Response to ISRP Review of Accord Proposal
200830800 – Willamette Falls Lamprey Escapement Estimate (ISRP 2009-23)

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We thank ISRP for their comments and consideration of this project. In the original narrative we would have liked to have provided more detail. We did not know how many lamprey could be captured for tagging and were less certain about the proportion of tagged fish we would be able to recapture and/or detect passing the half duplex monitoring stations (HDX; half-duplex antenna array with video camera monitoring). Additionally, because of the cryptic nature of lamprey, scope of the project and technological learning curve (*i.e.*, development of half duplex monitoring arrays and handling external interference) we knew there would be many challenges to developing this project.

During 2010, we learned a number of lessons and are able to address some of the uncertainty around project implementation. Clearly a stepwise approach is necessary as we continue to refine and develop methods and new monitoring stations. Following is a timeline with brief description project activities:

March 2010:

- Consulted with Tim Shibahara (PGE), Chris Peery (USFWS), Kirk Schroeder (ODFW), and Jeff Fryer (CRITFC) to discuss the location in the fish ladder to install the HDX antennae and cameras;
- Determined HDX site location (*fish ladder initial site*); and
- Sought permission from ODFW's engineering department to install equipment.

April 2010:

- Developed HDX flat-panels for installation in the fish ladder at Willamette Falls;
- Received approval from ODFW engineering to install equipment in fish ladder;
- Attempted to install HDX flat-panels (*fish ladder initial site*); however were unable to because of logistical constraints – ODFW was unable to draw the pool level down in the fish ladder low enough to install the panels. We did not get a chance to return with appropriate tools (*e.g.* pumps) because ESA listed spring Chinook were present and access was no longer allowed.

May 2010 – July 2010:

- Captured, marked, and recaptured adult Pacific lamprey using a dip net in the fish ladder and fish trap (Figure 1);
- Conducted creel surveys.
- Installed (July) HDX antenna on a lamprey ramp located on a riser board (Figure 2), to hold back water, along the rim of the falls. Difficulties were encountered due to limited time, access and safety, therefore no data was collected.

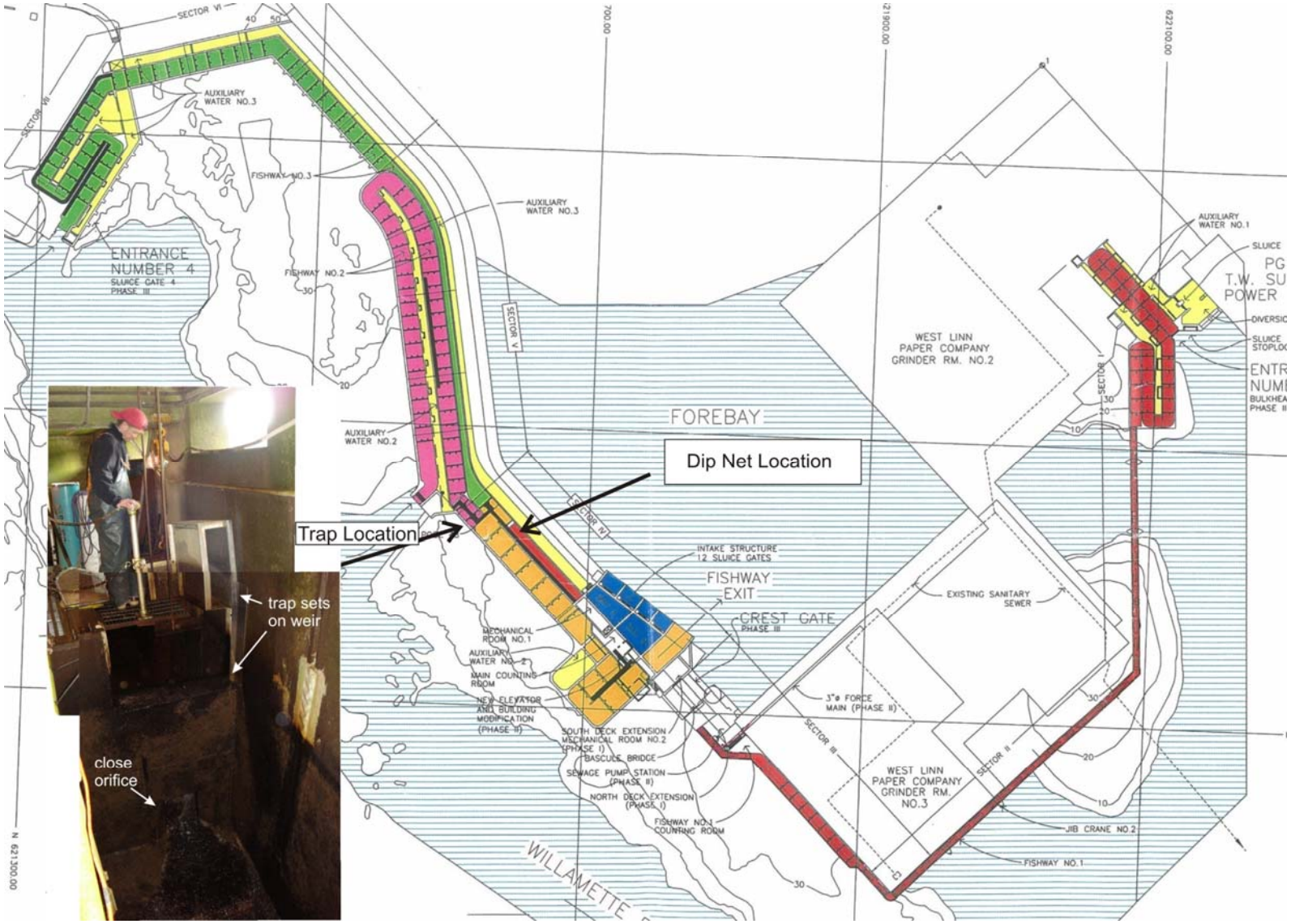

Figure 1. Capture location of lamprey at Willamette Falls fish ladder, Willamette River, Oregon, 2010.

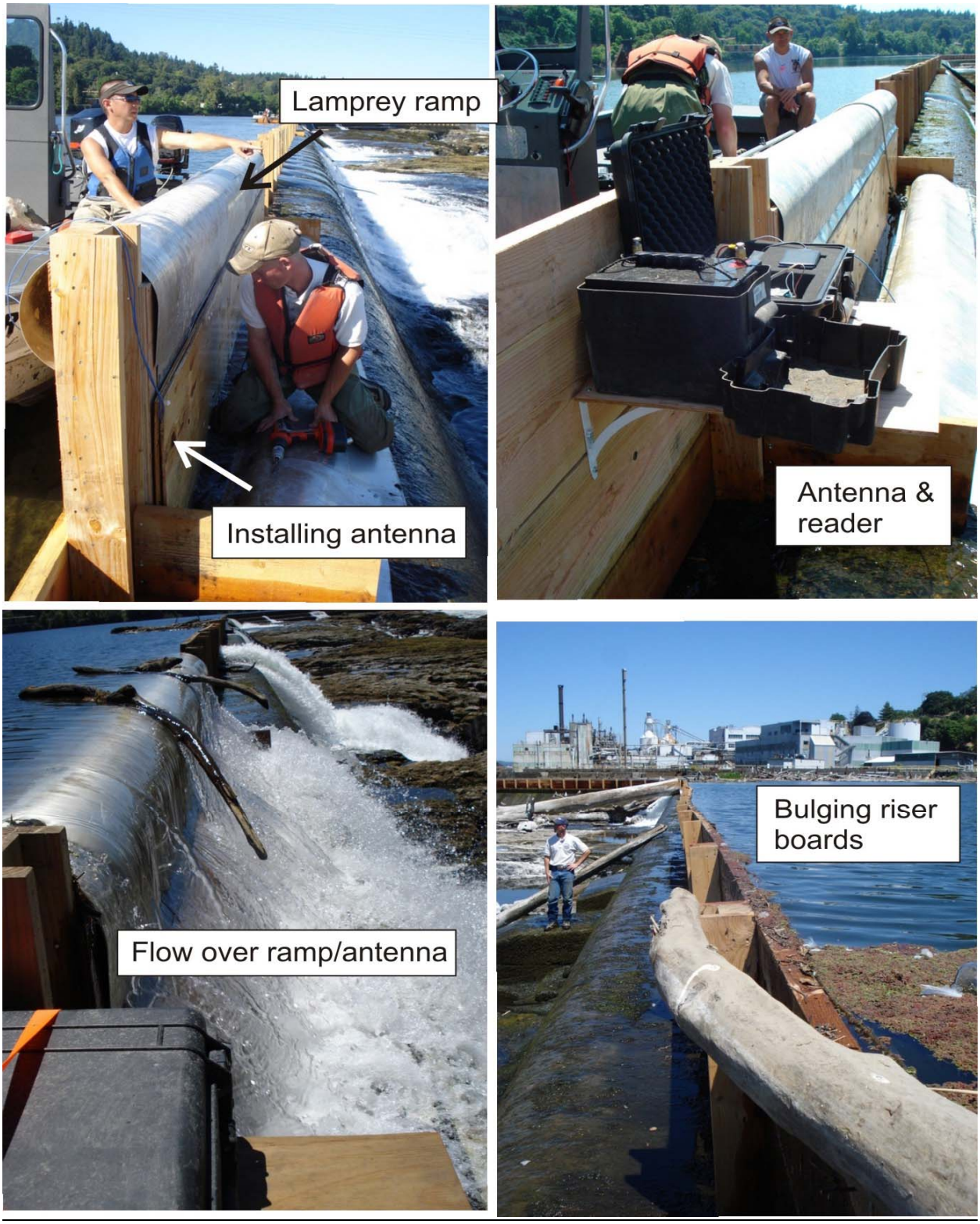

Figure 2. Installation of riser boards and lamprey ramps with HDX antenna at Willamette Falls, Willamette River, Oregon, 2010.

August 2010:

- Captured, marked, and recaptured adult Pacific lamprey using a dip net in the fish ladder and fish trap;
- Installed flat-panel antennae, cameras and infrared lights in the fish ladder at Willamette Falls (*fish ladder initial site*; Figure 3);
- Unable to tune HDX array and requested assistance from Mr. Warren Leach (owner Oregon RFID, HDX expert);
- Determined a full-duplex array upstream of our HDX was causing interference and were advised by Mr. Leach to remove the HDX and to consider redesigning the flat-panel antennas; and
- Tested second site for interference.

September 2010:

- Captured, marked, and recaptured adult Pacific lamprey using a dip net in the fish ladder and fish trap; and
- Converted camera footage for review.

October 2010:

- Removed HDX (*fish ladder initial site*);
- Converted camera footage for review;
- Began watching video to determine feasibility of counting lamprey through the fish ladder pool where the HDX antenna was located to determine a proportion tagged to untagged;
- Began construction of new HDX antennas (for *fish ladder second site*)– anticipating better performance; and
- Began consultation with ODFW engineering to install HDX array in second location.

November – December 2010:

- Consulted with Mr. Leach about installing and testing the new antennas (*fish ladder second site*);
- Received approval from ODFW engineering to install equipment at a new site in the fish ladder;
- Installed loop antennae (Figure 4), cameras and infrared lights to the new location (*fish ladder second site*);
- Tested for interference – preliminary results look good!

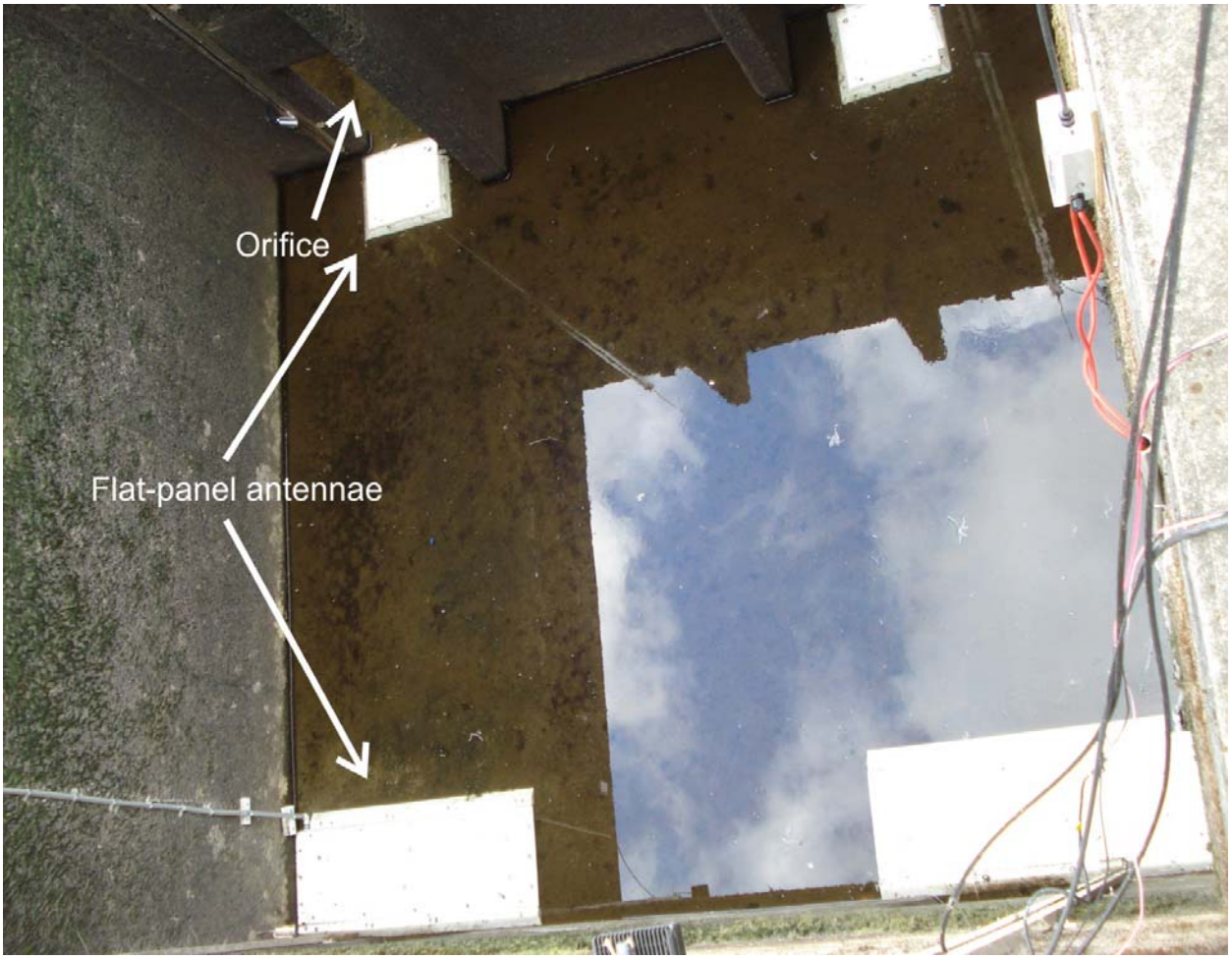

Figure 3. Flat-panel antennae installed in Willamette Falls fish ladder (*initial site*), Willamette River, August 2010.

Figure 4. HDX loop antenna and camera installed in Willamette Falls fish ladder (*second site*), Willamette River, November 2010.

With the number of unknowns (both methodology and technology) we set out to determine the feasibility of the following questions:

1. Can we develop, install, maintain, and be confident that HDX tagged lamprey are being detected at HDX sites (with cameras) within the fish ladder and at lamprey ramps?'
2. Can enough lamprey be captured to calculate an escapement estimate?; and
3. Can enough lamprey be recaptured/detected through a variety of second event samples (i.e., creel, observations at HDX, dip-netting in fish ladder)?

With one year of implementation completed, we acknowledge we were not able to answer each question with complete certainty; however, feel confident this project is implementable. Following is the question we attempted to answer with a brief description of the outcome (more detail is given further in the document):

1. *Can we develop, install, maintain, and be confident that HDX tagged lamprey are being detected at HDX sites (with cameras) within the fish ladder and at lamprey ramps?*

   This question was by far the most difficult to answer and still has a moderate level of uncertainty surrounding it. During August 2010, well into the lamprey run, we were able to set up the initial HDX site but were met with an unacceptable amount of interference. Since then this site has been removed and reinstallation has occurred in an area which appears to be more suitable for monitoring. A full assessment will need to be completed prior to April 2011 to ensure interference will not be a problem and read range is sufficient, allowing for an acceptable detection probability.

   We were able to collect data via video camera at the initial HDX site. Based on preliminary video observations, it is possible to count lamprey moving through the fish ladder. We will be able to more fully answer this question and refine methodologies after more video review has occurred during winter and spring 2011.

   We attempted to develop and install an HDX monitoring site along the rim of Willamette Falls, attached to a lamprey ramp. We were not successful at collecting data from this site. We are unsure as to why this occurred. It could be a single or accumulation of problems. Project staff has identified multiple potential issues including: the age of the equipment being used (equipment is recycled from another project); the ramp, being made from aluminum, decreased or eliminated read range of our antenna; and/or logistical limitations encountered during installation (*e.g.*, one day for installation, safety concerns about returning to the site to tune the antenna). In spring 2011, we will evaluate a new antenna design and testing it adjacent to the 6 m long aluminum sheet, which is part of the lamprey ramp, prior to installation.

   2. Can enough lamprey be captured to calculate an escapement estimate?
   We marked 2,158 adult Pacific lamprey through dip-netting in the fish ladder at Willamette Falls. With increased staff time and additional efforts, such as assisting with salvage efforts in an old, impassable fish ladder (in 2010 PGE collected 2500 during a one day effort) our

ability to capture and tag lamprey in high enough numbers to calculate abundance/escapement appears to be feasible.

3. *Can enough lamprey be recaptured/detected through a variety of second event samples (i.e., creel, observations at HDX, dipnetting in fish ladder)?*
We were able to recapture 85 lamprey (3.9%) through dip-netting in the fish ladder, operation of the fish trap and conducting the creel. While this recapture rate is low, there will be greater opportunities for recapturing fish in the future. These opportunities include the HDX monitoring sites (which we anticipate will increase recapture rates greatly) and through salvage efforts in the old fish ladder (Tim Shibahara, PGE, estimated seeing 10 tagged lamprey during 2010).

<u>Adult Pacific Lamprey Harvest and Creel Questions:</u>

"Based on lamprey harvest over the past few years, how many adults are anticipated to be captured by dip netting (page 7) during the migration season?"

"Finally, how often will creel surveys be conducted during the fishing season?"

Using harvest data from Willamette Falls would not have been a good indicator of anticipated lamprey catch (Table 1). In 2010, we collected nearly 2,200 lamprey. This exceeds harvest for 2007 and 2008 when combined.

There are multiple reasons to preclude the use of lamprey harvest data as an indicator of relative lamprey abundance, thus catchability; primarily, harvest occurs for a short window of time during upstream migration but also changes in harvest efforts, in part due to changes in regulations (Kostow 2002). The temporal distribution within the fish ladder at Willamette Falls was from early-May through early-September (lamprey were tagged May 3 – September 8); although, lamprey were present in small numbers post September 8, 2010. In May 2010, we initiated a creel to coincide with the ODFW harvest regulations (Thursday through Sunday, May through July, 6am to 7pm). The creel continued through July 31, 2010. We had a technician at Sportcraft Marina boat launch, Oregon City, Oregon, just downstream of Willamette Falls, during the entire period. Harvesters were only active for a little over a week after the riser boards were installed (July 6 – July 16, 2010). We had good participation by most harvesters. For those who did not allow us to creel, we were able to call a biologist from their tribe to get an estimate of harvest and Floy® tag number.

Further complicating the use of harvest data as an indicator of potential capture is inconsistent data collection. Kevleen Melcher (Ocean Salmon/Columbia River Program, ODFW-Clackamas) tracks lamprey harvest at Willamette Falls through the personal-use permit system. This is the only effort, by ODFW, to record lamprey harvest at Willamette Falls.

Table 1. Reported lamprey harvest, 2002-2008. Data courtesy of ODFW-Clackamas.

Year	Personal Use Permits	Tribal Harvest	Non-Tribal Harvest	Total Harvest
2002	58	2,967	1,149	4,116
2003	43	3,319	3,755	7,074
2004	64	4,600	416	5,016
2005	25	6,435	18	6,453
2006	24	1,553	18	1,571
2007	17	1,107	104	1,211
2008	20	170	30	200

References

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

HDX PIT Tagging Effect Questions:

"Is it possible to test the assumption of no tagging-related mortality by holding some lamprey for a few days before releasing them?"
Dr. Mary Moser (NOAA Fisheries) conducted a study to test effects of PIT tagging lamprey. She sent the following e-mail:

> "In 2004, we held lamprey with PIT tags that were implanted using an incision and closure with sutures, closure with cyanoacrylic glue (VetBond), and no closure for several weeks to assess tag effects. None of these fish died, but the sutures and glue caused increased wound redness and infection. Therefore we have been not closing the incision since that time. Unfortunately, this little experiment was not written up anywhere."

We do have the facilities to repeat Dr. Moser's study to test the effects of PIT tagging; however, feel it is not necessary. We will bring this up at the Willamette Falls lamprey technical group meeting, being held by USFWS, this winter. The topic of holding lamprey to study tagging-related mortality will be discussed.

"The proposal would also be improved by information/references on whether or not implantation of PIT tags affect behavior and physiology of lamprey. If this work has not been done, the studies need to be incorporated in the proposal."
Mueller et al. (2006) studied differences in swimming performance and short-term effects of PIT-tagged (12mm x 2.1mm) macrophalmia (120-171mm TL). Eyed outmigrants were caught at the juvenile bypass at John Day Dam and held in oxygenated, circular holding tanks with chilled

water (6°-8°C) for PIT retention, mortality and swimming tests. They found that sustained swimming speeds did not differ between the tagged and untagged groups (ANOVA, p=0.12, df=58) but maximum burst speed was significantly lower for the tagged group (t-test, p=0.02, df=29). After 40d in chilled water, tagged and untagged lamprey had similar mortality rates, 2.2% and 2.6%, respectively. Few tags were shed. In 2001, 722 macrophalmia were tagged (22 ga. hypodermic needle was used to make a 'pilot hole' then a 12 ga. PIT injector needle was inserted into the hole and the tag injected) and two tags were shed. In 2002, the procedure included one suture; out of 700 lamprey tagged, none were shed.

Results from Mueller et al. 2006 suggest that PIT tagging adult lamprey is not likely to affect sustained swimming ability or cause significant mortality, but may affect maximum burst speed. This work was done using full-duplex (12mm) tags on lamprey, which were approximately 140mm TL on average. We will be using half-duplex (HD, 23mm) tags on adult lamprey in the range of 49 to 76 cm TL (Close et al. 2003); the HD tags should represent a much smaller proportion of the adult body weight compared to the macrophalmia and not pose any greater affects.

References

Close, D. A., M. S. Fitzpatrick, C. M. Lorion, H. W. Li, and C. B. Schreck. 2003. Effects of interperitoneally implanted radio transmitters on the swimming performance and physiology of Pacific lamprey. North American Journal of Fisheries Management 23:1184-1192.

Mueller, R. P., R. A. Moursund, and M. D. 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.

Mark-recapture Uncertainty Related Questions:

"This project is directed at developing and testing methods for estimating abundance of adult lamprey returning to the Willamette above Willamette Falls. To accomplish this, the proponents propose to install PIT tag detectors at five passage locations near the Falls and underwater cameras for enumerating lamprey at two of these locations. The proponents propose to obtain estimates of abundance using mark-recapture methodology. There are many uncertainties associated with this approach. These include:

1)*can enough lamprey be caught and PIT tagged to provide reliable estimates of abundance;*
2)*can PIT tags be successfully detected (detection rate) at the passage locations;*
3)*can lamprey be reliably counted by the underwater cameras at the passage locations;*
4)*can issues related to fallback and multiple counts of the same individuals be resolved;*
5)*can mortality of lamprey due to predation below the Falls be estimated successfully"*

"Can enough lamprey be caught and PIT tagged to provide reliable estimates of abundance"
Mark-recapture methods for Pacific lamprey are extremely limited (BPA project 2002-016-00) therefore our ability to assess recapture rates prior to having multiple, fully-operational HDX arrays is impossible. We do understand the need to recapture/detect enough fish to calculate an estimate with an acceptable level of confidence. Therefore, we are working with a group of

biologist (e.g., CRITFC, ODFW, PGE, USFWS, UI) with experience at Willamette Falls and/or with similar technologies (PIT arrays and cameras) at main stem Columbia River dams to monitor lamprey.

Adult lamprey will be tagged over the entire span of spring/summer migration. In 2010, lamprey were tagged from May 3 – September 8, 2010. Effort to collect lamprey began in late April and ended on September 8, 2010, when numbers were significantly low enough it hindered our ability to capture fish. Through visual observations minimal numbers (N=1/day) were observed for a brief period post September 8, 2010.

We believe enough lamprey can be tagged for a mark-recapture study. We tagged nearly 2,200 lamprey. Of those tagged, 258 were HDX, 1,899 had Floy® tags, one had a dart tags only (Floy® tag fell out before release) and all had dart tags as a secondary mark. In future years, all lamprey captured will receive an HDX tag and secondary dart tag mark with the caveat there may be days this is logistically impossible.

Due to problems with the HDX arrays in the fish ladder and lamprey ramp, we cannot say with certainty that our ability to recapture lamprey is adequate, but feel confident improvements to both sites will increase recapture rates. We recaptured 85 lamprey through dip-netting in the fish ladder, fish trap operations and creeling (85/2158*100 = 3.9% recapture rate). To date, recaptures only include fish handled and visually inspected.

We have only viewed a small piece of the video footage captured in the fish ladder. Video quality appears to be good, and we feel enumeration of lamprey is possible. However, we do need to view more footage to evaluate if it can be used as a second event sample (inspection and recapture). If we can count the number of lamprey passing through the ladder possessing Floy® tags, the recapture rate will increase and confidence intervals around the estimate will contract. In addition, during June, Tim Shibahara noted 10 Floy® tags (but was not able to record numbers) during the fish salvage in the old fish ladder. After reviewing video from the fish ladder and meeting to discuss how best to analyze the data from 2010 with Rishi Sharma (CRITFC), we will have a better idea about confidence limits for lamprey abundance estimates for data collected in 2010. We also anticipate having our HDX array in the fish ladder operational during 2011. This should greatly increase the number of recaptures observed, assuming we are able to tag a large enough proportion of the population.

Methods will need to be adapted as the project matures to ensure the best product possible. We feel by taking a collaborative approach and encouraging outside input (through the development of a Willamette Falls Working Group) our goals are attainable.

"Can PIT tags be successfully detected (detection rate) at the passage locations"
Our ability to detect lamprey using PIT tags depends on the read range of our HDX antennae in the fish ladder and lamprey ramps and whether multiple lamprey pass through antennae at a time. We have the ability to test detection rates by sending a known number of wooden "test fish" that posses PIT tags through the antenna system. We can determine if we miss lamprey passing

antennae by reviewing digital images from video camera. HDX tagged lamprey will also be Floy® tagged and those numbers (HDX and Floy®-tagged fish) should correspond.

An assumption of the mark-recapture is that fish behavior will not be affected through capture or marking. The affects of capture, mark, and transport are unknown but should be negligible. Based on experience from the Deschutes River lamprey project (2002-016-00) no apparent behavioral changes have been observed. To minimize negative handling affects, fish will be handled appropriately (*e.g.,* minimizing process sing/tagging times, holding them before and during transport, buffering anesthesia) and staff will be trained to PIT tag fish based on proven methodologies.
In 2010, we were unable to determine detection rates at the HDX sites. We installed HDX antennae in the fish ladder and at one lamprey ramp along the top of Willamette Falls. Problems were encountered at both locations. Initially, we had installed the antennae array at a location in the fish ladder suggested by a researcher who works with HDX technology at Columbia River dams. The concern at this location was a full duplex (FDX) system in close proximity to the proposed HDX site which could potentially cause interference rendering our antenna inoperable. After equipment installation, interference was detected from the FDX system; therefore, this site was removed. An alternative location was suggested. Prior to moving the HDX array to the new site, we had Mr. Warren Leach, owner of Oregon RFID (company that manufactures HDX readers), visit the site. During the site visit, he tested the new site for interference. After Mr. Leach approved the new location, we built antennae according to revised specifications (loop design) and tested it in the new location of the fish ladder. The new antennae had read range throughout the entire orifice and extended outward several feet, which was a great improvement on the first design (flat-panel), which only had a read range of a few inches. We will also install a marker tag (product from Oregon RFID) mounted within the detection zone of the antenna to verify continuous operation of our antennae.

The new loop style antennae design should improve our ability to detect lamprey moving through the fish ladder at Willamette Falls. Lamprey researchers working at main stem Columbia River dams found that only 1% of lamprey swim through orifices in fish ladders while majority move along the bottom of the ladder (C. Peery, USFWS, pers. comm.). Therefore, the flat-panel design with limited vertical read range is sufficient. Our video and observation suggested that far more than 1% swim through orifices in weir walls.

Lessons learned from our HDX antennae experience in the fish ladder will be applied to the lamprey ramp in 2011. We designed and installed an antenna for one of four lamprey ramps in 2010. We had 8-inches of read range prior to installation but none after. Because of the very limited time we had to install the antenna, we were not able to pinpoint the exact cause of the problem or correct it. Installation was limited to when the riser boards were being installed. Once water was brought up to the top of the risers, we were not allowed to access the area by boat (as the boards were bulging from the water and there was a fear that touching them would cause them to collapse). Attempts were made to climb the falls and work on the antenna; however too much water was moving over the ramp. Based on lessons learned in 2010, we will be developing a new antenna design and installing it on the lamprey ramp prior to installation.

Testing will occur prior to the installation in hopes little or no alterations will need to be made once installed.

"*Can lamprey be reliably counted by the underwater cameras at the passage locations"*
We installed cameras to record lamprey moving into the fish ladder pool, through orifices in the weir walls, where the HDX antennae were installed. We have only begun to review video but can clearly see lamprey in the footage. Their swimming behavior (*e.g.*, back and forth movement in front of the camera) will make counting a challenge. We are in the process of resolving file compatibility issues between the DVR and computer. Once the problem is resolved and further viewing of the video is done, our next task is to develop criteria of how to count lamprey swimming past the cameras. We did not try to record video of lamprey swimming over the lamprey ramps, which should occur in conjunction with the HDX antenna. This will be addressed in 2011.

The initial proposal was to locate a video camera at the ODFW counting window but a latter assessment determined that this was not an option. Initially, it was thought that an advantage to having our equipment located at the ODFW counting window was that our abundance estimates could be indexed to video counts, which will continue after this study is complete, and some form of monitoring can continue. The problem encountered with locating our HDX antennae at the counting window was the proximity to the full-duplex system. Due to electrical interference from the full-duplex system, the HDX system would be inoperable. We need to have video capability at the site of the HDX antennae in order to determine the proportion of marked to unmarked fish for the abundance estimate. Therefore, we located our antenne and video equipment at a sufficient distance from the full-duplex system (and counting window) for proper operation.

"Can issues related to fallback and multiple counts of the same individuals be resolved"
Lamprey will be tagged using uniquely identifiable HDX PIT tags. This will allow fish to be individually identified upon detection. Antenna arrays, at each location, will consist of two antennae (two channels on the receiver) so directionality of movement can be determined. Fish that fallback can be subtracted from the total ascending Willamette Falls so double counting the same individual will not occur.

"Can mortality of lamprey due to predation below the Falls be estimated successfully"
This would really be a challenge given the protected status of sea lions, game fish status of sturgeon, size of the river, range of potential predators (sturgeon, sea lions and birds) and cost of such an endeavor. However, we have no reason to believe that predation rates for tagged to untagged lamprey would be unequal. If predation rates for tagged and untagged lamprey are equal then the effects of predation of tagged lamprey are offset by equal predation of untagged individuals. We have no reason to believe that tagging affects swimming behavior of lamprey or gives predators a significant visual advantage. HDX-tagged lamprey returned to the fish ladder as soon as one day after tagging. Since HDX tags are internal, they are not visible to predators. But, we also use Floy® tags as a secondary mark, which are small (<1mm dia., 1.5 cm long) and pink tags. There are no studies of increased vulnerability to predation of Floy®-tagged lamprey

that we are aware. There may be a slight increase in predation by visual predators, such as cormorants or other avian predators and possibly sea lions. Sturgeon are not visual predators.

Potential predators to lamprey in the Willamette River are white sturgeon, sea lions, and birds. Sturgeon are known to hold below Willamette Falls and lamprey are well-known to fisherman as a favored food of sturgeon. Sturgeon were observed on the east bank of the "horseshoe" in shallow water all summer. One of our PIT tagged lamprey was detected by ODFW while sampling sturgeon in the lower Willamette River. The lamprey was PIT tagged May 5, 2010, and was recaptured in a sturgeon (FL 126 cm) captured on July 13, 2010 at Elk Rock Island (rkm 19, near Milwaukie) by ODFW (Tucker Jones, ODFW Clackamas, pers. Comm.).

Sea lions are another potential source of predation on lamprey. A story was relayed by a fisherman who observed a sea lion grabbing lamprey with its mouth, flipping them onto shore then eating them. The fisherman said that this one sea lion consumed 100 lamprey in a short period of time. Many sea lions are observed at Willamette Falls through the spring Chinook run which also overlaps with the early part of the lamprey run. While, in general, fishermen view sea lions with animosity, anecdotal information can serve a purpose so long as it is used with caution.

Beyond sturgeon and sea lions, Tim Shibahara mentioned observing avian predation on lamprey at Willamette Falls. Predation is one aspect of this study that is very important to understand but will be difficult to obtain. If there were a method to estimate the abundance of sturgeon in the vicinity, perhaps by hydroacoustic survey, then relate of the number of lamprey consumed per sturgeon (unknown) an estimate of the predation rate could be made. For sea lion predation, it may be possible to observe behavior and estimate the number of lamprey consumed per individual but if sea lions also fish and consume lamprey under water an estimate may be difficult to obtain. Following one of your comments advising a staged approach, we may have to approach the predation issue one step at a time. In 2010 we made observations and obtained information from other observers and researches. Presently, we have no way of validating our assumption that predation rates on tagged and untagged lamprey are equal.

Data Analysis Questions:

Is the expansion of the data a feasible method? It seems to have a number of interrelated uncertainties about it, as mentioned above. More detailed review of statistical methods is needed in light of these possible problems.
More evidence should be presented indicating that statistical methodologies are available to accommodate the uncertainties of tag detection and visibility difficulties. For example the proponents state that estimates of tag loss and predation can be accomplished by using simulation and bootstrap techniques, but more evidence, such as literature references, should be provided to document that these approaches can adequately address anticipated uncertainties.

Dr. Rishi Sharma, CRITFC, provided the following response:
Develop statistical model for population estimate

A simple mark-recapture could be used to determine the adult escapement (using equations 1 and 2, Seber 1982):

(1) $$\hat{N}_{i,t} = \frac{(n_{i,t}+1)(n_{e,t}+1)}{m_{e,t}+1} - 1$$

(2) $$v\left[\hat{N}_{i,t}\right] = \frac{\hat{N}_{i,t}(n_{i,t}-m_{e,t})(n_{e,t}-m_{e,t})}{(m_{e,t}+1)(m_{e,t}+2)}$$

where $\hat{N}_{i,t}$ is the adult lamprey in the Willamette at time *t*, $n_{i,t}$ is the number of lamprey marked at the capture facility with pit tags, $n_{e,t}$ is the total number of adults sampled at the trap when moving up again after release below the falls, and $m_{e,t}$ is the number of lamprey in that sample (recaptured) with the mark (possibly a pit-tag or external mark).

Assumptions of the model for population estimate are that fish do not shed their PIT tags, tagged fish are not removed from the population (*e.g.* predation, harvest), and there is no mortality between the time fish are tagged and when they are detected. In conjunction with marking and recapturing adult lamprey, a single access site creel survey will be conducted to estimate tribal harvest of adult Pacific lamprey

Estimates of tag loss could be estimated with double tagging (Seber and Felton 1981), When there is double tagging, a correction for tag loss can be made based on the numbers recaptured that retain one or both tags, provided we can assume independence of the tags (Seber and Felton 1981). We can estimate this if we think this is a serious problem after a feasibility study is done in the pilot phase of the project.

Note, we can correct for estimates of tag loss and predation by using simulation, and bootstrap based techniques (Korman et. al. 2002). Such techniques are standard techniques used to evaluate the possible bias on the estimate and its associated variance. If we look at equation 1 above, a biased estimate of $m_{e,t}$, i.e. if tag loss or predation occurs will inflate the population estimate $\hat{N}_{i,t}$, as it will also inflate the variance. Thus a range of tag loss values will be assessed either through direct double tagging (Seber and Felton 1981) or through sensitivity analysis and a range of values will be presented for the estimate.

In addition, close form solution of variance will provide a means of performing a parametric bootstrap on the overall population thus showing the overall population size as a function of capture efficiency and tag loss. This is a function of the initial number sampled ($n_{i,t}$) and the overall estimate of the population $\hat{N}_{i,t}$ and is distributed Binomial $\left(\hat{N}_{i,t}, \frac{n_{i,t}}{\hat{N}_{i,t}}\right)$.

References

Korman, J., R.N.M Ahrens, P. S. Higgins, and C. J. Walters. 2002. Effects of observer efficiency, arrival timing, and survey life on estimates of escapement for steelhead trout (*Oncorhynchus mykiss*) derived from repeat mark–recapture experiments. Can. J. Fish. Aquat. Sci. 59: 1116–1131.

Seber, G. A. F. and R. Felton. 1981. Tag loss and the Petersen mark-recapture experiment. Biometrika.68:211-219.

Other approaches we could investigate, but I need to spend more time reading these are:

Mäntyniemi, S. and A. Romakkaniemi. 2002. Bayesian mark–recapture estimation with an application to a salmonid smolt population. Can. J. Fish. Aquat. Sci. 59(11): 1748–1758.

Rosenberger, A.E. and J. B. Dunham. 2005. Validation of Abundance Estimates from Mark–Recapture and Removal Techniques for Rainbow Trout Captured by Electrofishing in Small Streams. North Am. Jr. of Fish Mgt. 25: 1395-1410.

Gazey, W.J., and M.J. Staley. 1986. Population estimation form Mark-Recapture experiments using a sequential Bayes Algorithm. Ecology 67:941-951.
