U.S. Fish and Wildlife Service
Columbia River Fish and Wildlife Conservation Office

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

*2021 Annual Report*

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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). Pictures by William Simpson.*

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# Monitoring the Entrainment of Juvenile Pacific Lamprey at Irrigation Canals of the Umatilla River 2021 Annual Report

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*and authored by*

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**Disclaimers**

# Monitoring the Entrainment of Juvenile Pacific Lamprey at Irrigation Canals of the Umatilla River
# 2021 Annual Report

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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. These fish 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 2021 and no fish tagged in previous years were detected in the canal for 2021. No juvenile Pacific Lamprey were detected as stranded or killed within the irrigation canal during mobile PIT tag detection 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 2021, suggesting that the bypass of entrained juvenile lamprey may be well documented in future years. The

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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. 2014). 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. 2014). Because of this uncertainty, the Bureau of Reclamation (Reclamation) wants to identify techniques to reduce entrainment, trapping, and mortality of lamprey at many of the diversion structures they operate 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 $m^3$ per second (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 m3/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 2021 water year, the headgate supplying water to Feed Diversion Canal opened intermittently beginning on December 21st 2020 (Table 1). The canal headgate operates while juvenile Pacific

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 Diversion Rate ($m^3$/s) |
|---|---|---|---|---|
| 2017 | 1/23/2017 | – | 5/12/2017 | 5.0 |
| 2018 | 11/29/2017 | – | 4/3/2018 | 5.5 |
| 2019 | 12/19/2018 | – | 4/29/2019 | 4.9 |
| 2020 | 1/22/2020 | – | 3/20/2020 | 5.2 |
| 2021 | 12/21/2020 | – | 4/2/2021 | 4.8 |

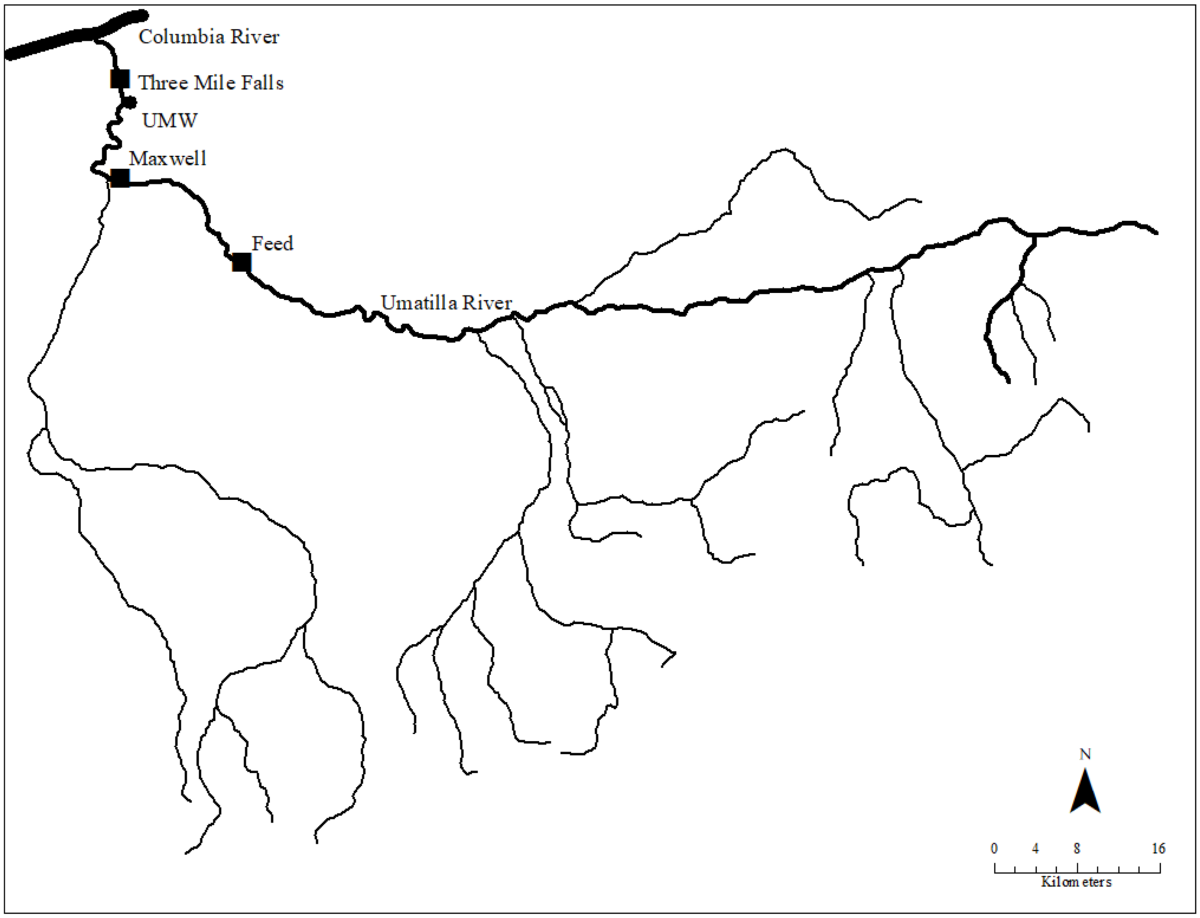


Figure 1. A map of the Umatilla River basin. Squares represent Bureau of Reclamation diversion dams and the diversion points of their associated canals. The circle marks the currently operating mainstem array site.

Lamprey are known to move downstream. On April 2nd 2021 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 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

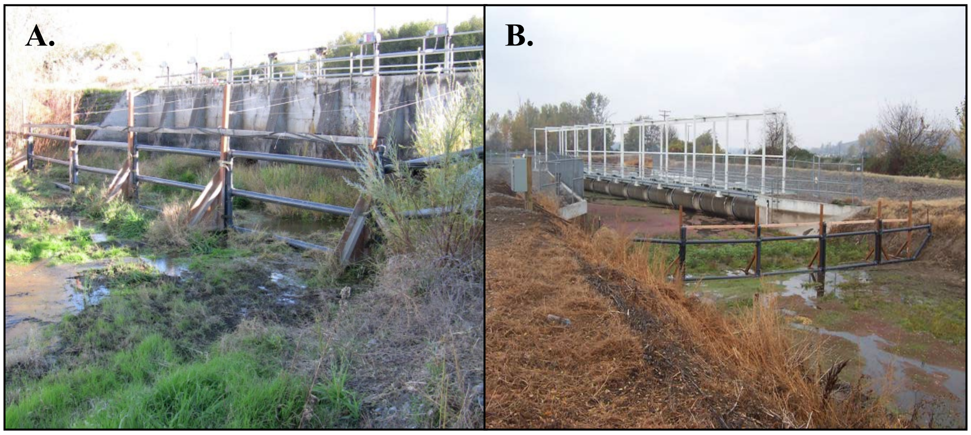


Figure 2. PIT arrays within Feed Diversion Canal. (A) Upstream PIT antenna array and the headgate. Instream posts and cables provide antenna support. The two parallel inductive loops of these antennas more evenly distribute the magnetic field generated by the antenna. As a result, the read range of PIT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

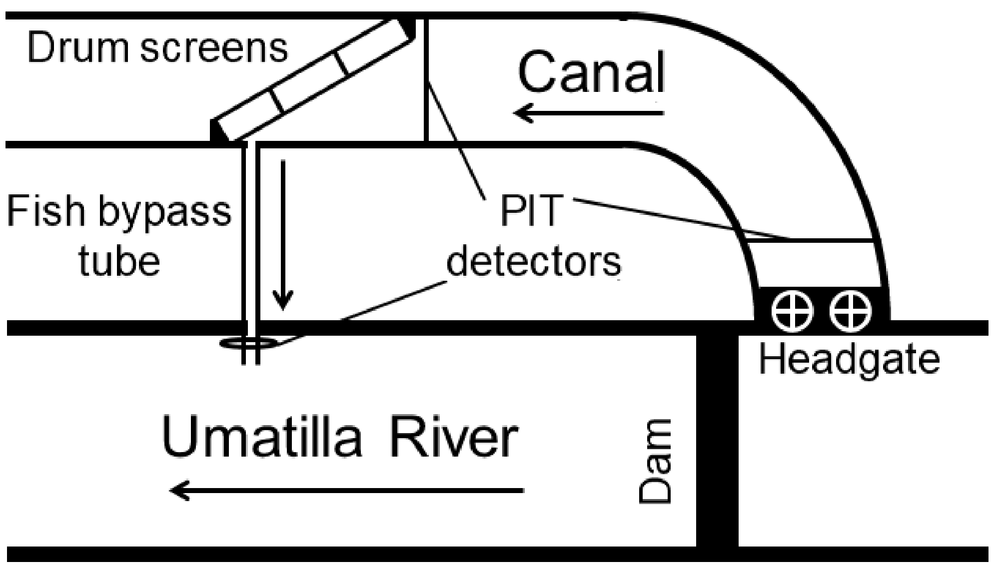


Figure 3. Diagram of Feed Diversion Dam. The diagram illustrates the headgate and screen infrastructure of Feed Canal, and PIT detector arrays (modified from Simpson 2018).

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. In addition, a custom-made battery switcher was installed to power the headgate

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

array in December of 2018 based on testing that suggests it may also mitigate noise. 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).

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


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

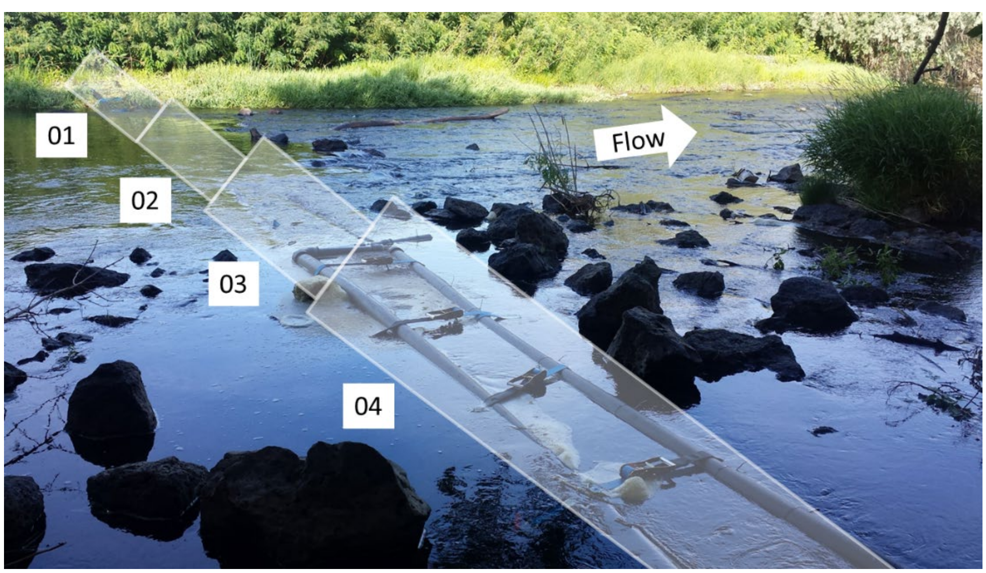


Figure 6. Umatilla River PIT array adjacent to the Hermiston Recycled Water Facility (UMW). The four individual antennas are numbered.

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).

## PIT array Maintenance and Operations

The screen and headgate array within Feed Diversion Canal operated the entire time the canal was diverting water. In 2021, the only PIT antenna operating in the UMW array was antenna 3, which operated the entire year (Table 2). The other antennas were damaged in the previous years, and repairs or replacement were not conducted due to challenges brought about by malfunctions of antenna construction equipment. The UMW array detected 659 salmonids in 2021 (Appendix A).

Table 2. The number of days (% days) each antenna in the UMW array operated in 2021.

| Antenna | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Days operated (%) | 0 (0%) | 0 (0%) | 365 (100%) | 0 (0%) |

# 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). In 2021 no lamprey were captured or tagged from the screw trap; 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. In late 2020 and early 2021 no lamprey were captured, tagged, or released

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 | N/A | N/A |
| 2021 | Release group(s) | 0 | 0 | N/A |
| 2021 | Volitional | N/A | 0 | N/A |

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.

*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 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 prior to 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 8-mm 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 placement of the first tag was determined by a random start. Fifteen tags were seeded while the canal was still diverting water (seeded on 3/27/2018, 3/8/2019, and 3/17/2021), and again after the canal stopped diverting water (seeded on 4/30/2018, 5/15/2019, and 4/21/2021). 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 days before dewatering in 2018 to 52 days before dewatering in 2019. 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 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.

*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 30$^{th}$), 2019 (May 15$^{th}$), and 2021 (April 22$^{nd}$). 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 2021. 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. Biologist also scanned piles of fine sediment located just downstream of the fish screens for PIT tags associated with lamprey. GPS locations of PIT tags detected within the canal were taken to roughly estimate tag movement within the canal.

Figure 7. An IS1001ACN-based mobile PITpack reader. (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 with a PITpack detection wand, 2015.

# Results

*Detection of Entrained Juvenile Lamprey Using Fixed PIT Arrays within Feed Canal*- No PIT-tagged juvenile lamprey released in previous years were detected at the headgate, screen, or bypass array of Feed Diversion Canal in 2021. Detections of juvenile lamprey in previous years and their travel time through the canal are detailed in Tables 4 and 5. 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. However, during the 2021 water year Chinook Salmon (N=343) and steelhead (N = 11) were detected either within the canal or at the bypass outfall PIT array (Appendix B). Many of these fish were detected within the canal (headgate and screen array, $N_{Chinook}$ = 257, $N_{steelhead}$ = 5), and the majority were detected at the bypass outfall ($N_{Chinook}$ = 332, $N_{steelhead}$ = 11). 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 68 of 72 fish (94%) detected both within the canal and downstream of the canal were also detected at the bypass outfall. Numerous PIT-tagged juvenile steelhead, and to a lesser extent Chinook Salmon, were detected outmigrating at the downstream UMW array after Feed Diversion Canal stopped operating from early April to late June (Appendix A). Yet only three Chinook Salmon and two steelhead were detected at the bypass outfall antenna after the canal dewatered (Appendix B), suggesting that the bypass outfall antenna on the Umatilla riverbank largely detects bypassed fish, and not outmigrating fish in the Umatilla River mainstem. Two of these fish were detected at the bypass outfall within 8 days of the canal dewatering and could represent fish that escaped the canal during maintenance flows.

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 detection has been observed at Maxwell Diversion Canal.

Table 4. 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) detected 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 by expanding the number of 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 |

Table 5. 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 |

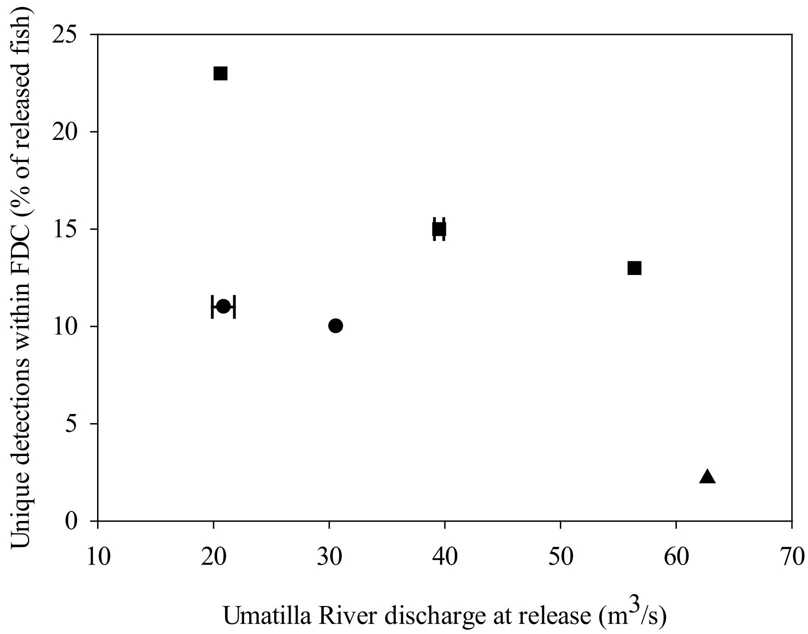


Figure 8. Relation between Umatilla River discharge and lamprey detected in Feed Diversion Canal. Discharge ($m^3$/sec) measured adjacent to Feed Diversion Canal (UMUO gage) during lamprey releases. The percentage of released juvenile lamprey detected as entrained is shown for 2017 (●), 2018 (▲), and 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.

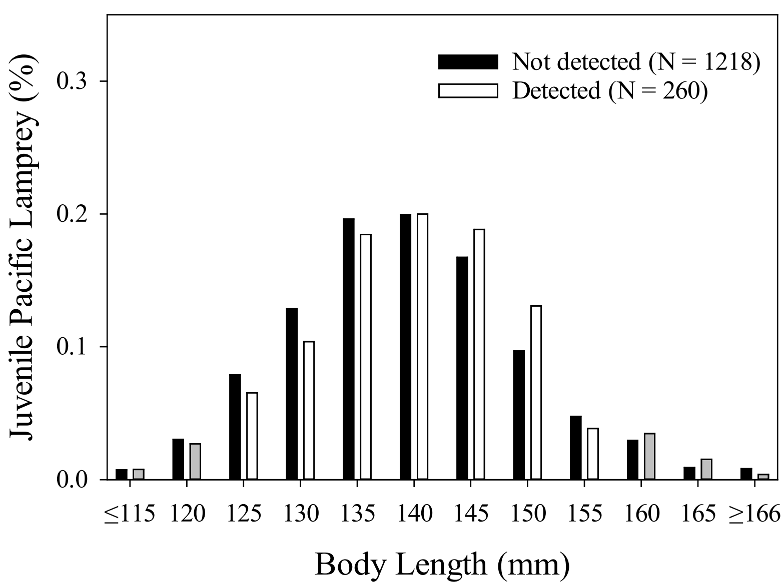


Figure 9. The size distribution at tagging of juvenile Pacific Lamprey by FDC detection in 2020. Distributions are compared between fish that were detected (entrained) shortly after their release, and those lamprey that were not detected as entrained into Feed Diversion Canal.

*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. The detection efficiency of mobile surveys for 8-mm PIT tags seeded within the canal was 63% in 2018 ($n_{2018}$ = 19), 43% in 2019 ($n_{2019}$ = 13), and 90% in 2021 ($n_{2021}$ = 27). These efficiencies reflect detection of those tags placed in the same year as the mobile survey. Detection efficiency was often higher for PIT tags seeded after the canal was dewatered ($n_{2018}$ = 11, 73%; $n_{2019}$ = 8, 50%; $n_{2021}$ = 14, 93%) compared to tags that were seeded while the canal was diverting water ($n_{2018}$ = 7, 50%; $n_{2019}$ = 5, 33%; $n_{2021}$ = 13, 87%). In total, 66% of tags were detected in the year they were first seeded (n = 59), 13% of tags were first detected a year or more after they were first seeded (n = 12), 18% of tags were never detected despite having the opportunity to be redetected in subsequent years (n = 16), and 3% of tags were not detected without the opportunity to be redetected in subsequent years (n = 3). The linear distance between where PIT tags were seeded and the canal headgate is a measure of tag distribution within the canal. Fewer PIT tags placed on the apron close to the canal screen appeared to be detected over multiple annual surveys relative to those placed centrally within the canal (Figure 10). There was a significant difference in the proportion of seeded tags redetected for tags seeded during different canal operations (diverting/not diverting) and seeded on different types of canal bottom substrate (rock pavers/concrete apron, Fishers Exact Test $P = 0.02$). Tags seeded on the canal apron while the water was diverting were redetected 40% of the time (n = 4), but tags seeded on the apron while the canal was dewatered were redetected at similar percentages (83%, n = 10) as tags seeded upstream of the apron both during (80%, n = 28) and after (88%, n = 29) water diversion. Seeded PIT tags were not detected crossing the fixed screen array upstream of the apron between 2018 and 2021, nor were they detected crossing the bypass array in 2021. A smaller percentage of tags seeded during water diversion were redetected in 2019 (53%, n = 8) when tags were placed in the canal 52 days before dewatering, compared to years when tags were seeded within 16 days of dewatering (80%, n = 24). The difference in linear distance between where PIT tags were seeded while the canal was diverting water and where they were detected inside the canal after it was dewatered was small ($mean_{2018}$ = 3 m, $range_{2018}$ = -3 to 7 m; $mean_{2019}$ = 5 m, $range_{2019}$ = 1 to 14 m; $mean_{2021}$ = 3 m, $range_{2021}$ = -2 to 11 m). We did not detect any PIT tags associated with the 2017, 2019, or 2020 release of tagged lamprey upstream of Feed Diversion Canal during mobile antenna surveys conducted after canal dewatering.

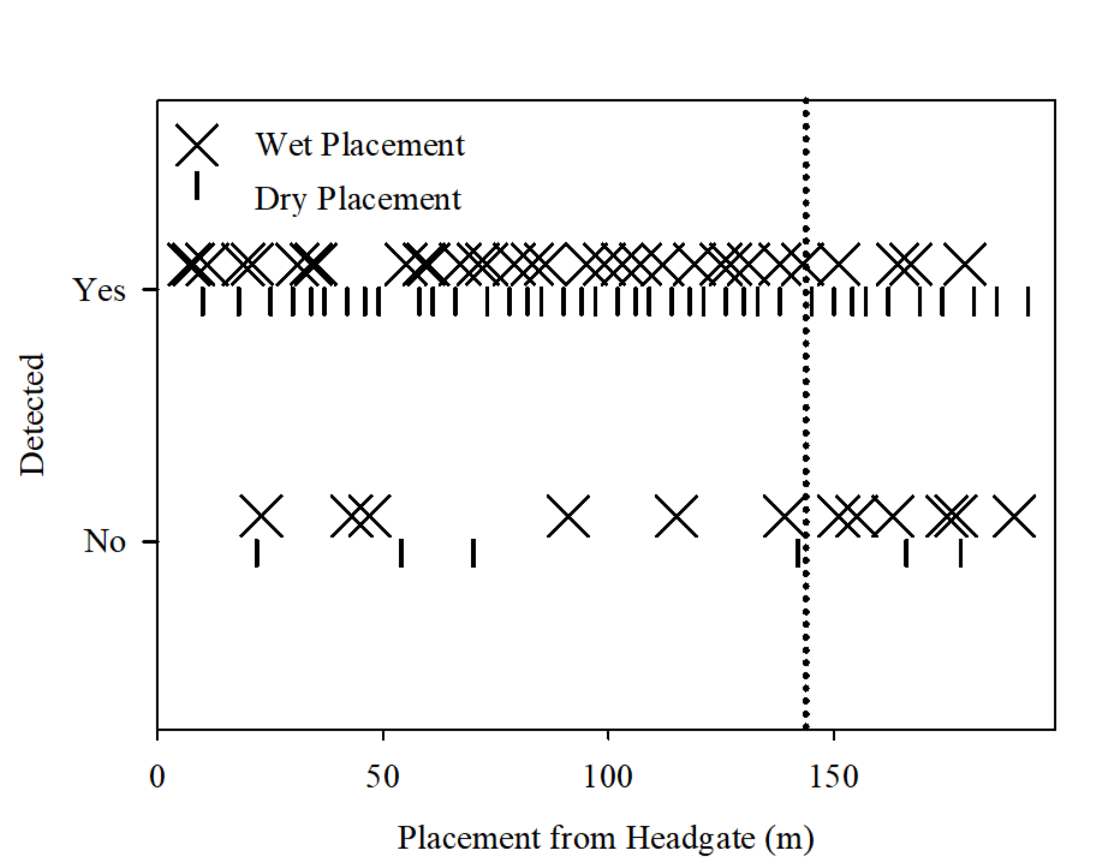


Figure 10. The detection of seeded PIT tags based on tag placement within Feed Diversion Canal. PIT tags were seeded while the canal was diverting water (wet placement) or after the canal was dewatered ('dry' placement) and at various distances from the Feed Canal headgate that correspond with different 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 three years (2018, 2019, 2021). Some tags were detected in years after 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 as a whole (Moyle and Israel 2005). Developing a better understanding of factors that influence lamprey entrainment and screening 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 faces 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 faces 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 potential changes to irrigation canal operations (diversion timing, average rate, or volume) can be restricted. 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) to alter canal operations when possible.

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, but most individuals leave during spikes in movement associated with high river flows and rain events (Goodman et al. 2015). As a result, many outmigrating juvenile Pacific Lamprey may encounter diversions during higher flow conditions that may be less conducive to entrainment. This also may provide an opportunity to minimize entrainment through short reductions or suspensions of water diversion during these windows of outmigration used by many juvenile Pacific Lamprey.

Factors that influence PIT-tagged juvenile lamprey entrainment were examined in this study by observing detection patterns after their release. 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 because most steelhead entrainment occurred at Maxwell and West Extension Diversion Canals, and steelhead release groups were released at various locations upstream of Pendleton, OR. Although river flows during lamprey entrainment events were within the range observed for spring-emigrating juvenile steelhead (Simpson and Peterson 2016), some differences in the percent of fish entrained could be due to canal-specific characteristics (e.g., headgate orientation and location; Simpson and Ostrand 2012) and differences in mortality experienced between the various release and entrainment sites. Unfortunately, a useful expanded estimate of entrainment was only generated at Feed Diversion Canal in 2020. In 2020 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 entrained fish may also be juvenile lamprey. If so, this would support the findings of other studies that the majority of lamprey migrate during high flow events, and that the timing of group releases may 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 consistent, so when the Umatilla River is experiencing higher flows, a relatively smaller proportion of the river is 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 antenna installed at the Feed Diversion Canal bypass should improve the efficiency estimates within Feed Canal, thereby facilitating a more detailed analysis.

The entrainment of juvenile Pacific Lamprey did not appear size selective across the lengths of PIT-tagged juvenile lamprey and at river discharges experienced after their release (22–62 $m^3$/sec). In this analysis, juvenile lamprey that were not detected were assumed not to be entrained, but poor detection efficiency within the canal makes it likely that some of these fish were actually entrained. Improved detection at the newly installed bypass outfall array should help clarify these relationships in the future.

Another potentially effective 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). Unfortunately, few fish screens are evaluated for lamprey exclusion and bypass. In addition, many entrained lamprey may die or hold in the canal before they even reach the fish screens. For example, detections of PIT-tagged juvenile Pacific Lamprey at fish bypasses are more common when fish released just upstream of the rotary drum screens and the fish bypass (82%, Lampman and Beals 2019), compared to when they are placed near the headgate within an irrigation canal (3–19%). This illustrates that often little is understood about the fate (killed pre-bypass, bypassed, or removed from the population by passing through the fish screen) of individual lamprey once they enter the diversion canals or how the size and configuration of fish screens affect bypass success, particularly for juvenile lamprey that may not hold in fine sediment upstream of fish screens the same way larval lamprey often do.

PIT-tagged juvenile lamprey detected at the fixed headgate array within Feed Diversion Canal either left the canal largely undetected by the fixed screen PIT array, or they became trapped or killed within the canal, but their PIT tags went undetected during the mobile PIT surveys. Few entrained juvenile lamprey were detected at both fixed arrays within the canal over all three years of monitoring, which can be indicative of the poor detection of 8-mm and 10-mm PIT tags at both fixed arrays within Feed Diversion Canal. Many entrained salmonids with larger 12-mm PIT tags were detected at the fixed arrays within Feed Diversion Canal in 2021 (Appendix B). The annual detection efficiencies traditionally observed for juvenile salmonids with 12-mm PIT tags at the fixed Feed Canal arrays were relatively high (2006–2016; mean headgate = 80%, mean screen = 54%). The detection efficiency for juvenile lamprey at the fixed antenna arrays could also be lower than typically observed for juvenile salmonids due to behavioral differences 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 (tag collisions). In contrast, the detection efficiency for mobile PIT tag surveys of 8-mm PIT tags seeded within the canal was 43–93%, suggesting mobile PIT tag surveys would have detected if significant numbers of juvenile lamprey were trapped or killed after their entrainment into Feed Diversion Canal. However, this efficiency estimate may be biased high for two reasons. First, tags seeded 52 days prior (early March) to dewatering, and closer to the time release groups were entrained at the canal (late January to early February), were redetected at lower rates than tags seeded within 16 days of dewatering. Secondly, tags seeded over the concrete apron and near the fish screen while the canal was in operation were less likely to be detected. Since fish dying from an interaction with the fish screen is a presumed mechanism of harm for lamprey within the canal, these mobile surveys may be less likely to document some portion of deceased fish in the canal. The detection locations of tags seeded upstream of the concrete apron suggest that the movement of most ghost tags through the canal is minimal, but some ghost tags seeded on the apron or tagged lamprey may have passed through the fish screens. However, no tags were detected just downstream of the drum screen during mobile surveys, and other studies have shown that few lamprey greater than 100 mm pass through drum screen infrastructure (Lampman and Beals 2019).

Few canal-entrained juvenile Pacific Lamprey were documented returning to the Umatilla River through screen and bypass infrastructure via redetection outside the canal (19%), so the ultimate fate most fish is unknown. The lack of redetections could be due to the limited use of the fish bypass system by lamprey or by poor redetection of PIT-tagged juvenile Pacific Lamprey at mainstem arrays on the Umatilla River and at hydropower projects on the Columbia River once they have escaped the canal. No PIT tags associated with lamprey were detected during surveys within the canal and the few lamprey detected downstream at Columbia River hydropower projects or at Umatilla River arrays were detected at multiple locations. This suggests that most entrained juvenile Pacific Lamprey were successfully bypassed into the Umatilla River, but redetection of tagged lamprey was hindered. Based on bypass detections of juvenile steelhead and Chinook Salmon in 2021, the new fixed antenna on the bypass outfall of Feed Canal should improve the ability to detect tags associated with juvenile lamprey leaving the canal. Such improvements should allow the direct documentation of juvenile lamprey that return to the Umatilla River, and a comparison of bypass rates between juvenile lamprey and other entrained juvenile salmonids, and compare bypass rates among other types of bypass infrastructure (e.g., louvers and vertical traveling screens; Goodman et al. 2017).

## Additional Actions in 2022

Reinstalling or repairing missing or nonfunctional PIT antennas at the UMW site in 2022 would create additional opportunities to document entrained lamprey that escaped Feed Diversion Canal. Antenna replacement was not completed in 2021 due to failure of antenna construction equipment and challenges associated with COVID-19 while river discharge was low enough for antenna attachment. Our goal is to have 3 or 4 operational antennas at this site by the end of 2022 with two replacement antennas already built and ready for installation. In addition, next year we plan to assess how well the detection of seeded tags represents the ability to detect any ghost tags left by deceased juvenile lamprey by placing more tags in the canal in early February, and by seeding more tags over the concrete apron. However, all proposed field activities for 2022 listed above may continue to be constrained by COVID-19 guidance (social distancing) and stay at home orders.

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## Literature Cited

Bond, RM, CL Nicol, JD Kiernan, BC Spence. 2019. Occurrence, fate, and confounding influence of ghost passive integrated transponder tags in an intensively monitored watershed. Canadian Journal of Fisheries and Aquatic Science 76:286–298.

Dauble, DD, RA Moursund, MD Bleich. 2006. Swimming behavior of juvenile Pacific Lamprey, *Lampetra tridentata*. Environmental Biology of Fishes 75:167–171.

Cameron, WA, SM Knapp, and RW Carmichael. 1997. Evaluation of juvenile salmonid bypass facilities and passage at water diversions on the lower Umatilla River. Bonneville Power Administration, Final Report, Portland, OR.

Clemens, BJ, and 20 others. 2017. Conservation challenges and research needs for Pacific Lamprey in the Columbia River basin. Fisheries 42(5):268–280.

Clemens, BJ, K Anlauf-Dunn, M Weeber, T Stahl. 2020. Coastal, Columbia, and Snake Conservation Plan for Lampreys in Oregon. Oregon Department of Fish and Wildlife, Salem, Oregon. 192 pp.

Goodman, DH, SB Reid, N Som, W Poytress. 2015. The punctuated seaward migration of Pacific Lamprey (*Entosphenus tridentatus*): environmental cues and implications for streamflow management. Canadian Journal of Fisheries and Aquatic Sciences 72:1–12.

Goodman, DH, SB Reid, RC Reyes, BJ Wu, BB Bridges. 2017. Screen efficiency and implications for losses of lamprey macrophthalmia at California's largest water diversions. North American Journal of Fisheries Management 37:30–40.

Hill, MS, GB Zydlewski, JD Zydlewski, JM Gasvoda. 2006. Development and evaluation of PIT tag detection units: PITpacks. Fisheries Research 77:102–109.

Lampman, R and T Beals. 2019. Exploring techniques to reduce lamprey and salmonid entrainment into canals. Yakama Nation Pacific Lamprey Project Final Progress Report (Project ID No. 2621). Prepared for the U.S. Department of Interior, Bureau of Reclamation, Boise, ID.

Luzier, CW, HA Schaller, JK Bronstrom, C Cook-Tabor, RD Nelle, K Ostrand, B Streif. 2011. Pacific Lamprey (*Entosphenus tridentatus*) assessment and template for conservation measures. U.S. Fish and Wildlife Service, Portland, Oregon. 282 pp.

McMichael, GA, JA Vucelick, CS Abernathy, DA Neitzel. 2004. Comparing fish screen performance to physical design criteria. Fisheries 29(7):10–16.

Moser, ML, AD Jackson, MC Lucas, RP Mueller. 2014. Behavior and potential threats to survival of migrating lamprey ammocoetes and macrophthalmia. Reviews in Fish Biology and Fisheries 25(1):103–116.

Moyle, PB, and JA Israel. 2005. Untested assumptions: effectiveness of screening diversions for conservation of fish populations. Fisheries 30(5):20–28.

Muller, RP, RA Moursund, MD Bleich. 2006. Tagging juvenile Pacific Lamprey with passive integrated transponders: methodology, short-term mortality, and influence on swimming performance. North American Journal of Fisheries Management 26:361–366.

PSMFC (Pacific States Marine Fisheries Commission). 2021. The Columbia basin PIT-tag information system (PTAGIS). PSMFC, Portland, Oregon. Available: www.ptagis.org. (December 2021).

Reclamation (US Bureau of Reclamation). 2016. Exploring techniques to reduce lamprey and salmonid entrainment into canals. Proposal to Science and Technology Program, Research and Development Office, Bureau of Reclamation.

Simpson, WG. 2018. The entrainment and screening of returning and postspawning adult salmonids at irrigation canals of the Umatilla River, Oregon. Journal of Fish and Wildlife Management 9:285–295.

Simpson, WG, DP Peterson. 2016. Fisheries monitoring system: Umatilla Project facilities. Annual report to Bureau of Reclamation, Hermiston, OR.

Simpson, WG, KG Ostrand. 2012. Effects of entrainment and bypass at screened irrigation canals on juvenile steelhead. Transactions of the American Fisheries Society 141:599–609.

Stout, JB, MM Conner, P Budy, PD Mackinnon. 2019. We ain't afraid of no ghosts: tracking habitat interactions and movement dynamics of ghost tags under differing flow conditions in a sand-bed river. North American Journal of Fisheries Management 39:1337–1347.

Walters, AW, DM Holzer, JR Faulkner, CD Warren, PD Murphy, MM McCluer. 2012. Quantifying cumulative entrainment effects for Chinook Salmon in a heavily irrigated watershed. Transactions of the American Fisheries Society 141:1180–1190.

# APPENDIX A
# PIT-tagged Fish Detected at the mainstem Umatilla River array UMW in 2021

| Fish species/run | Capture/tagging site | Release site | Dates released | Dates detected | Unique fish (N) |
|---|---|---|---|---|---|
| Steelhead/Summer | Birch Creek | Birch Creek | 1/26/2021 – 5/18/2021 | 4/18/2021 – 5/24/2021 | 17 |
| Steelhead/Summer | Bonneville Dam Complex | Imeques Acclimation Pond | 4/21/2021 | 5/15/2021 – 6/5/2021 | 7 |
| Steelhead/Summer | Irrigon Hatchery | Imeques Acclimation Pond | 4/21/2021 | 5/18/2021 – 6/29/2021 | 9 |
| Steelhead/Summer | Meacham Creek | Meacham Creek | 5/15/2021 | 6/29/2021 | 1 |
| Steelhead/Summer | Irrigon Hatchery | Pendleton Acclimation Pond | 4/22/2021 | 5/5/2021 – 7/14/2021 | 30 |
| Steelhead/Summer | Wells Hatchery | Salmon Creek | 4/22/2021 | 5/28/2021 | 1 |
| Steelhead/Summer | Three Mile Falls Dam | Umatilla River | 3/23/2021 – 6/8/2021 | 5/7/2021 – 7/19/2021 | 529 |
| Steelhead/Summer | Umatilla River | Umatilla River | 10/14/2020 – 4/30/2021 | 5/11/2021 – 6/27/2021 | 2 |
| Steelhead/Summer (Wild Adult) | Birch Creek | Birch Creek | 4/30/2019 | 9/30/2021 | 1 |
| Steelhead/Summer (Unknown adult) | Bonneville Adult Fish Facility | Bonneville Adult Fish Facility | 7/27/2020 – 7/15/2021 | 1/7/2021 – 9/19/2021 | 7 |
| Steelhead/Summer (Hatchery Adult) | Lyons Ferry Hatchery | Curl Lake Rearing Pond | 4/30/2019 | 2/22/2021 | 1 |
| Steelhead/Summer (Wild Adult) | Lower Granite Dam Adult Fish Ladder | Lower Granite Dam Adult Fish Ladder | 9/21/2020 – 4/1/2021 | 3/19/2021 – 4/13/2021 | 2 |

| Fish species/run | Capture/tagging site | Release site | Dates released | Dates detected | Unique fish (N) |
|---|---|---|---|---|---|
| Steelhead/Summer (Wild Adult) | Meacham Creek | Meacham Creek | 5/10/2018 – 5/13/2020 | 1/3/2021 - 4/13/2021 | 2 |
| Steelhead/Summer (Wild Adult) | John Day River | North Fork John Day River | 4/28/2020 | 9/22/2021 | 1 |
| Steelhead/Summer (Wild Adult) | Priest Rapids Dam Adult Fish Ladder | Priest Rapids Dam Adult Fish Ladder | 8/5/2020 | 3/22/2021 | 1 |
| Steelhead/Summer (Wild Adult) | Three Mile Falls Dam | Umatilla River | 3/29/2018 – 6/2/2019 | 1/7/2021 – 3/31/2021 | 6 |
| Chinook/Fall | Lyons Ferry Hatchery | Captain John Rapids Acclimation Pond | 5/12/2021 | 5/30/2021 | 1 |
| Chinook/Fall | Bonneville Dam Complex | Pendleton Acclimation Pond | 2/14/2021 – 3/8/2021 | 2/18/2021 – 3/10/2021 | 12 |
| Chinook/Fall | Umatilla Hatchery | Pendleton Acclimation Pond | 5/17/2021 | 5/19/2021 – 6/5/2021 | 12 |
| Chinook/Spring | Irrigon Hatchery | Imeques Acclimation Pond | 4/8/2021 | 4/9/2021 – 4/10/2021 | 5 |
| Chinook/Spring | Irrigon Hatchery | Pendleton Acclimation Pond | 4/5/2021 | 4/6/2021 – 4/7/2021 | 4 |
| Chinook/Spring | Irrigon Hatchery | Thornhollow Acclimation Pond | 4/7/2021 | 4/8/2021 – 4/10/2021 | 4 |
| Chinook/Spring | Umatilla River | Umatilla River | 11/17/2021 | 1/10/2021 | 1 |
| Chinook/Spring (Hatchery Adult) | Umatilla Hatchery | Imeques Acclimation Pond | 2/7/2019 | 5/6/2021 | 1 |
| Chinook/Unknown (Unknown Adult) | Umatilla River | Bonneville Adult Fish Facility | 5/4/2021 | 5/19/2021 – 5/25/2021 | 2 |

# APPENDIX B
# PIT-tagged Salmonids Detected at the Feed Diversion Canal Arrays (FDC) for Water Year 2021

| Fish species/run | Capture/tagging site | Release site | Dates released | Dates detected | Unique fish (N) |
|---|---|---|---|---|---|
| Steelhead/Summer | Birch Creek | Birch Creek | 1/26/2021 – 3/18/2021 | 2/3/2021 – 3/23/2021 | 6 |
| Steelhead/Summer | Bonneville Dam Complex | Imeques Acclimation Pond | 4/21/2021 | 4/29/2021 | 1 |
| Steelhead/Summer | Irrigon Hatchery | Pendleton Acclimation Pond | 4/22/2021 | 4/22/2021 | 1 |
| Steelhead/Summer | Three Mile Falls Dam | Three Mile Falls Dam | 6/17/2020 | 3/9/2021 | 1 |
| Steelhead/Summer | Umatilla River | Umatilla River | 10/24/2020 – 10/25/2020 | 12/25/2020-2/16/2021 | 2 |
| Chinook/Fall | Cedar Flats Acclimation Facility | Cedar Flats Acclimation Facility | 6/8/2020 | 1/17/2021 | 1 |
| Chinook/Fall | Bonneville Dam Complex | Pendleton Acclimation Pond | 2/14/2021 – 3/8/2021 | 2/16/2021 – 3/15/2021 | 333 |
| Chinook/Spring | Irrigon Hatchery | Imeques Acclimation Pond | 4/8/2021 | 3/10/2021 – 4/27/2021 | 4 |
| Chinook/Spring | Umatilla River | Umatilla River | 10/25/2020 – 10/30/2020 | 12/26/2020 – 3/14/2021 | 5 |

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