Response to ISRP Review of Accord Proposal
200830800 – Willamette Falls Lamprey Escapement Estimate (ISRP 2011-6)

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We would like to thank ISRP for their continued review of this project. We continue to move forward in addressing uncertainties and technological "bugs" as well as identify new potential logistic constraints. Our intent is to continue to use a step-wise approach for installing additional monitoring equipment, work through uncertainty, and develop a final study plan in upcoming years.

In project review ISRP 2011-6, the following qualifications were:

1. ***"The first qualification is that upon completion the full-scale project design be reviewed. The project design should demonstrate clear evidence of the effectiveness of the technologies to meet project objectives: the long-term monitoring protocol(s) and an index of abundance for adult Pacific lamprey at Willamette Falls. This should include a statistical estimate of how many lampreys would have to be tagged to obtain valid abundance estimates."***

2. ***"The second qualification is that the ISRP review a progress report at the end of 2011 or early 2012 on two key uncertainties that have not been completely resolved: can PIT-tagged lamprey be successfully detected at passage locations and can lamprey be reliably counted by underwater cameras. The proponents expect to make significant progress toward addressing these uncertainties in 2011."***

In response to qualification 2, we have attached a copy of the 2011 progress report to BPA (no citation as it hasn't been finalized by BPA). Both uncertainties (successful detection and reliability of counts through video) are discussed in the report. Detecting lamprey at passage locations does not appear to be problematic (page 17). Of 2,370 Pacific lamprey half-duplex (HDX) PIT tagged, 45.7% (1,084) were detected at fixed sites in the fish ladder. On page 19, video capture and review are discussed. A total of 662 hours (the tape was not run continuously throughout the run due to human error) of video was recorded. Of the tape reviewed, 11,979 lamprey were counted. Further discussion of video review and logistical constraints follow.

Development of a final study plan is not anticipated in the next few years. We continue to work through logistic constraints, learn important lessons about technology and it's constraints, as well as adapt our way of thinking as we better understand lamprey movements at Willamette Falls and the tribal fishery. Following is a brief description of our thoughts on video counts and using harvest as an index of abundance.

Our initial thought was to develop an index of abundance by relating video counts of lamprey through the fish ladder at Willamette Falls to yearly abundance estimates. This assumed it would be possible to use motion detection software (*e.g.*, FishTick®, Salmonsoft, Portland, OR); offering a cost effective method for obtaining counts rather than estimates from a mark-recapture field experiment. Due to the lack of contrast between lamprey and the fish ladder floor (even with the white high-density plastic ramp, algae colonizes so quickly that contrast is quickly lost) the motion-detection software is unable to identify lamprey (Jeff Fryer, CRITFC/Salmonsoft, pers. comm.). Image recognition software for lamprey is in its early stages of development (Chris Peery, USFWS, pers. comm.). Presently, we are manually counting lamprey recorded by video in the fish ladder.

Beyond development of an abundance index for lamprey, video counts combined with HDX PIT array detections, would be used to improve the mark-recapture estimate. Using HDX antenna detections in the fish ladder would increase the number of recaptures (*e.g.*, in 2011, instead of 69 recaps, HDX antennae detected 1,030 [p. 17] which was 45.7% of marked fish) but this hinged on whether the video could be used as a method of inspecting tagged and untagged lamprey (or devise a stratification scheme such as use video counts and corresponding PIT tag detections 10 minutes out of every hour to reduce video review to a manageable level). It was not possible to use the video counts in this manner in 2011, mostly due to lingering technical difficulties (*e.g.*, insufficient lighting, error in extracting hard drives) both of which have been resolved.

Video counts in 2011, were used to characterize diel migration patterns through the fish ladder and to provide a complimentary method of assessing abundance of lamprey through the fish ladder. While we are doubling our effort reviewing video of lamprey through the fish ladder in 2012, the extent to which video review can be used as a method of inspecting marked and unmarked lamprey is uncertain. It does seem probable that, with the lack of automation for video review of lamprey through the fish ladder, video counts of lamprey will not provide a cost-effective, reliable index of abundance for lamprey ascending the ladder at Willamette Falls.

The ISRP had suggested using lamprey catch data may contribute to the development of an index of abundance. In our narrative, we quoted Kostow (2002) who summarized the history of lamprey harvest at Willamette Falls and explained why these data were not good indicators of lamprey abundance because of inadequate creel census and changes in regulations through the years. Since current regulations only allow personal and subsistence use, that variable has been remedied. After the last two years of monitoring lamprey harvest at Willamette Falls, we have more understanding of how the fishery operates and how it may be used as an index of abundance. In the past two years, the four Columbia River treaty tribes and two Oregon coastal tribes, Confederated Tribes of Grand Ronde, and Confederated Tribes of Siletz Indians of Oregon have primarily participated in this fishery. Our creel surveys are voluntary but we have had great participation by harvesters allowing us to inspect fish for tags and estimate abundance. Access is also in our favor as harvesters can only get to the fishing area by boat and almost always launch from Sportcraft Marina.

The ISRP's point is well taken that the fishery may provide the most cost-effective index of abundance for lamprey at Willamette Falls. In 2011, we separated the lamprey estimate through the fish ladder from lamprey that failed to return to the ladder and either remained downstream of the falls or ascended Willamette Falls in another location. In comparing the estimates through the fish ladder and harvest in 2010 and 2011, the harvest as a percentage of the estimate was 6% and 8.8%, respectively (Table 1). If variability remains low (<5%) among years through the end of the study (2017) then catch data will provide a good method for an index of abundance.

Table 1. Willamette Falls (WF) lamprey harvest as a percent of the estimated escapement through the fish ladder, 2010 – 2011.

Year	Estimate of Pacific lamprey through WF ladder	Harvest	Harvest as % of ladder estimate
2010	26,677	1,606	6.0
2011	49,072	4,318	8.8

To use data in Table 1 as indices of abundance, harvest must be standardized by fishing effort. Expressing catch per effort in this fishery is somewhat complicated. People harvest lamprey at Willamette Falls in groups. Individuals within the group may fish for various amounts of time and often put their fish in one tote or a number of burlap sacks, but catch within the party is aggregated. In 2010 and 2011, number of fishers in each group were not recorded consistently and total time groups fished was not recorded. In 2010, catch per person ranged from 3.3 to 20.4 fish per person (n=4 groups out of 13). In 2011, catch per person ranged from 16.2 to 64.3 fish per person (n=4 groups out of 18). In 2012, CTWSRO creelers will ask harvesters how many people fished, how long each person fished, then calculate the average catch-per-unit effort for each harvester in the group because there is no way of separating catch on a per-person basis. The CTWSRO will continue to work towards improving methods for estimating abundance of lamprey that remain downstream of Willamette Falls, quantifying lamprey that move through the Falls in other areas besides the ladder (*e.g.*, newly restored passage through the old fishway, lamprey ramps), escapement through the fish ladder and estimating harvest.

As this project continues, we will send yearly findings (through BPA annual progress reports) to ISRP. Based on lessons learned and adapting of methods, it is fair to say that we will not have a final study plan for years to come.

Kostow, K. 2002. Oregon lampreys: Natural history, status, and analysis of management issues. Oregon Department of Fish and Wildlife, 2002-01.

Willamette Falls Lamprey Escapement Estimate

Annual Report to BPA

Project No. 2008-308-00; Contract 00051834

March 2011 – March 2012

Confederated Tribes of the Warm Springs Reservation of Oregon

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Executive Summary

Pacific lamprey abundance and distribution has been dramatically reduced or extirpated throughout much of their historic range. Persistence of this culturally significant species is of primary concern to the four Columbia River treaty tribes (Confederated Tribes of the Warm Springs Reservation of Oregon [CTWSRO], Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes and Bands of the Yakama Nation, and the Nez Perce Tribe). Due to the value of Willamette Falls, located at rkm 42.6 on the Willamette River, understanding abundance and escapement is important, as it is one of the last harvest locations available for Pacific lamprey in the Columbia River Basin. In 2010, the CTWSRO began a multiple year feasibility project to estimate lamprey escapement at Willamette Falls, funded by the Bonneville Power Administration, through the Columbia River Accords. The complex nature of both the study area and lamprey behavior requires a step-wise approach incorporating new technologies, addressing statistical error, and understanding of lamprey biology and behavior. In 2011, lamprey estimates were partitioned into escapement through the fish ladder and abundance of fish in congregational areas or straying below the Falls. Partitioning the estimate allowed error and uncertainty to be compartmentalized. Based on statistical changes in 2011, the 2010 abundance and escapement estimates were recalculated.

The study design revolved around mark-recapture methods (MRC), in which lamprey abundance was estimated using Chapman's modification of the Peterson Estimator. From April 27 to September 12, 2011, lamprey were captured (first event sampling) in the fish ladder at Willamette Falls using two methods: dip net and a lamprey trap. Dip netting occured approximately 1.5 hours before sunrise and 1.5 hours after. The lamprey trap was fished from Sunday evening continuously through Friday morning. Captured lamprey received a half-duplex (HDX) passive integrated transponder (PIT) tag and a secondary mark. The second event also took place at the Willamette Falls fish ladder where fish were recaptured through dip netting or the lamprey trap. Additionally, HDX antennae and video equipment was installed in the fish ladder to detect lamprey passing upstream and record movement of non-tagged fish, respectively. Half duplex antennae were also installed at the crest of the Falls along "lamprey ramps". Initially it was thought that these technologies could be used to increase the number of fish recaptured (detections at the HDX antennae) and inspected (fish counted through the video); however, a delayed start for install of equipment, logistics and technological difficulties precluded this from happening. In order to use this information to increase recaptures and inspections, ultimately reducing confidence intervals, both technologies would need to be operating in concert throughout the lamprey run.

The half-duplex (HDX) PIT tags and antennae provided estimates for lamprey returning to the fish ladder (45.7%) and for lamprey that failed to return to the ladder but were likely congregating areas downstream of the Falls, referred to as strays (54.3%). The assumption of a closed population of the MRC was violated as recapture of individuals that failed to the ladder had very low capture probability compared to the ladder; however, calculation of return and stray rates allowed a correction to compensate for using a closed population model. Estimated escapement of lamprey through the fish ladder between May 25 and September 12, 2011 was 49,072. The abundance of lamprey below the falls for the same period was 58,217. This period does not include the first 22.7% of the run. Based on cumulative catch in 2010, the estimate was expanded for a total escapement through the ladder of 63,483 and 75,313 below the Falls. Video from the fish ladder was used to support that the estimated escapement was credible.

Introduction

Pacific lamprey (*Entosphenus tridentatus*) populations in the Columbia River Basin are in decline compared to early 20th century, based on counts at Bonneville Dam (Fish Passage Center 2012), Appendix A), observations and data collected from biologists (Close et al. 1995; Close et al. 2002; Kostow 2002) and anecdotal information from lamprey fishermen (Kostow 2002; Patton 2011). Pacific lamprey is an important fish species for Native American tribes in the Pacific Northwest, for subsistence, ceremonial and medicinal use (Close et al. 1995; Hunn and Selam 1991; Pletcher 1963). Tribal members of the Pacific Northwest historically harvested lamprey at multiple locations throughout the Columbia River Basin. Primary fishing sites for the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) were located at waterfalls including Celilo Falls on the Columbia River, Seufert Falls on Fifteenmile Creek, Sherars Falls on the Deschutes River at, and Willamette Falls on the Willamette River. After construction of The Dalles Dam during the 1950s, the most prominent site for fishing, trade, and cultural exchange, Celilo Falls, was inundated on March 10, 1957 (Barber 2005). While populations of Pacific lamprey in the Columbia River have declined and fishing opportunities have diminished, the Pacific lamprey fishery at Willamette Falls has continued to provide a harvest opportunity for tribal subsistence fisherman. However, limited data from the Willamette Basin indicate abundance of Pacific lamprey has also declined, yet the Willamette River remains the most important production area in the Columbia Basin (Primozich and Bastasch 2004).

In 2010, the first abundance estimate of lamprey at Willamette Falls was made (Baker and Graham 2011). This was a feasibility-level study for estimating abundance of adult Pacific lamprey present at Willamette Falls during summer 2010. Uncertainties in lamprey behavior and passage capability over the Falls, previously identified in radio-telemetry studies, continues to confound estimates of escapement. Based on radio-telemetry results, lamprey released below the Falls either: 1) returned to the fish ladder and passed upstream to spawn (23% to 43% of tagged lamprey released downstream of the Falls); 2) resided in congregating areas at the base of the Falls, or; 3) moved further downstream in the Willamette River (Karchesky et al. 2011; Mesa et al. 2009; Mesa et al. 2010). It was found the proportion of river flow over the Falls (east side of river) versus powerhouse discharge (west side of river) influenced lamprey behavior and passage. Early in the spring and summer, during periods of higher discharge, the greatest proportion of flow was over the Falls attracting lamprey to the horseshoe. As flows diminished and river water was diverted to the powerhouse, lamprey were attracted to the powerhouse tailrace (also known as the cul-de-sac). Attraction flows to different areas had a bearing on which of the three fish ladder entrances lamprey would use or whether they would congregate in the horseshoe or move back downstream. The high proportion of lamprey that returned to the Falls but did not pass upstream (58% to 73% of the radio-tagged lamprey) was an important factor to consider for adult escapement study design and data interpretation. The uncertainty of the fate of lamprey that congregates in the horseshoe remains the most significant challenge to better understanding lamprey ecology in the Willamette River.

In 2011, study objectives focused on: 1) improving the abundance estimate of lamprey through the fish ladder; 2) documenting lamprey movement over the crest of the falls on the east side of the river at structures known as lamprey ramps; 3) recording data from the lamprey salvage operation at the old fishway to advance understanding on movement patterns; 4) estimating lamprey harvest, and; 5) continue to participate in the Willamette River lamprey working group.

Study Area

The Willamette River is the 13th largest river in the lower 48 states but has the distinction of producing the greatest volume of water per drainage area (Benke and Cushing 2005). Willamette Falls (hereafter referred to as the Falls) is located at river kilometer (rkm) 42.6 on the Willamette River (Figure 1). It is a natural falls created by a 12 m drop over volcanic bedrock (Benke and Cushing 2005).

Portland General Electric Company (PGE) operates the T.W. Sullivan Hydroelectric Plant on the west side of Willamette Falls. The fish ladder is owned and operated by Oregon Department of Fish and Wildlife (ODFW), but these two facilities are largely integrated as they essentially occupy the same site, Moore's Island. Since the mid-1800's there have been a number of human alterations at the Falls including construction of navigation locks, a hydroelectric facility, various mills, a concrete cap on the crest of the Falls, and two fish ladders (Corning 2004; Master Fish Warden 1903; Master Fish Warden 1907; Portland General Electric Company 2012). Having the characteristics of an industrial site, one must meander through the West Linn Paper Company to access the fish ladder, housed in a complex of buildings on the west bank. Annually in June or July, depending on flows, PGE installs flashboard risers on the concrete cap around the crest of the Falls directing water to the west side of the river to run turbines at the T.W. Sullivan Plant. As part of the installation of the flashboards, ramps are installed to facilitate lamprey passage over the flashboard risers.

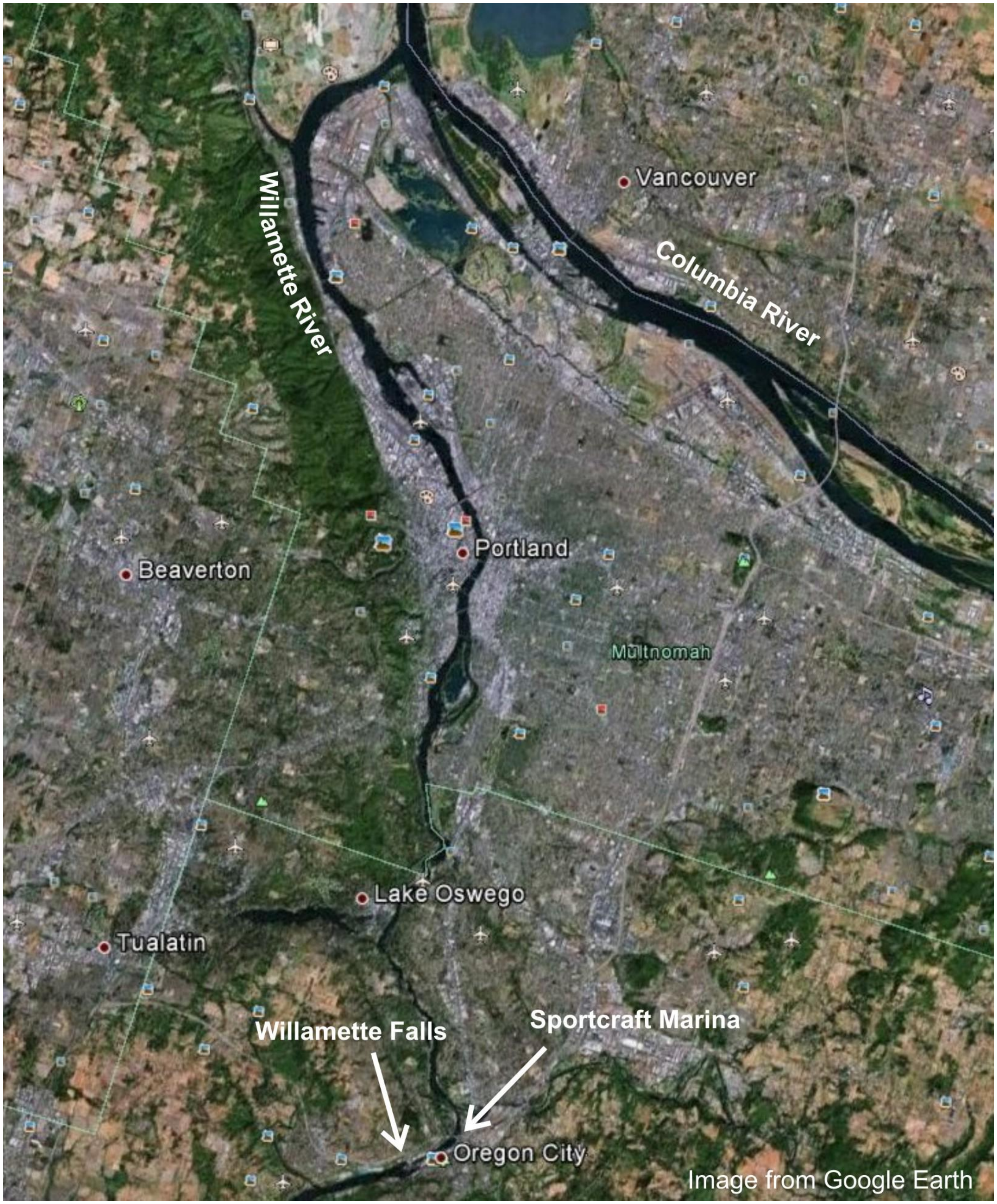


Figure 1. Vicinity map of Willamette Falls and Sportcraft Marina, Willamette River, OR.

Fish ladder

The constructed environment at the Falls has been modified over time as collaborating agencies and stakeholders have evaluated fish passage (Karchesky *et al.* 2011). A first fish ladder ("old" fish ladder or fishway) at Willamette Falls was completed November 1904 (Master Fish Warden 1907). It was, "constructed by blasting a channel out of solid rock, forming steps or pools (Master Fish Warden 1907)." Though rough-hewn, the ladder did help fish move above the falls. Technology and knowledge of fisheries advanced over time, and ODFW designed the current fish ladder, which was completed in 1971. The "new" fish ladder has three legs (Figure 2, see also Appendix C). Leg 1 entrance is in the cul-de-sac. The entrance to Legs 2 and 3 are on the west side of the horseshoe (Figure 2). All three legs converge at a location known as Pool 48 (48 refers to the elevation above mean sea level) and fish proceed up past the counting window and to the forebay (Figure 2). With the construction of the new fish ladder in 1971, the historic fish ladder was bisected by Leg 3. After the old fishway was severed by Leg 3, fish could climb halfway up but could not pass. Prior to installing flashboards on the concrete cap, PGE salvages lamprey in the downstream end of the old fishway so that they do not become stranded and die when water levels further recede. The salvage operation involves capturing lamprey in the lower segment of the old fishway, placing them in totes and carrying them to the base of the falls to return them to the river so that they may find passage. During 2011, PGE modified the old fishway to restore passage for lamprey.

The pool below Willamette Falls is a natural location for upstream migrating fish to congregate before ascending the falls, fish ladders or passage ramps (Figure 2). The location of the falls is the only area open to lamprey fishing on the Willamette River. Lamprey harvest generally begins immediately after the installation of the flashboard risers, as flows decrease over the falls and conditions are more conducive for harvesters to access the bottom of the falls by boat and climb on the rocks and face of the falls to capture lamprey. This location also presents an opportunity to estimate adult Pacific lamprey escapement in the Willamette River.

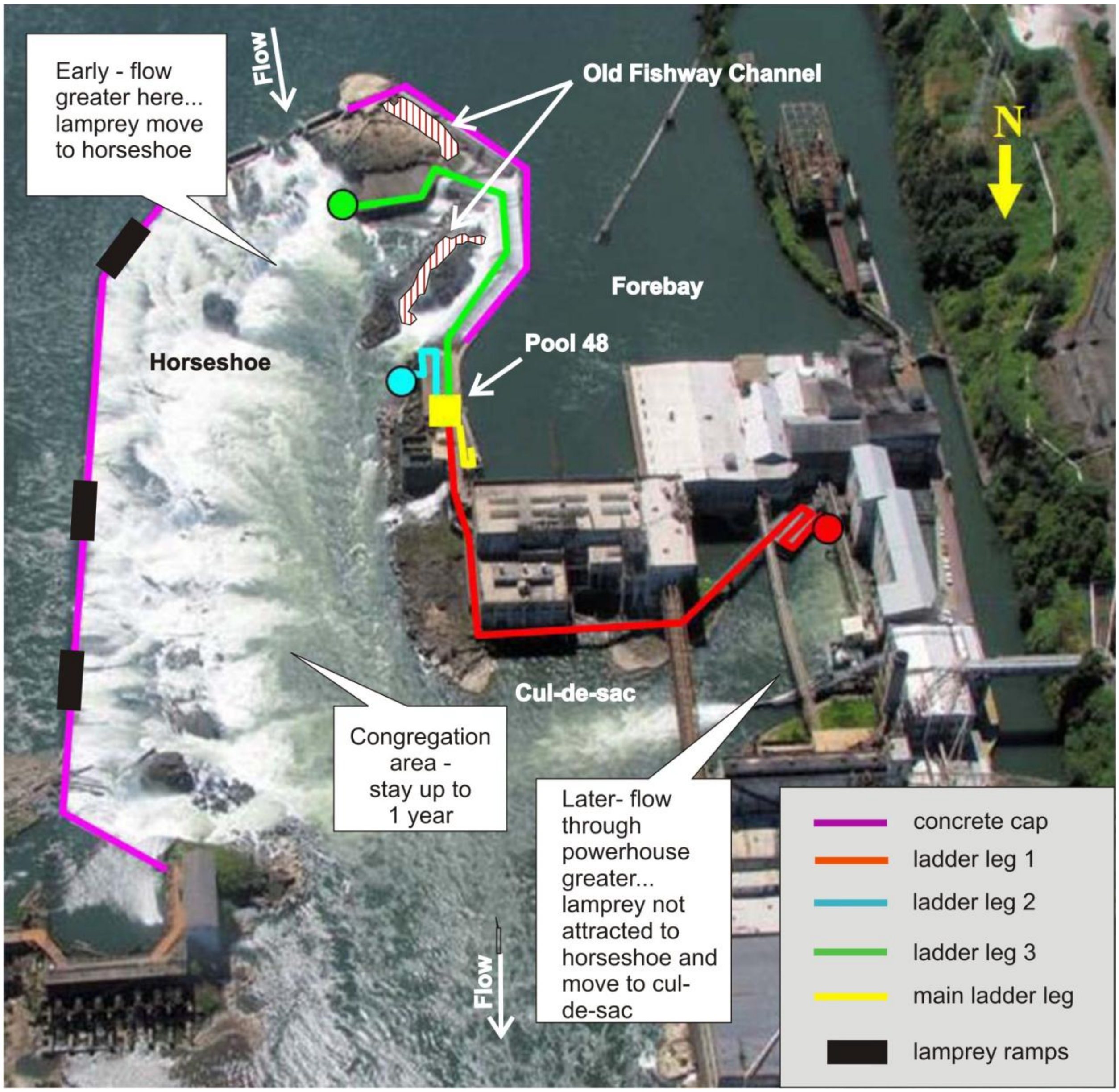


Figure 2. Legs of the modern fish ladder constructed in 1971 and other areas of Willamette Falls, Willamette River, OR.

Release site

Sportcraft Marina (rkm 41.0), maintained by the City of Oregon City Parks and Recreation Department, is located 1.6 km downstream of Willamette Falls (Figure 1). The boat launch is on the east side of the Willamette River, at the confluence of Abernethy Creek, just under the I-205 Bridge between Oregon City and West Linn.

Methods

Improvements in estimating escapement of lamprey at Willamette Falls in 2011 centered on the installation of electronic equipment to increase the number of lamprey recaptured through detections of HDX PIT tags and number of inspected lamprey through video observation. Four HDX antennae were installed in the fish ladder December 2010 and the new system for recording video of lamprey moving through the fish ladder was expected to be installed prior to the lamprey run in 2011. At the beginning of the sampling season, April 2011, the intention was to implant HDX tags in all lamprey caught (marked fish) and use detections of PIT tags (recaptured fish) and video counts (inspected fish) to improve estimates by increasing the number of recaptured and inspected fish. This scheme hinged on having the video recording system installed prior to the lamprey run and that technology would operate unfailingly throughout the run.

Lamprey collection

The lamprey trap (Figure 3), developed by U.S. Geologic Survey (USGS) and PGE for capture of lamprey for radio telemetry (Mesa et al. 2010), was located in Leg 2 near "Pool 48 (Figure 4)" and was fished Sunday night through Thursday morning. The trap was checked every morning. Lamprey were also collected via dip net from Legs 1-3 of the fish ladder just downstream of Pool 48 Monday through Friday mornings, beginning May 25, 2011. The dip net (2 m fiberglass handle, 6.4mm nylon, atlas mesh) was used to capture lamprey. Lamprey were collected from the side or weir-walls of the ladder. Typically, lamprey were collected via dip net approximately 1.5 hours before sunrise to two hours after sunrise, depending on movement through the ladder.

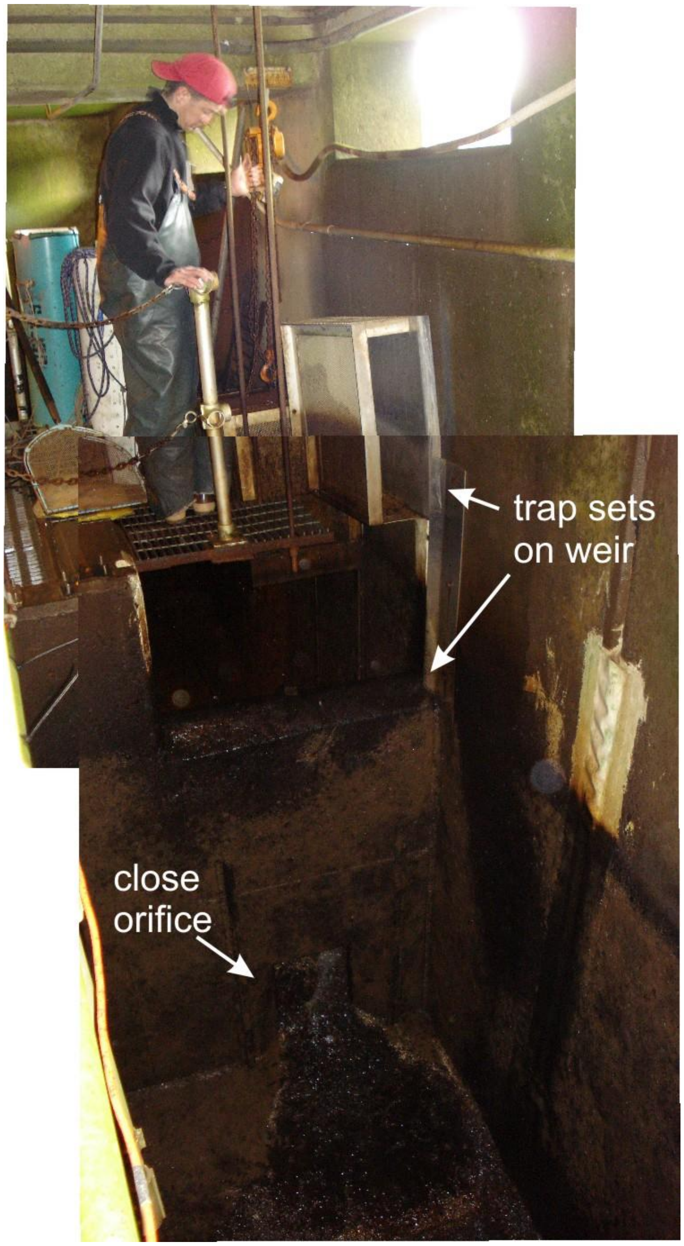


Figure 3. Lamprey trap sets on the top of a weir wall on Leg 2, prior to fish entering Pool 48, Sullivan Plant, Willamette Falls, Willamette River, OR.

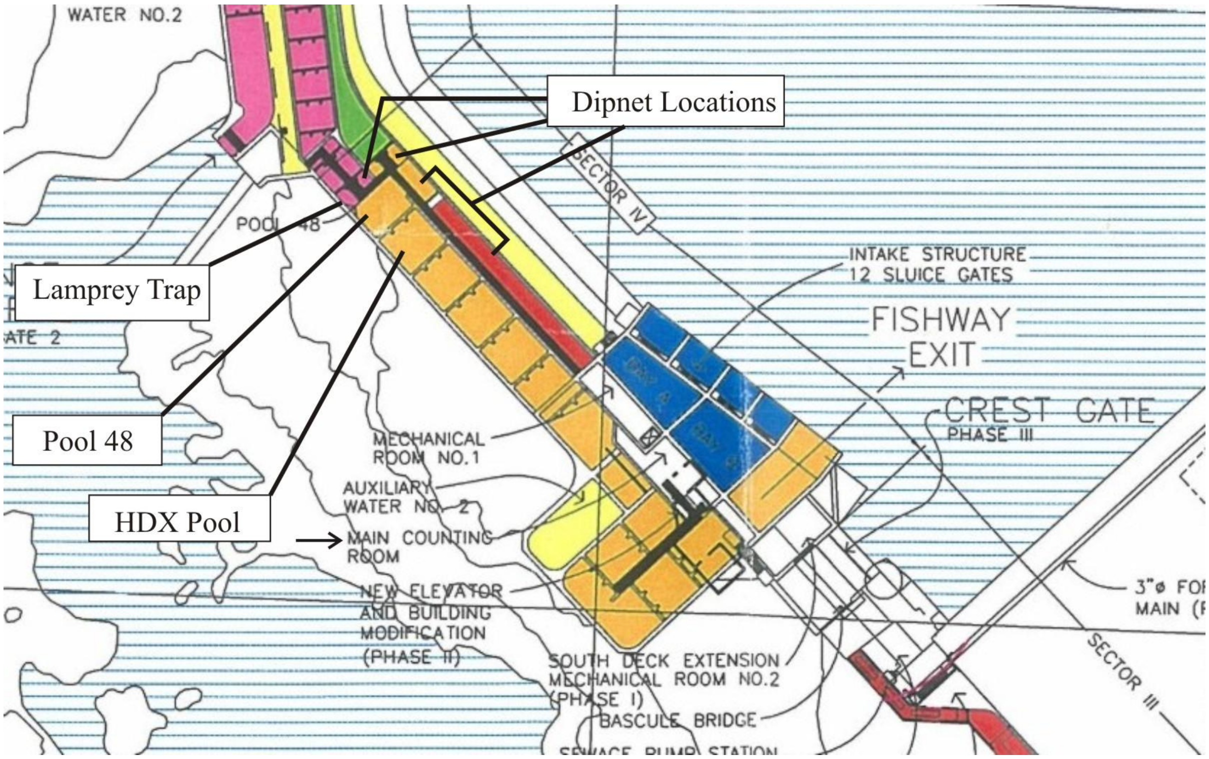


Figure 4. Location of the HDX pool in the fish ladder at Willamette Falls, Willamette River, OR, 2011.

Tagging adult lamprey

After collection, lamprey were held in 125-liter plastic tubs with fresh water running continuously, inspected for tags, measured, and tagged if no previous tag was found. All fish were measured for total length (nearest mm), and a proportion (first 30 per week) were weighed (nearest g). Tissue samples were collected for genetic analysis by clipping a small portion of the dorsal fin and placing it on Whatman® filter paper. Samples were sent to Dr. Jon Hess at Columbia River Inter-Tribal Fish Commission's Genetics Lab in Hagerman, Idaho. Lamprey were either tagged with uniquely-numbered, fluorescent pink, t-bar anchor tags (hereafter referred to as t-bar tags, Floy Tag & Mfc., Inc., Seattle, WA) or uniquely coded, 23mm, half-duplex (HDX) passive integrated transponder (PIT) tags (23mm length, 3.65mm dia., 0.6g, Oregon RFID, Portland, OR). Procedures for PIT tagging lamprey were based on Columbia Basin Fish and Wildlife Authority tagging standards (CBFWA 1999). Half-duplex PIT tags were surgically implanted into lamprey body cavities similarly to Cummings et al. (2008). Anesthetized lamprey were laid on their dorsal side supported by a damp cloth with a 3 mm incision made just left of the ventral midline, directly below the anterior-most portion of the first dorsal fin. The HDX PIT tag was inserted into the incision, pushed in using fingers, and massaged into the cavity away from the incision to reduce the potential for the tag to be expelled. Lamprey were returned to aerated, 125-liter tubs for recovery for 30 minutes to two hours. To assess tag loss, lamprey were double tagged (Seber and Felton 1981). All lamprey were marked with a secondary tag: orange, monofilament-nylon flag anchor tags (hereafter referred to as flag tags, Floy Tag & Mfc., Inc., Seattle, WA). Lamprey were transported in aerated tanks to the release site and released approximately 1.6 rkm downstream of Willamette Falls at Sportcraft Marina.

PIT tag antennae installation

In December 2010, HDX antennae were installed within the fish ladder, located in the pool immediately upstream of Pool 48 (hereafter referred to as the HDX pool). In the HDX pool, there are four orifices through which fish pass. Two orifices on the downstream weir wall are 107 cm (h) by 46 cm (w) and two on the upstream weir wall are 122 cm (h) by 74 cm (w). HDX antennae were constructed in a loop design that encircles each orifice. A high-density plastic ramp was bolted to the floor of the ladder to facilitate lamprey passage over the antennae. Each antenna was constructed from 1.9cm diameter plastic conduit with size-8 American wire gauge (AWG), stranded, copper stereo wire inside (Figure 5). All but one antenna had two strands of 8 AWG wire. The exception was the antenna on the downstream weir wall nearest the river, in which three stands of 8 AWG wire were used in order to develop enough amperage (~0.6A minimum for antennae to properly function).

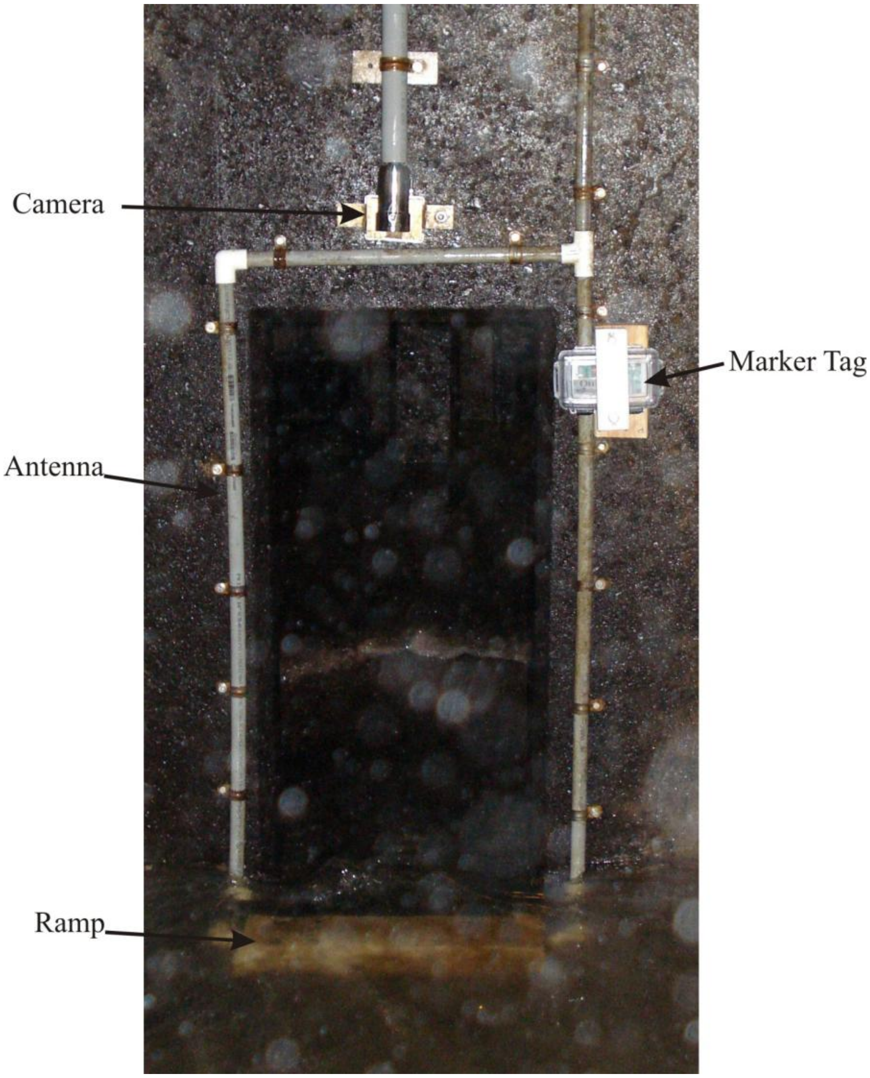


Figure 5. As-built view of an HDX antenna in the fish ladder at Willamette Falls, OR, 2010.

Each antenna wire was routed through conduit (1.9cm diameter) to a tuning capacitor. Each tuning capacitor (standard remote tuner box, Oregon RFID, Portland, OR) was connected to radio-frequency identification (RFID) reader (HDX multi-antenna system, Oregon RFID, Portland, OR) via Twinax cable (Oregon RFID, Portland, OR). The HDX system was powered by 12-V DC current.

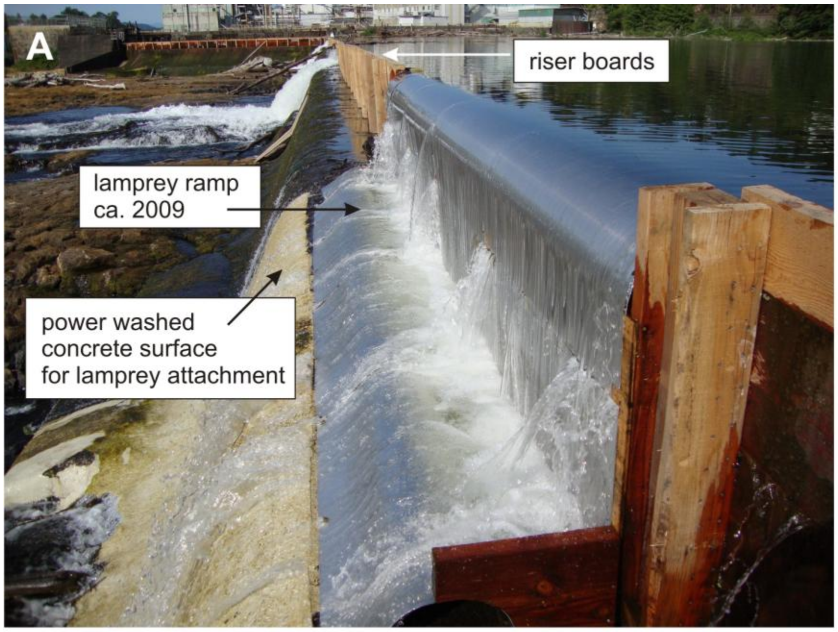
Testing electromagnetic fields of antennae to determine detection probabilities of tagged lamprey

Marker tags (Oregon RFID, Portland, OR), devices used to confirm continuous operation of antenna systems, were mounted over the top of each antenna in the ladder. A marker tag consists of a waterproof case, AAA batteries, a circuit board and HDX PIT tag. A HDX PIT tag is concealed from the antenna other than timed intervals when the signal is uncovered. Marker tags were set to read every half hour. A gap in the detection record would indicate a failure of the reader, antenna or battery supplying reader or marker tag.

In addition to confirming the temporal stability of electromagnetic fields of antennae, they were also periodically tested to ensure that the spatial extent of the field remained intact. When ODFW would draw water down in the fish ladder to clean the counting window or other maintenance, CTWSRO would test antennae fields and clean camera lens. This would typically occur just before (March) and after (June) the spring Chinook run (early April and late May) and approximately monthly thereafter. In testing the spatial extent of antennae fields, a HDX PIT tag would be taken into the HDX pool while dewatered and positioned at various locations throughout the orifice holding the tag with one's hand. As the tag was detected at the positions tested, a piezo buzzer (Oregon RFID, Portland, OR) connected to the reader would be audible, indicating the integrity of the field. The tag was tested at positions within the orifice as well as upstream and downstream positions of the orifice.

Lamprey ramp antennae

Two lamprey ramp antennae were constructed using one loop of 12 AWG, stranded, copper wire housed in 1.9cm diameter PVC pipe under a plywood sheet that was coated with resin. Dimensions of the antennae were 5.2 m wide by 1.5 m high. Each antenna was bolted to the face of lamprey ramps and a strip of flashing (30 cm wide) was screwed to the top edge of the antennae to provide a smooth surface for lamprey to pass (Figure 6). Installation of antennae on the two downstream ramps (Figure 2) took place during a very limited period, as PGE installed riser boards for flow control July 6 and 7, 2011. Each antenna wire was connected to one tuning capacitor (standard remote tuner box, Oregon RFID, Portland, OR) that was connected to radio-frequency identification (RFID) reader (HDX single-antenna system, Oregon RFID, Portland, OR) via Twinax cable (Oregon RFID, Portland, OR). The HDX system was powered by 12-V DC current and recharged using a solar panel. Detected PIT tags were stored on the reader and downloaded after equipment was removed from the Falls in late summer 2011.



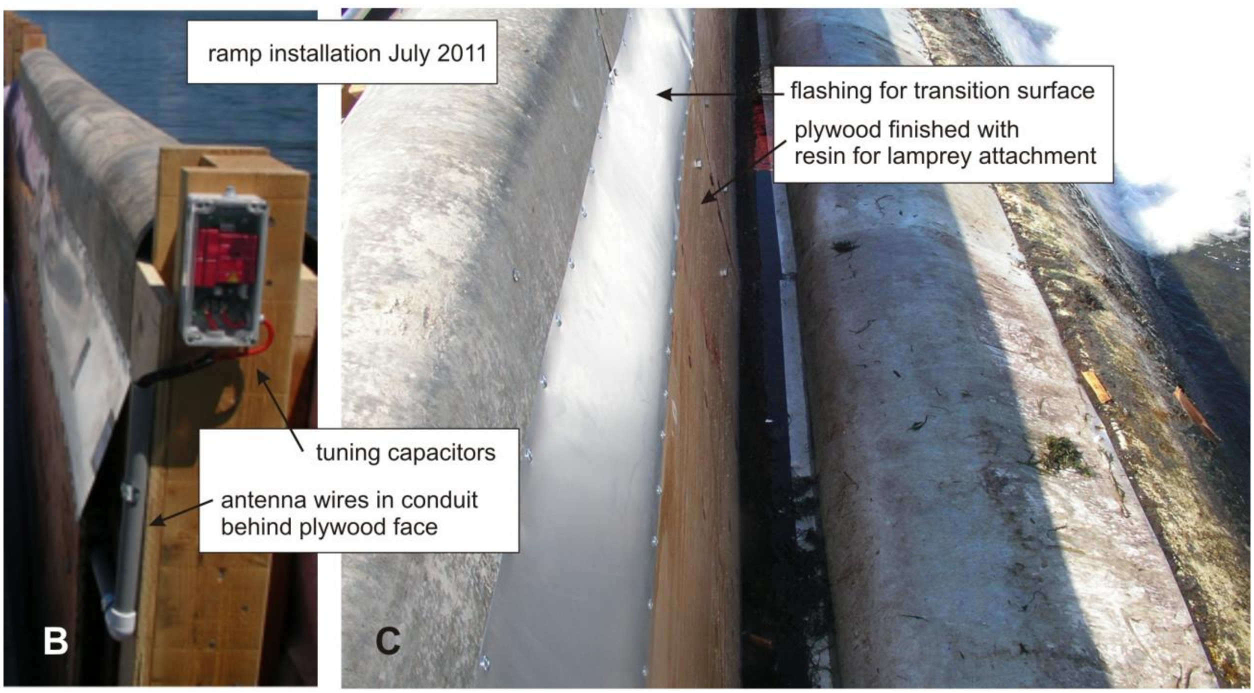


Figure 6. Lamprey ramps on the east side of Willamette Falls ,Willamette River, OR., July 2011. A. overall view (ca. 2009, photo courtesy of PGE Co.); B. antenna wiring and tuning capacitors (2011); C. plywood face of antenna and flashing (2011).

Video camera monitoring

Two Delta Vision® under water cameras (Ocean Systems, Everett, WA) were mounted immediately above orifices on the upper weir wall of the HDX pool in the fish ladder (Figure 5).

Camera cables were connected to portable, compact digital video recorders (DVR, model NDT-200, Fast Forward Video, Salt Lake City, UT) for 24-hour/day recording. Standard definition video was recorded at 30 frames per second and stored on removable hard drives (500GB Travelstar hard drives, Hitachi Global Storage Technologies, San Jose, CA).

While cameras had built-in infra-red lights, they were insufficient to fully light the orifices and produced backscatter. Additional light sources were installed above the camera and at an angle to provided sufficient illumination and reduce backscatter. Two infra-red lights (15 cm x 10 cm, 850 nm IR LED, 50 m beam distance, Aventura Technologies, Inc., Hauppauge, NY) were installed just under the surface of the water above cameras on the upstream weir wall in the HDX pool. It was necessary to install the cameras under the surface of the water as infra-red light bounces off water surface but the weatherproof rating did not include the underwater environment of the fish ladder at Willamette Falls. The final solution was standard outdoor flood lights mounted just above the water surface with 150W bulbs.

Video was reviewed using Final Cut Studio X software (Apple, Inc., Cupertino, CA). Video was recorded onto hard drives in files that represent 21.3 minutes of real time. Each hard drive contained approximately 161 files each, or about 2.4 days. Files for review were stratified by date such that all files were reviewed through August 15, 2011 and thereafter, 50% of the remaining files were randomly selected for review. According to 2010 results, 90% of the lamprey catch had occurred by August 15. The reviewer recorded camera (both on upstream weir wall #1 on left looking downstream, #2 on right), date and time range for each file, number of lamprey that moved upstream through the weir wall and the number that fell back.

Creel

Creel clerks were stationed at Sportcraft Marina and Clackamette Park (the next boat launch downstream), every day of the week from June 1 through July 31, 07:00 to 18:00. Lamprey harvest usually begins immediately after installation of the riser boards on the concrete cap at the top of the falls by PGE. Installation of riser boards depends on flow but generally occurs in late June or early July. When harvesters return to the boat launch from the Falls, creelers ask if they would participate in the voluntary survey. The creeler would then record the lengths of the first 10 fish, scan all of the fish for PIT tags and t-bar tags, and either weigh the catch (by burlap sack full of lamprey on a bathroom scale) or tally the catch.

Total catch was estimated by either: 1) counting the number of lamprey collected from each harvester; or 2) estimating number of lamprey from weight of the catch and dividing by weight of the average lamprey caught during the harvest period. Individual counts and estimated counts were added for an estimate of the total catch.

Abundance and Escapement Estimates

Abundance of adult Pacific lamprey at Willamette Falls was estimated using Chapman's modification of the Lincoln-Petersen estimate (Seber 1982). Estimated abundance (N^*) was

Equation 1
$$N^* = \frac{(M+1)(C+1)}{(R+1)}$$

where M was number of fish marked in the first sampling event, C was the number of fish inspected for marks and R was the number of fish inspected for marks in the second event that possess marks applied in event 1.

Chapman's modifications to the Lincoln-Petersen model (Seber 1982) are used to reduce statistical bias of estimated abundance. It is appropriate whenever sampling during the second event is done without replacement or early sampling during this event affects the fraction of marked fish in the population. Chapman's modified estimate uses a Poisson approximation to the hypergeometric distribution and approaches a minimum variance unbiased estimator of population size with a variance approximated by:

Equation 2
$$V(N^*) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}$$

Confidence intervals were calculated by:

Equation 3
$$95\%\ CI\ (N^*) = \frac{(M+1)(C+1)}{(R+1.92) \pm \left(1.96\sqrt{R}+1\right)+1}$$

Assumptions for closed captures models are (Otis et al. 1978):

1. The population is closed (geographically and demographically);
2. Animals do not lose their marks during the experiment;
3. All marks are correctly noted and recorded at each trapping occasion, and;
4. Each animal has a constant and equal probability of capture on each trapping occasion. This also implies that capture and marking do not affect the catchability of the animal.

Escapement of adult Pacific lamprey over Willamette Falls was estimated by subtracting the harvest estimate from the abundance estimate (Equation 4).

Equation 4 *Escapement Estimate = Abundance Estimate – Harvest Estimate*

Environmental data

Water temperatures (nearest 0.1°C) in the fish ladder were recorded hourly using a data logger (Hobo Pro v2 data logger, Onset Computer Corp., Pocasset, MA). River stage data from U.S. Geologic Survey gage site, Willamette River below Willamette Falls at Oregon City (14207770), was used to describe river conditions during the lamprey run in 2011.

Results

Capture and marking of adult lamprey in Willamette Falls fish ladder

A total of 2,558 adult Pacific lamprey were collected from Willamette Falls fish ladder and tagged from May 25 through August 24, 2011. Collection efforts continued through September 12, 2011 but the last lamprey tagged was August 24, 2011. The first lamprey of the 2011 season was caught on April 27. Floy® t-bar tags were used to mark lamprey from May 25, 2011 to June 2, 2011. After June 2, 2011, the primary tag used to mark lamprey were HDX PIT tags. Of the 2,558 lamprey, 187 were marked with t-bar tags and 2,370 were PIT tagged and one had only the secondary tag, a flag tag.

The maximum number of lamprey tagged in one day was 158 on June 3, 2011 and the average tagged per day was 35.1 lamprey. The maximum lamprey handled (tagged, inspected and/or recaptured) was 217 on June 6, 2011, and the average caught and handled was 41.5 lamprey per day (Figure 7). Half of the total catch was recorded by early July (between July 1 and 3, 2011 Figure 8). Water temperatures fluctuated between 10.8°C and 23.1°C between May 25 and September 12, 2011 with the average of the daily average water temperature 18.3°C during this period (Figure 7). While the Willamette River is tidally influenced below Willamette Falls fluctuations are muted. Between May 25 and September 12, 2011, the maximum daily difference in stage was 0.3 m but on average the tide swing was 0.1 m. The average daily average stage during this period was 3.4 m (11.3 ft; Figure 7).

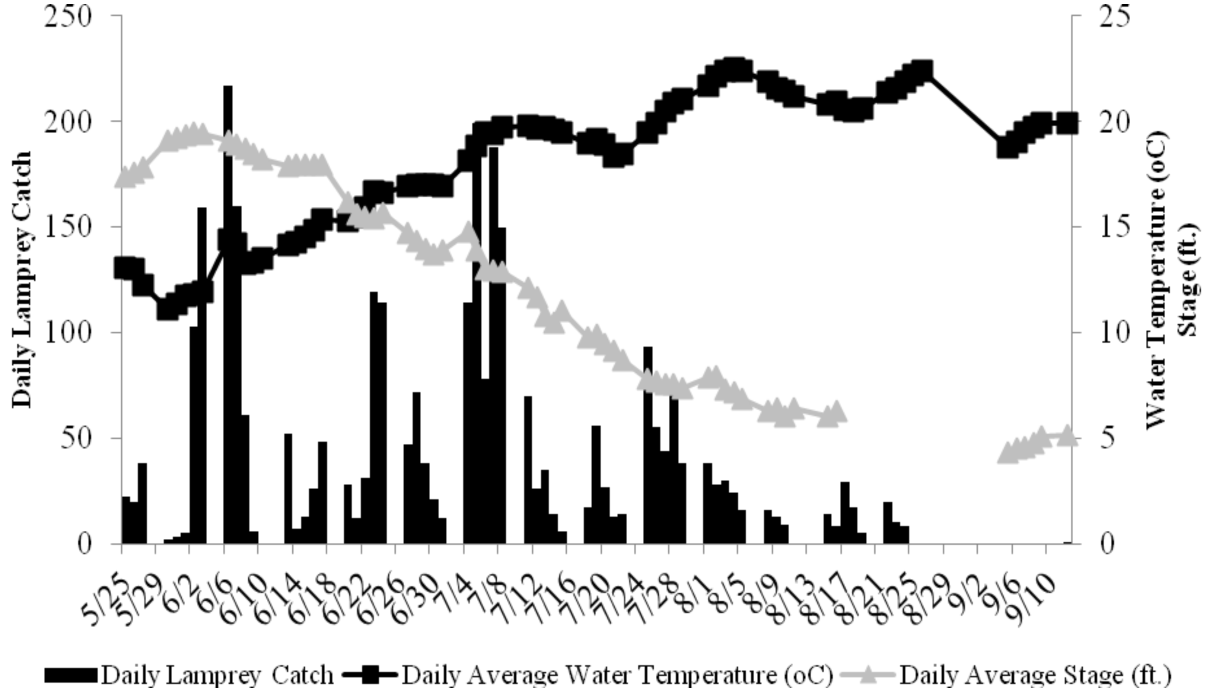


Figure 7. Daily lamprey catch (tagged, inspected and recaptured) at Willamette Falls fish ladder, Willamette Falls, Oregon, May 25 to September 12, 2011.

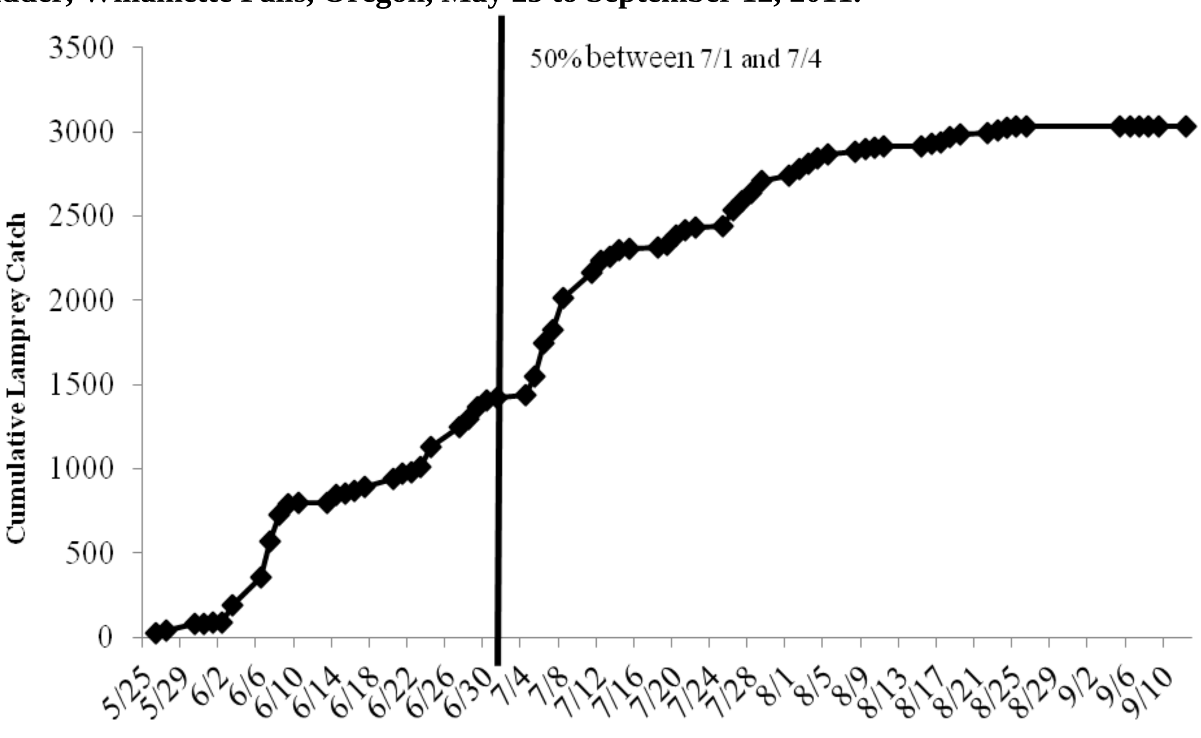


Figure 8. Cumulative lamprey catch (tagged, inspected and recaptured) at Willamette Falls fish ladder, Willamette Falls, Oregon, May 25 to September 12, 2011.

Recaptured marked lamprey in fish ladder

A total of 69 lamprey tagged at Willamette Falls in 2011 and released at Sportcraft Marina, were recaptured in the fish ladder between June 3 and August 23, 2011. Of the 69 recaptures, 64 had HDX PIT tags, four had t-bar tags and one had a flag tag (secondary tag). Out of the recaptured lamprey, 1.4% lost the primary tag but the secondary tag was present. Total lengths of recaptured lamprey (n = 67) averaged 589 mm and ranged in length between 470 and 685 mm. Lamprey which were tagged and lengths measured (n = 2,546) ranged from 335 to 730 mm with an average of 586 mm. There were no significant difference in median lengths (W = -2721.5, p = 0.66, α = 0.05) between tagged and recaptured lamprey. Lamprey were recaptured via dip net from one to 54 days after initial tagging (n = 67, average = 9 days, standard deviation = 10.4 days).

Antennae detections in fish ladder

Of 2,370 lamprey which were HDX PIT tagged at Willamette Falls in 2011, 1,084 were detected by HDX antennae in the fish ladder. This is a return rate of 45.7%; alternatively a stray rate of 54.3%. Straying, in this case, refers to fish that do not return to the fish ladder and are not subject to recapture (in effect, an adjustment to compensate for the assumption that the population is closed). Of those detected (n = 1,084), 1,030 (95%) were last detected moving through the upstream weir wall suggesting upstream passage. The remaining 54 lamprey were either last detected by an antenna on a downstream weir wall (51 of 54 lamprey), suggesting fall back, or there were no antenna recorded with the last detection (3 of 54 lamprey).

The last HDX PIT tagged lamprey detected via antennae array in 2011 was on October 15, 2011. The average number of days for a lamprey to return to the fish ladder for detection was 10 days but ranged from the next day to 82 days. There was one lamprey with a HDX PIT tag that was detected on February 29, 2012. The tag number (0A0F9812) did not match any tagged by CTWSRO in 2011 or in 2010 but was close to numbers in our tag series (*i.e.*, similar tag numbers used by CTWSRO began with 0A0F9 [n=726] or 0A0F98 [n=1, 0A0F9814]).

Mean length of HDX PIT tagged lamprey that returned to the fish ladder (average length = 593 mm, n=1077) was larger ($t=5.67$, $p < 0.001$, $\alpha=0.05$) than those that failed to returned to the fish ladder (average length = 583 mm, n=1289, Figure 9). The 95% confidence interval for the mean difference in length was 6.6 mm to 13.5 mm. Even after removing the far outliers (red points, Figure 9, 335, 355 and 390 mm) the mean difference in length was significant ($t=5.92$, $p<0.001$, $\alpha=0.05$).

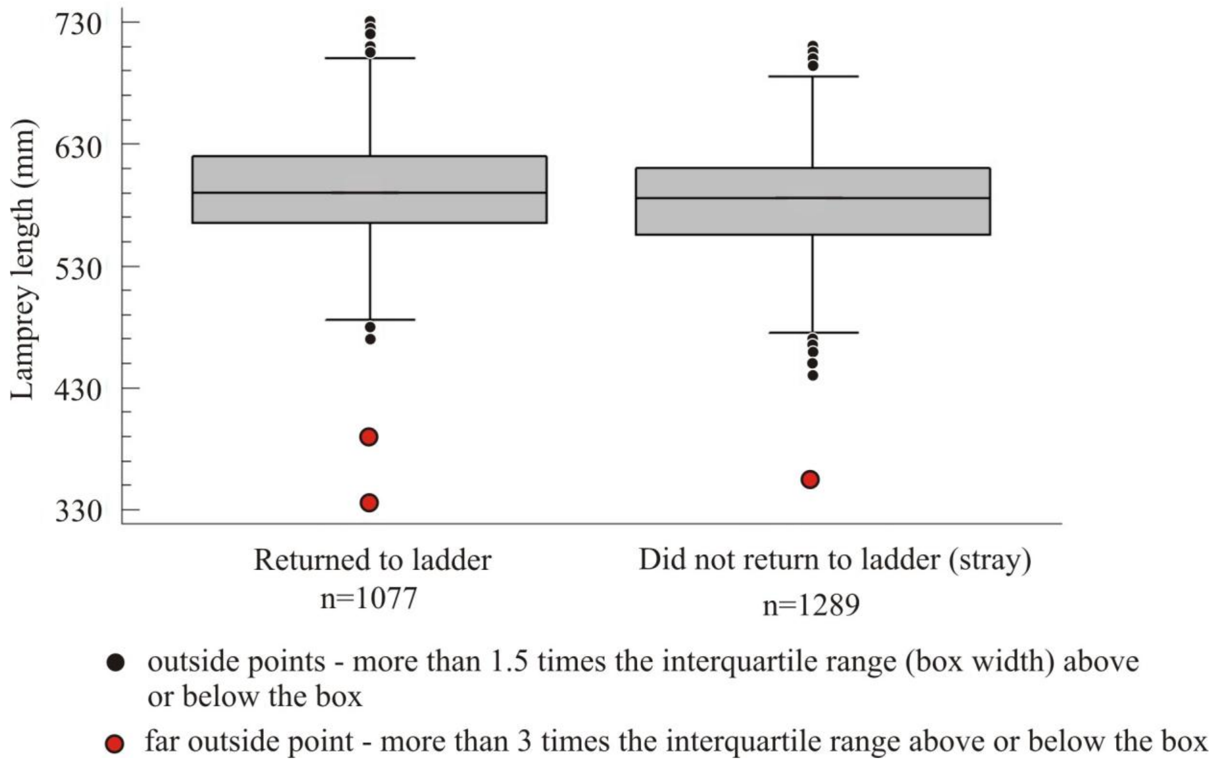


Figure 9. Length distributions from HDX PIT tagged lamprey that returned to the fish ladder and those that failed to return to the fish ladder at Willamette Falls, Oregon, 2011.

Testing antennae in fish ladder

Marker tags were installed at each of four antennae on March 15, 2011. Shortly thereafter, it was realized that three out of four marker tags needed to be repositioned in order for antennas to detect the tag; however water in the ladder could not be drawn down until after the spring Chinook run. Marker tags were repositioned on June 2, 2011. Antennae 1 and 2 are located on the upstream weir wall and antennae 3 and 4 are located on the downstream weir wall of the HDX pool. The marker tag on antennae 1 recorded the test HDX PIT tag 24 hours per day from June 3 through the sample period (ending September 12, 2011). The marker tag on antennae 2 failed to record test tags during the sample period. The marker tag on antennae 3 recorded the test HDX PIT tag 24 hours per day from July 29 through September 12, 2011. The marker tag on antennae 4 recorded 24 hours per day from March 16 through September 12, 2011, except for September 4 and 5 when there were 20 and 16 hours recorded, respectively. Testing the electromagnetic field of each antenna, orifices had full antenna coverage throughout and one-half meter upstream and downstream from the weir wall each month tested.

Lamprey ramp antennae detections

Two lamprey ramps were installed at the crest of the Falls on July 6, 2011. Both antennae had sufficient read range to detect a PIT tagged lamprey climbing the surface of the antennae (ca.10 cm) when tested prior to installation. After installation, the downstream most antennae retained the read range but the field collapsed on the upstream antenna rendering it inoperable. The remaining antenna was operational through September 28, 2011. No PIT tags were detected and recorded, although the recorder registered operation throughout the period. The solar panel kept the battery charged from 12.7V to 13.8V during the period of operation.

Escapement Estimate of adult Pacific lamprey through the fish ladder

Based on number of lamprey marked, recaptured and inspected in the fish ladder and the proportion of lamprey that strayed from returning to the ladder, 54.3% as determined by HDX PIT antenna detections and the total number of lamprey tagged in 2011, the escapement of adult lamprey through the fish ladder from May 25, 2011 to September 12, 2011 was 49, 072 (Table 1). Ninety-five percent confidence intervals around this estimate range from 38,895 to 61,870 lamprey with a coefficient of variation of 11.4%.

Table 1. Estimated Escapement of adult lamprey through fish ladder at Willamette Falls, May 25 through September 12, 2011.

Marked (M)	Recaptured (R)	Inspected (C)	Estimate (N)	Lower 95% CI	Upper 95% CI
1,169[1]	69[2]	2,935	49, 072	38,895	61,870

[1]adjusted number of marked fish for stray rate of 54.3%, total number marked was 2,558
[2]recaptured lamprey for this estimate includes only those caught in the fish ladder and does not include recaptured lamprey from harvest or salvage

Given the proportion of marked lamprey that returned to the fish ladder (45.7%) and strayed (54.3%), and lamprey escapement through the ladder (49,072), the estimated number of lamprey that failed to return to the fish ladder from May 25 through September 12, 2011 was 58,217. Due to the uncertainty of whether or what proportion of lamprey ascend the Falls, escapement of the 58,217 lamprey in the horseshoe to the upper Willamette River will not be estimated until further data on behavior and movement patterns can be ascertained.

Video Capture and Review

Video of lamprey moving through the upstream weir wall in the HDX pool was recorded from July 10, 2011 through September 22, 2011. The last file reviewed was from August 21, 2011 as time for review drew to a close in late March 2012. The period of recorded video was not continuous as technicians had intermittently made a small but important error while changing hard drives; the hard drive was pulled out before files were formatted onto the hard drive. This resulted in a blank hard drive. Review of 1,856 files totaling 662 hours of video resulted in a tally of 11,979 lamprey that passed through the upstream weir wall from July 10 through August 21, 2011 (Figure 10).

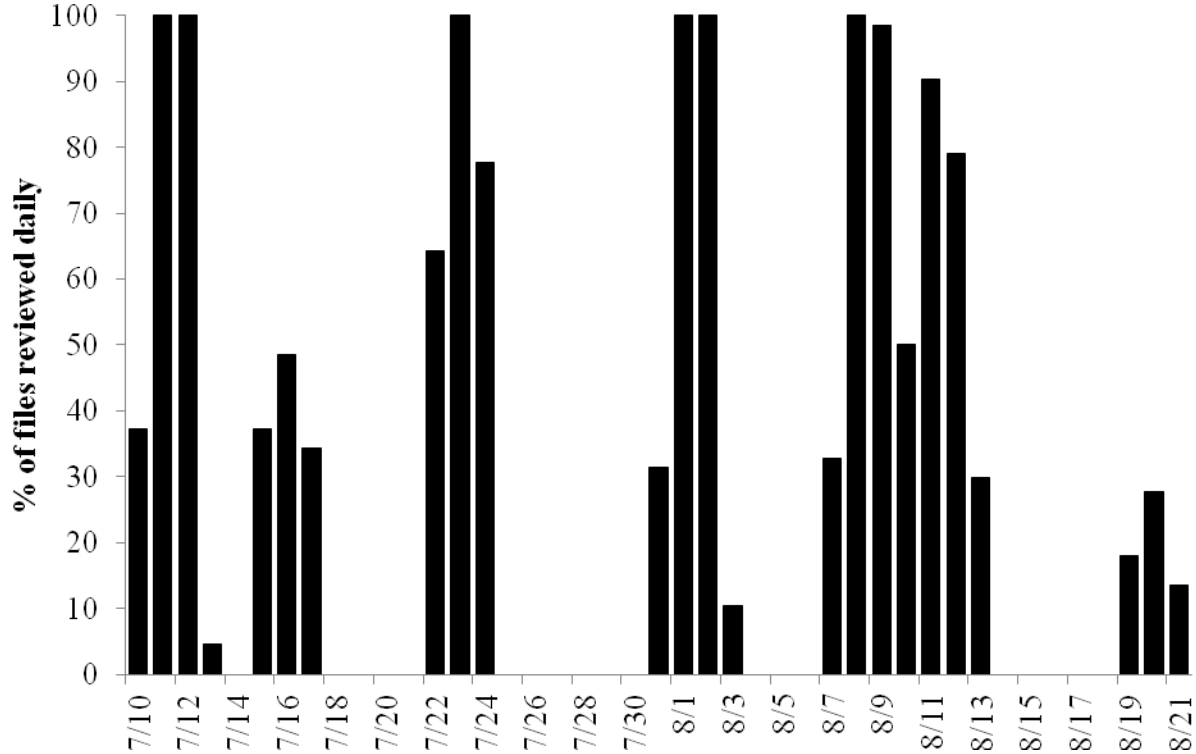


Figure 10. Percentage of files reviewed out of total possible per day, July 10 – August 21, 2011.

Lamprey were counted moving through the fish ladder at every hour of the day between July 10 and August 21, 2011. On average, there were 77 files for each hour of the day represented in video counts but ranged from 67 files (3 am) to 90 files (6 pm). The peak hour of lamprey movement through the fish ladder was 03:00, when average lamprey per hour counted was 49.6 (Figure 11). From 11pm (2300 hrs) to 3 am, hourly counts increased 9.1 lamprey per hour (regression line during these hours $y = 9.1189x + 5.4737$, $r^2=0.99$). While the majority of lamprey movement occurred between 11pm and 6am (58.9%) a smaller peak of lamprey movement through the fish ladder occurred late-morning through afternoon, with a peak at 1pm (16.8 lamprey, 1300 hrs, Figure 11).

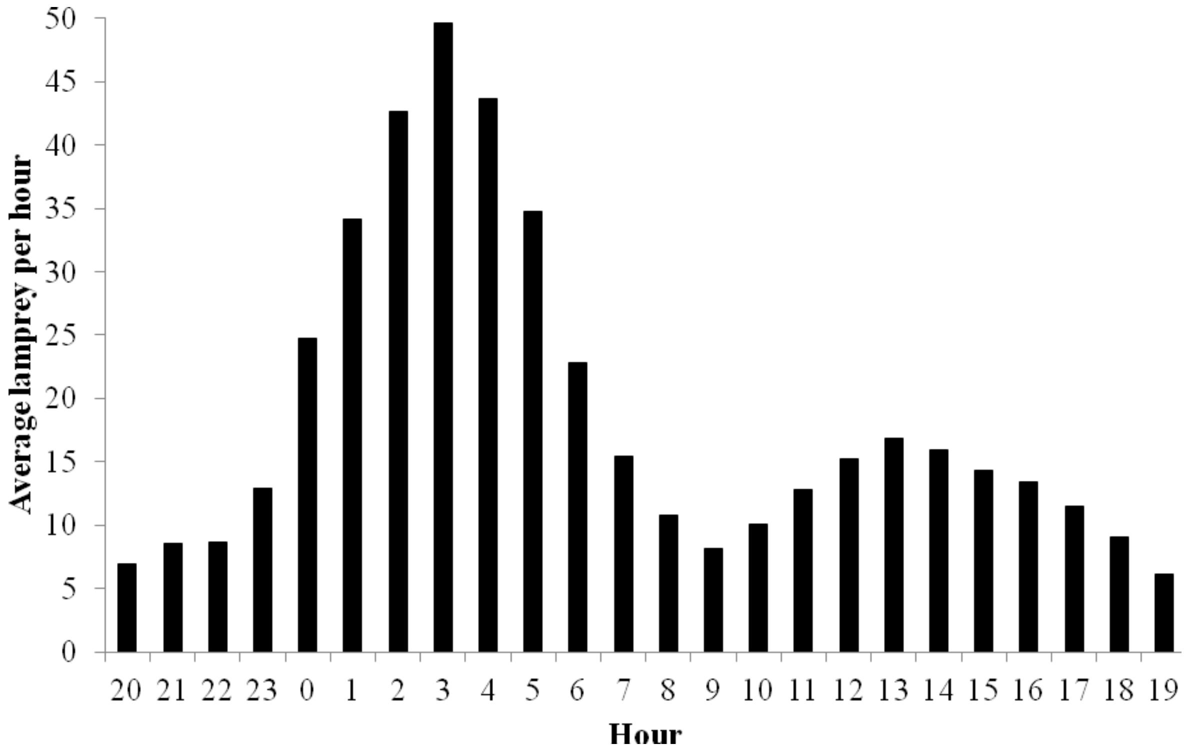


Figure 11. Average number of lamprey per hour counted in video recorded July 10 – August 21, 2011 in fish ladder at Willamette Falls, Oregon.

Creeling harvest of adult lamprey at Willamette Falls

All observed harvesters participated in the creel survey for lamprey at Willamette Falls in 2011. Six groups of harvesters were identified, including members from Confederated Tribes of the Warm Springs Reservation of Oregon, Confederated Tribes of the Umatilla Reservation, Confederated Tribes and Bands of the Yakama Nation, Nez Perce Tribe, Confederated Tribes of Grand Ronde, and Confederated Tribes of Siletz Indians of Oregon.

The first lamprey harvester was creeled on June 24, 2011. The majority of the catch (70%) was harvested the weekend following the installation of the riser boards around the crest of the Falls between July 8 and 10, 2011. Total estimated harvest of lamprey through July 29, 2011 was 4,318 lamprey. Creelers counted and weighed samples of lamprey to establish a length-weight relationship of the catch. This length-weight relationship ($y = 1.8887x - 31.559$, $r^2 = 0.97$, $n=6$) was used to estimate numbers of lamprey in weighed burlap sacks. Thirty-six lamprey that were harvested had t-bar or PIT tags that were inserted by CTWSRO at Willamette Falls in 2011.

Average size of lamprey creeled was 592 mm. Mean length of lamprey creeled (n = 167, range 475 to 690 mm, std. dev .= 38.7 mm) and lamprey caught in the fish ladder (n = 1192, range 450 to 730 mm, std. dev. = 42.2 mm) for mark-recapture during the same period (June 24 to July 29, 2011) were not significantly different (two-sample t-test, $t = 1.03$, $p = 0.30$, $\alpha = 0.05$, standard deviation tested due to unequal sample size, F-test = 0.84, $p = 0.16$, $\alpha = 0.05$).

Lamprey salvage in the old fishway

Prior to installation of the riser boards around the crest of the Falls, PGE conducts a salvage operation in the old fishway (Figure 2). At this time, river levels were falling (Figure 7) and lamprey were in danger of becoming stranded and perishing if not removed. On June 22, 2011 CTWSRO personnel assisted PGE biologists in their salvage efforts. Lamprey were captured by the hand, placed in burlap sacks, weighed and released just downsteam of the Falls (Figure 12). During late-morning and early afternoon, 495 kg of lamprey were collected and released. The average weight of lamprey caught in the fish ladder between June 15 and June 27, 2011 was 0.35 kg. Converting total catch by weight to number of individuals with the average weight of 0.35 kg, equates to approximately 1,341 lamprey salvaged in about four hours. Of the lamprey salvaged, eight were tagged by CTWSRO between May 25 and June 21, 2011. Biologist from PGE salvaged approximately 4,000 lamprey (including the 1,341 above) and observed about 20 tagged lamprey in 2011 (Tim Shibahara, PGE fish biologist, pers. comm.).

Figure 12. Lamprey salvage in old fishway, Willamette Falls, Oregon, June 22, 2011.

Willamette River Pacific Lamprey Working Group

The Willamette River Pacific Lamprey Working Group (WRPLWG) began with a sign-up sheet at the technical session, "Latest Lamprey News", moderated by Bianca Streif, U.S Fish and Wildlife Service, during the 2010 annual Oregon American Fisheries Society Conference. Members include biologists conducting research on Pacific lamprey in the Willamette Basin, agency biologists, and others interested in the status of this population. The group's purpose is to provide a forum for discussion and information exchange on the biology and ecology of lamprey in the Willamette Basin, share techniques for gathering data as they are developed, and improve communication among agencies and entities engaged in lamprey research or related management of natural resources that might not otherwise be inclined to interact. Meetings have generally occurred on an ad hoc basis. The exception to the informal nature of the group was a workshop organized and hosted by CTWRO and ODFW on November 2, 2011, held at the Columbia Inter-Tribal Fish Commission offices in Portland. The keynote presentation was delivered by a CTWSRO cultural anthropologist and CTWSRO tribal member, Brigette Whipple, about the historic use of the Willamette Falls lamprey fishery by CTWSRO members, cultural significance of the fishery and lamprey, and importance of this resource to CTWSRO presently. Speakers were invited to present results from research conducted on Pacific lamprey in the Willamette Basin (see presentations posted at http://www.dfw.state.or.us/fish/species/lampreys.asp). Kathryn Kostow, ODFW, moderated the workshop, after presentations, a discussion followed this well-attended, collegial meeting.

Another opportunity to present results of the Willamette Falls Pacific lamprey escapement estimates and receive feedback was at the 2012 annual Oregon American Fisheries Society Conference held in Eugene February 28 – March 1, 2012. The presentation compared escapement through fish ladders in 2010 and 2011, explained uncertainties of lamprey behavior in the horseshoe and the unknown proportion that ascend the Falls from the horseshoe, detection of HDX PIT tagged lamprey through the fish ladder, which improved escapement estimates from 2010, and improved results of counting lamprey with video recorded and reviewed with the new system installed in 2011. Other WRPLWG participants presented at the same session, entitled, "Beyond the adipose fin: Oregon's non-game native species", moderated by Tim Hardin, ODFW. This session was well-attended by other WRPLWG colleagues as well as lamprey researchers working in the Columbia River. Productive discussions followed the presentations and perspectives from other researchers were offered.

Discussion

Escapement

In 2011, an escapement estimate with associated confidence interval (Table 1) was calculated for the ladder only. This allowed for partitioning of uncertainty (*i.e.*, whether lamprey in the horseshoe ascend the Falls, fall back to the lower Willamette River or tributaries, or whether they spawn and/or die below the Falls) and estimating return (passage) rates (RR) as well as stray rates (SR). Lamprey that were PIT tagged and last detected moving through the upstream weir wall (used to calculate return rate) likely migrated upstream of the Falls to overwintering and spawning areas in the main stem Willamette River or tributaries (Clemens 2011). Using HDX antennae detections, return rate can be estimated annually. The RR in 2011 of 45.7% was close to that in 2009 (42%). Additionally, because we are able to estimated RR of HDX PIT tagged lamprey to the fish ladder, we will be able to calculate a yearly SR (2011 SR = 54.3%), removing the necessity to rely on a previous work (SR 23% - 42%) at the Falls (Karchesky *et al.* 2011; Mesa *et al.* 2009; Mesa *et al.* 2010) as a correction factor for yearly escapement estimates.

In recalculating the 2010 escapement estimate to partition the uncertainty of whether lamprey in downstream of the Falls ascended, the return rate of 42% from the 2009 radio-telemetry study was used, rather than the 2005 or 2006 rates of 35% and 23%, respectively (Karchesky et al. 2011; Mesa et al. 2009; Mesa et al. 2010). Multiple passage improvements were made for lamprey between the 2006 and 2009 radio-telemetry studies as part of the new Federal Energy Regulatory Commission relicensing agreement for the Willamette Falls Hydroelectric Project, (Karchesky *et al.* 2011). Modifications included installation of a flow-control structure at the apex of the Falls, flashboard height changes, an additional fish bypass at the powerhouse and improvements to the entrance of ladder leg 1 (Figure 2, Appendix B), which included design elements for facilitate lamprey entrance (Karchesky *et al.* 2011). In addition to modifications, the 2006 RR was considered a consequence of atypical hydrologic conditions in which the powerhouse was shut down on June 9 (Mesa *et al.* 2009). The recalculated estimate for lamprey escapement through the fish ladder at Willamette Falls in 2010, using 42% as a return rate, was 26,677 (95% CI = 21,537 – 33,936). This is 46% lower than the 2011 estimate of 49,072 (95% CI = 38,895 - 61,870). Given the revised 2010 estimate with a 42% RR and a 58% SR, the estimated number of lamprey that failed to return to the ladder was an estimated 36,840. This is 37% lower than the 2011 estimate of 58,217.

While the estimated 2011 ladder escapement was almost twice (1.8 times) that of 2010, the first part of the 2011 lamprey run (April 27 – May 24, 2011; tagging began May 25, 2011) is not represented. This is due to efforts to improve escapement estimate methods, logistics and/or contracting for installing video, lights and other equipment at the project site. Fitting the 2010 cumulative curve to 2011 data (April 27 – May 24, 2011, Appendix C), with a beginning date of April 27, 2011, an estimated 22.7% of the run was not represented in the 2011 ladder estimate. Accounting for this would increase the estimate to 63,483 lamprey that ascended the ladder. Based on the 2011 SR and including the first 22.7% of the run, would increase the number of lamprey that congregated below the Falls to 75,313 for a total abundance lamprey abundance estimate of 138,000.

Using the Lincoln-Peterson estimator in conjunction with HDX antennae detections to estimate RR provided an estimate with a reasonably narrow confidence interval (*i.e.,* SE = 11.4% of the estimate). While Assumption 1 of the closed population model was violated (Methods Section; Otis et al. 1978), using estimates of HDX PIT tagged lamprey RR to the fish ladder compensates for this violation. This assumption was violated because tagged fish must be available for recapture and those in congregating areas below the Falls would have a very low probability or recapture as compared to those that return to the ladder. Assumptions 2 – 4 (Otis et al. 1978) were met. Dual tagging ensured marks were not lost between sampling occasions (Assumption 2, Methods Section). There was one instance (1.4% of recaptured lamprey) out of 69 recaptured lamprey that the t-bar was missing or PIT tag had been lost and only the flag tag remained. There were no occurrences of a flag tag missing from lamprey possessing a t-bar or PIT tag. Errors in PIT tag code recordings were improved by connecting the PIT tag reader to a computer so the 10 character code was electronically registered and stored for downloading and analysis (Assumption 3, Methods Section). However, it appears there were errors associated with the PIT tag reader failing to read or record the tag number in the computer software as one antenna detection was only two characters difference from one implanted by CTWSRO (so, likely a CTWSRO tag) and for which we have no record of inserting. Additionally, there were 33 other HDX PIT tags detected by the antennae array that may have been implanted by CTWSRO at Willamette Falls or these tags may belong to other researchers. One small but significant difference in full- and half-duplex tags is that with full duplex tags, the purchaser is issued an electronic file with all of the tag codes sent. The HDX tag buyer is without this list and therefore cannot check to whom a tag was issued. All HDX PIT tags that CTWSRO inserts into fish are registered on the Pacific States Marine Fisheries PIT Tag Information Systems (PTAGIS) database. As more researchers using HDX PIT tags upload data onto the PTAGIS database, tag information will become more accessible. Assumption 4 was not violated, as whether marked or not, all lamprey were subject to capture via dip net or trap in the fish ladder (Assumption 4, Methods). Only the secondary marks (flag tag) was visible. However, there is only dim lighting in the fish ladder and flag tags remain imperceptible to samplers until fish are handled. Therefore, they were not more likely to be captured than non-tagged lamprey. Mortality of tagged fish is another important factor in meeting the assumptions of the closed population model. Mortality of tagged may have higher mortality rates than non-tagged lamprey (e.g., due to the tagging procedure, fish are more visible and prone to predation. Dr. Mary Moser conducted a study to test the effects of surgically implanted PIT tagged lamprey with three treatments of incision closure (suture, cyanoacrylic glue, and no closure) for several weeks in 2004. None of the fish died during the study. She reported that no closure had least effects; sutures and glue caused increased wound redness and infection (Dr. Moser, NOAA Fisheries pers. comm.). Predation on lamprey by sea lions (*Zalophus californianus)*, adult sturgeon (*Acipenser transmontanus*), and great blue herons (*Ardea herodias*) have been observed (Tim Shibahara, fisheries biologist, PGE; Carson McVay, fisheries technician, CTWSRO, pers. comm.). It is assumed predation rates for tagged and untagged lamprey are not significantly different. This has not been validated or quantified. Predation rates may be difficult to quantify given sea lions are federally protected under the Marine Mammal Protection Act and sturgeon are a highly prized game fish that are carefully managed (Beamesderfer and Farr 1997) as their demographic characteristics (*i.e.*, 13 - 16 years to maturity for females, Wydowski and Whitney 2003) make population recovery a long process (*e.g.*, sacrificing animals and examining gut contents is not an option). It may be possible to estimate predation rates by great blue herons at lamprey ramps using additional video monitoring in the future.

Improvements to escapement/abundance estimates of Pacific lamprey at Willamette Falls

Improvements to escapement estimates occurred as a result of using more advanced technology but not in the way initially expected. The use of HDX PIT tags, antennae, and video of lamprey passing through the HDX Pool was expected to greatly increase the number of lamprey recaptured (including tagged lamprey caught in the ladder and those detected by HDX antennae) and inspected (including lamprey caught in the ladder and counted by video), which would be expected to contract confidence intervals. However, this strategy required that only those lamprey detected by HDX antennae can be counted as recaptured only if there are corresponding video counts of inspected lamprey for the same time period as that of the lamprey detected by the antenna arrays (*i.e.*, lamprey without tags must have the same probability of being captured, recaptured and inspected as those with tags). Technical difficulties with camera lighting, delays in installation of video recording equipment, and errors in completing formatting before ejecting the hard drive limited the video imagery captured in the fish ladder. In addition, it was unknown whether it would be possible to review all video captured as there are currently no known automated method. Because of the lack of contrast between lamprey swimming through orifices and the floor of the fish ladder, motion detection software was ineffective. Image recognition software to count lamprey through fish ladders in the Columbia River is being developed and tested but is not generally available (Chris Peery, U.S. Fish and Wildlife Service, pers. comm.). While the limitation to improving the escapement estimate in the manner described above lied in the limitation of video capture and review, detections of HDX PIT tags in the fish ladder provided a very accurate estimate of return and stray rates and video counts during July and August 2011 provided further corroboration that the estimate of lamprey escapement through the fish ladder is credible.

While video counts were not used as part of the mark-recapture estimate, these data indicated hourly patterns in movement through the ladder and provide a comparison of lamprey abundance in the fish ladder by an alternate method lending evidence that the estimated escapement is reasonable, if not conservative. Primary hours of lamprey movement through the fish ladder at Willamette Falls were from 2300 to 0600 (59% of lamprey migrated during these hours), which is similar to results of radio tagged lamprey moving through Bonneville Dam in which 67% passed the counting window between 2200 and 0600 (Moser and Close 2003). Similar nocturnal migration behavior was reported from radio-telemetry studies of lamprey in the Deschutes River where lamprey passed fixed site antennae primarily between 2100 and 0300 (CTWSRO Natural Resources Branch Fisheries Research Dept. 2012) and the John Day River, where post-overwinter migrants traveled between sunset and sunrise (Robinson and Bayer 2005). Lamprey counted during video review for the period July 10 through August 21, 2011 migrated during the last 29% of the run (Figure 8). Comparing video counts (11,979) and 29% of the estimated 49,072 lamprey that passed through the ladder (14,231), video counts were 16% lower than the estimate. Because of lingering technical difficulties, 31% of the total hours between July 10 through August 21, 2011 were reviewed for lamprey passage. It is unknown what proportion of the total number of lamprey was counted. However, video counts were only 16% lower than the escapement estimate for the latter 29% of the lamprey run was and 69% of the time period was not reviewed by video. This suggests that video counts may be very close, if not larger, than the estimate if all were reviewed or if an expansion, weighted by hour of day or some other factor, were applied to the counts. Notwithstanding, video counts give support to the validity of the escapement estimate.

Uncertainties in lamprey abundance in the horseshoe and congregation areas below the Falls

The fate and whereabouts of lamprey that approached but deferred ascending the Falls is largely unknown. Radio telemetry studies found that tagged lamprey that were released downstream and returned to the Falls but did not ascend the fish ladder spent several days or weeks in the horseshoe or cul-de-sac (Figure 2), of these, half or more (73% in 2005, 69% in 2006, and 49% in 2009) eventually moved downstream by the end of the summer beyond the study area (Karchesky et al. 2011; Mesa et al. 2009; Mesa et al. 2010). Only one lamprey PIT tagged in 2011 was detected passing upstream through the fish ladder in 2012 after overwintering. It has been suggested that there may be substantial spawning activity downstream of the Falls in the lower Willamette River or tributaries (Mesa et al. 2009) or back to the Columbia River (Mesa et al. 2010). Mesa et al (2010) reported that out of 17 radio-tagged lamprey that attempted to ascend the Falls in 2005, none were successful and in 2006, out of 19 that attempted to ascend the Falls, two successfully passed. In 2005 and 2006, 89% of the attempts to ascend the falls were made by mid-July (Mesa et al. 2010). Karchesky et al. (2011) reported five lamprey attempting to ascend the Falls, all in May, but none were successful.

One of the two HDX antennae installed on the lamprey ramps remained operational through the summer but no PIT tagged lamprey were detected. Given the HDX PIT tagged lamprey tagged at Willamette Falls in 2011 (2,370) minus those HDX PIT tagged lamprey that were detected moving through the fish ladder (1,084) and harvested (33), there would have been 1,253 HDX PIT tagged lamprey remaining below the Falls out of the potential 58,217 estimated lamprey that remained in the lower river, which is 2.15%. This is similar to the percentage of tagged lamprey moving through the fish ladder with respect to the estimated number that passed through, 2.21% (1084 tagged/49,072 estimated) but lamprey in the horseshoe have many avenues for passage, whereas once in the ladder and into the HDX pool, lamprey either pass through or fall back. Once HDX PIT tagged lamprey moved past Pool 48 into the HDX Pool, electromagnetic fields of the HDX arrays provided full spatial and temporal coverage through the orifices and marker tags indicated the antennae and readers were operating properly. Mesa et al. (2009) contrasts physical differences for lamprey moving through the area of Willamette Falls in contrast with Columbia River dams and points out the complexities of the "natural waterfalls, powerhouse, dam, navigation lock, and seasonal flashboards that, because of fishway, paper mill, and other demands, often experiences uncontrolled spill over basalt ledges and shelves of rock, gravel, and woody debris."

Despite the lack of HDX PIT tagged lamprey detected over the crest of the Falls in 2011, non-tagged lamprey were observed passing over lamprey ramps during the first week after flashboards were installed (ca. 20 lamprey during the week of July 10, 2011, Carson McVay, CTWSRO fisheries technician, pers. comm.). Non-tagged lamprey were also observed passing over lamprey ramps during radio telemetry studies (Karchesky et al. 2011). Regardless of preparation to test both antennae, only one out of the two lamprey ramp antennae were operational in 2011. Technical consultation was sought and another attempt was made later to restore the electromagnetic field of the disabled antenna the afternoon of July 6 but time was limited as water was rising on the newly constructed flashboards and conditions to access the equipment became unsafe.

Genetic analysis

Columbia River Inter-Tribal Fish Commission's Genetics Laboratory has been studying lamprey collected in rivers in British Columbia, Washington, Oregon and California to identify a set of genetic markers to understand lamprey population dynamics (see Appendix D for Dr. Hess' full description). Researchers included samples from lamprey populations, including the Willamette River at Willamette Falls, that represented a large portion of the geographic range on the west coast and included adult and larval life stages. A subset of the samples analyzed included those that were collected about 15 years apart, adult phenotypes that had the "dwarf" body form and which included run-timing differences (early versus late). This study identified 20 single nucleotide polymorphism loci that had significant associations with geography, run-timing, and dwarf life history and 13 of these could be placed in known genes or highly conserved genomic regions using the genome browser available for sea lamprey. These are important findings that reconcile contrasting results from previous studies that include both evidence for Pacific lamprey population genetic heterogeneity and panmixia (Goodman et al. 2008; Lin et al. 2008; Spice et al. 2012). Neutral variation can discern regional differences, but adaptive variation could explain finer spatial patterns leading to within-region heterogeneity. Results are expected to appear in a special issue in the journal Molecular Ecology on restriction site associated DNA sequencing in non-model organisms. This issue is scheduled for print in spring 2013.

Future Work

Separating estimates of lamprey moving over the Falls via the fish ladder and those that fail to return to the fish ladder allows compartmentalization of uncertainties related to lamprey behavior in congregation areas below the Falls. The horseshoe area of the Falls, including lamprey ramps and the old fishway, is where the majority of the uncertainty lies in the lamprey escapement estimate and will become the focus of improvements 2012 and beyond. Efforts will be made to quantify lamprey that ascend the falls via ramps and through the old fishway to the extent possible.

Video monitoring equipment will be installed in 2012 and focus on quantifying lamprey that pass over the two most downstream lamprey ramps. Video review at the lamprey ramps will quantify non-tagged lamprey over ramps and great blue heron predation. This will further refine the estimate of lamprey that fail to return to the fish ladder but escape past the Falls versus those that stray. The fate of lamprey remaining below the Falls is beyond the scope of this project.

Passage through the old fishway was restored during fall 2011. A concrete curb was poured over fish ladder Leg 3 (enclosed in concrete vault), which created a channel for lamprey to pass through to the top of the old fishway (Figure 13). In 2013, CTWSRO plans to install HDX antennae in the old fishway and monitor lamprey passage by video (and perhaps predation by great blue herons). Given the number of lamprey that PGE biologists had salvaged prior to restoring passage (ca. 4000), and the number of tagged lamprey they observed (ca. 20), it is expected that significant proportion of the lamprey that failed to return to the fish ladder will be accounted for and may be added to the escapement estimate.

Figure 13. Passage improvements to restore lamprey passage through the old fishway, October 2011 (picture courtesy of Tim Shibahara, PGE).

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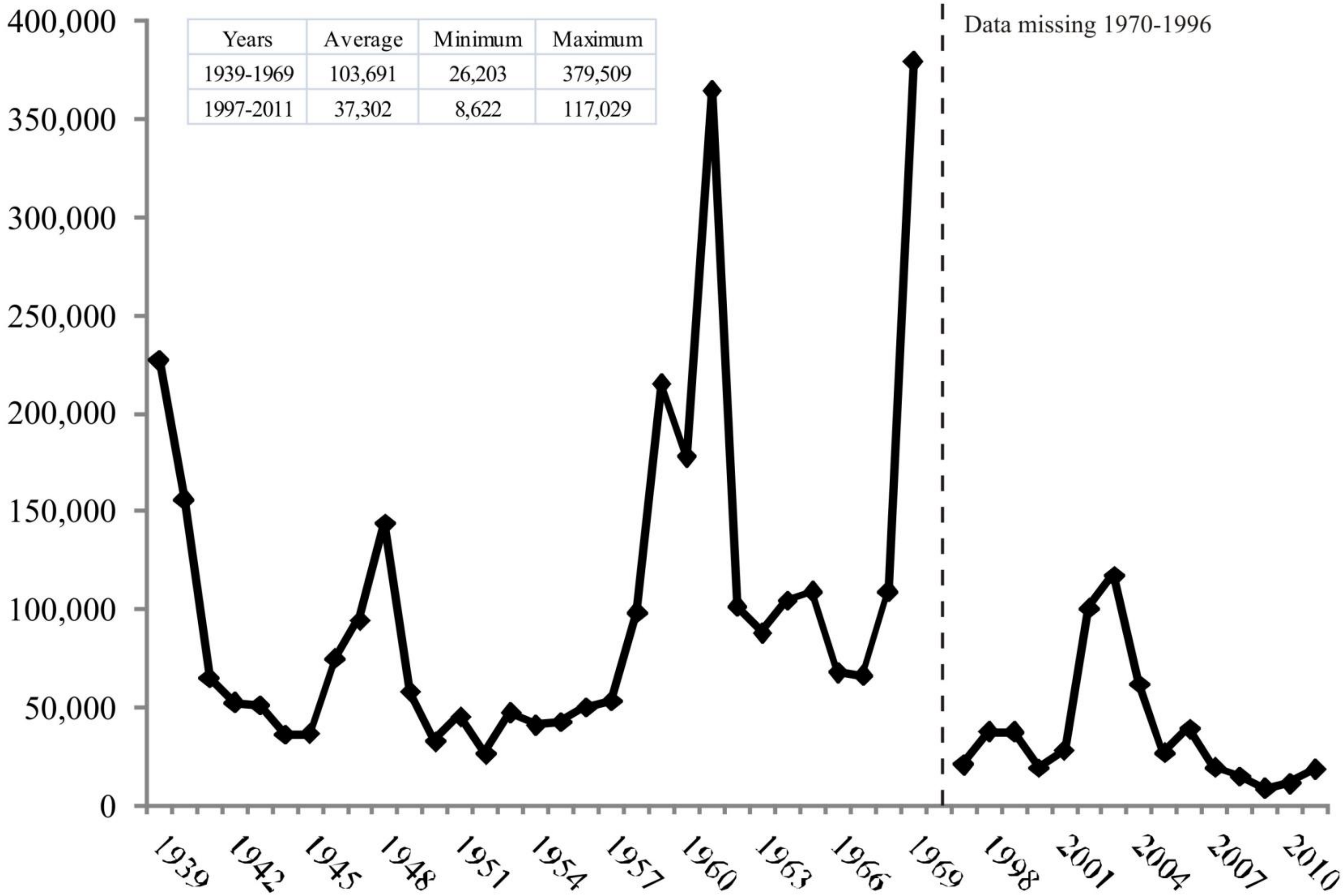
Appendix A. Bonneville Dam lamprey counts, 1939 to 2011.

Data courtesy of the Fish Passage Center.



Appendix B. Schematic of Willamette Falls, fish ladder, T.W. Sullivan Plant, and West Linn Paper, Co.

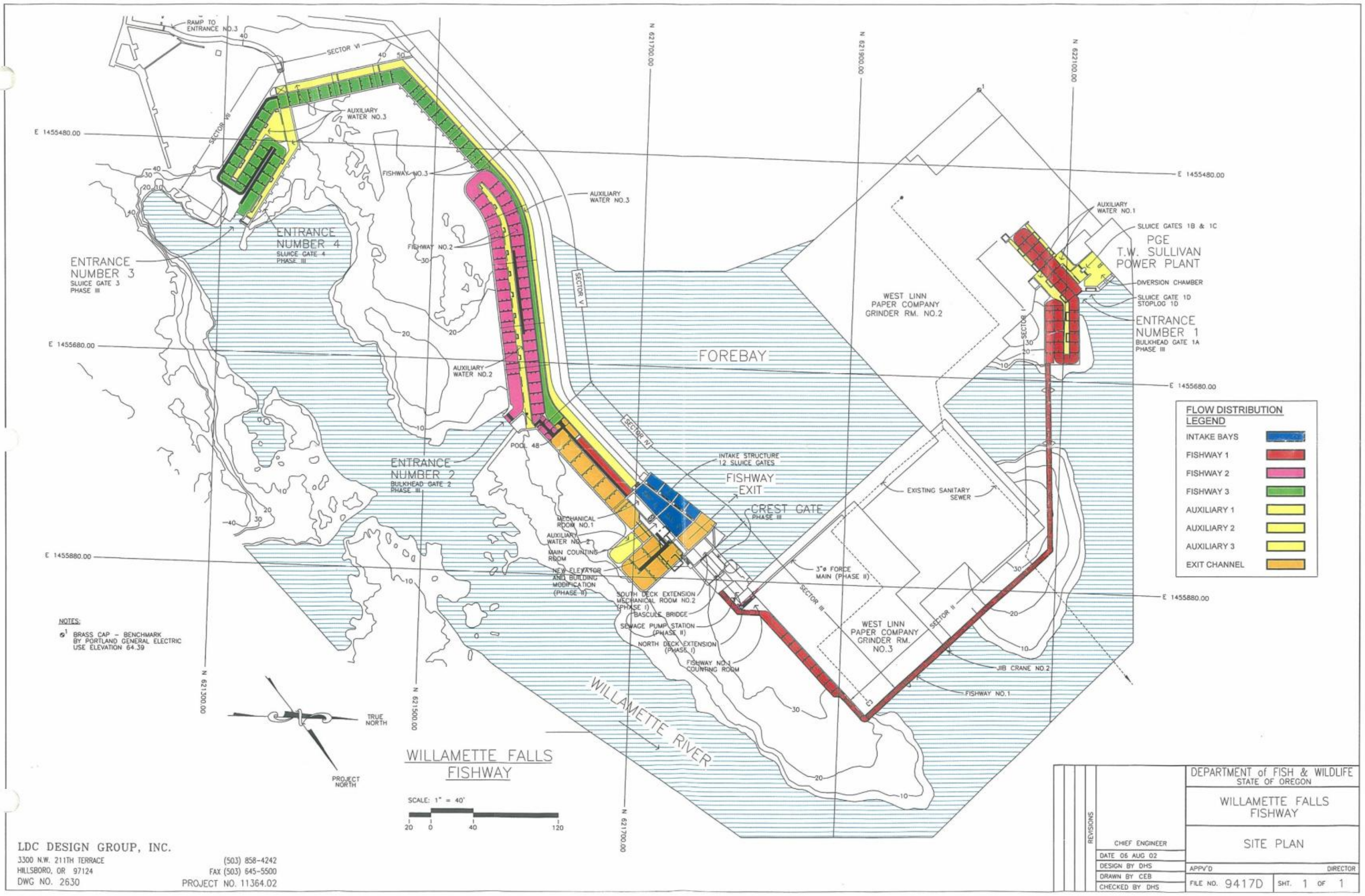
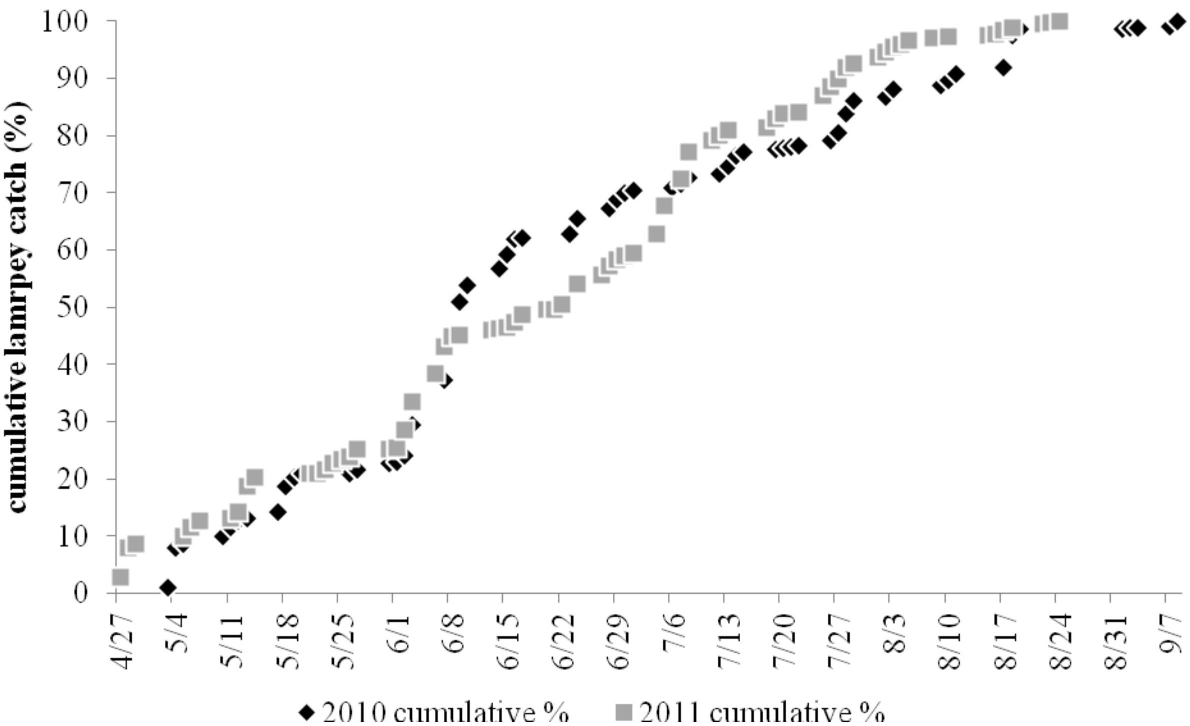


Image courtesy of PGE

Appendix C. Lamprey cumulative catch at Willamette Falls, Oregon, 2010 and 2011.



Note: The cumulative curve from April 27 – May 24, 2011 was based on the first 22.7% of the 2010 run (May 3 – May 31, 2010).

Appendix D. Pacific Lamprey Genetics Study by CRITFC's Genetics Lab, provided by Dr. Jon Hess, Conservation Geneticist, Hagerman, ID.

We employed Restriction site Associated DNA (RAD) sequencing to genotype 6453 single nucleotide polymorphism (SNP) loci for 574 individuals collected from rivers in British Columbia, Washington, Oregon, and California. This study was designed to identify a set of neutral and adaptive genetic markers to better understand lamprey population biology by using these markers to address the following major questions:

1) Is neutral genetic variation associated with geography, life stage, or adult phenotypes?
2) Is adaptive variation associated with geography or adult phenotypes?

3) What is the relationship between effective population size (Ne) and life stage and Ne through time?

To address these questions, we chose collections of Pacific lamprey distributed broadly to represent a large portion of their Northeastern Pacific range and included both adult and larval life stages. The adult phenotypes that we analyzed were praecox "dwarf" body form and run-timing differences (early versus late). A subset of collections also were temporal replicates from the same locations but separated by ~15 years which spans a generation.

Twenty-one collections were made to obtain 574 tissues from lampreys collected from rivers in British Columbia, Washington, Oregon, and California. To address our study questions related to adult phenotypes, praecox body form and run-timing, we obtained praecox collections from Stamp R., Hood Canal, and Coquille R. and individuals with known return time (sampled June to October in 2011) from Willamette R., 15 Mile Cr., and Deschutes R., respectively. Two life stages were represented among the collections: larvae from six collections and adults from the remaining fifteen. We also obtained temporal samples in two locations, the Willamette R. from Willamette Falls and in the Deschutes R. from Sherars Falls, and these samples were separated by a span of 15 years to examine changes in genetic composition across a generation. In most cases, 30 individuals were targeted from each collection but availability and tissue quality determined the final totals.

Our analyses identified 20 SNP loci with significant associations with geography, run-timing, and dwarf life history and 13 could be placed in known genes or highly conserved genomic regions using the genome browser available for sea lamprey. This study provides both neutral and adaptive context for observed genetic divergence among collections, and thus reconciles previous findings of population genetic heterogeneity within a species that approaches panmixia.

Results will be submitted June 30th, 2012 to a special issue in the journal Molecular Ecology on RAD sequencing in non-model organisms. This issue is scheduled for print in spring 2013.

Use of paired-end RAD sequencing, which provides relatively long sequence read lengths (~100-200 bp), will allow informative SNPs identified in this study to be developed into high throughput assays for future parentage and population genetic applications. We have plans and funding in fall of 2012 to develop at least 100 SNPs for future reproductive success studies to monitor reintroduction sites, and verify the success of translocation programs. These markers will be optimized for high accuracy for parentage asssignment, and will hopefully include a few markers that can determine sex and species identification (i.e. distinguish Pacific lamprey from Western brook, river lamprey in the Lampetra genus), as well as markers that are associated with adaptive traits.