatchery	Pendleton Acclimation Pond	4/13/2022 – 4/28/2022	4/16/2022 – 5/29/2022	34
Steelhead/Summer	Meacham Creek	Meacham Creek	1/28/2022 – 3/24/2022	4/19/2022 – 4/24/2022	2
Steelhead/Summer	Three Mile Falls Dam	Umatilla River	5/18/2021 – 5/27/2022	6/29/2021 – 5/28/2022	152
Steelhead/Summer	Umatilla River	Umatilla River	11/13/2020 – 11/11/2021	1/11/2022 – 4/18/2022	4
Steelhead/Summer (Wild Adult)	Birch Creek	Birch Creek	4/29/2020 – 4/27/2021	4/2/2022 – 12/31/2022	7
Steelhead/Summer (Unknown adult)	Bonneville Adult Fish Facility	Bonneville Adult Fish Facility	9/17/2021 – 8/15/2022	2/20/2022 – 11/10/2022	2
Steelhead/Summer (Wild Adult)	Fox Creek NF John Day River	Fox Creek NF John Day River	10/23/2019	3/23/2022	1
Steelhead/Summer (Hatchery Adult)	Irrigon Hatchery	Imeques Acclimation Pond	4/21/2021	11/7/2022	1
Steelhead/Summer (Hatchery Adult)	Irrigon Hatchery	Pendleton Acclimation Pond	4/22/2021	11/10/2022	1
Steelhead/Summer (Hatchery Adult)	Magic Valley Hatchery	Pahsimeroi Weir	4/16/2019	4/6/2022	1

Fish species/run	Capture/tagging site	Release site	Dates released	Dates detected	Unique fish (N)
Steelhead/Summer (Wild Adult)	Three Mile Falls Dam	Umatilla River	4/26/2020 – 5/11/2021	2/6/2022 – 12/29/2022	9
Steelhead/Summer (Hatchery Adult)	Umatilla Hatchery	Pendleton Acclimation Pond	4/20/2020	3/13/2022 – 12/30/2022	5
Chinook/Fall	Bonneville Hatchery	Pendleton Acclimation Pond	3/8/2022	3/9/2022 – 3/11/2022	8
Chinook/Spring	Umatilla Hatchery	Imeques Acclimation Pond	4/7/2022	4/9/2022 – 4/10/2022	14
Chinook/Spring	Umatilla Hatchery	Thornhollow Acclimation Pond	1/1/2022 – 4/7/2022	1/7/2022 – 4/11/2022	10
Chinook/Spring	Umatilla Hatchery	Umatilla River	9/26/2022 – 10/11/2022	11/18/2022 – 11/30/2022	2
Chinook/Fall (Hatchery Adult)	Lyons Ferry Hatchery	Lyons Ferry Hatchery	5/18/2021	10/27/2022 – 10/29/2022	1
Chinook/Spring (Hatchery Adult)	Irrigon Hatchery	Imeques Acclimation Pond	4/13/2021 – 4/8/2021	5/23/2022 – 5/25/2022	3
Chinook/Unknown (Unknown Adult)	Bonneville Adult Fish Facility	Bonneville Adult Fish Facility	5/12/2022 – 10/6/2022	5/21/2022 – 12/18/2022	3
Coho (Hatchery Adult)	Kooskia National Fish Hatchery	Kooskia National Fish Hatchery	4/14/2021	11/1/2022	1

APPENDIX B: PIT-tagged Salmonids Detected at the Feed Diversion Canal Arrays (FDC) for Water Year 2022

Fish species/run	Capture/tagging site	Release site	Dates released	Dates detected	Unique fish (N)
Steelhead/Summer	Birch Creek	Birch Creek	1/15/2022 – 4/1/2022	1/17/2022 – 4/2/2022	6
Steelhead/Summer	Irrigon Hatchery	Pendleton Acclimation Pond	4/13/2022 – 4/28/2022	4/16/2022 – 4/30/2022	9
Steelhead/Summer	Meacham Creek	Meacham Creek	10/9/2021 – 3/24/2022	12/28/2021 – 3/30/2022	3
Steelhead/Summer	Umatilla River	Umatilla River	9/21/2021 – 11/15/2021	1/11/2022 – 4/23/2022	8
Steelhead/Summer (Adult)	Birch Creek	Birch Creek	3/18/2020 – 5/1/2020	3/2/2022 – 3/19/2022	2
Steelhead/Summer (Adult)	Bonneville Adult Fish Facility	Bonneville Adult Fish Facility	7/26/2021 – 10/1/2021	3/3/2022 – 3/29/2022	2
Steelhead/Summer (Adult)	Lower Granite Dam	Lower Granite Dam	4/26/2019	4/4/2022	1
Steelhead/Summer (Adult)	Three Mile Falls Dam	Umatilla River	5/6/2020 – 5/8/2020	3/3/2022 – 3/15/2022	2
Steelhead/Summer (Adult)	Umatilla Hatchery	Pendleton Acclimation Pond	4/20/2020	3/15/2022	1
Chinook/Fall	Bonneville Hatchery	Pendleton Acclimation Pond	3/7/2022 – 3/8/2022	3/8/2022 – 4/15/2022	943
Chinook/Fall	Bonneville Dam Complex	Pendleton Acclimation Pond	3/8/2021	3/10/2022 – 3/15/2022	1
Chinook/Fall	Irrigon Hatchery	Pendleton Acclimation Pond	5/26/2022	5/28/2022 –	1
Chinook/Spring	Umatilla Hatchery	Imeques Acclimation Pond	4/7/2022	4/8/2022 4/13/2022	2

Fish species/run	Capture/tagging site	Release site	Dates released	Dates detected	Unique fish (N)
Chinook/Spring	Umatilla Hatchery	Thornhollow Acclimation Pond	1/1/2022 – 4/7/2022	1/6/2022 – 4/14/2022	25
Chinook/Spring	Umatilla River	Umatilla River	9/16/2021 – 2/14/2022	1/18/2022 – 4/1/2022	14

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